



Bachelor Thesis

Optimising the batch sizes and inventory parameters for Twentsche Kabelfabriek BV

Publication date: 01-07-2021

Student

B.N. Zentveld (Bram) - s2068877
b.n.zentveld@student.utwente.nl
*Industrial Engineering and
Management
University of Twente*

Supervisors

UNIVERSITY OF TWENTE

Dr. E. Topan (Engin)
*Faculty of Behavioural, Management
and Social Sciences (BMS), Industrial
Engineering & Business Information
Systems (IEBIS)*

Dr. I. Seyran Topan (Ipek)
*Faculty of Behavioural, Management
and Social Sciences (BMS), Industrial
Engineering & Business Information
Systems (IEBIS)*

Twentsche Kabelfabriek BV

R. Peek (Ron)
*Manager Supply Chain &
Industrial Engineering*

T. Bijen (Tom)
Capacity planner



TKF CONNECTIVITY SOLUTIONS

**UNIVERSITY
OF TWENTE.**

Preface

Dear reader,

You are about to read the bachelor thesis “Optimising the batch sizes and inventory parameters at Twentsche Kabelfabriek BV”. This research has been performed at TKF Haaksbergen and was part of the bachelor Industrial Engineering and Management (IEM) at the University of Twente. The thesis aims for determining the optimal batch sizes and inventory parameters. Due to the confidential nature of the data or results, some quantitative values are multiplied by factor X or not shown at all.

At Twentsche Kabelfabriek BV I gained many new valuable insights, and I am grateful for this opportunity. Particularly, because they allowed me to work there during this extraordinary COVID-19 pandemic.

I want to give a special thanks to my supervisors Ron Peeks and Tom Bijen. They both guided me during the research and always helped me when needed. Furthermore, I could always count on their extensive feedback. I really enjoyed working with them. During my research, I was also often in the production facility and therefore I want to thank all employees which helped me with my research.

Undoubtedly, I would like to thank my UT supervisor Engin Topan. Because of his large enthusiasm and interest in inventory systems and batch sizes, we always had fruitful discussions and meetings. This really helped me to get the most out of my bachelor thesis. Besides that, he always put in full effort and I really enjoyed working with him. I would also like to thank Ipek Seyran Topan for supporting me during the bachelor thesis preparation module as well as for being my second supervisor. She always provided the help I needed and asked me how I was doing, and this was really kind.

Finally, I want to thank my friends, housemates, and family for their support. They always supported and helped me if needed. In special I want to thank Gerco Mussche. With our weekly meetings, we helped each other to stay motivated and to improve our thesis by providing extensive feedback and opinions on the research. This really helped me, and I am grateful for that.

I hope you will enjoy reading my bachelor thesis!

Kind regards,

Bram Zentveld

Enschede, July 2021

Management summary

Intro

This research has been performed at Twentsche Kabelfabriek BV (TKF) in Haaksbergen. TKF is a cable manufacturing company which developed itself to a technologically leading supplier of connectivity solutions. Their solutions are offered to three market segments which are building, industrial and telecom segment.

Problem description

In today's production environment there is an enormous need for insights in the optimal batch size and accurate inventory parameters. Since TKF is producing most of their important cables to stock (MTS), finding optimal inventory levels for finished goods is key. However, these decisions have implications on production and inventory levels. At the moment, TKF has no proper balance between production and inventory levels and this results in high combined cost. Therefore, the main research question is defined as:

How can the batch ordering decision optimally be determined and what is the impact of the optimal batch ordering on the combined cost of production and inventory?

The management of TKF decided that the aimed norm will be a reduction in the combined cost of setup and inventory holding cost by 5%. This will apply to our scope that is defined as all MTS standard products for the installation and multiconductor department.

Approach

In this study, we create insights in the setup and inventory holding cost and use these insights to calculate the optimal batch size. The optimal batch size will then make sure that the combined cost of setup and inventory holding are optimized. This is although not completely solving TKF's problem since also lead times, review period, demand, and service levels are involved. Therefore, we implemented Bijvank's algorithm to make sure also demand uncertainty, service level agreements with customers, production lead time, and inventory review period are also taken into consideration. For this reason, two models are created. One for the optimal batch size calculation and one for the determination of the optimal inventory parameters.

Results

The results of the bachelor thesis are discussed in this section. Since, we did not have an insight in the setup and inventory holding cost, our first results are in terms of the current situation (reality). At this moment, the weights between the inventory holding and setup cost of the entire scope are 27% and 73% respectively. Looking at the different portfolios which are included in this scope it can be seen that the instrumentation process technique and the pipes, wires, and cords portfolio are outliers and deviate from the overall weights. For the pipes, wires, and cords portfolio the combined cost of setup and inventory holding cost is 19.1% lower than the average. The other outlier is the instrumentation process technique portfolio and is an outlier to the upside. In contrast with the pipes, wires, and cords portfolio this outlier is only caused by the high setup cost involved in this portfolio instead of both factors. The overall results of the tool are given in Table 1.

Table 1 - Overall results when the inventory levels are implemented as suggested by the tool

Results (Current model)		
Suggested average EOQ	21317	[meters]
Current average prod.length	4518	[meters]
Average meand demand (year)	29755	[meters]
Flexibility loss	471,82	[%]
average stock per current batch	0,15	[# of years]
average stock per EOQ batch	0,72	[# of years]
Savings (on average)	0,48	[€/meter]
Costprice (on average)	3,76	[€/meter]
Savings (percentage)	12,66	[%]

In this table, the current average production length of the scope could be seen. Next to that, the suggested average EOQ of the scope is displayed. With these numbers the flexibility loss is calculated. This could be done since implementing the EOQ results in longer batch sizes and therefore less flexibility for TKF. Below the flexibility loss, the average stock per current batch as well as the average stock per optimal batch (EOQ) can be seen. This number is referring to the amount of yearly demand that could be satisfied with one batch size. At last, the savings are displayed. The savings (percentage) is calculated over the average cost price if all EOQs would be implemented. This resulted in approximately 12.7% savings on cost price.

Conclusion and recommendation

By applying the tools and analysing the results, we made the following main conclusions:

- Both tools could be used as a decision supportive model to determine the inventory parameters and batch size.
- As could be concluded from the overall results as well as the bad alignment between inventory holding and setup cost (27% versus 73%) it is proven that a lot of savings could be achieved by TKF by using the tool. Besides, also the norm of 5% improvement is largely exceeded.
- Since the tool is not considering all practical constraints, like for example production capacity, large inventory levels, and production flexibility, but only the most optimal savings, the trade-off between savings versus flexibility and inventory space could be made. Everything closer to the EOQ will namely already help with savings.

Based on the conclusions and performed research, we also made recommendations for TKF. The main recommendations are:

- To calculate the optimal batch size and inventory parameters, we suggest making use of the proposed optimal batch size and inventory parameter models
- The quality of the output is depending on the quality of the input values. Hence, we recommend performing the future research as suggested below for improving the quality of the input values. Also, after implementing this it is recommended to do a sensitivity analysis.
- Since there is a trade-off between optimal savings and flexibility and inventory levels, we recommend the management of TKF to decide upon their preferred strategy concerning this trade-off.
- The last recommendation we have for TKF is to improve the database (structure) and data.

At last, we summed some aspects for further research. These aspects are:

- Enlarging the scope of the tool to all MTS articles
- Consider extra handling cost when external terrain is used.
- Add a constrain to the cost of capital (loan by TKH-group)
- Add the depreciation of cables
- Check the correctness of the used data from TKF's database

Table of Contents

Preface.....	i
Management summary	ii
Reader's guide	vi
List of Acronyms	vii
Glossary	viii
List of figures	ix
List of tables	x
1. Introduction.....	1
1.1 Company description.....	1
1.2 The problem	2
1.2.1 Problem identification.....	2
1.2.2 Action problem.....	3
1.3 Research design.....	6
1.3.1 Research questions.....	6
1.3.2 Deliverables	6
2. Literature review	8
2.1 Inventory policies	8
2.2 Periodic review inventory systems with a service level criterion	9
2.2.1 Service level.....	9
2.2.2 Demand distribution and mean demand	10
2.2.3 Lead time	10
2.2.4 Wilson's lot size formula	11
2.2.5 Review period length.....	11
2.3 Conclusion	11
3. Context analysis.....	12
3.1 Setup cost.....	12
3.1.1 Calibration and down-time cost.....	13
3.1.2 Waste of raw materials	14
3.1.3 Over-length.....	18
3.2 Inventory holding cost.....	18
3.2.1 Cost of capital.....	19
3.2.2 Cost of risk	19
3.2.3 Cost of handling and storage.....	20
3.3 Overview of inventory holding and setup cost	21
3.4 Demand distribution	22

4. Inventory model	24
4.1 Bijvank's algorithm	24
4.2 Adaptions to Bijvank's algorithm	25
4.3 Overview of the dashboard of the inventory model.....	26
5. Numerical results.....	27
5.1 Results of the inventory holding and setup cost model.....	27
5.1.1 Instrumentation process technique portfolio	30
5.1.2 Pipes, wires, and cords portfolio	30
5.2 Results inventory policy model	30
6. Discussion	34
6.1 Limitations	34
6.1.1 Overall	34
6.1.2 Input values	35
6.1.3 Optimal batch size model.....	35
6.1.4 Inventory parameters model.....	35
6.2 Validity and reliability.....	36
6.2.1 Validity.....	36
6.2.2 Reliability	38
7. Conclusion and recommendation	39
7.1 Conclusion	39
7.2 Recommendation	39
7.3 Future research	40
7.4 Contribution to theory and practice	41
7.4.1 Theoretical contribution.....	41
7.4.2 Practical contribution	41
References.....	43
Appendices	45
A. User manual tool.....	45

Reader's guide

Across the eight chapters, we describe how the research at Twentsche Kabelfabriek BV is performed. In this reading guide we shortly introduce these chapters.

Chapter 1: Introduction

In chapter 1 we introduce the research. This is done by describing the company, the problem and the research design.

Chapter 2: Literature review

In chapter 2 we link the problem with the literature. Moreover, we will provide insights in periodic review inventory systems with a service level criterion.

Chapter 3: Context analysis

In chapter 3 we perform a context analysis about Wilson's lot-size formula and the demand distribution. Wilson's lot-size formula and the demand distribution are necessary inputs for the inventory model which will be discussed in chapter 4.

Chapter 4: Inventory model

In chapter 4 we will discuss the chosen method for determining the inventory parameters for TKF. Also, the necessary adaptations to this model are discussed.

Chapter 5: Numerical results

In chapter 5 the results of the optimal batch size calculations model and inventory parameters model are discussed.

Chapter 6: Discussion

In chapter 6 a general discussion is provided which discusses the limitations, validity, and reliability of the methods used in the research.

Chapter 7: Conclusion and recommendation

In the first part of chapter 7 conclusions about the performed research are given. This includes an answer to the research questions and a discussion about the norm and reality. In the second part of chapter 7 recommendations are made for TKF. In the third part of chapter 7 future research is suggested. In the last part of chapter 7 the contributions to theory and practice are discussed.

List of Acronyms

Table 2 - List of acronyms

Acronym	Description
MTO	Make to order
MTS	Make to stock
TKF	Twentsche Kabelfabriek BV
BTO	Buy to order
BTS	Buy to stock
EOQ	Economic order quantity (also referred to as Wilson's lot-size formula)

Glossary

Table 3 - Glossary

Term	Explanation
Reel	“A cylinder, frame, or other device that turns on an axis and is used to wind up or pay out something” (<i>Reel Definition of Reel at Dictionary.Com</i> , n.d.)
Multiconductor department	Multiconductor is the department in TKF where the smaller types of cable are produced. To give an example, these are the cables which are used in houses.
Installation department	Installation is the department in TKF where the cables are produced for the building sector. The cables are therefore bigger, and this requires bigger machines, and therefore a different department.
Energy department	The energy department produces the biggest cables in TKF. These cables are produced for the energy sectors and can reach from subsea cables to high voltage cables.
Qualified team	Qualified team is the word TKF uses to indicate machine processes. MC ISOLATIELIJN 3 is an example of a qualified team.
Clustered order	Clusters are identical articles from a different order, scheduled behind each other so the machine does not have to be switched

List of figures

Figure 1 - Overview standard production process at TKF	1
Figure 2 - Overview of the problem cluster at Twentsche Kabelfabriek BV	3
Figure 3 - Overview of the combined cost of inventory and setup per meter per department and portfolio type.....	4
Figure 4 - Overview of the inventory cost per meter per department and portfolio type	5
Figure 5 - Overview of the setup cost per meter per department and portfolio type	5
Figure 6 - Overview of the inventory model	9
Figure 7 - Overview of optimal batch size calculation model	12
Figure 8 - Overview database joins for calculating calibration and downtime cost	13
Figure 9 - Overview database connection for determining extruder waste	17
Figure 10 - Overview of dashboard setup and inventory holding cost	21
Figure 11 - Demand pattern of a cable.....	23
Figure 12 - Negative binomial distribution with varying success probability (UCSF, n.d.).....	23
Figure 13 - Negative binomial distribution with varying number of failures until the experiment is stopped (UCSF, n.d.).....	23
Figure 14 - Overview of Bijvank's algorithm (Bijvank, 2014).....	24
Figure 15 - Overview of the inventory model dashboard	26
Figure 16 - Reality MTS without filter	27
Figure 17 - Reality MTS department filter.....	27
Figure 18 - Reality MTS portfolio filter (part 1)	28
Figure 19 - Reality MTS portfolio filter (part 2)	29
Figure 20 - Differences between the filters.....	30
Figure 21 - Visualization of the difference between EOQ and current situation	31

List of tables

Table 1 - Overall results when the inventory levels are implemented as suggested by the tool	iii
Table 2 - List of acronyms.....	vii
Table 3 - Glossary	viii
Table 4 - Rule of thumb for selecting the form of the inventory policy (Silver et al., 2017).....	8
Table 5 - Method for determining the service level.....	10
Table 6 - Overview of the calibration and downtime cost	14
Table 7 - Overview of the switches for Multiconductor.....	14
Table 8 - Overview of the links between waste place codes and production places.....	15
Table 9 - Overview of the waste place codes and waste places names.....	16
Table 10 - Overview of the waste types	17
Table 11 - Overview of the waste table by Installation.....	18
Table 12 - Overview of the raw material cost per switch per production process.....	18
Table 13 - Depreciation of the specific reel types	20
Table 14 - Cable cost price surcharge percentage for insurance tax cost.....	20
Table 15 - Overall results when the inventory levels are implemented as suggested by the tool	32
Table 16 - Largest savings according to the proposed inventory parameters	33
Table 17 - Inventory holding cost in practise by 1Cory Lynn Harms, Iowa State University (Harms, 2001) and 2Dr. Jim Weber, Weber Consulting (Russell, 2017)	37
Table 18 - Impact of different inventory holding costs on results	37

1. Introduction

In this chapter, the company will be introduced in subchapter 1.1, the problem will be introduced in subchapter 1.2 and the research approach will be discussed in subchapter 1.3.

1.1 Company description

My bachelor thesis takes place at Twentsche Kabelfabriek BV (TKF). TKF is a cable manufacturing company which developed itself since its founding in 1930, from cable manufacturer to a technologically leading supplier of connectivity solutions. They have a broad portfolio of cables, services, and systems. TKF offers customers worldwide solutions for creating reliable and safe data and energy connections. These solutions are delivered to three market segments which are the building, industrial and telecom segment (Twentsche Kabelfabriek, n.d.). At the moment, TKF produces more than 10.000 cables which are produced according to make to order (MTO) and make to stock (MTS). The production of these cables is divided over the factory in three departments: Multi Conductor, Energy, and Installation. This division is based upon the use and thickness of the cable. Since all these cables are made for different uses, they require different material requirements. Therefore, a lot of different production processes are performed. However, to illustrate an idea, the most standard production process is described, see Figure 1. Most of the time the process starts with large reels of thick copper wire. These wires then go into a wire drawing machine which makes sure the right thickness is reached. Then the wires are getting their isolation layer for protection and conduction. They are now called “conductors”. Most of the cables have multiple conductors inside them and to make that happen a gathering and braiding process is performed. To make sure that the cables are strong and not vulnerable they are also armoured by adding an extra layer of metal around it. This also makes sure the core of the cable stays in place and sometimes for neutralising the magnetic field. Finally, we come to the last step in the production process, which is the mantling process. This step is necessary for preventing dirt and water from getting into the cable and seals the cable from the outside. After this is finished, the cable gets extensively tested for quality and when it suffices it will be transported to the customer.

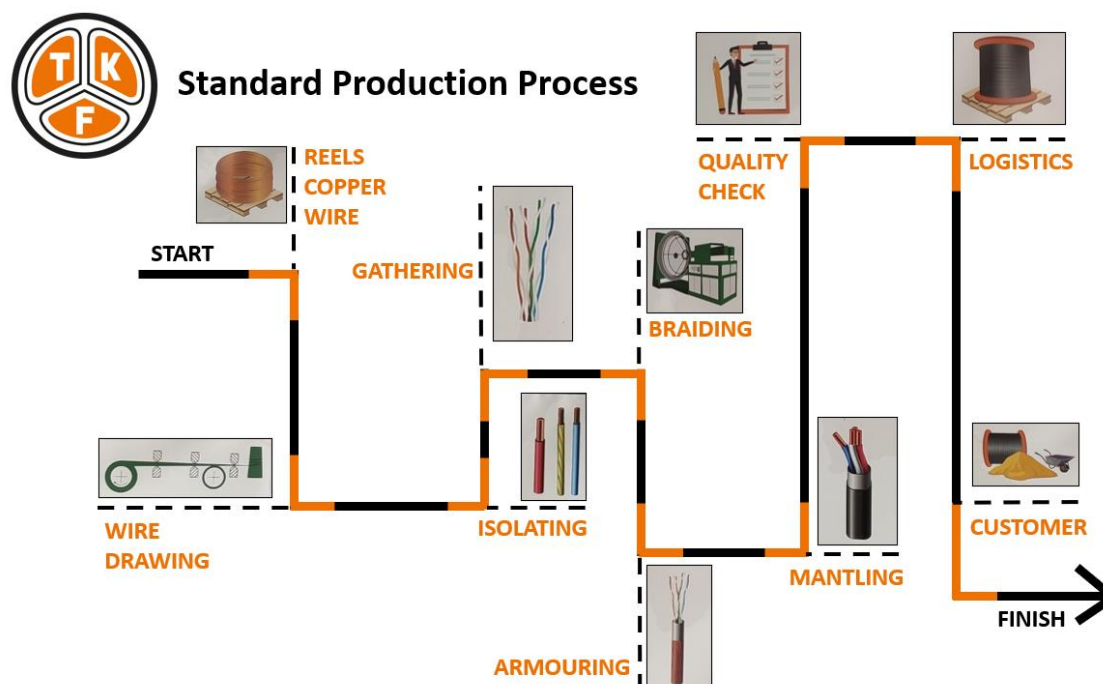


Figure 1 - Overview standard production process at TKF

TKF is part of the TKH Group. The TKH Group is a technology company which focusses on high-end innovative technologies in high growth markets within these three market segments. TKH Group is active on a global scale and their growth is concentrated in North America, Asia, and Europe (TKH Group, n.d.).

1.2 The problem

At the start of the research, TKF was experiencing a problem. This problem will be elaborated in this subchapter. We will do this by identifying the problem in subsection 1.2.1 and defining the action problem in subsection 1.2.2. Besides the action problem, also the norm and reality, and the scope will be described in subsection 1.2.2.

1.2.1 Problem identification

The management of TKF want to manage the inventory and cable production as efficiently as possible and this puts large pressure on the capacity and production planners. Next to this, the combined inventory holding and setup cost are high and reasons for this should be investigated. As problems always arise from an underlying cause, a problem cluster is made to map all the problems involved (Heerkens & van Winden, Solving Managerial Problems Systematically, 2016). This problem cluster can be seen in Figure 2. After doing research, it became clear that the underlying problem was no approach for the optimal batch size. This was our starting point for the problem identification phase.

The reason for the high combined cost of inventory holding and setup is the bad alignment between inventory holding and production cost. This is caused by the current method used for batch size planning. This method uses the insights of the production planner as well as the stock level parameters but lacks insight on the impact of the batch sizes. Therefore, the current method does not give the optimal batch size. This leads to higher production and/or inventory holding cost. The stock level parameters are set by the capacity planner and help the production planners to produce more efficiently. These parameters are called the red line, and the green line. The red line is the inventory level that should be kept at stock. This is determined based on agreements with sales and the safety stock. The safety stock is based on production lead time and sometimes the lead time of the raw materials if they are not kept in stock. The green line, however, is the maximum allowed inventory level. This is determined based on intuition, but ideally this must be based on the optimal batch size plus the red line value. Since this is not the case, the production planners must fill in this gap themselves and this is done based on their own insights. These insights are therefore not only different per department but also dependent on who the production planner is. The most influencing aspect for this is their experience and is caused by the absence of a standard method for determining the production batch size. So, an efficient production and inventory system highly depends on the experience of the planners. For the multi conductor department, this insight is based on the reels used to roll the output product on. For the installation department, this insight is based on the reels used for the input materials (mainly copper). However, these insights are also based on the awareness that producing more leads to a better production price, so they often round the production batch size up. Therefore, it can be said that the current batch size determination is not working optimally, and this should be changed by introducing a standard batch size method. The reason why there is no standard production batch size method is because there is no insight in the setup cost, as well as the inventory cost. There is no insight in the setup and inventory handling cost because they are hard to determine in practise (Durlinger, 2014). This is the case because it can not directly be derived from the financial statements of the company. Because of this, relevant costs need to be identified by us and then be calculated. This will be discussed in chapter 3 context analysis. Next to the beforehand described difficulties, there is also limited literature about this subject because of the difficulty of the subject as well as the fact that it is not generalisable. This latter is the case because it is highly company specific situation. Therefore, we also do not have insight in the effect of the different batch sizes.

Problem cluster

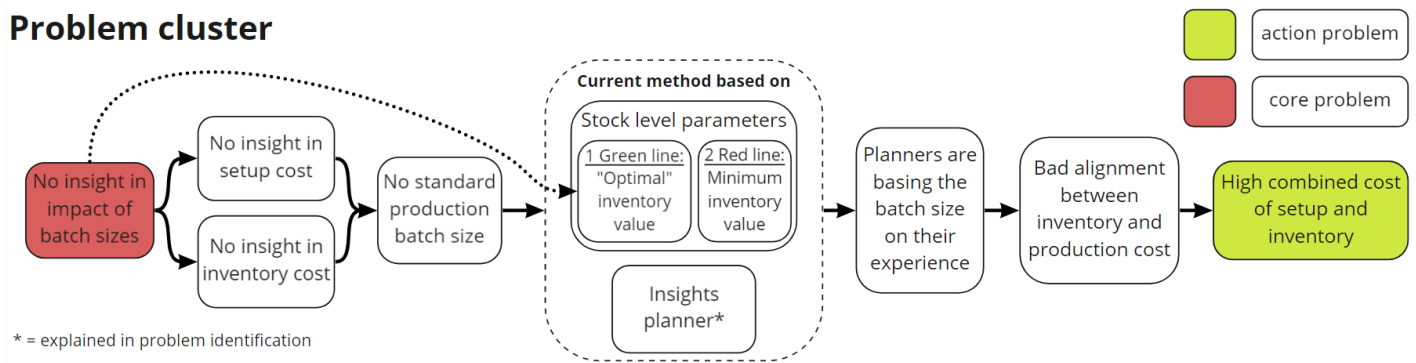


Figure 2 - Overview of the problem cluster at Twentsche Kabelfabriek BV

1.2.2 Action problem

The action problem is described in this section, by first defining the current situation and scope, and subsequently the norm and reality.

Current situation and scope

The bachelor thesis must be completed within 10 weeks. Since these strict time limitations, a clear scope must be set to enable an efficient and achievable research. After discussing this with TKF, the following scope was set:

- Only for the MTS standard end articles the optimal batch size decision (and inventory parameters) will be investigated. Therefore, if we refer to an MTS article in this report it will always be an end product. This is done because these products have the highest priority for TKF and should therefore be investigated first. The result of this is that number of cables is limited from 10.000 to approximately 900. This also makes sure that most of the cables are at least comparable to each other. In other words, they could differ in thickness and materials, but are not that different in the production process. Therefore, assumptions about for example setup waste could more easily be made.
- As I already mentioned, most of the 900 cables are comparable but not all. Therefore, all products are analysed, and a prioritisation has been made. In this analysis 40 cables are identified that needed special care in terms of waste assumptions. These cables are part of the energy department. The other cables are part of the installation and multiconductor department and are comparable. Therefore, first the assumptions for the large group of cables will be made. Then these will be evaluated and discussed with the manager of energy, to see if different assumptions should be made or if they are also applying for these types of cables. However, when there is no time for this evaluation these cables will be left out entirely.
- Lastly, from the 860 cables that are left approximately 200 are managed by the expedition instead of a manufacturing department like multiconductor, installation, or energy. This of course has a reason and will be described here. The cables that are managed by expedition, are all mother cables. These are cables which could be manufactured to different article numbers and therefore different end products. The difference between these end products is mainly created by the different lengths of the cables as well as the reels they are rolled on. Since this process is performed by the expedition department it is not strange that they are also the manager of these type of products. However, due to the time constraint we could not include these articles since they require extra research. Therefore, they are left out. This brings us to a scope of around 660 products.

The main research question is therefore defined as:

How can the batch ordering decision optimally be determined and what is the impact of the optimal batch ordering on the combined cost of production and inventory?

This led to the following action problem:

At Twentsche Kabelfabriek BV, a method must be created that determines the optimal batch in order to optimise the combined cost of production and inventory.

Norm and reality

To see if solving the core problem really helps by solving our action problem, it should be expressed in terms of norm and reality. The action problem “high combined cost of setup and inventory” is, however, currently not measurable due to a lack of insights. In addition to that, determining the setup cost and inventory holding cost has been proven to be difficult. For this reason, the norm and reality could only be set after a method for determining it was created. The reality is created by calculating the setup and inventory holding cost for the MTS products defined in the scope. Therefore, the latest MTS products according to these criteria should be identified. These then needed to be put in our model, so the setup cost could be calculated. At last, the results were printed in a table and saved so they could be used for analysis of the reality. Now the second part of the reality needed to be calculated. This is the inventory holding cost. For the inventory holding cost, a database join had to be made between the production order line table and the article table. Here, a filter was added on department to make sure only the articles that are defined in the scope will come out. Then the production length over the last period is retrieved. With this information, the average production length is calculated. The production lengths with a value of zero are eliminated because these will negatively influence the average while these are not relevant, because they have not been produced. Now that the average production length per article number is known it can be used to calculate the inventory holding cost per article number. By running this for all the relevant MTS articles, the reality could be created. This is displayed in multiple graphs as can be seen in Figure 3, Figure 4 and Figure 5.

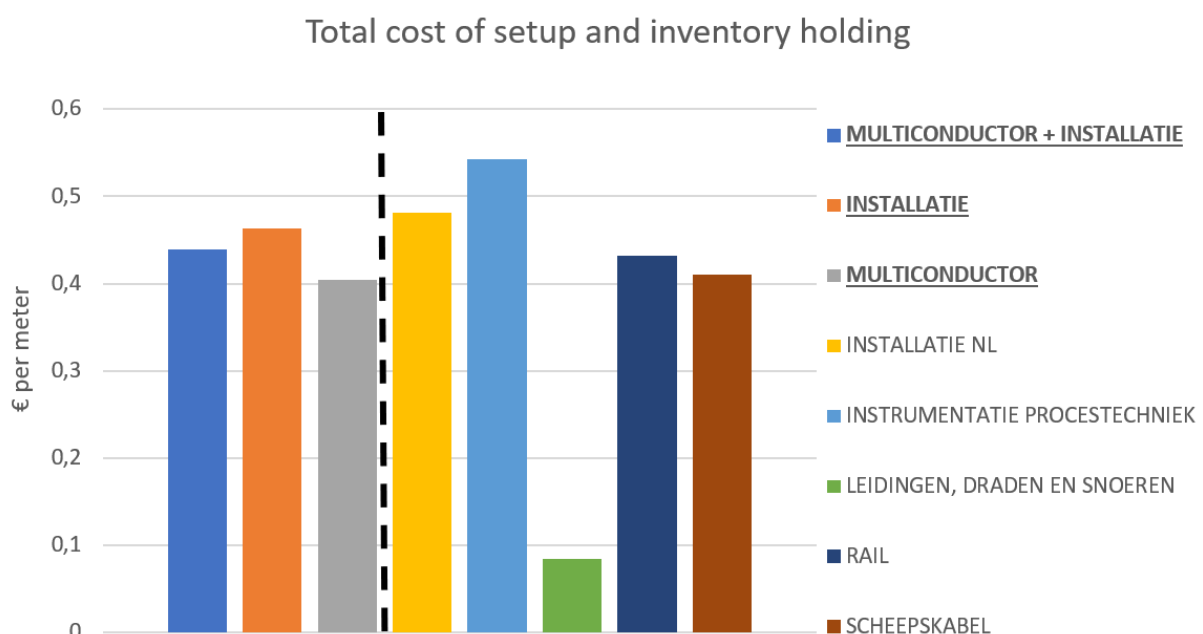


Figure 3 - Overview of the combined cost of inventory and setup per meter per department and portfolio type

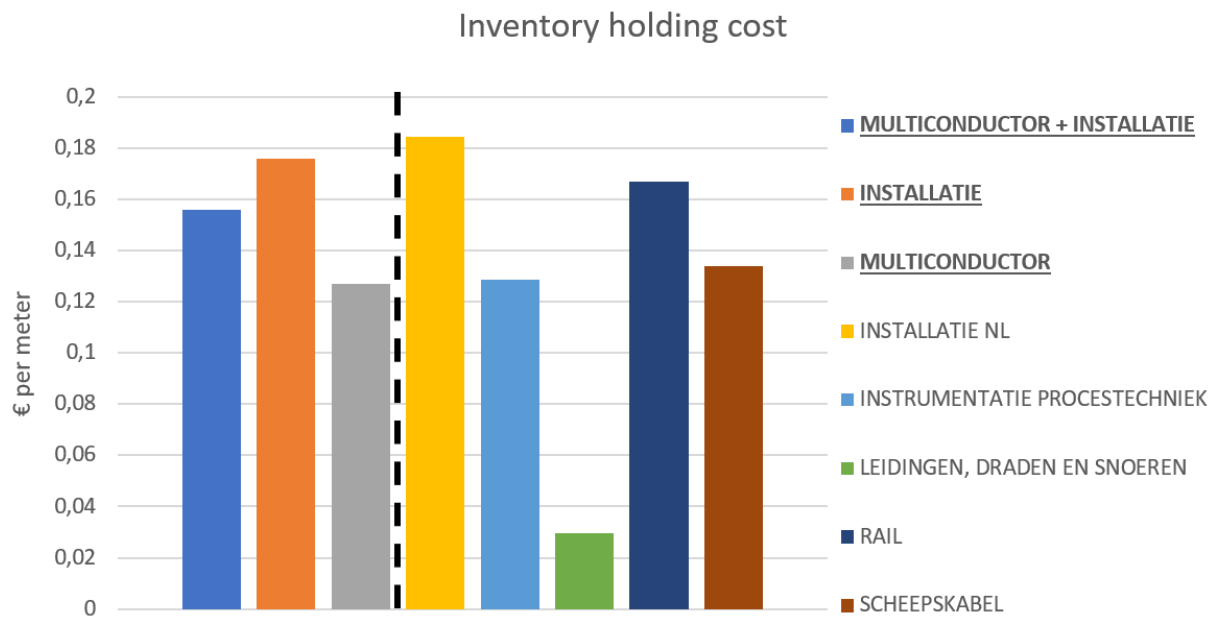


Figure 4 - Overview of the inventory cost per meter per department and portfolio type

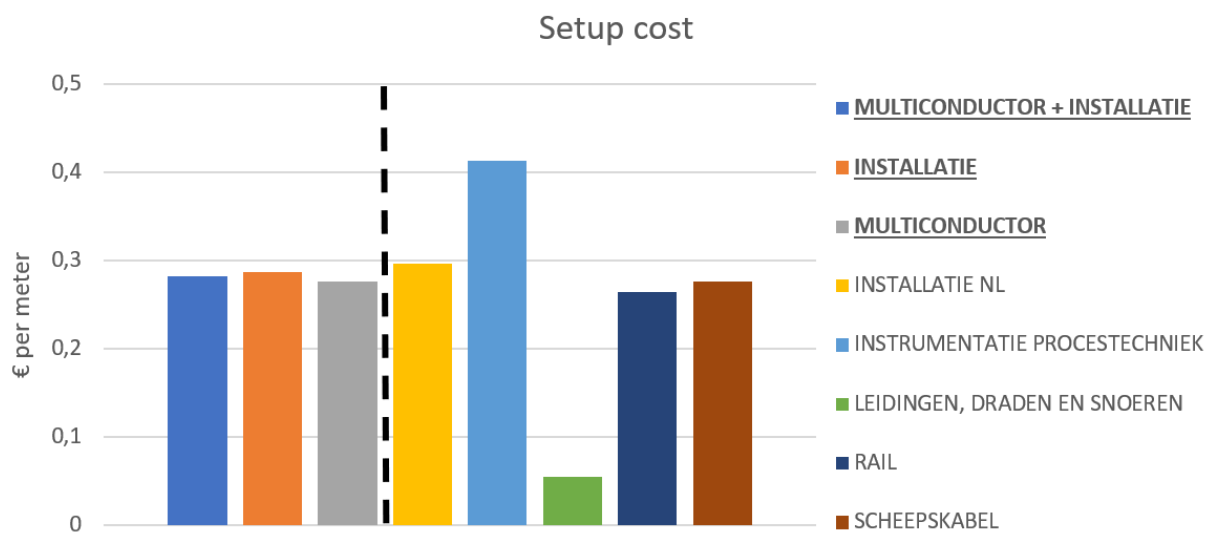


Figure 5 - Overview of the setup cost per meter per department and portfolio type

On the left side of the figures, the average for the installation and multiconductor department as well as the overall average can be seen. These departments handle different type of cable portfolios and to make the differences between them more visible, a distinction between the portfolios is made. The largest deviation is caused by the “pipes, wires and cords” portfolio. Next to that, the total cost for the portfolios “Installation NL” and “Instrumentation process techniques” are above average. While the portfolios “Rail” and “Ship’s cable” are under average. At last, the observation is made that the inventory holding cost per meter are higher for multiconductor than for installation. While the setup cost per meter is higher for the installation department. This is not surprising, because there are on average more qualified teams involved with producing installation cables which causes the higher setup cost. For the higher inventory cost of multiconductor, the reason is due to the standard reel it is rolled on. Most of the time, the clients want them in a shorter length (so smaller reel), which take more space per meter of cable than the larger reels and that makes them more expensive to hold in inventory. As could be concluded from this, the total cost of inventory and setup is deviating a lot from each other and therefore hard to make it portfolio or department specific. Therefore, the management

of TKF decided that the aim is to reduce the combined cost in total by 5%. Another reason why they chose for this is because TKF did not have an insight in the setup cost and inventory holding cost which makes it hard to decide on, because we could not track the trend it has been following through the years. The last insight in the current situation we found was the average production length for our scope. This is 4518 meter and is useful to compare the results of the models with.

1.3 Research design

To solve the action problem, the seven phases of the MPSM will be used. This tool is developed by Heerkens and van Winden (2021) and designed to create a structured problem-solving approach. The research questions created by this approach can be read in subsection 1.3.1. Then, in subsection 1.3.2 the deliverables could be found. The limitations of the research design are described in chapter 5.

1.3.1 Research questions

Based on the phases described in the MPSM, we came up with knowledge questions. These need to be answered step by step to come up with the solution in the end. Phases 1 and 2 (defining the problem and formulating your problem-solving approach) are already performed as preparation phases for the bachelor thesis and therefore not relevant anymore. Therefore, these questions are left out.

Phase 3: Analysing the problem

- 1) What factors influence the core problem? (*Chapter 1 Introduction*)
- 2) How can the inventory cost be determined per production length? (*Chapter 3 Context analysis*)
- 3) What factors influence the production cost and how can they be determined per production length? (*Chapter 3 Context analysis*)
- 4) What is the norm and reality of the inventory and production cost? (*Chapter 1 Introduction*)

Phase 4: Formulating (alternative) solutions

- 5) What theories could determine the optimal production batch size with stochastic demand and what pros and cons do they have (with respect to risks, uncertainties, consequences, limitations, and benefits)? (*Chapter 2 Literature study*)

Phase 5: Choosing a solution

- 6) What is TKF's preference in terms of theories for determining the optimal batch size based on the obtained insights about the presented theories? (*Chapter 2 Literature study*)

Phase 6: Implementing the solution

- 7) How can the theory be implemented for TKF? (*Chapter 4 Inventory model*)
- 8) Which data does the theory require for execution and how can this data be obtained? (*Chapter 2 Literature study & Chapter 4 Inventory model*)
- 9) Does the Excel model take the requirements and wishes of TKF into consideration? (*Chapter 6 Discussion*)

Phase 7: Evaluating the solution

- 10) Are the solutions applicable in practise? (*Chapter 5 Numerical study*)
- 11) Does the solution have the desired results or in other words, is the norm reached? (*Chapter 7 Conclusion and recommendation*)
- 12) Can the model be improved? (*Chapter 6 Discussion & Chapter 7 Conclusion and recommendation*)

1.3.2 Deliverables

Together with Twentsche Kabelfabriek, the main deliverable has been defined as:

“A method, where the optimal batch size decision and inventory parameters for MTS products can be determined”

This deliverable depends on three important factors. First, insights in the factors influencing the optimal production batch size should be obtained. This is part of the core problem. Secondly, a method to use these insights to define the optimal production batch size should be obtained. Thirdly, a method needs to be implemented in Excel tool which uses the optimum production batch size to calculate the corresponding inventory parameters. This was the most important requirement of TKF. Other requirements were:

- easy in interpretation
- user friendly
- easy to maintain
- connected with the ERP data system of TKF which is Citrix/ Navision.

The reason why it should be easy in interpretation, is because all involved stakeholders: finance, supply chain, production, R&D, and sales, must understand what the results of the tool are without having to discuss about the interpretation. So therefore, a clear tool must be provided. The easy to maintain requirement is mainly for the capacity planner. He is going to use it to determine the maximum inventory level, but it is highly probably that he finds certain things he wants to add to the tool and therefore this should be possible and easy.

2. Literature review

For coming up with a solution, it is important that a theoretical perspective is created first. Therefore, this will be done in this section. To come up with a good theoretical perspective, an extensive systematic literature review (SLR) is performed. The results of this are discussed in this chapter. Next to that, the link between the problem and the literature will be explained. In subchapter 2.2, the inputs for the chosen model will be evaluated. The implementation and the results of this model will be discussed in later chapters (chapter 4 and chapter 5). At last, in subchapter 2.3 a conclusion will be given which summarizes this chapter.

2.1 Inventory policies

Determining only the optimal batch size decision is not enough to guarantee the best possible cost while maintaining a certain service level. Therefore, a research is performed to inventory policy models and system requirements to fulfil TKF's assignment as good as possible. In (Silver et al., 2017) the four most common inventory policy are described. These are the (s, Q) inventory system, (s, S) inventory system, (R, S) system and the (R, s, S) inventory system. The (s, Q) inventory system is a policy which orders Q units every time the inventory level drops below s (reorder point). The (s, S) system on the contrary also orders when the inventory drops below s but will always order up to the predetermined S (order-up-to-level). Then we have the (R, S) policy. This policy is also known as the replenishment cycle system and orders every R units of time as much inventory as needed to raise the inventory to S . At last, we have the (R, s, S) policy. This policy is a combination of the (s, S) and (R, S) policy. With this system we check every R units of time the inventory level and when it is below s , we raise it to S . Since these inventory policies all have their pros and cons, (Silver et al., 2017) created a rule of thumb to determine the most suitable for the situation. This could be seen in Table 4.

Table 4 - Rule of thumb for selecting the form of the inventory policy (Silver et al., 2017)

	<i>Continuous Review</i>	<i>Periodic Review</i>
A items	(s, S)	(R, s, S)
B items	(s, Q)	(R, S)

As could be concluded from this rule, the most suitable policy for TKF will be the (R, s, S) policy. Reasons for this are that they already use a periodic review policy as well as the priority system for the articles. As defined in the scope, we will focus on the highest prioritized items, so A items. In literature, full-cost inventory models are studied the most. However, service level constraints are more common in practical settings. This is the case because shortage costs are hard to determine. In particular, the cost of losing customer goodwill (Bijvank, 2014). Therefore, alternative methods should also be considered. In literature the following are identified: simple-minded approach, customer service level, and aggregate considerations. Examples of simple-minded approaches are specified cost for stockout or equal time supplies. For customer service level examples are probability of no stockout per cycle, fill rate, and ready rate. Aggregate consideration examples are minimizing the ETSOPY or the ETVSPY (Silver et al., 2017). Computing these inventory control variables can be divided in two categories: heuristics and exact methods. Most studies in the second category derive most of the time bounds to reduce the search space. The actual algorithm is most of the time either iterative or enumerative (Silver et al., 2017).

For TKF, this (R, s, S) policy will have to deal with lead times, stochastic demand, and the alpha service level. This is the case, because TKF, has to deal with production times. Therefore, after an order is placed, it will not be delivered immediately. So, this needs to be considered by determining the inventory policy. Next to that, the demand TKF is experiencing is not according to a constant distribution but follows a different pattern. Hence, this should be modelled as good as we can to make

sure the service level is satisfied. Lastly, TKF chose the alpha service level as criteria for the inventory policy. The alpha service level is an easy but powerful indicator that makes sure that TKF delivers up to their promises made with the client. More information on this will be provided later in this chapter. When all these factors are taken into consideration, TKF wants to set the parameters of this inventory policy in such a way that it optimizes the total cost. In this situation it could be the case that Wilson's lot size formula satisfies the criteria and actually gives a good optimum, but it could also be that fixing one of the parameters does not lead to the most optimal solution. Therefore, the decision is made to look for a method that does take this into account. This was the starting point of the systematic literature review. The only paper that included all these criteria was the paper of Bijvank (2014). His paper provided a search procedure that determines s and S based on the exact expression, which makes sure the service level always suffices. Besides that, he created an efficient search procedure which is able to minimize the costs according to the service level criterion. Since he does not impose any limitations on s or S , the solutions are also applicable to more general settings if compared with other approaches found in literature. While doing this, the model also delivers the best solution compared to the other literature. It outperforms them in both service level and cost. The only limitation that was found, is the fact that it is a single item/ one-dimensional search procedure. Therefore, the production constraints and other articles are not taken into consideration. The impact of this will be discussed in the limitations chapter.

2.2 Periodic review inventory systems with a service level criterion

For using this model, certain key aspects are required and will be discussed here. This is the service level requirement, demand distribution and mean, lead time, Wilson's lot size formula, and the review period length. The overview can be seen in Figure 6.

Inventory model

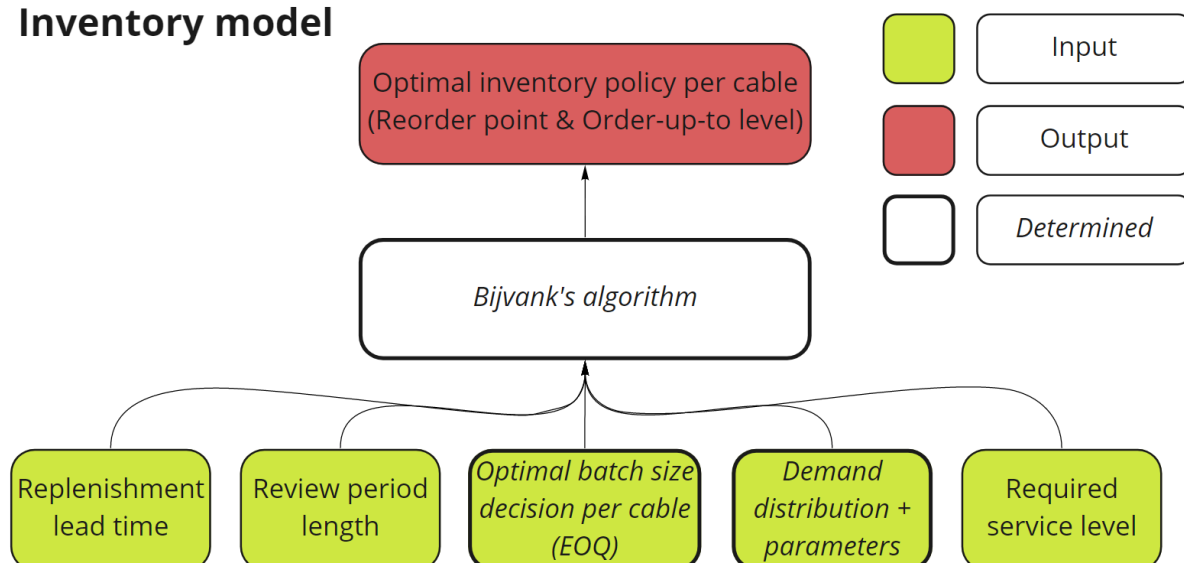


Figure 6 - Overview of the inventory model

2.2.1 Service level

The service level is at this moment a very popular topic within TKF. This is caused due to the production capacity constraint versus the high demand of their customers. Of course, you do not want to disappoint anyone, but some customers or cables are more important than others. Now, the question arises how to determine which of these cables has the highest priority to ensure the best service and profit. This is quite hard and TKF is therefore busy with developing such a system that divides the subgroups (MTS-A, MTS-B, and MTS-C) in even smaller groups with their own specified service level. It seems very likely that TKF is going to choose for a 2-axis system. However, the criteria are not certain

yet. This is also the case for the service levels corresponding to the specific groups. An example of such a system is given in Table 5. Since TKF is still deciding upon this decision and we already defined a group of important articles, the decision from the management of TKF is made to set a 95% service level for all articles defined in the scope. It should, however, be possible for TKF to implement the new service level system in the tool if such a system is chosen.

Table 5 - Method for determining the service level

# of order lines	X	98%	96%	94%
	Y	96%	94%	92%
	Z	94%	92%	90%
		A	B	C
		Revenue		

2.2.2 Demand distribution and mean demand

For determining the demand distribution of a certain cable, the data for the previous 14 months is retrieved from the database. Then a variance to mean ratio (VMR) is used to test the characteristics of the distribution. The VMR is calculated by dividing the variance over the mean (*Variance/Mean Ratio* - *Statistics.Com: Data Science, Analytics & Statistics Courses*, n.d.). If the distribution is for example more uniform than randomly distributed, then the VMR is smaller than 1. This could indicate a constant random variable for $VMR = 0$ or a binomial distribution if $0 < VMR < 1$. When the distribution is random, it can be modelled by a Poisson process (if $VMR = 1$) or a negative binomial if $VMR > 1$. In our case the $VMR > 1$ and therefore hints to a negative binomial distribution (Bijvank, 2014). To make sure this is a good way of modelling the demand, a literature search has been performed. In this search, it was found that the negative binomial distribution is an efficient distribution which represents the high variability in demand well for retailing environments. This high variability in demand is caused due to competitors' promotions, weather, and other random fluctuations. Therefore, using the negative binomial distribution for the inventory policy will lead to lower cost and more reliable levels of customer service (Agrawal & Smith, 1996). Next to that, a $VMR > 1$ means that the demand distribution has "over-dispersion". This arises when demand is "aggregated", "clumped", and "clustered" in space or time. From literature it is known that the negative binomial distribution models this appropriate (Ross & Preece, 1985). Parameters from the negative binomial distribution are the r (sometimes called n), which represents the number of failures until the experiment is stopped, k , which represents the number of successes, and p , which is the success probability in each experiment. These parameters could be calculated with the mean and the variance of the sample. The mean equals $(p * r)/(1 - p)$, while the variance equals $(p * r)/((1 - p)^2)$ (Agrawal & Smith, 1996). These calculations and extra explanation about the distribution and parameters can be found in chapter 3. The algorithm, however, can be found in chapter 4.

2.2.3 Lead time

In inventory policies, multiple assumption about lead time can be made. Examples for this are zero lead time, a fixed lead time, or a stochastic lead time. In TKF's case fixed values are used for lead time and these values differ per article depending on the production process. Since TKF is also using this

number for their models, I decided with my supervisor to use the same values for my model. However, if this would not be the case the model remains the same if it is stochastic, provided that the probability of crossing orders in time is negligible. If this would not be the case more advanced techniques have to be used such as simulation (Bijvank, 2014).

2.2.4 Wilson's lot size formula

Another input needed for determining the parameters of the inventory policy, is Wilson's lot size formula. Wilson's lot size formula is also known as the EOQ model and calculates the optimal batch size. Wilson's formula is expressed as $\sqrt{2K\mu_R/h}$ rounded to the nearest integer. It uses the parameters K , which equals the setup cost, μ_R , which is the mean demand during the review period, and h , which is the inventory holding cost per meter of cable. While this seems like an easy formula to compute it is quite hard due to the difficulty of determining the setup and inventory holding cost. For this reason, the way how this is done is explained in chapter 3, context analysis.

2.2.5 Review period length

As last input variable, we need the review period length. The review period length is determined by TKF based on the planning strategies, this can be MTO, MTS, BTS, and BTO. The make-to-order (MTO) as well as the buy-to-order (BTO) are both triggered when an order comes in, so there is no need to review it during specified time intervals. Therefore, these are left out. However, TKF makes a clear distinction between the buy-to-order and the make-to-order articles. The BTS products are reviewed once every two weeks, so $R = 14$ (days). The MTS products are reviewed every day by the production planners which makes the $R = 1$ (days). As defined in the scope, for my research it is only necessary to look for the MTS products, so therefore the R will always be equal to one.

2.3 Conclusion

In literature, there are many different inventory parameters that suit different situations the best. According to rule of thumb created by Silver et al. in 2017, the (R, s, S) policy is suiting TKF the best. Therefore, this was our starting point for the systematic literature review. Within this search we discovered that TKF had some other requirements that were needed in addition to this (R, s, S) policy. These were the production lead time, demand uncertainty, service level agreements with the customer and inventory review period. The only paper which satisfied all these criteria was Bijvank's algorithm. He created a cost-effective and efficient algorithm which uses the input values: service level, demand distribution, lead time, Wilson's lot-size formula (EOQ), and review period length to determine the optimal inventory parameters.

3. Context analysis

TKF wants to be as cost efficient as possible while being able to serve their customers with a specific service level. Factors to take into consideration for this are demand distribution, Wilson's lot size formula (optimal batch size), review period length, and replenishment lead time. Because not all factors are known, these need to be calculated. However, due to interdependence of the parameters of the inventory system, it is desirable to determine them simultaneously. Since this is already a topic on itself, we chose to devote a separate chapter for discussing this (chapter 4). This chapter will focus on the parameters needed for determining Wilson's formula and the demand distribution. For Wilson's lot size formula, two parameters are necessary. These are the fixed setup cost and the inventory holding cost per meter. This is the case because when determining the optimal batch size, you have to make the trade-off between gaining production advantage by producing more against the extra cost of holding more inventory. This chapter is structured as follows: in subchapter 3.1 the fixed setup cost will thoroughly be described. In subchapter 3.2 the inventory holding cost per meter will be discussed. In subchapter 3.3 the dashboard of the setup and inventory cost will be provided and discussed to create a clear and structured overview. In subchapter 3.4 the demand distribution will be covered. An overview of the entire context can be seen in Figure 7.

Optimal batch size calculation model

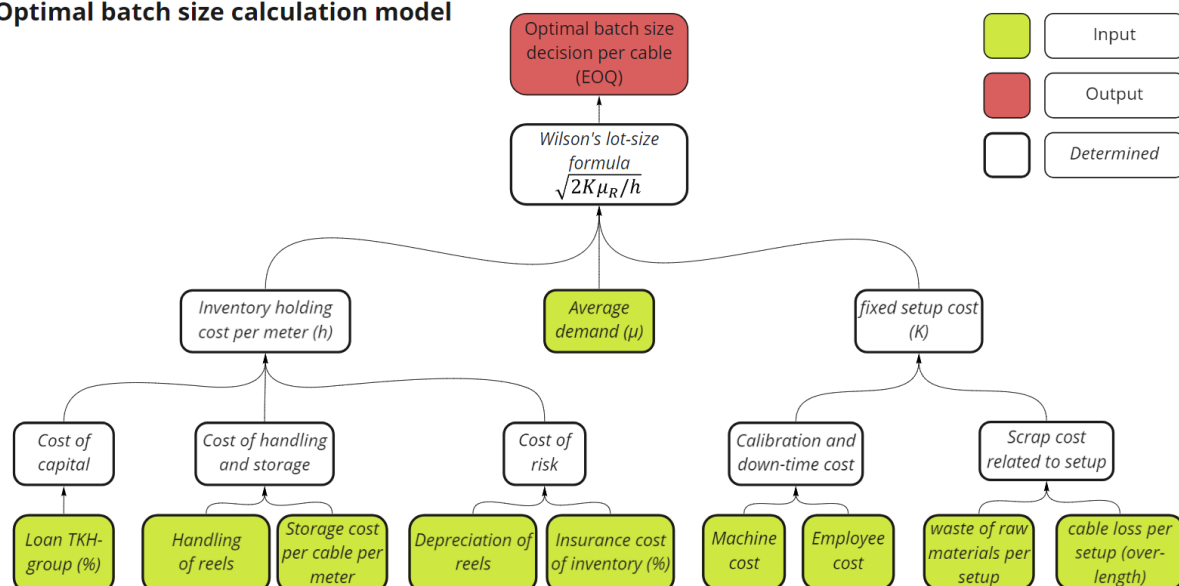


Figure 7 - Overview of optimal batch size calculation model

3.1 Setup cost

According to literature the setup cost includes costs such as calibration cost, down-time cost, and scrap costs associated with the preparation of the equipment to produce the next cable (Reid & Sanders, 2005). These will be discussed below, but first the reasons why they are relevant will be described. When considering setup cost, we are specifically looking for costs which are related to the setup of the machines. These costs are therefore independent of the production length and are fixed. The calibration and down-time cost are fixed, irrelevant to production length and caused by setups. Therefore, they are necessary to take into consideration. Then we have the waste of raw materials. Although this sounds like it is dependent on the length of production, there is also a component in it which should be considered in the setup cost. The reason for this is because the hot processes like mantling and isolating involve materials that are supplied by extruders due to their high volume. If it is then decided to setup for another cable, the materials in the extruder are thrown away. This is independent of the length and therefore important to take into consideration when determining the setup cost. The last important factor are the costs involved with over-length. Over-length is the extra

length that is necessary as input for a production process, that will go lost in the process because the process is starting up and therefore not producing the quality or thickness that is required. In TKF's situation, this is measured per reel of input material because most of the time when the reel of input material is empty it needs to be switched and the machine then needs some time before it reaches the required thickness and quality again. When the production lengths get longer, the more often the reels with input material needs to be switched and that makes it related to the production length and not necessary for a setup cost. However, when a setup is incurred, the machine always needs to warm up for the first reel. Therefore, the first reel does need to be included for setup cost.

3.1.1 Calibration and down-time cost

The calibration and down-time cost can be treated as one cost consisting of machine cost and employee cost. For each qualified team, a specific down time for calibration and cleaning is reserved. This down time is calculated in the past based on experience and can be found in TKF's database. Due to time limitations, the validity of these numbers can not be checked, but this will be discussed in chapter 6. The downtime for the machines is associated with lost production hours (also called machine cost) and employee cost for preparing the machine for production. Due to the fact that multiple qualified teams are involved by producing a cable, the right connections should be identified first in the database. This is done to make sure all qualified teams come up when you add an article number. The overview of this database query is given in Figure 8.

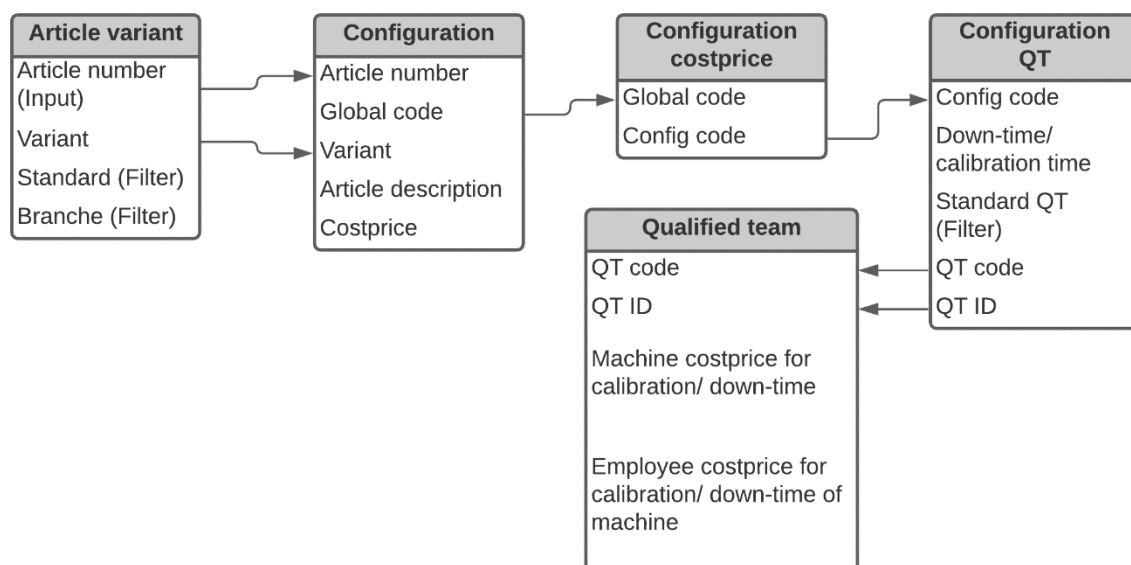


Figure 8 - Overview database joins for calculating calibration and downtime cost

As can be seen from this figure, the article number is the input, so our starting point. The reason why this one is chosen as starting point is because TKF wants a solution which is product specific. Therefore, the information should be acquired per product. Then with the use of filters on standard production methods as well as a filter on branch, we will get the standard variant. We chose for this because the other variants are most of the time tests of R&D or old manufacturing methods and are not used very often in practice. Then this article number in combination with the variant will be used in the configuration table for getting the global code, article description, and the cost price. The global code is then used for making the connection with the specific config codes used during the process. This will then be linked to the QT code and ID as well as the downtime and calibration time. Here again a filter is applied. This time on standard QT. This makes sure that we use the best and most realistic production method. Then the link with the last table is made. This is to acquire the last data which is necessary for

calculating the downtime and calibration cost. The machine cost for calibration and downtime can be calculated by multiplying the calibration and downtime for a machine (in minutes) with the cost price. The employee cost however needs an additional step. There the number of employees working on the calibration will be multiplied with the cost of calibrating the machine and multiplying that with the calibration/ downtime (in minutes). The outcome of this can be seen in Table 6.

Table 6 - Overview of the calibration and downtime cost

ID	Global Code	Article number	Description	Costprice	Config. code	Description QT	QT ID	EMPLOYEE COST CALIBRATION/ DOWNTIME	MACHINE COST CALIBRATION/ DOWNTIME	Calibration/ downtime (minutes)
CONF149469-Samenslag uitgebreid	CONF149469			0,016	CONF149469	Samenslag uitgebreid	QT311	32,5875	62,475	70
CONF149469-Vullen/mantelen	CONF149469			0,0502	CONF149469	Vullen/mantelen	QT069	130,395	57,9375	40
CONF149469-Keuren	CONF149469			0	CONF149469	Keuren	QT179	0	0	5
CONF148492-Vuldraad spuiten	CONF149469			0,0194	CONF148492	Vuldraad spuiten	QT138	65,1975	46,5825	30
CONF142919-Isoleren	CONF149469			0,0038	CONF142919	Isoleren	QT023	65,1975	61,6425	15
CONF142923-Isoleren	CONF149469			0,0038	CONF142923	Isoleren	QT023	65,1975	61,6425	15
CONF142927-Isoleren	CONF149469			0,0038	CONF142927	Isoleren	QT023	65,1975	61,6425	15
CONF142931-Isoleren	CONF149469			0,0036	CONF142931	Isoleren	QT023	65,1975	61,6425	10
CONF142935-Isoleren	CONF149469			0,0085	CONF142935	Isoleren	QT023	65,1975	61,6425	90
C004174001-Draadtrekken	CONF149469			0,0856	C004174001	Draadtrekken	QT225	61,44	146,745	75
C004174001-Draadtrekken	CONF149469			0,0856	C004174001	Draadtrekken	QT225	61,44	146,745	75
C004174001-Draadtrekken	CONF149469			0,0856	C004174001	Draadtrekken	QT225	61,44	146,745	75
C004174001-Draadtrekken	CONF149469			0,0856	C004174001	Draadtrekken	QT225	61,44	146,745	75
C004174001-Draadtrekken	CONF149469			0,0856	C004174001	Draadtrekken	QT225	61,44	146,745	75

Not all calibration and downtime cost should be included. This is the case because TKF is showing multiple times the same wiredrawing processes. This is done to give insight in the number of cores within the cable. Therefore, it should only be taken into consideration once. The same applies for the isolating processes because we only switch the colour here. This makes the calibration and downtime cost negligible for that process. Therefore, if the QT ID is the same as the QT ID of the row before, the calibration and downtime cost should not be included.

3.1.2 Waste of raw materials

In contrast with the previous chapter, the waste of raw materials is way harder to calculate because they are not directly retrievable from the database. Therefore, the most important scrap processes must be observed and measured first. The most scrap occurs during the setup of the mantling and isolating processes (hot processes). These scrap cost can be divided into two categories. The first category is the amount of cable that is thrown away because it does not have the desired thickness or quality (starting loss). The last category is the waste that is left in the extruder after a production run. Most of the time this has to be thrown away and it therefore should be taken into consideration. The amount of waste will be determined by looking at the amount of extruder filling that is thrown away each week (measured by TKF) divided by the amount of production run switches multiplied by the price. Because TKF's databases do not keep track of the switches, we created a method for determining the switches ourselves. First, we determine the number of different productions orders that occurred in a certain period. Second, we look at the clustered orders in the same period. Thirdly, we determine the switches by taking the number of different production orders and decrease this by the number of switches. This needs to be done because in practice clusters are used to decrease the setup cost, because no switch is necessary. An overview for the results can be found in Table 7.

Table 7 - Overview of the switches for Multiconductor

Production place	Different Prod.Orders	Clustered Prod.Orders	Switches
MC ISOLATIELIJN 3	579	172	407
MC ISOLATIELIJN 4	558	212	346
MC ISOLATIELIJN 5	137	35	102
MC MANTELLIJN 1	516	39	477
MC MANTELLIJN 2	678	90	588
MC MANTELLIJN 3	233	33	200
MC MANTELLIJN 4	238	63	175

Because we want to avoid differences in booking time for the waste and finished production orders, we have to make sure that we calculate the switches over a sufficiently large period. The trade-off for this is that if you take a too large period your model calculation time increases significantly, so for this reason, half a year is chosen as a reliable number. Next to that, you do not want that a part of your

calculation is for example including the finished production orders, while the corresponding waste is not booked yet. This bookings date difference is caused by the fact that the waste is only booked when the container is full and can therefore take quite longer. To eliminate this, a filter is created which starts 40 days earlier and then takes a range of half a year. However, the half-year is a variable and could be adjusted by the user. Another filter that is added to this database search is to make sure it saves time and operates more efficiently. This is the production place filter. This filter makes sure only switches for relevant production places are calculated. The production place is seen as relevant if the amount of relevant waste is not equal to zero at this specific production place. To calculate the amount of relevant waste, the production places need to be linked to the corresponding waste places. Normally, this would be easy because the names of the waste places would correspond. However, this is not the case now because the layout of the factory as well as the name and type of production places has changed. Therefore, this should manually be connected and investigated. This is then also the limitation, because when the production places and/ or waste places change again, the model will not update this automatically and this should be taken into account. The results of this investigation are given in the tables below.

Table 8 - Overview of the links between waste place codes and production places

Code	Omschrijving	Nr.	Afdelingnr.	Code	Omschrijving	Nr.	Afdelingnr.
IN_T	EI Armeerlijn 1	EI ARMEERLJN 1	INSTALLATIE	MC_F	Armeerlijn 1	MC ARMEERLJN 1	MULTICONDUCTOR
IN_H	Vlechtlijnen, Draadwikkelen	EI DRAADWIKKELEN 1	INSTALLATIE	MC_J	Draadwikkelpakketten	MC DRAADWIKKELEN 3	MULTICONDUCTOR
IN_H	Vlechtlijnen, Draadwikkelen	EI DRAADWIKKELEN 2	INSTALLATIE	MC_L	Eindkeuring Multiconductor	MC EINDKEURING	MULTICONDUCTOR
IN_G	Samenslag 3 en 4, Drumtwister 3	EI DRUMTWISTER 3	INSTALLATIE	MC_E	Grote samenslag 2-3	MC GROTE SAMENSLAG 2	MULTICONDUCTOR
IN_Q	Eindkeuring Installatie	EI EK-INSTALLATIE	INSTALLATIE	MC_E	Grote samenslag 2-3	MC GROTE SAMENSLAG 3	MULTICONDUCTOR
IN_E	Mantellijn 4-5-6, Hulpaderlijn	EI HULPADERLJN	INSTALLATIE	MC_B	Kleine samenslag 1-2-3-4	MC GROTE SAMENSLAG 4	MULTICONDUCTOR
IN_A	Isolatielijijn 3	EI ISOLATIELJN 3	INSTALLATIE	MC_B	Kleine samenslag 1-2-3-4	MC GROTE SAMENSLAG 5	MULTICONDUCTOR
IN_F	Isolatielijijn 3-4-5	EI ISOLATIELJN 3		MC_P	Isolatielijijn 3	MC ISOLATIELJN 3	MULTICONDUCTOR
IN_B	Isolatielijijn 4	EI ISOLATIELJN 4	INSTALLATIE	MC_A	Isolatielijijn 1-2-3	MC ISOLATIELJN 3	
IN_F	Isolatielijijn 3-4-5	EI ISOLATIELJN 4		MC_N	Isolatielijijn 1	MC ISOLATIELJN 4	MULTICONDUCTOR
IN_C	Isolatielijijn 5	EI ISOLATIELJN 5	INSTALLATIE	MC_A	Isolatielijijn 1-2-3	MC ISOLATIELJN 4	
IN_F	Isolatielijijn 3-4-5	EI ISOLATIELJN 5		MC_O	Isolatielijijn 2	MC ISOLATIELJN 5	MULTICONDUCTOR
IN_H	Vlechtlijnen, Draadwikkelen	EI LITZEVLECHTER 1	INSTALLATIE	MC_A	Isolatielijijn 1-2-3	MC ISOLATIELJN 5	
IN_H	Vlechtlijnen, Draadwikkelen	EI LITZEVLECHTER 2	INSTALLATIE	MC_B	Kleine samenslag 1-2-3-4	MC ISOLATIELJN 6	MULTICONDUCTOR
IN_H	Vlechtlijnen, Draadwikkelen	EI LITZEVLECHTER 3	INSTALLATIE	MC_C	Kleine samenslag 5-6-7, Bedrukljijn	MC KLEINE SAMENSLAG6	MULTICONDUCTOR
IN_E	Mantellijn 4-5-6, Hulpaderlijn	EI MANTELLJN 4	INSTALLATIE	MC_C	Kleine samenslag 5-6-7, Bedrukljijn	MC KLEINE SAMENSLAG7	MULTICONDUCTOR
IN_E	Mantellijn 4-5-6, Hulpaderlijn	EI MANTELLJN 5	INSTALLATIE	MC_C	Kleine samenslag 5-6-7, Bedrukljijn	MC KLEINE SAMENSLAG8	MULTICONDUCTOR
IN_E	Mantellijn 4-5-6, Hulpaderlijn	EI MANTELLJN 6	INSTALLATIE	MC_H	Mantellijn 1-2	MC MANTELLJN 1	MULTICONDUCTOR
IN_E	Mantellijn 4-5-6, Hulpaderlijn	EI MANTELLJN 7	INSTALLATIE	MC_H	Mantellijn 1-2	MC MANTELLJN 2	MULTICONDUCTOR
IN_E	Mantellijn 4-5-6, Hulpaderlijn	EI MANTELLJN 8	INSTALLATIE	MC_I	Mantellijn 3	MC MANTELLJN 3	MULTICONDUCTOR
IN_G	Samenslag 3 en 4, Drumtwister 3	EI SAMENSLAGLJN 3	INSTALLATIE	MC_E	Grote samenslag 2-3	MC MANTELLJN 4	MULTICONDUCTOR
IN_I	Samenslag anders van Iso 3	EI SAMENSLAGLJN 3		MC_H	Mantellijn 1-2	MC MANTELLJN 4	
IN_J	Samenslag anders van Iso 4	EI SAMENSLAGLJN 3		MC_C	Kleine samenslag 5-6-7, Bedrukljijn	MC NUMMERBEDRUKLJN	MULTICONDUCTOR
IN_K	Samenslag anders van Iso 5	EI SAMENSLAGLJN 3		MC_K	Vlechters	MC VLECHTER 24-10	MULTICONDUCTOR
IN_G	Samenslag 3 en 4, Drumtwister 3	EI SAMENSLAGLJN 4	INSTALLATIE	MC_K	Vlechters	MC VLECHTER 24-4	MULTICONDUCTOR
IN_I	Samenslag anders van Iso 3	EI SAMENSLAGLJN 4		MC_K	Vlechters	MC VLECHTER 24-5	MULTICONDUCTOR
IN_J	Samenslag anders van Iso 4	EI SAMENSLAGLJN 4		MC_K	Vlechters	MC VLECHTER 24-6	MULTICONDUCTOR
IN_K	Samenslag anders van Iso 5	EI SAMENSLAGLJN 4		MC_K	Vlechters	MC VLECHTER 24-7	MULTICONDUCTOR
IN_I	Samenslag anders van Iso 3	EI SAMENSLAGLJN 5	INSTALLATIE	MC_K	Vlechters	MC VLECHTER 24-8	MULTICONDUCTOR
IN_J	Samenslag anders van Iso 4	EI SAMENSLAGLJN 5		MC_K	Vlechters	MC VLECHTER 24-9	MULTICONDUCTOR
IN_K	Samenslag anders van Iso 5	EI SAMENSLAGLJN 5		MC_K	Vlechters	MC VLECHTER 36-2	MULTICONDUCTOR
IN_H	Vlechtlijnen, Draadwikkelen	EI VLECHTER 24-1	INSTALLATIE	MC_K	Vlechters	MC VLECHTER 36-3	MULTICONDUCTOR
IN_H	Vlechtlijnen, Draadwikkelen	EI VLECHTER 24-10	INSTALLATIE				
IN_H	Vlechtlijnen, Draadwikkelen	EI VLECHTER 24-2	INSTALLATIE				
IN_H	Vlechtlijnen, Draadwikkelen	EI VLECHTER 24-3	INSTALLATIE				
IN_H	Vlechtlijnen, Draadwikkelen	EI VLECHTER 24-4	INSTALLATIE				
IN_H	Vlechtlijnen, Draadwikkelen	EI VLECHTER 24-5	INSTALLATIE				
IN_H	Vlechtlijnen, Draadwikkelen	EI VLECHTER 24-6	INSTALLATIE				
IN_H	Vlechtlijnen, Draadwikkelen	EI VLECHTER 24-7	INSTALLATIE				
IN_H	Vlechtlijnen, Draadwikkelen	EI VLECHTER 24-8	INSTALLATIE				
IN_H	Vlechtlijnen, Draadwikkelen	EI VLECHTER 24-9	INSTALLATIE				
IN_H	Vlechtlijnen, Draadwikkelen	EI VLECHTER 36-1	INSTALLATIE				
IN_H	Vlechtlijnen, Draadwikkelen	EI VLECHTER 36-3	INSTALLATIE				

Table 9 - Overview of the waste place codes and waste places names

Code	Omschrijving	Afdelingnr.
IN_A	Isolatielijn 3	INSTALLATIE
IN_B	Isolatielijn 4	INSTALLATIE
IN_C	Isolatielijn 5	INSTALLATIE
IN_E	Mantellijn 4-5-6, Hulpaderlijn	INSTALLATIE
IN_F	Isolatielijn 3-4-5	INSTALLATIE
IN_G	Samenslag 3 en 4, Drumtwister 3	INSTALLATIE
IN_H	Vlechtlijnen, Draadwikkelen	INSTALLATIE
IN_I	Samenslag aders van Iso 3	INSTALLATIE
IN_J	Samenslag aders van Iso 4	INSTALLATIE
IN_K	Samenslag aders van Iso 5	INSTALLATIE
IN_Q	Eindkeuring Installatie	INSTALLATIE
IN_R	Algemeen Installatie	INSTALLATIE
IN_T	EI Armeerlijn 1	INSTALLATIE
IN_Z	Foutmeldingsafval	INSTALLATIE
MC_A	Isolatielijn 1-2-3	MULTICONDUCTOR
MC_B	Kleine samenslag 1-2-3-4	MULTICONDUCTOR
MC_C	Kleine samenslag 5-6-7, Bedruklijn	MULTICONDUCTOR
MC_D	Grote samenslag 1	MULTICONDUCTOR
MC_E	Grote samenslag 2-3	MULTICONDUCTOR
MC_F	Armeerlijn 1	MULTICONDUCTOR
MC_G	Armeerlijn 2	MULTICONDUCTOR
MC_H	Mantellijn 1-2	MULTICONDUCTOR
MC_I	Mantellijn 3	MULTICONDUCTOR
MC_J	Draadwikkelsokken	MULTICONDUCTOR
MC_K	Vlechts	MULTICONDUCTOR
MC_L	Eindkeuring Multiconductor	MULTICONDUCTOR
MC_M	Algemeen Multiconductor	MULTICONDUCTOR
MC_N	Isolatielijn 1	MULTICONDUCTOR
MC_O	Isolatielijn 2	MULTICONDUCTOR
MC_P	Isolatielijn 3	MULTICONDUCTOR
MC_Z	Foutmeldingsafval	MULTICONDUCTOR

Now that the links are identified, the relevant waste is determined. Here it is important to make sure that only waste related to setup is included and that this one is not overlapping with the overlength waste. Next to that, it is important to determine the price of the waste per unit. This also needs to be done manually because there is no information about this in the system. The limitation here is therefore, that the cost prices are not up to date. So, this should also be taken into consideration when using the system. The complete list can be found in Table 10. Here it could be seen that it is only relevant to setup cost if the material is raw material that goes in an extruder. The reason why for example, copper is not included here is because these losses are already taken into consideration with the overlength cost calculations. More information about this can be found in the overlength part of this chapter.

Table 10 - Overview of the waste types

Identifier	Artikelfalgroep	Code	Omschrijving	Kostprijs Uitleg kostprijs	Relevant als setup grondstofafval
0#0	0	0	Bedrijfsafval	0,9 stortkosten € 90/ton	Nee
0#1	0	1	Glasvezel afval	200 gemiddelde kostprijs glasvezel	Nee
0#2	0	2	Tube afval	2,6 PBT kostprijs	JA
0#3	0	3	Kabelafval glasvezel (GVK)	15 gemiddelde kostprijs gvk	Nee
0#4	0	4	Geïsoleerd staal / opgedikt staal	1,5 gemiddelde kostprijs staaldraad + kunststof	Nee
1#1	1	1	Blank koper	7,4 gemiddelde kostprijs kopergeleiders	Nee
1#10	1	10	Voortrekdraad vertind 1.80 mm (Cu Sn)	7,15	Nee
1#2	1	2	Vertind koper	7,75 gemiddelde kostprijs vertind koperen geleider	Nee
1#3	1	3	Blank aluminium	2,7 gemiddelde kostprijs alu geleiders	Nee
1#4	1	4	IJzer-, staaldraad- en staalbandafval	1,4 gemiddelde kostprijs staaldraad	Nee
1#5	1	5	Alpol	4,2	Nee
1#6	1	6	Aramide	28	Nee
1#7	1	7	Lood	2	Nee
1#8	1	8	Voortrekdraad 3.00 mm (Cu)	6,72	Nee
1#9	1	9	Voortrekdraad 1.80 mm (Cu)	6,78	Nee
2#1	2	1	Papier - niet vervuild	1	Nee
2#10	2	10	Kunststof haspels	1	Nee
2#2	2	2	Hout (m.u.v. pallets)	1	Nee
2#3	2	3	Pallets	1	Nee
2#4	2	4	Verpakkingsfolie, plastic	1	Nee
2#5	2	5	Haspel afdekfolie	2,5 kostprijs biplex kanaalplaat	Nee
2#6	2	6	Lege glasvezelhaspels	1	Nee
2#7	2	7	PET omsnoeringsband	1	Nee
2#8	2	8	Kleine haspels multiplex	1	Nee
2#9	2	9	Houten haspels	1	Nee
3#1	3	1	Grof ijzer / schroot	1,4	Nee
4#1	4	1	Aluminiumkabel	2,1	Nee
4#2	4	2	Loodkabel	3,75	Nee
4#3	4	3	Koper dik zonder Alpol/IJzer	3,9	Nee
4#4	4	4	Koper dik met Alpol/IJzer	3,9	Nee
4#5	4	5	Koper dun zonder Alpol/IJzer	3,9	Nee
4#6	4	6	Koper dun met Alpol/IJzer	3,9	Nee
4#7	4	7	Geleiders van speciale metalen	50	Nee
5#1	5	1	Brokken vervuild	1,8 HF018/27 als gemiddelde	JA
5#10	5	10	Brokken XLPE	1,6 gemiddelde XLPE kostprijs	JA
5#2	5	2	PE schoon	1,65 gemiddelde PE kostprijs	JA
5#3	5	3	PVC schoon	1,4 gemiddelde PVC kostprijs	JA
5#4	5	4	PP schoon	1,6 gemiddelde PP kostprijs	JA
5#5	5	5	PBT schoon	2,6 PBT kostprijs	JA
5#6	5	6	Granulaat PVC	1,4 gemiddelde PVC kostprijs	JA
5#7	5	7	Granulaat PE	1,65 gemiddelde PE kostprijs	JA
5#8	5	8	Granulaat MBZH	1,65	JA
5#9	5	9	Vulrubber	1	JA

The database connections used for determining the extruder waste are explained here. Because this should be done manually per department and is very time consuming, I only did this for the departments defined in the scope. An overview of the database connections is given below in Figure 9. After running this database query, the results are shown in Table 11. In addition to this, rows are added for the corresponding cost price, relevance, and the calculated total cost.

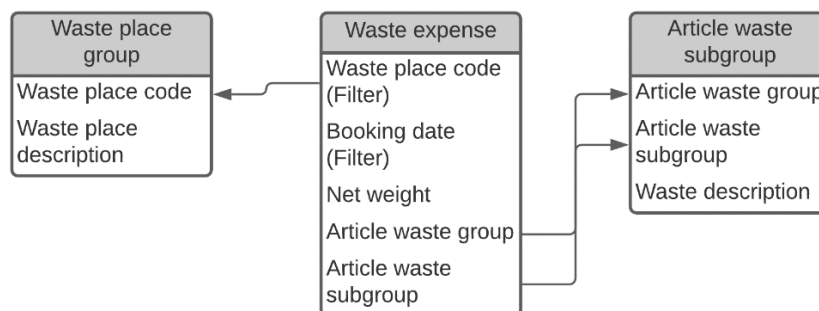


Figure 9 - Overview database connection for determining extruder waste

Table 11 - Overview of the waste table by Installation

Identifier	Waste place code	Description waste place	Article waste group	Article waste subgroup	Description waste	Net weight	Bookings date	Costprice	Cost	Relevant
0#0	IN_E	Mantellijn 4-5-6, Hulpaderlijn	0	0	Bedrijfsafval	40	25-9-2020	0,9	36	Nee
4#4	IN_E	Mantellijn 4-5-6, Hulpaderlijn	4	4	Koper dik met Alpol/IJzer	220	25-9-2020	3,9	858	Nee
4#5	IN_E	Mantellijn 4-5-6, Hulpaderlijn	4	5	Koper dun zonder Alpol/IJzer	185	25-9-2020	3,9	721,5	Nee
4#6	IN_E	Mantellijn 4-5-6, Hulpaderlijn	4	6	Koper dun met Alpol/IJzer	420	25-9-2020	3,9	1638	Nee
5#1	IN_E	Mantellijn 4-5-6, Hulpaderlijn	5	1	Brokken vervuild	295	25-9-2020	1,8	531	JA
1#1	IN_F	Isolatielijn 3-4-5	1	1	Blank koper	680	25-9-2020	7,4	5032	Nee
5#1	IN_F	Isolatielijn 3-4-5	5	1	Brokken vervuild	205	25-9-2020	1,8	369	JA
5#10	IN_F	Isolatielijn 3-4-5	5	10	Brokken XLPE	165	25-9-2020	1,6	264	JA
4#3	IN_A	Isolatielijn 3	4	3	Koper dik zonder Alpol/IJzer	295	27-9-2020	3,9	1150,5	Nee
4#3	IN_E	Mantellijn 4-5-6, Hulpaderlijn	4	3	Koper dik zonder Alpol/IJzer	298	27-9-2020	3,9	1162,2	Nee
4#4	IN_E	Mantellijn 4-5-6, Hulpaderlijn	4	4	Koper dik met Alpol/IJzer	258	27-9-2020	3,9	1006,2	Nee
5#1	IN_F	Isolatielijn 3-4-5	5	1	Brokken vervuild	295	27-9-2020	1,8	531	JA
5#10	IN_F	Isolatielijn 3-4-5	5	10	Brokken XLPE	285	27-9-2020	1,6	456	JA
4#5	IN_E	Mantellijn 4-5-6, Hulpaderlijn	4	5	Koper dun zonder Alpol/IJzer	190	28-9-2020	3,9	741	Nee
5#1	IN_F	Isolatielijn 3-4-5	5	1	Brokken vervuild	270	28-9-2020	1,8	486	JA
5#10	IN_F	Isolatielijn 3-4-5	5	10	Brokken XLPE	325	28-9-2020	1,6	520	JA
4#4	IN_E	Mantellijn 4-5-6, Hulpaderlijn	4	4	Koper dik met Alpol/IJzer	210	29-9-2020	3,9	819	Nee
4#5	IN_E	Mantellijn 4-5-6, Hulpaderlijn	4	5	Koper dun zonder Alpol/IJzer	245	29-9-2020	3,9	955,5	Nee
5#3	IN_E	Mantellijn 4-5-6, Hulpaderlijn	5	3	PVC schoen	330	29-9-2020	1,4	462	JA
1#1	IN_F	Isolatielijn 3-4-5	1	1	Blank koper	455	29-9-2020	7,4	3367	Nee
5#10	IN_F	Isolatielijn 3-4-5	5	10	Brokken XLPE	225	29-9-2020	1,6	360	JA

Now the relevant waste per production process as well as the switches at the specific production processes are known, we can calculate the average cost for raw material waste per switch. This can be seen in Table 12. By connecting this information to the production processes used for producing the cable, we can calculate the raw material wasted involved with the cable production.

Table 12 - Overview of the raw material cost per switch per production process

Installatie					Multiconductor				
Afvalplaats	Codes	Totale kosten grondstofafval door setup	Aantal keer ombouw	Gemiddelde kosten grondstofafval per ombouw	Afvalplaats	Codes	Totale kosten grondstofafval door setup	Aantal keer ombouw	Gemiddelde kosten grondstofafval per ombouw
Isolatielijn 3-4-5 Totaal	IN_ISO	93805,4	1204	77,91146179	Isolatielijn 1-2-3 Totaal	MC_ISO	36208,4	855	42,34900585
Isolatielijn 3-4-5 combi	IN_F	93233,4	1204	77,43637874	Isolatielijn 1-2-3 combi	MC_A	36208,4	855	42,34900585
Iso 3 IN_A		572	454	-	Iso 1 MC_N		0	346	-
Iso 4 IN_B		0	271	-	Iso 2 MC_O		0	102	-
Iso 5 IN_C		0	479	-	Iso 3 MC_P		0	407	-
Mantellijn 4-5-6, Hulpaderlijn	IN_E	65551,35	2195	29,86394077	Kleine samenslag 1-2-3-4	MC_B	0	-	-
Samenslag 3 en 4, Drumtwister 3 Totaal		0	0	-	Kleine samenslag 5-6-7, Bedrukklijn	MC_C	0	-	-
Samenslag 3 en 4, Drumtwister 3 combi	IN_G	0	0	-	Grote samenslag 1	MC_D	0	-	-
Samenslag aders van Iso 3 IN_J		0	0	-	Grote samenslag 2-3	MC_E	0	175	-
Samenslag aders van Iso 4 IN_J		0	0	-	Armeerlijn 1	MC_F	0	-	-
Samenslag aders van Iso 5 IN_K		0	0	-	Armeerlijn 2	MC_G	0	-	-
Vlechtlijnen, Draadwikkelen	IN_H	0	0	-	Mantellijn 1-2	MC_H	39692,95	1240	32,01044355
Eindkeuring Installatie	IN_Q	0	0	-	Mantellijn 3	MC_I	8141,4	200	40,707
EI Armeerlijn 1	IN_T	0	0	-	Draadwikkelpokken	MC_J	0	-	-
Algemeen Installatie	IN_R	0	0	-	Vlechtsers	MC_K	0	-	-
					Eindkeuring Multiconductor	MC_L	0	-	-
					Algemeen Multiconductor	MC_M	0	-	-

3.1.3 Over-length

The amount of cable that is thrown away because it is not thick or qualitative enough will be measured by looking at the output of the process compared to the input of the following process. However, this should be done carefully because the variable cost which is related to the production length should not be included. The reason why this is important, is because it is measured in overlength per reel. This means that when you want to produce more at some point you need more reels as input which means more overlength. However, this makes it dependent on the production size and that is not part of the setup cost. Still, this number can be used because when you are setting up a process you will always start with one reel, so that is independent of the production length. Therefore, the setup waste in terms of overlength will be the overlength in meters of one-reel times the cost price of the over-length per meter. Then summing this for all the involved production processes leads to the overlength cost for the production of a certain cable.

3.2 Inventory holding cost

According to the literature, inventory holding costs are the variable cost of keeping inventory on hand. It is a combination of costs associated with storage, insurance, opportunity costs, shrinkage, and other variables (Holsenback, 2007). Most of the time, the inventory holding cost is expressed as a percentage

of the value of an item. In a survey conducted by Harding (Harding, 2005), the following factors were identified for determining the inventory holding cost: scrap, obsolescence, shrinkage, and inventory losses; facility overhead cost and storage; inventory and handling personnel; inventory-handling capital equipment; rework and repair of inventory; and other business-specific factors. In another paper by (Durlinger, 2014), the inventory holding cost are divided in three categories: cost of capital (to finance inventory), costs of handling and storage of the inventory, and cost of risk (pilferage, obsolescence, insurance, etc.). Since, all papers are describing the same factors, the last method is chosen because it indicates a clear distinction between the different factors. The inventory holding cost will be expressed per meter of cable and all specific categories therefore need to be expressed per meter of cable as well. The cost of capital is relevant to take into consideration for the inventory holding cost, because when TKF decides to produce more than they need they spend money on the production of the cable and that money cannot be spend elsewhere. Therefore, this should be compensated in the inventory holding cost. Furthermore, when holding inventory there is risk involved. This should also be considered for the inventory holding cost. This is discussed in subsection 3.2.2. At last, the inventory should be stored somewhere. This involves space on the terrain which has a cost as well as the handling of the inventory. Both are relevant to the inventory holding cost and should therefore be included.

3.2.1 Cost of capital

The first category is the cost of capital. According to the finance department, TKF is using a loan from their holding firm, TKH-group. This loan has an interest rate of █%. To express this per meter, the interest rate will be calculated over the cost price per meter of cable.

3.2.2 Cost of risk

The second category is the cost of risk. This category comprises everything connected with the risks of holding inventory. Elements to take into consideration are obsolescence, insurance, and pilferage. Because this category is very related to the type of products that are produced not all factors might be relevant (Durlinger, 2014). TKF is a cable manufacturing company and obsolescence with respect to cables is not relevant. Cables are not deteriorating and only get damaged very incidentally, so this is therefore not necessary to take into consideration. However, in terms of reels it is necessary to take depreciation into consideration. This is because the reels are wearing out fast and therefore need to be amortised in three years. This can be seen in Table 13. Next to this, also the cost of insurance of the cables needs to be taken into account. For TKF this is █%. This is calculated by looking at the tax insurance related cost and divide them over the inventory value to calculate the cable cost price surcharge percentage. This calculation can be seen in Table 14.

Table 13 - Depreciation of the specific reel types

Reel Code	Price	Depreciation per year
H100	€ 90,76	€ 30,25
H100EXS	€ 90,76	€ 30,25
H120	€ 136,13	€ 45,38
H120B	€ 136,13	€ 45,38
H120DB	€ 136,13	€ 45,38
H120EXG	€ 136,13	€ 45,38
H120EXS	€ 136,13	€ 45,38
H150	€ 204,20	€ 68,07
H150B	€ 204,20	€ 68,07
H150DB	€ 150,00	€ 50,00
H150EXG	€ 204,20	€ 68,07
H160	€ 249,58	€ 83,19
H160EX	€ 249,58	€ 83,19
H175EXG	€ 195,51	€ 65,17
H180	€ 317,65	€ 105,88
H180B	€ 317,65	€ 105,88
H180DB	€ 317,65	€ 105,88
H180EX	€ 317,65	€ 105,88
H185T	€ 340,34	€ 113,45
H210	€ 398,00	€ 132,67
H210B	€ 398,00	€ 132,67
H210EX	€ 398,00	€ 132,67
H210ST	€ 398,00	€ 132,67
H220EXB	€ 350,00	€ 116,67
H225	€ 544,54	€ 181,51
H225EX	€ 544,54	€ 181,51
H2500/1410	€ 635,29	€ 211,76
H2500/1450	€ 635,29	€ 211,76
H2500/1451	€ 635,29	€ 211,76
H2500/1452	€ 635,29	€ 211,76
H250EX	€ 517,00	€ 172,33
H250EXB	€ 517,00	€ 172,33
H250STB	€ 517,00	€ 172,33
H2650/1450	€ 748,74	€ 249,58
H2800/1400	€ 1.025,00	€ 341,67
H2800/1700	€ 1.179,83	€ 393,28
H3000/1630	€ 1.315,96	€ 438,65
H3000/1700	€ 1.500,00	€ 500,00
K1000/500	€ 55,00	€ 18,33
K1200/500B	€ 55,00	€ 18,33
K1200/500S	€ 55,00	€ 18,33
K400/175	€ 4,31	€ 1,44
K400/202	€ 5,83	€ 1,94
K600/250	€ 10,98	€ 3,66
K800/400	€ 30,00	€ 10,00
T050	€ 5,10	€ 1,70
T060	€ 10,00	€ 3,33
T066	€ 10,80	€ 3,60
T075	€ 14,28	€ 4,76

Table 14 - Cable cost price surcharge percentage for insurance tax cost

Netherlands	Company
	B.V. Twentsche Kabelfabriek

Insured address	City	Total inventory	Premium %	Premium	Insurance tax %	Insurance tax	Total	Fee	Insurance tax Fee	Total
Everdenberg 11	Oosterhout									
Kwinkweerd 3	Lochem									
Spinnerstraat 15	Haaksbergen									
Concordiastraat 84	Velsen Noord									

Insurance tax over inventory value %


3.2.3 Cost of handling and storage

The last category is the handling and storage cost of the inventory. This consists of two cost types. The first is the handling cost of the inventory and the second is the storage cost. TKF's handling costs are the transportation of the reels to and from production to and from stock. To identify the costs involved with this process, an interview was conducted with the logistics manager of TKF. The following numbers were obtained: For each reel used in production, it costs on average 5 minutes to store it. When this product is a semi-finished product, it will on average be used 3 times before it is empty. This means that it will be picked from inventory and brought back 3 times. According to the logistics manager this process takes approximately 7.5 minutes each time. At last, the end-product needs to be brought back to the inventory again which also takes 5 minutes. Therefore, 32.5 minutes is the handling time per reel. Because these actions need to be made by the forklift driver, the cost for a forklift driver are investigated and turned out to be 35 euros per driver per hour. We are calculating this cost per reel, so only 1 driver at a time is involved with a reel so therefore 1 time the employee cost. By multiplying these factors, the handling cost per reel is determined. In TKF's case this is €18,96.

Determining the storage cost was a lot harder. This is because the cost for storing a cable per meter is unknown. Therefore, a method should be created that enables us to calculate this. First, a look was taken at the available information. This was the surface of storage terrain of TKF, the average price of a m^2 storage terrain per year, the actual number of reels in storage, dimensions of the reels, and maximum cable length on a reel. Then with this information the space that is needed per reel is determined. With this calculation, we also took the paths and room needed for manoeuvre into consideration. Now that the price per m^2 as well as the needed space is determined, we could determine the price for storing a reel. This on itself then can be calculated per meter of cable which leads to the price for storing a meter of a cable.

3.3 Overview of inventory holding and setup cost

To create a clear and structured overview of subchapters 3.1 and 3.2, the dashboard from the tool we created is provided. This can be seen in Figure 10. Since TKF is a Dutch company, the decision was made to deliver the tool in Dutch. Therefore, it could be hard to interpret for internationals. For this reason, we will explain the most important parts. As can be seen, the tool is built up from different components. On the left side from top to bottom this is input, setup cost, and inventory holding cost. On the right-hand side, we first have buttons to run the tool. This can be done by only calculating the setup cost, only calculating the inventory holding cost or calculating both (with the method described in chapter 3). Underneath those buttons, the following categories are created: raw material cost updater and a storage cost updater. These are not directly updated during running the tool because they do not have to be updated daily and it makes the tool way faster. The last component of the dashboard is the reality component. In this component the current performance in terms of setup cost and inventory holding cost can be seen.


Dashboard setup en inventory holding cost (model)

Input
ArtikelNr

Opstartkosten

Over-lengte kosten	69,20	[€]
Grondstof kosten	111,79	[€]
Opstartkosten materiaal	180,98	[€]

Machinekosten	398,06	[€]
Werknemerskosten	352,20	[€]
Opstartkosten insteltijd	750,26	[€]

Opstartkosten materiaal	180,98	[€]
Opstartkosten insteltijd	750,26	[€]
Totale opstartkosten	931,25	[€]

Inventory holding kosten

Kapitaalskosten (lening TKH group, %) [€/meter]	
---	--

Verwerkingskosten	0,003	[€/meter]
Opslag kosten	0,007	[€/meter]
Verwerkings- en opslagkosten	0,010	[€/meter]

verzekeringskosten (%) [€/meter]		
Haspelafschrijving	0,003	[€/meter]
Risico kosten	0,003	[€/meter]

Kapitaalskosten	0,0001	[€/meter]
Verwerkings- en opslagkosten	0,010	[€/meter]
Risico kosten	0,003	[€/meter]
Inventory holding kosten	0,01	[€/meter]

Bereken setup & inventory cost
Ververstijd ± 7 sec

Bereken setup cost
Ververstijd ± 1 sec

Bereken inventory holding cost
Ververstijd ± 1 sec

Informatie verversen (grondstofkosten)

Terugkijktijd grondstofkosten	182	[dagen]
-------------------------------	-----	---------

MC Isolatielijijn 1-2-3 Totaal	41,95	[€/ ombouw]
MC Mantellijn 1-2	34,92	[€/ ombouw]
MC Mantellijn 3	40,26	[€/ ombouw]
IN Isolatielijijn 3-4-5 Totaal	77,91	[€/ ombouw]
IN Mantellijn 4-5-6, Hulpaderlijijn	29,86	[€/ ombouw]

Ververs Installatie grondstofkosten
Ververstijd: ± 10 min

Ververs MC grondstofkosten

Informatie verversen (opslagkosten)

Oppervlakte opslagterrein	33600	[m ²]
Huurprijs terrein	15	[€/m ² /jaar]

Haspels op voorraad	8956	[aantal]
Oppervlakte inname haspels	9501,25	[m ²]
Manoevreerruimte percentage t.o.v. totaal	71,72	[%]
Manoevreerruimte opslag t.o.v. haspelafmeting	353,64	[%]

Ververs voorraad info
Ververstijd: ± 1 min

Ververs haspel info
Ververstijd: ± 1 sec

Ververs QT info

Realiteit

Gemiddelde productie lengte	900,00	[meter]
Gemiddelde Inventory holding kosten	12,20	[€]
Totale opstartkosten	931,245	[€]

Figure 10 - Overview of dashboard setup and inventory holding cost

3.4 Demand distribution

In the literature review, the negative binomial distribution and the VTM are already described. However, no insight was given about the connection of the literature with our data. Therefore, this subchapter was created to provide insights on the demand of a cable, the way the VTM is calculated, the calculations of the p and r (parameters of the negative binomial distribution), and the effect of the values of these parameters on the distribution.

To create an insight in the demand of a cable, Figure 11 is created. With this demand, the corresponding mean and variance is determined. Since this mean and variance are impacted by the period involved, the mean and variance for all relevant periods are calculated. In our case, these are $t = R$, $t = 2R$, and $t = L + R$, because these are necessary inputs for our inventory model. Then the VTM is calculated by dividing the mean by the variance (σ^2/μ). For all investigated cases, this was larger than 1 and therefore the negative binomial distribution. To make sure this will be checked before running the entire inventory model, a check will be built in the tool to check if the right distribution is used. When this is known the formulas for calculating the parameters for the negative binomial distribution could be used. Since these formulas are in the form of variance or mean equals a certain formula with the involved parameters, the formulas needed to be adapted to the right form. These original formulas can be seen below.

$$\mu = \frac{(p * r)}{(1 - p)} \quad \text{and} \quad \sigma^2 = \frac{(p * r)}{(1 - p)^2}$$

Both can then be written in the form:

$$\mu(1 - p) = (p * r) \quad \text{and} \quad \sigma^2(1 - p)^2 = (p * r)$$

Since both equations have the same formula after the equal sign, they could be set equal to each other.

$$\mu(1 - p) = \sigma^2(1 - p)^2$$

Solving this for P yields:

$$\frac{\mu}{\sigma^2} = 1 - p$$

$$p = 1 - \frac{\mu}{\sigma^2}$$

Now P is expressed in terms of μ and σ^2 we could fill in P in the equation of μ . This yields the following formula which finally leads to r .

$$\mu(1 - p) = (p * r) \Rightarrow r = \frac{\mu(1 - p)}{p}$$

At last, to create an insight in the effect of the parameters on the distribution, Figure 12 and Figure 13 are added.

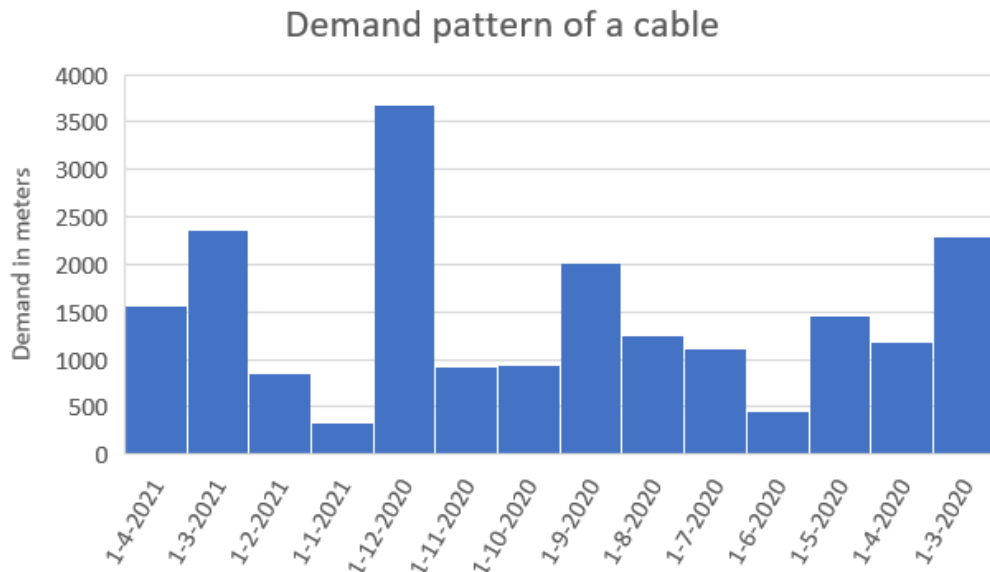


Figure 11 - Demand pattern of a cable

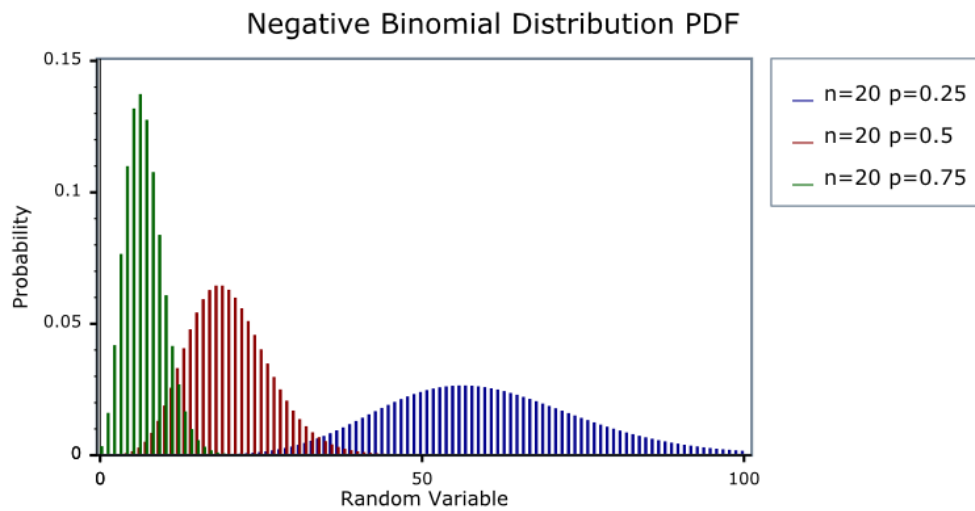


Figure 12 - Negative binomial distribution with varying success probability (UCSF, n.d.)

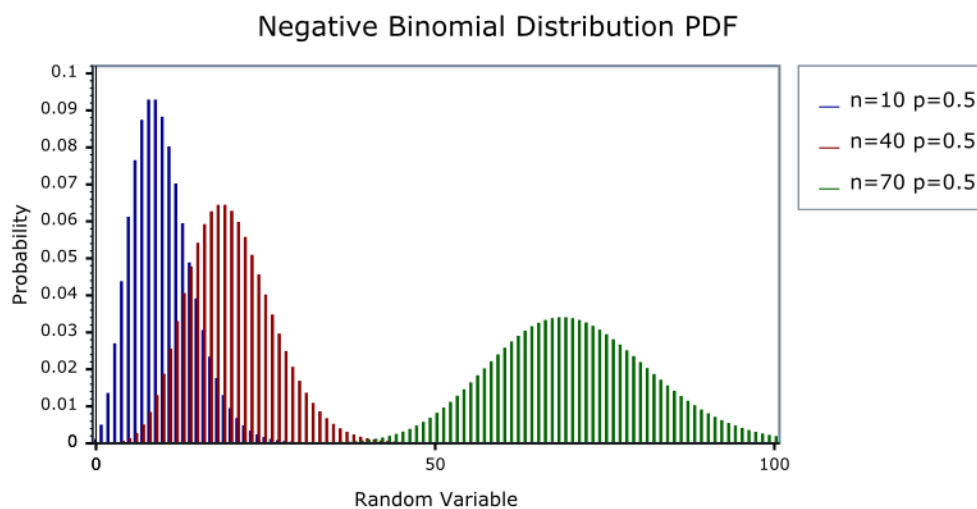


Figure 13 - Negative binomial distribution with varying number of failures until the experiment is stopped (UCSF, n.d.)

4. Inventory model

In this chapter, all information on the inventory model will be discussed. This is done by first describing Bijvank's algorithm and then describing the adaptations that we made to make it work for TKF's situation. Lastly, an overview will be provided from the inventory model dashboard.

4.1 Bijvank's algorithm

As discussed in subchapter 2.1 "Link with literature", Bijvank's model is an efficient and cost-effective heuristic method for inventory management. However, the way Bijvank's algorithm is doing this is not discussed there. Therefore, this will be described here. His algorithm is consisting of 11 steps and the overview can be seen in Figure 14.

Algorithm 1: Heuristic Procedure for Service Model

```

1  set  $\Delta$  equal to  $\sqrt{2K\mu_R/h}$  rounded to the nearest integer
2  determine  $s_0$  as the smallest  $s$  to satisfy the service
   constraint where  $S - s = \Delta$ 
3  set  $S_0 = s_0 + \Delta$ 
4  if  $1 - G_{2G}^0(S_0 - s_0 - 1) \leq 0.96$  then
5      return  $(s_0, S_0)$ 
6  else
7      determine  $S_1$  as the smallest  $S$  to satisfy the service
       constraint where  $s = S - 1$ 
8      determine  $s_1$  as the smallest  $s$  to satisfy the service
       constraint where  $S = S_1$ 
9      if  $\tilde{C}(s_0, S_0) \leq \tilde{C}(s_1, S_1)$  then return  $(s_0, S_0)$ 
10     else return  $(s_1, S_1)$ 
11 end

```

Figure 14 - Overview of Bijvank's algorithm (Bijvank, 2014)

In the first step of Bijvank's algorithm, delta (Δ) is determined with the use of Wilson's lot size formula (see subchapter 2.2.4 Wilson's lot size formula for more information). In step 2 and 3, this delta is used to calculate the initial values of the inventory policy (s_0, S_0) . Important to mention here is that the smallest s to satisfy the constraints will be set as s_0 . S_0 will then be calculated as $s_0 + \Delta$. The involved constraints are the $S - s = \Delta$ and the service constraint. The service constraint is given by the equation $\alpha(s, S) = \sum_{x=s+1}^S G_{L+R}^0(x) \pi_{X^+}(x)$. In this equation the sum of $x = s + 1$ is taken until S for $G_{L+R}^0(x) \pi_{X^+}(x)$. S can then be written as $\Delta + s$ due to the $S - s = \Delta$ constraint. $G_{L+R}^0(x)$ is the cumulative distribution of $g_{L+R}(j)$ and is equal to $\sum_{j=0}^d g_{L+R}(j)$. Here, $g_{L+R}(j)$, is denoting the probability that the total demand D_{R+L} in $R + L$ consecutive periods equal d units. d is then an element of $Z^+ = \{0, 1, 2, \dots\}$. To make the notation clearer, let σ_{L+R}^2 be the variance of D_t and $\mu_{L+R} = E[D_{L+R}]$. As discussed in subchapter 3.4 Demand distribution, the negative binomial demand is chosen for the dataset because it fits the demand the best. Excel uses the negative binomial function with the parameters: number of failures, number of successes, probability of a success, and cumulative for this. With the last line, it can be chosen if the function needs to be $G_{L+R}^0(x)$ if "True" is entered, while "false" will return the $g_{L+R}(j)$. Since the negative binomial has multiple different time periods during the algorithm, these will be discussed here. The first form is explained above and is the $L + R$. This means that the period of the distribution equals the lead time + the review period. Other forms are $2R$ which basically represents 2 times the review period, and R which is only the review period. The last input parameters for calculating the service level for a certain inventory policy is $\pi_{X^+}(x)$. $\pi_{X^+}(x)$ represents the probabilities that $X_t^+ = x$. X_t^+ is the inventory at period t after ordering. Modelling this as a steady state distribution yields $\pi_{X^+}(x) = \frac{f(S-x)}{\sum_{i=s+1}^S f(j-i)}$ for $s+1 \leq x \leq S$. In this function f is either

equal to 1 for $f(0)$ or $f(j) = \frac{g_R(i)}{1-g_R(0)} * f(j-i)$ when $j \geq i$. Now that we have the initial values of the inventory policy. It is time to move to step 4 of the algorithm. In this step it is checked if Wilson lot-size formula gives a good answer. Literature has shown that for relative small fixed order cost K , Wilson lot-size formula will result in too large values of Δ and this is not desired (Wagner & Lundh, 1965). Bijvank therefore created a function to check this. This function is given as $1 - G_{2R}^0(S_0 - s_0 - 1) \leq 0.96$ and when this is true, we will not search further for a better solution. Else, we will determine S_1 as the smallest S that satisfies the service constraint $s = S - 1$. This is done in the same way as we calculated the smallest s but the $S - s = \Delta$ constraint is then switched for the $s = S - 1$ constraint. The s is now calculated by fixing the S as the before calculated S_1 in the same approach as for the S_1 and S_0/s_0 . Since we now have two local optimal inventory policies to compare to each other the costs involved are calculated and the lowest cost will point out the inventory policy which has the global optimal value. This one is then picked as the inventory policy parameters. The costs of the involved policies are calculated by the formula $\frac{K+c(S_i)+\sum_{d=0}^{S_i-s_i-1} g_R(d)*c(S_i-d)}{1+G_R^0(S_i-s_i-1)}$ for $i = 0, 1$. K represents the setup cost here and $c(x)$ refers to $h(x - \mu_{L+R} + G_{L+R}^1(x))$ with h as the inventory holding cost.

4.2 Adaptions to Bijvank's algorithm

Since it was not possible to use Bijvank's algorithm directly, multiple adjustments were made. These are discussed in this subsection. To make sure Bijvank's algorithm really comes up with the optimal solution, the best fitting distribution for the data should be chosen. Since my project involves approximately 680 different cables with different demand, it could occur that they do not all follow the negative binomial distribution. For this reason, a check is added in the tool to see if it is allowed to model it according to the negative binomial distribution. If this is not the case a message pops up, so the user of the tool is aware of this and could handle the outcome with special care. Next to this, the negative binomial distribution also had to be changed. The reason for this is because it can only handle integer numbers for the number of successes and failures. However, in our continuous situation also successes or failures which are not integer valued could occur. To make sure that this was not rounded or giving an error (for $s < 1$), the negative binomial distribution was modelled with a gamma function instead of factorial, so it could handle it. However, this gave errors for large numbers of EOQ since the outcome of the gamma distribution rose to almost infinity. For this reason, if the numbers become larger than 150 the Stirling approximation was used. Stirling's formula is known as a good approximation of a factorial for large values and therefore perfectly fitting for our case (Mortici, 2010). The formula for Stirling's approximation is $n! \sim \sqrt{2\pi n} * \left(\frac{n}{e}\right)^n$. As defined in the deliverables, TKF wanted a tool which did not take too much time to compute. With this in mind, we decided to determine the parameters per 100 meters instead of 1 meter. TKF is namely not interested in a solution which is 1 meter specific and per 100 meters was perfectly fine for them. This made sure the tool is approximately 100 times quicker. These adaptions to Bijvank's algorithm led to the code in appendix A. The results of this heuristic are discussed in chapter 5 numerical results.

4.3 Overview of the dashboard of the inventory model

To implement our model, we created a dashboard. This dashboard can be seen in Figure 15. In the first row, you can see the last month with sales data. This is important because the demand data needs to be updated manually. The user of the tool therefore should assess if it should be updated or that it is recent enough. To make that as easy as possible this indication is added. The demand is printed in the table on the right side of the dashboard. This data goes back from last month until 13 months earlier. However, this can be adapted to the user's preference. Next to that, the user can change the service level and the review period if necessary. When we move a box lower in the dashboard, we come to the box where all inputs for Wilson's lot-size formula, as well, as the answer to Wilson's lot size formula are displayed. This is all updated automatically, and the user does not have to do anything for this. This applies for all grey areas. Only the white box with article number should be filled in by the user. The box below Wilson's lot size formula is the box where the variance to mean is calculated. This is added to make sure the demand is modelled according to the right distribution. When we again move a box lower, we come in the box where the parameters of the negative binomial distribution are calculated for each of the time intervals. Next to that, the initial values of the inventory parameters are calculated as well as the alternative. As discussed in subchapter 4.1, this one only gets calculated when the criterion is met. Otherwise, the dashboard displays it as zero to make clear to the user that this is the case. Then we move to the last box. In this box the final value of the inventory policy is printed. These are selected based on the cost of the involved parameters. At last, we have the button with "run tool" on it. When clicking this number Bijvank's algorithm gets started and the optimal inventory parameters get calculated.

T

K

F

Dashboard voorraadparameters (heuristic)

Laatste maand met verkoopdata

2021-04

ArtikelNr

Input

α

Service level

Kans om niet uit voorraad te raken tijdens een periode

96

[%]

T

Afname periode

Periode om de demand over te berekenen

14

[maanden]

R

Review period length

1 dag voor alle MTS producten (scope)

1

[dagen]

L

Leadtime

Bufferklasse

22

[dagen]

K

Setupcost

Berekent met model uit andere dashboard

1864,274375

[€]

h

Inventory holding cost per jaar

Berekent met model uit andere dashboard

0,573969496

[€/meter]

h

Inventory holding cost per dag

Inventory holding cost/365

0,001572519

[€/meter]

D

Afname over de periode

Som van aantal

20457

[meter]

μ_t

Gemiddelde afname per dag (t=1)

Afname van de periode/ (aantal maanden*dagen in een maand)

0,480399217

[100meter]

Δ

Wilson's lot size formule

Afgerond naar het dichtstbijzijnde hele getal; $\sqrt{2K\mu/h}$

10673

[meter]

σ_t

spreiding per dag (t=1)

VMR

Variance-to-mean ratio

Distributie type

VMR = σ^2 / μ

VMR = 0 Constant random variable, 0<VMR<1 binomial, VMR = 1 Negative binomial distribution

Poisson en VMR>1 Negative binomial distribution

2,908458834

17,60854823

Negative binomial distribution

p_R

slagingskans experiment in t=R periode (neg. Binomial)

r_R

aantal van mislukkingen tot einde experiment (neg. Binomial)

p_{R+L}

slagingskans experiment in t=R+L periode (neg. Binomial)

r_{R+L}

aantal van mislukkingen tot einde experiment (neg. Binomial)

p_{2R}

slagingskans experiment in t=2R periode (neg. Binomial)

r_{2R}

aantal van mislukkingen tot einde experiment (neg. Binomial)

S_o

startwaarde reorder point

S_o

startwaarde order-up-to-level

S_1

verbeterde reorder point

S_1

verbeterde order-up-to-level

$\sigma^2 = (p^*r)/((1-p)^2) \ \& \ \mu = (p^*r)/(1-p) \longrightarrow p = 1 - (\mu/(\sigma^2))$

$\sigma^2 = (p^*r)/((1-p)^2) \ \& \ \mu = (p^*r)/(1-p) \longrightarrow r = (\mu*(1-p))/p$

$\sigma^2 = (p^*r)/((1-p)^2) \ \& \ \mu = (p^*r)/(1-p) \longrightarrow p = 1 - (\mu/(\sigma^2))$

$\sigma^2 = (p^*r)/((1-p)^2) \ \& \ \mu = (p^*r)/(1-p) \longrightarrow r = (\mu*(1-p))/p$

$\sigma^2 = (p^*r)/((1-p)^2) \ \& \ \mu = (p^*r)/(1-p) \longrightarrow p = 1 - (\mu/(\sigma^2))$

$\sigma^2 = (p^*r)/((1-p)^2) \ \& \ \mu = (p^*r)/(1-p) \longrightarrow r = (\mu*(1-p))/p$

0,943209401

0,028924817

0,997530844

0,02734969

0,971604701

0,028079485

S_o

startwaarde reorder point

S_o

startwaarde order-up-to-level

S_1

verbeterde reorder point

S_1

verbeterde order-up-to-level

1600

12300

0

0

[meter]

[meter]

[meter]

[meter]

RL

Rode Lijn

GL

Groene Lijn

1600

12300

[meter]

[meter]

Run tool

#

Maand

Aantal

1

2021-04

1573

2

2021-03

2361

3

2021-02

861

4

2021-01

342

5

2020-12

3685

6

2020-11

927

7

2020-10

932

8

2020-09

2018

9

2020-08

1251

10

2020-07

1119

11

2020-06

461

12

2020-05

1456

13

2020-04

1185

14

2020-03

2286

Figure 15 - Overview of the inventory model dashboard

5. Numerical results

In this chapter, the results of the inventory holding and setup cost calculation model, and the results of the inventory policy model are discussed.

5.1 Results of the inventory holding and setup cost model

As could be seen from Figure 10 in subchapter 3.3, the inventory holding and setup cost are calculated specifically per product. In that chapter, also the way how we did this is described. In this subchapter we describe the overall results of this model with the articles defined in the scope. We created multiple categories to make the impact clearer. These filters are: no filter, filters on department, or filters on portfolio. The results of these filters are summarized in Figure 16, Figure 17, Figure 18 and Figure 19. Note that these are all insights in the current situation (reality) and not the EOQ. The EOQ will be provided in subchapter 5.2.

ZONDER FILTER

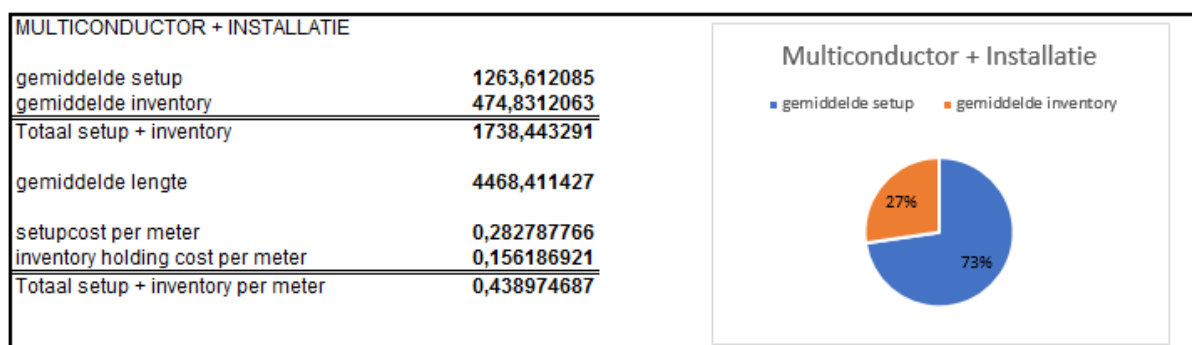


Figure 16 - Reality MTS without filter

PER DEPARTMENT

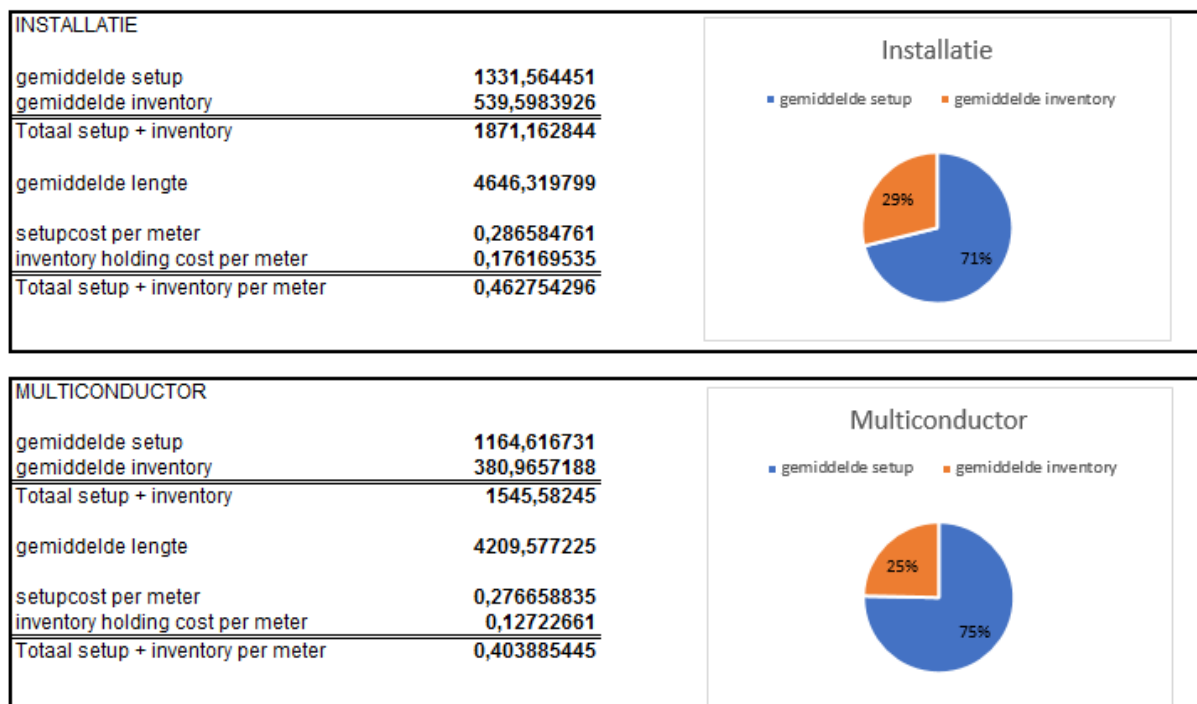


Figure 17 - Reality MTS department filter

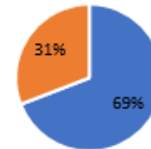
PER PORTFOLIO

INSTALLATIE NL

gemiddelde setup	1287,938441
gemiddelde inventory	575,0988397
Totaal setup + inventory	1863,037281
gemiddelde lengte	4342,084286
setupcost per meter	0,296617559
inventory holding cost per meter	0,184523996
Totaal setup + inventory per meter	0,481141554

Installatie NL

■ gemiddelde setup ■ gemiddelde inventory

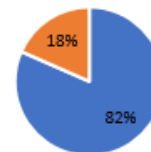


INSTRUMENTATIE PROCESTECHNIEK

gemiddelde setup	1270,279164
gemiddelde inventory	286,7032879
Totaal setup + inventory	1556,982452
gemiddelde lengte	3071,6996
setupcost per meter	0,413542771
inventory holding cost per meter	0,128824998
Totaal setup + inventory per meter	0,542367769

Instrumentatie Procestechniek

■ gemiddelde setup ■ gemiddelde inventory



LEIDINGEN, DRADEN EN SNOEREN

gemiddelde setup	1118,565092
gemiddelde inventory	387,3966942
Totaal setup + inventory	1505,961786
gemiddelde lengte	20601,25
setupcost per meter	0,054295982
inventory holding cost per meter	0,029612741
Totaal setup + inventory per meter	0,083908722

Leidingen, Draden en Snoeren

■ gemiddelde setup ■ gemiddelde inventory

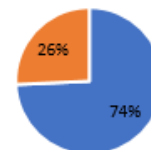


Figure 18 - Reality MTS portfolio filter (part 1)

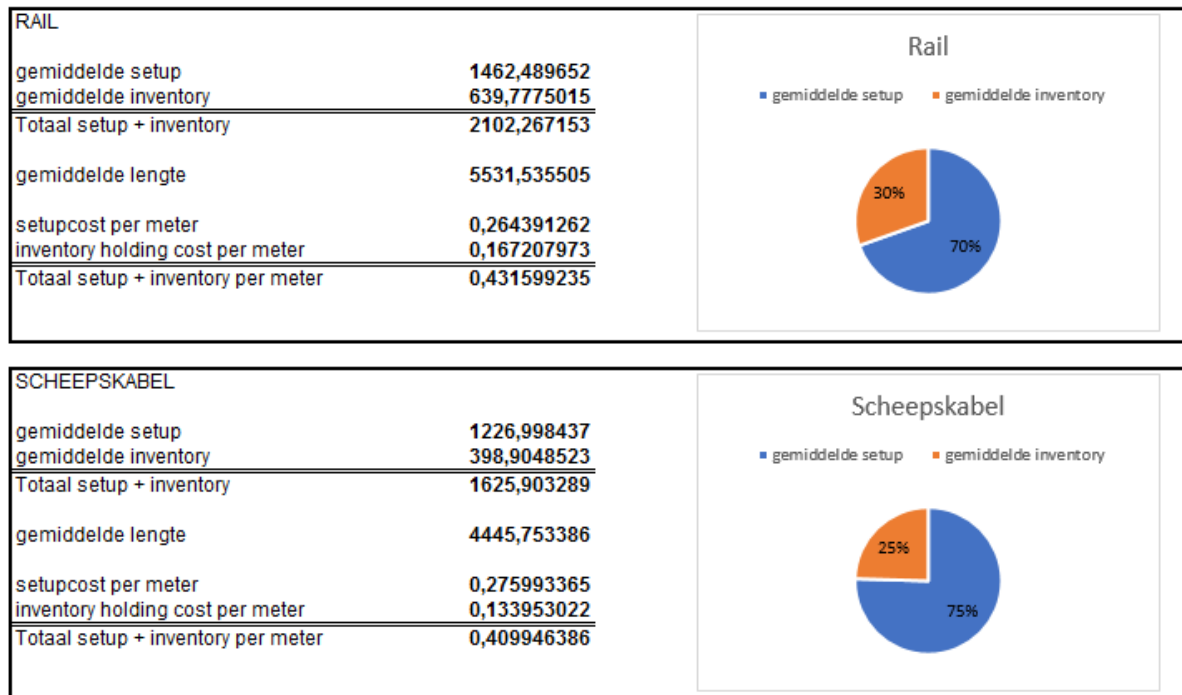
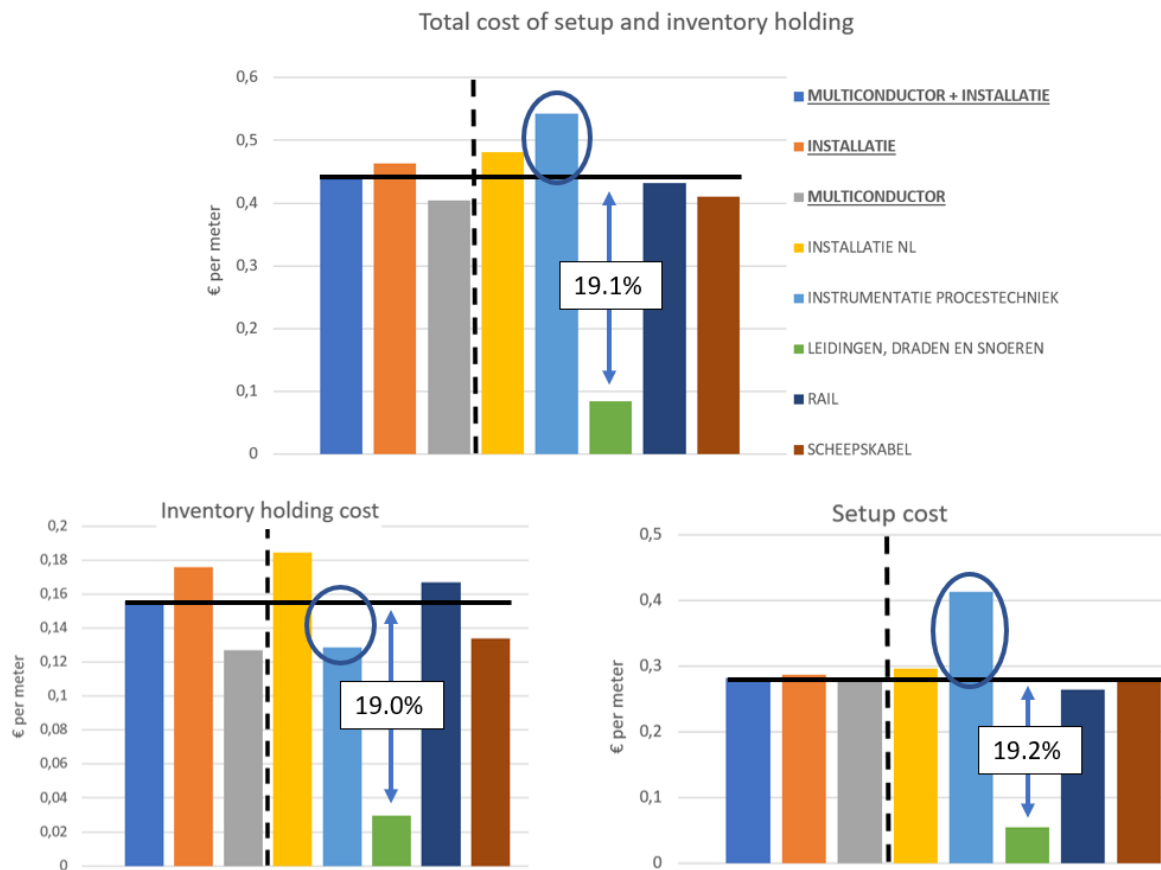


Figure 19 - Reality MTS portfolio filter (part 2)

In these figures, we can see the ratio of the average setup and inventory holding cost over the combined cost of both per filter. Considering all data (no filter), it could be said that the average weights are 27% for inventory holding cost versus 73% for setup. For the installation department, the average weights are 29% for inventory holding versus 71% for setup. While for multiconductor department these weights are 25% for inventory holding versus 75% for setup. These differences are not significant and therefore no further investigation in these parts is done. The differences however become relevant when using the portfolio filter. There the instrumentation process technique portfolio is an outlier with an inventory holding cost weight of only 18%. Next to that, the pipes, wires, and cords portfolio is an outlier. This is in terms of combined cost of setup and inventory per meter, as can be seen in Figure 20. The comparison of all filters in one graph, can also be seen in the norm and reality part (subsection 1.2.1). However underneath also a summary is given with an indication of the differences.



5.1.1 Instrumentation process technique portfolio

The instrumentation process technique portfolio is a portfolio which contains all cables which are used for communication purposes. Remarkable here is that the setup cost is almost the same as the average for all scope articles. However, the batch sizes are smaller which makes the cost per meter way higher. Next to that the inventory holding cost are lower. This is the case because the cables for communication are mostly cheaper cables because they are less complex and thinner. Therefore, it is no surprise that the weight of the inventory cost is so much lower than the average of 27%.

5.1.2 Pipes, wires, and cords portfolio

The cables that belong to the pipes, wires, and cords portfolio are even more simple than the instrumentation process technique cables. Were the cables from the instrumentation process technique portfolio are involving the standard production processes as defined in Figure 1, are the cables of the pipes, wires, and cords portfolio only involving the wire drawing and isolating processes. Next to that, they are produced in way higher batch sizes and are very thin. The setup cost can therefore be spread over very high lengths which clarifies the differences of the 19.2% with the overall average. The reason why also the inventory holding cost is lower, is because these cables are very thin and therefore very many kilometres fit on a reel. This lowers the storage cost by a lot and since this is one of the largest costs for determining the inventory holding cost this also decreases a lot.

5.2 Results inventory policy model

In this subchapter, the results of the inventory policy model are discussed. This is done by first looking at the results of an individual cable. Then there will be looked at the results of the entire scope. This

will be evaluated based on the savings. To gain a better understanding of the savings and the impact of these inventory levels, multiple additional analyses are performed. These are discussed at last.

In the end of chapter 4, the dashboard of the inventory policy tool was provided. The cable specific calculations, inputs, and outcomes of the tool could be seen there. However, this does not directly give us a good insight in the difference between the reality and the EOQ of a specific cable. Therefore, Figure 21 is provided. The inventory holding cost is a fixed number per meter and therefore a straight line in the figure. The setup cost is however varying based on the batch size. The combined cost of these two can then be seen in grey. Next to these variables, also two blue vertical lines are added. The first one represents the reality (current average production size) and the second one the EOQ as calculated by Wilson's lot-size formula. As could be seen from the figure, the suggested EOQ is approximately 4 to 5 times as big as the current production batch size. Therefore, this needs to be investigated over the entire scope and implications should be discussed. This is done later in this chapter.

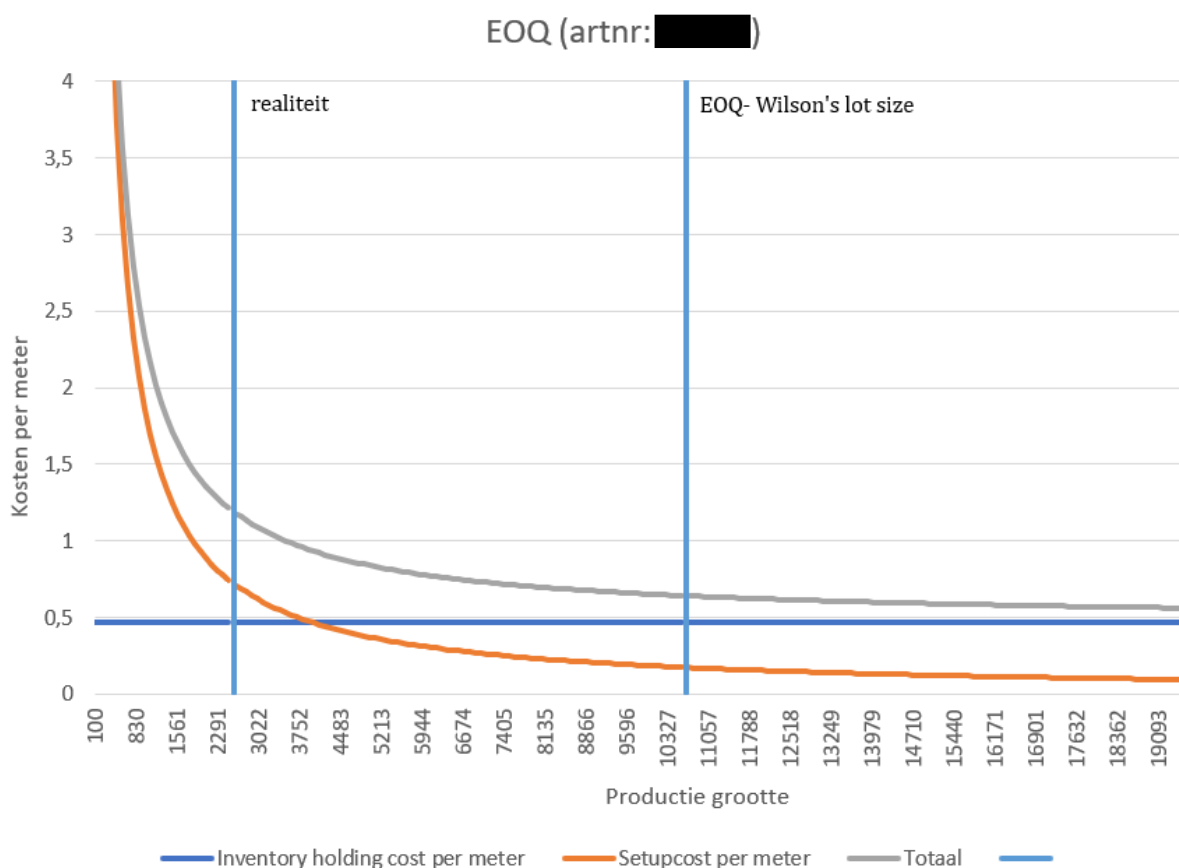


Figure 21 - Visualization of the difference between EOQ and current situation

Now that we have an insight in the individual results, it is time to move on to the overall results. This is done by first calculating the average value of the EOQ, current production length, cost price, and the savings. With these values the flexibility is calculated as well as the savings in percentage. The results are summarized in Table 15. Here it can be seen that the flexibility is decreased by approximately 472% because the production batch sizes are on average increased by 472%. Longer production runs will make it less easy to switch to other products and therefore make TKF less flexible. Besides that, longer production quantities also imply higher levels of stock. This can be seen in the average stock per EOQ batch. So, these are the trade-off for the 12.7% savings on average on the cost price. TKF could however also choose to partially implement the suggested EOQs or to raise all of them to a certain

level that is between the current production batch size and the suggested EOQ. This will then lower the savings but will also result in less flexibility loss and lower inventory levels.

Table 15 - Overall results when the inventory levels are implemented as suggested by the tool

Results (Current model)		
Suggested average EOQ	21317	[meters]
Current average prod.length	4518	[meters]
Average meand demand (year)	29755	[meters]
Flexibility loss	471,82	[%]
average stock per current batch	0,15	[# of years]
average stock per EOQ batch	0,72	[# of years]
Savings (on average)	0,48	[€/meter]
Costprice (on average)	3,76	[€/meter]
Savings (percentage)	12,66	[%]

Since this flexibility loss is extremely high, we investigated the number of cables which are currently produced above EOQ and the cables which are produced underneath. Momentarily, there are 628 cables above, while 19 are underneath EOQ. These 628 cables are contributing to the flexibility loss because these will be produced in a larger batch size then before. However, the 19 cables above EOQ will increase TKF's flexibility. So, if TKF for example wants to keep the same flexibility, they could choose to use the flexibility gain from the articles above EOQ. This gain is equal to a total reduction in batch sizes of approximately 40282 meters and represents 1,38%. Since this is relatively small in comparison with the total loss, a list of the 50 articles with the largest impact on the savings are printed. Also, insights in the corresponding EOQ, average production length, mean demand per year, and the number of years of stock this EOQ yields are added to this. This could be seen in Table 16. The conclusion that is made from this is that the EOQ lies way higher than TKF is currently doing, and this results in stocks that are multiple times the demand per year (high inventory levels). Implementing the suggested EOQ would then yield some other practical constraints besides the flexibility loss. This is for example the production capacity constraint as well as the cable depreciation policy of TKF. We will elaborately discuss this in chapter 6 Discussion. Next to this, it is also remarkable that the first three products have approximately a difference in cost price of 100% or higher. However, if you do some research about it, it is not that strange. As known, the cost price is calculated for a specific batch size and when this is deviating from the standard it could differ a lot in price. In other words, the actual cost price is higher than the standard cost price because a lower batch size is produced then the batch size the standard cost price is calculated for. Since this is important to know, we created an indicator that reveals the amount of cables which have a combined cost of setup and inventory below and above the standard cost price. This resulted in 643 cables which are under the standard cost price, while three are above cost price. Important to mention here is that the combined cost of setup and inventory is not equal to the cost price, because the variable cost are not taken into consideration.

Table 16 - Largest savings according to the proposed inventory parameters

Largest difference (top 50)					
Art. nr.	Mean demand (year)	Current avg. prod. length	EOQ	# of years on stock	Difference (% costprice)
	1328,571429	1063	10546	7,937849462	274,7750643
	2571,428571	900	12761	4,962611111	236,4948454
	706,2857143	633	11536	16,33333333	98,60367253
	9749,142857	2103	24951	2,559301917	67,29934924
	2821,714286	1298	10974	3,889125152	59,11159263
	447,4285714	1243	4591	10,26085568	56,54559344
	7442,571429	3207	20683	2,77901263	55,46487904
	1327,714286	1070	7068	5,323434474	55,31182318
	258,8571429	633	2649	10,23344371	55,1010938
	6908,571429	4443	24893	3,603205128	54,06421753
	853,7142857	752	4346	5,090696118	49,72356089
	10807,71429	2293	19963	1,847106564	48,76557453
	27142,28571	4304	46152	1,700372639	48,48148969
	10154,57143	2889	21631	2,130173602	48,23255814
	2804,571429	2076	10538	3,757436838	47,63886376
	64,28571429	500	3094	48,12888889	47,46535029
	1267,714286	1464	7592	5,988731125	45,45132952
	8628	3034	18438	2,136995828	44,71285324
	2432,571429	1969	6391	2,627260982	44,67935166
	945,4285714	2418	6771	7,161831369	43,75499943
	67080	6994	77237	1,151416219	43,17137229
	227,1428571	500	1992	8,769811321	42,82061935
	5963,142857	1972	12022	2,01605098	41,85145123
	2804,571429	1341	7607	2,712357376	40,81657378
	3671,142857	2178	11345	3,090318313	39,39788446
	1917,428571	1181	6353	3,313291611	38,51262269
	4914,857143	1723	14217	2,89265783	37,40988671
	235,7142857	1200	2981	12,64666667	37,17026379
	2414,571429	2064	8827	3,655721216	36,09721229
	7485,428571	3949	13136	1,75487614	36,05307736
	8218,285714	5075	23088	2,809345015	36,00741943
	7467,428571	1834	13558	1,815618304	35,65370138
	1712,571429	2002	8265	4,826076076	35,53959903
	931,7142857	500	8091	8,68399264	35,4133382
	4525,714286	3033	15607	3,448516414	34,95756052
	1937,142857	873	5764	2,975516224	34,92837309
	235,7142857	1993	5638	23,91878788	34,76869363
	1132,285714	1950	7075	6,248422912	34,66847091
	4414,285714	3456	15293	3,464433657	34,22159888
	1158,857143	1993	7046	6,080128205	33,94673499
	1624,285714	1729	7077	4,356992084	32,81907433
	13242,85714	4455	25377	1,916278317	32,68895855
	2939,142857	2580	10182	3,464275299	32,25493054
	1809,428571	3250	10246	5,662561187	31,5970386
	7643,142857	2313	15501	2,028092408	31,28782456
	2329,714286	3454	10202	4,379077753	31,02035048
	20964	4434	28638	1,366056096	30,29131986
	3335,142857	1576	9581	2,872740512	30,25063362
	3419,142857	1191	8237	2,409083312	30,20509926
	4457,142857	3053	15842	3,554294872	29,68680289

Next to these results, we also look at the inventory parameters. The conclusion that we make from that is that the large majority of articles in the scope have a reorder point of zero and an order-up-to-level of the EOQ. Normally, we would consider this as strange because in practise there is always a chance that a customer comes in and places an order when our inventory is zero during lead time and review period. This will then lead to the fact that we cannot satisfy this order and that leads to a drop in service level. However, because the EOQ is very high and results in multiple years of stock it happens only very occasionally. So, we therefore do not think that the tool calculates this wrongly, but we will elaborate this further in chapter 6 discussion. The last result of the tool is concerning the criterion in Bijvank's algorithm. This criterion checks if the Wilson's lot-size formula yields a good approximation for the EOQ that is used in the inventory parameters. Currently, for all articles in the scope this is satisfied. Therefore, the tool always returns the first calculations of the inventory parameters according to the constraint $S - s = \Delta$. The second part of the tool thus never gets used.

6. Discussion

The quality of the output is determined by the quality of the input values and the quality of the model. Therefore, the input values and the models need to be checked on their quality. This is done in this chapter. Through the entire report assumptions have been made to make the modelling of these input values and models possible. However, the assumptions are not all the time as realistic as should and therefore form limitations. This is discussed in subchapter 6.1 limitations. The other factor that we need to consider is the quality of the model. This will be checked in subchapter 6.2 validity and reliability.

6.1 Limitations

The limitations that occurred during the research are divided in four categories: overall, input values, optimal batch size model, and the inventory parameters model. These are discussed in detail below.

6.1.1 Overall

The limitation that effected my work the most was the time limitation. When we started in module 12, it had to be completed within 10/11 weeks. However, in this time also the green light meeting and the colloquium should be done. This meant that only the first 6 weeks are useable for research. Week 7 will then be used for creating the draft report, so the green light could be performed in week 8. Then we would be able to do the colloquium in week 11. The weeks between the green light and the colloquium can then be used to implement the received feedback as well as preparing for the colloquium. Since, 6 weeks are relatively short it is very important to define a good scope. This scope is defined in subsection 1.2.2 action problem. By defining a scope, we automatically start including and excluding articles which brings us to the next limitation. The first criterion of the scope makes sure only the MTS standard articles are considered. This filters out all other production types like buy to order (BTO), buy to stock (BTS), and MTO. The limitation that arises from this is that we do not know the optimal batch size for these types of products. Since insights in this would also yield savings, this limitation should not be forgotten. Then within the MTS standard products not all products are comparable. After researching this, the decision was made that all cables from the energy department were excluded. The tool will therefore not work for MTS products from the energy department. The last product group of MTS products that are left out are the mother cables. The mother cables are defined in a special way in the databases and therefore giving an error in the tool. This could unfortunately not be added to the tool in time and is therefore left out. So, the main limitation of the scope is the fact that products are left out which could contribute by cost savings. Another overall limitation is corona. When writing this bachelor thesis, COVID-19 is unfortunately still preventing us from going back to the normal situation. This will of course influence the research, but we must make sure this will be as little as possible. Since not everyone is present at the company, interviews need to be scheduled at later times or online. This is of course hard because much flexibility is needed and that hinders the practicality of the research somewhat.

Besides the above-mentioned overall limitations, we also encountered some data(base) limitations. First of all, some of the data required for determining the optimal batch sizes was not available in TKF. Therefore, we had to calculate them ourselves or use estimates or averages. Second of all, we also encountered some gaps between certain database tables. This was the case because some of the tables could not be joined due to differences in name (inconsistent or outdated) or because we do not keep track of necessary information. Therefore, some links had to be laid manually and this means that these need to be checked before running the tool. The reason why this is of great importance is because it will impact the outcomes of the tool if these manual links are incorrect or outdated. The links that should be checked are described in chapter 3.

The last overall limitation is the fact that the model is only assessing the situation based on one article at a time. Therefore, practical constraints like production and storage capacity are hard to consider.

For this reason, it could not be assumed that just implementing the results of my tool will yield the best results possible, but it will still improve the current inventory system a lot.

6.1.2 Input values

As discussed in the introduction of this chapter, the quality of the model and the quality of the input data are independently influencing the outcome. For this reason, we created an additional subsection discussing the limitation on the input values. The first limitation is concerning the raw material per setup cost. At this moment, something is considered a switch when it is a different production order that is not clustered. However, colour switches are not considered by this method since they have their own production and article number. Therefore, the amount of switches is higher than they should be because a colour switch is negligible in cost and therefore not necessary to consider. This will result in more switches than we actually have in practice and yields a lower raw material waste cost per switch than the reality. The second limitation is concerning the storage cost per cable per meter. Currently we calculate this by computing the price of storing a reel and then dividing this by the maximum length that fits on that reel. However, the limitation here is that we assume that a reel always gets filled to the maximum. Although in practice this might be different and that leaves us with a storage price that is lower than the reality. The third limitation is about the loan provided to TKF by the TKH-group. This loan is lower than when we for example would go to the bank since TKH is TKF's holding firm. It is therefore very attractive to use this money to put articles to stock, but there is a limit to this. TKH is willing to give TKF the loan as long as TKF is really using this loan effectively. This means that we are not allowed to use it to create too large amounts of stocks, since they could gain more profit when investing it. So, this is deviating from the reality and therefore a limitation. The fourth limitation is about the cable depreciation. This cost is at this moment not considered at all but after doing research this should be included. Therefore, this is considered a limitation. The last limitation is about the handling of reels. As discussed with TKF, it was not needed to put a constraint on the storage capacity since hiring external terrain was an option they would consider if the tool suggested so. However, hiring external terrain also involves extra handling cost. This is currently not considered and is therefore a limitation.

6.1.3 Optimal batch size model

The quality of the output of the optimal batch size model (EOQ) is determined by the quality of the input values as well as Wilson's lot size formula. The quality of the EOQ is therefore determined by all limitations mentioned in subchapter 6.1.2 and possible limitations in Wilson's lot-size formula. Since Wilson's lot-size formula is a very simple formula which is easy to check, no limitations were found here.

6.1.4 Inventory parameters model

In terms of Bijvank's inventory parameters model, all limitations discussed in subsection 6.1.3 apply since this EOQ is an input for the algorithm. However, there are also additional limitations. The first limitation is about the statistical errors that could occur. The first category of statistical errors is the deviation from the service level that is used as input. This could occur if the stock-out constraint is not satisfied. This type of error is called the absolute measure error. The second category of statistical errors is the relative measure error. With this error we refer to the fact that the cost increase compared with the best (s, S) policy if the stock-out constraint is satisfied. The second limitation is about the increment size that I used in the tool. In theory, the algorithm could be modelled that it computes the inventory policy precise on the metre. However, this makes the algorithm very time consuming since it is desired by TKF to determine it for the entire scope. For this reason, we decided with TKF to determine them per 100 meter if the EOQ is smaller or equal to 20000 meters. When the EOQ is larger than 20000 but smaller than 30000 it will be calculated per 1000 meter and when it is larger than 30000 it will be calculated per 2000 meter.

6.2 Validity and reliability

The validity and reliability determine the scientific quality of the research and the results (Heerkens & van Winden, 2021). Therefore, it is important to look critically at the validity and reliability.

6.2.1 Validity

Validity is content-related, and has three components: internal validity, external validity, and construct validity (Heerkens & van Winden, 2021).

In terms of internal validity there should be looked at the mismatches in the model. We did this by using extreme values as input values to check if the model is doing what is expected. Some small errors were discovered during this analysis and solved. Furthermore, an extensive check and debug is performed to make sure the model is living up to the required validity. When performing this analysis, a few aspects were discovered which could (not) be solved. The first aspect was about the calibration and downtime and could be found in TKF's database. However, no one at TKF could guarantee us the quality of this number. Since checking the correctness ourselves was not possible due to the time limitation, the validity of the calibration and downtime is questionable. The second aspect is about the lead time. The lead time is article specific and retrieved from the database. TKF gave the lead time a fixed number but when comparing it to reality this is of course not the case. Unfortunately, the impact of this deviation from reality could also not be investigated due to the time limitation. The last aspect, however, could be investigated. This is about the validity of the inventory holding cost. We did this by looking at the average inventory holding cost in practise and compared it to our own calculations. Then we performed a sensitivity analysis. The first part of the inventory holding cost is the cost of capital. In TKF's case this is █%. This is deviating a lot with the best practises found in literature. However, we do not think that this is wrong because they have a loan with their holding firm instead of for example a bank and this is of course much cheaper. Still, there needs to be a constraint to this as discussed in the limitations. In terms of warehousing the literature is also deviating a lot. The reason for this is because it is highly dependable on your product. In TKF's case for example, they only need to rent an outside terrain and that's not very expensive. The 0.58% is therefore fine. Then we have the handling cost. For TKF this is only 0.09% while in literature it is mostly between 1% and 5%. With our calculation, we only took the handling of the products in consideration on our own terrain. However, if external terrain is used the cost rise. This is currently not modelled (as discussed in the limitations). The next part of the inventory holdings cost is the depreciation. Currently, this is only consisting of the reel depreciation, but depreciation of the cables is then totally forgotten. This is discussed in the limitations and is added as future research. If it would be added, the depreciation cost will increase a lot and be probably higher than the numbers found in literature. However, this will be fine since it is according to TKF's own policy. Then we have the insurance cost. In TKF's case these are █% and are low in comparison with the numbers found in literature (0.25% - 4%). This could be explained by the fact cables are not popular to steel, and most of the time no insurance is not needed. So that clarifies this lower number. The last factor which should be included according to literature is the obsolescence. However, this is irrelevant for cables. So, to conclude the validity of my inventory holding cost, I would suggest implementing the constrains on loan as well as the deterioration since then the numbers are perfectly in line with literature and valid. The complete explanation for this can be found in chapter 8 recommendation.

Table 17 - Inventory holding cost in practise by 1Cory Lynn Harms, Iowa State University (Harms, 2001) and 2Dr. Jim Weber, Weber Consulting (Russell, 2017)

Upper and lower category limits of combined carrying cost ranges ¹		Best Practice Inventory Carrying Costs (typical ranges +/- 10%) ²		
Category	Percentage			
Cost of capital	6 - 25 %	1 - Capital Costs	Interest, Opportunity	12.0 %
Warehousing/ Inventory Control	0.25 - 11 %	2 - Inventory Service	Taxes, Insurance	1.5 %
Handling/ Distribution/ Transportation	1 - 5 %	3 - Storage Space	Warehousing	3.0 %
Insurance	0.25 - 4 %		Clerical/ Recording Keeping	1.5 %
Taxes	0.50 - 6 %		Inventory Counting	0.7 %
Deterioration/ Damage/ Pilferage	2 - 10 %		Material Handling	1.3 %
Obsolescence	1 - 10 %		Depreciation	1.0 %
Total	11 - 71 %	4 - Inventory Risk	Obsolescence	4.0 %
		Total		25.0 %

Now that the analysis on input values suggests that the numbers could deviate from how they are calculated currently, it is time to perform a sensitivity analysis to see the effects on the possible outcomes. We chose to compare the current outcomes of the tool with the outcomes of the tool if the inventory holding cost would be 10%, 15%, 20%, 25%, and 40% of the cost price. This can be seen in Table 18. From the table, we concluded that the differences with the current situation are still significant and would result in large savings for TKF.

Table 18 - Impact of different inventory holding costs on results

Results (Current model)			Results (IHC of 20% costprice)		
Suggested average EOQ	21317	[meters]	Suggested average EOQ	10714	[meters]
Current average prod.length	4518	[meters]	Current average prod.length	4518	[meters]
Average meand demand (year)	29755	[meters]	Average meand demand (year)	29755	[meters]
Flexibility loss	471,82	[%]	Flexibility loss	237,14	[%]
average stock per current batch	0,15	[# of years]	average stock per current batch	0,15	[# of years]
average stock per EOQ batch	0,72	[# of years]	average stock per EOQ batch	0,36	[# of years]
Savings (on average)	0,48	[€/meter]	Savings (on average)	0,28	[€/meter]
Costprice (on average)	3,76	[€/meter]	Costprice (on average)	3,76	[€/meter]
Savings (percentage)	12,66	[%]	Savings (percentage)	7,41	[%]
Results (IHC of 10% costprice)			Results (IHC of 25% costprice)		
Suggested average EOQ	15152	[meters]	Suggested average EOQ	9583	[meters]
Current average prod.length	4518	[meters]	Current average prod.length	4518	[meters]
Average meand demand (year)	29755	[meters]	Average meand demand (year)	29755	[meters]
Flexibility loss	335,37	[%]	Flexibility loss	212,11	[%]
average stock per current batch	0,15	[# of years]	average stock per current batch	0,15	[# of years]
average stock per EOQ batch	0,51	[# of years]	average stock per EOQ batch	0,32	[# of years]
Savings (on average)	0,38	[€/meter]	Savings (on average)	0,24	[€/meter]
Costprice (on average)	3,76	[€/meter]	Costprice (on average)	3,76	[€/meter]
Savings (percentage)	10,23	[%]	Savings (percentage)	6,27	[%]
Results (IHC of 15% costprice)			Results (IHC of 40% costprice)		
Suggested average EOQ	12371	[meters]	Suggested average EOQ	7576	[meters]
Current average prod.length	4518	[meters]	Current average prod.length	4518	[meters]
Average meand demand (year)	29755	[meters]	Average meand demand (year)	29755	[meters]
Flexibility loss	273,82	[%]	Flexibility loss	167,68	[%]
average stock per current batch	0,15	[# of years]	average stock per current batch	0,15	[# of years]
average stock per EOQ batch	0,42	[# of years]	average stock per EOQ batch	0,25	[# of years]
Savings (on average)	0,33	[€/meter]	Savings (on average)	0,13	[€/meter]
Costprice (on average)	3,76	[€/meter]	Costprice (on average)	3,76	[€/meter]
Savings (percentage)	8,70	[%]	Savings (percentage)	3,40	[%]

For external validity, two factors need to be considered. The first discusses if the method will also work for other companies. At this moment in time, we do not think this will be the case because the results are coming from a single case study. In these cases, it is typically hard to generalize the results, so it

can be applicable to certain situations but due to limitations in time and scope of the research, it is not entirely generalizable. The second point is about the reality and if it can be assumed that our model will work in a real system. For this situation we do think our model will suffice, if the most important limitations on input values get solved. This will be discussed in the recommendations and future research.

For construct validity, the focus lies on abstract concepts. Here it is important to reflect if they are operationalized well, and where possible, based on available scientific knowledge (Heerkens & van Winden, 2021). Therefore, we take a critical look at the literature study (Chapter 2). Since the literature study, is created based on the systematic literature review, the validity of the scientific knowledge can be assumed. However, it should also be focused on how it should be implemented in TKF. Good and clear explanations are therefore important. Next to that, we made sure that the concepts that deviate from theory such as modifications and changes are properly explained. Chapter 3 and chapter 4 are examples of this.

6.2.2 Reliability

In this subsection the reliability issues are discussed. This are the issues concerning the stability of the research. This means that the research results should be the same when the research is performed with the same circumstances later. When using the model for determining the optimal batch size, it will rely on the data from the database for calculations and results. So, when the situation stays the same (no different way of producing and no revised cost for certain processes) the method will consistently give the same results. Therefore, the conclusion can be made that the results are reliable and will not change over time. However, when TKF decides that a cable has a new standard way of production, it is made sure that the tool is always using the new standard. For the second model, we also performed a reliability analysis. Here we concluded that the inventory parameters model is also returning the same results under the same circumstances. Note that reliability here only says something over giving consistent results and not if the method is suitable.

7. Conclusion and recommendation

During the report, all questions stated in research design are investigated and answered. In this chapter we will provide an answer to the main research questions as well as making conclusions and recommendations. Next to this, the contributions of this research and suggestions for future research will be provided.

7.1 Conclusion

We started our research with the following main research question:

How can the batch ordering decision optimally be determined and what is the impact of the optimal batch ordering on the combined cost of production and inventory?

In this subchapter of the report, we will answer the main research question and give a conclusion. According to the literature review that we performed, the batch ordering decision can optimally be determined by the use of Wilson's lot-size formula. This EOQ will then be used together with the lead time, demand distribution, review period, and service level as an input for Bijvank's algorithm to determine the corresponding inventory policy parameters. The reason why we chose to extend the batch size decision to the inventory parameters is because in reality much more factors play a role and only the EOQ will therefore not provide the best answer to TKF's problem. These factors are demand uncertainty, service level agreements with the customers, production lead time, and inventory review period. For determining Wilson's lot-size formula, first the setup cost and inventory holding cost needs to be calculated. For the setup cost this is done by considering the calibration and downtime cost, and the scrap cost related to setup. For the inventory holding cost this is the cost of capital, the cost of handling and storage, and the cost of risk. Then modelling this in Excel yields the tool.

The results of the tool suggest TKF, to enlarge their batch sizes on average with 472% to have a cost saving of 12.7%. However, we should keep in mind that this is against the trade-off of a flexibility loss of 472% and higher stock levels (0.15 years on stock per batch size versus the suggested 0.72 years on stock per EOQ batch size). TKF could therefore, also choose to partially implement the EOQ or enlarging the current batch sizes by a certain amount (not to the EOQ) to keep the flexibility loss and inventory rise to a minimum. The 12.7% cost savings still sounds very promising if we compare it to the norm that was set by TKF at the beginning of the research. There we defined that we want to see a drop of approximately 5% of the combined cost of setup and inventory holding cost. Considering then that the 12.7% is calculated over the cost price this will result in an even higher percentage. This is the case because the variable cost should be excluded to express it in the same unit as the norm. The high savings percentage is although not completely unexpected since we already observed the bad alignment between inventory holding and setup cost TKF currently has (27% versus 73% respectively).

As could be concluded from the discussion part, improvements could be made to make the input values more realistic. For both models we, however, do not have any limitations and these could therefore safely be used. To see the impact of changing the input values, a sensitivity analysis was performed. From this analysis we concluded that the savings for TKF will still be significant.

7.2 Recommendation

Based on the results and the performed research, we created a list with recommendations for Twentsche Kabelfabriek BV.

1. In order to calculate the optimal batch size and the optimal inventory parameters, it is recommended to make use of the models explained in Chapters 3 and 4.
2. To make sure the results remain valid, it is recommended to update the inventory parameters and optimal batch sizes on a regular basis. This could be done by running the tools. Since some

parts of the tool need to be refreshed manually it is also recommended to do this once a month. For more information on these manual parts see Appendix A.

3. The quality of the output is depending on the quality of the input values. The input values therefore need to be as realistic as possible. Hence, we recommended to perform the future research that is suggested in subchapter 7.3 for improving this. Besides that, we recommend doing a sensitivity analysis after the new implementation (as done in Chapter 6) to ensure the validity of the tool. Reasons why we highly recommend doing this further research, is because the results from the sensitivity analysis (performed in Chapter 6) showed that different input values still yield significant savings for TKF. So definitely worth the time.
4. As discussed in the results and the conclusion, TKF has a trade-off between optimal savings, flexibility and inventory levels. Since the tool currently is only suggesting the optimal savings practical constraints like flexibility, production capacity, and large inventory levels are not considered. Therefore, we would suggest the management of TKF to take this into consideration when interpreting the results of the tool. In other words, if they see that a flexibility loss that is caused by implementing the results is not possible in practise, that they know that they could also determine which level would be possible and partially implement some of the EOQs. The reason why we are suggesting this is because every production size that is closer to the EOQ will yield savings for TKF and is therefore beneficial.
5. In the overall results of the tool, we only consider the entire scope. Therefore, no insights between the differences between the results of the MTS A, MTS B and MTS C articles could be seen as well as the differences between the portfolios. This could of course bring very useful insights and we therefore recommend TKF to do further research on how this could be added. Next to this, also the distinction between the MTS A, MTS B, and MTS C articles could not be found in the current situation (reality). So, we would also recommend adding this distinction here.
6. When we are looking at the overall results of the tool all results are concrete except for the flexibility. We do not know to which scale this number goes and it therefore does not really say something. Since time limitation hindered us in solving this problem, we recommend TKF to solve this. We suggest doing this by expressing this in the number of products that could be made in production per month if the EOQ batch sizes are used.
7. The last recommendation we have for TKF is to improve the database (structure) and data. At this moment, we saw that due to inconsistencies in name or outdated data it was hard to create the joints to retrieve the required data. This resulted in gaps between the database tables and needed workarounds like for example manual created joints which do not update automatically. Also, we would recommend looking at required data that has not been collected yet and look for solutions the market offers for this problem since data can really help optimising the production facility. Besides that, it would also enable a more efficient decision-making.

7.3 Future research

This research has been performed in a scope of ten weeks. Therefore, extensive research was not possible. Besides, the research has been performed during the COVID-19 pandemic, which could cause some invalid time measurements. In this subchapter we therefore discuss the limitations and the possible future research. Since TKF is already very busy with their daily operations due to understaffing, only the future research with the highest effects will be discussed here.

- Since the timespan of the research is relatively short, the tools are not working for all MTS articles. Future research can therefore be performed on how to make the tool working for all MTS articles. We suggest doing this by focusing on adding the cables managed by the energy and expedition department.
- At this moment, the input value for the handling cost is based on the handling time on the terrain of TKF. However, when the total stock that can be handled on TKF's current terrain

exceeds the maximum, we will hire external terrain. However, this results in higher handling cost which are currently not taken into consideration. Therefore, we suggest doing future research on how this cost can be modelled more realistically. An example for this could be by determining an overhead for the extra cost of external terrain with the logistics manager of TKF. The overhead should then include the extra transportation cost from TKF's production facility to the new location, the extra cost for the increased complexity of the inventory management, and the costs which are made by the employees which are handling the inventory on the external location.

- The input value for the cost of capital (loan by TKH-group) is currently not constrained. However, after researching this we concluded that this is not always the case. TKH knows that investing the money yields more interest than TKF is currently paying to TKH and therefore they do not want that TKF is just lying everything on stock if this is not necessarily needed. Since this is not a hard constraint, we suggest scheduling a meeting with TKH-group to find out what hard constraint should be put on this loan to make it more realistic.
- The input value for the depreciation of cables is currently not considered at all. Therefore, we suggest TKF to investigate ways of taking this into consideration. A suggestion for this is by implementing a loop in the EOQ calculation. In the first loop, we will calculate EOQ without considering the depreciation of the reels. Based on these outcomes we calculate the chances of how long it will be in stock. The depreciation per cable will then be calculated by multiplying the chance that the product stays in stock for one year by 33% of the cost price, the chance of two years in stock will be multiplied by 67%, and three or more years in stock will be multiplied by 100% of the cost price. Then the model will be run again (loop two) and this will yield an EOQ that does consider the depreciation per cable.
- The input value for storage cost is currently linearly calculated based on the assumption that the reels get filled to their maximum capacity. However, this is not always the case in practice and therefore the cost is not calculated realistically. Our advice to solve this is by calculating with the cost of one reel independent of the length, until the maximum capacity gets exceeded. Then you should calculate the cost of two reels, and so on.
- As discussed in subsection 6.2.1 there are some unsolved validity issues which could not be solved due to the time limitation of the research. This was concerning the validity of the calibration and downtime and the lead time. Both values can be found in TKF's database, however, no one in TKF could guarantee me the correctness of both. Since these input values affect the outcome of the tool, it is suggested to perform a research to the quality of these two. This could for example be done by measuring these times manually ourselves or by purchasing sensors which could keep track of this.

7.4 Contribution to theory and practice

In this subchapter, we describe the theoretical and practical contributions of the research.

7.4.1 Theoretical contribution

In this research, we performed a literature study on the topic of inventory models. We found that Bijvank (2014) created a time and cost-efficient heuristic method of simultaneously determining the inventory parameters under an alpha service level constraint (chance of not running out of stock during a cycle). We have proven that this method is indeed working for determining the optimal inventory parameters for a cable manufacturing company. The research is however contributing more in a practical way.

7.4.2 Practical contribution

This research is performed at Twentsche Kabelfabriek BV. The practical contributions for the company are the models described in chapter 3 context analysis and chapter 4 inventory model. By using these

models as decision supportive tools, TKF can make practical decisions on inventory parameters and batch sizes based on the performed research.

We have proven that we successfully implemented the theoretical insights of Bijvank's algorithm into a practical decision tool which can be used by TKF in practice. Besides that, we created a method for correctly determining the demand distribution and parameters that were necessary for computing the optimal inventory parameters. This was done by performing a variance-to-mean analysis.

For the optimal batch size calculation model, we determined the setup and inventory holding cost. At the beginning of the research, TKF had no insights in setup cost and inventory holding cost. During the research we identified that the setup cost is consisting of calibration and down-time cost and the scrap cost related to setup. The calibration and down-time cost are on itself consisting of the machine cost and employee cost while the scrap cost related to setup is consisting of the waste of raw materials due to setup and cable loss due to start-up. For the inventory holding cost we identified that it is consisting of the cost of capital, the cost of handling and storage, and the cost of risk. The cost of risk is then consisting of the depreciation of the reels and the insurance cost of the inventory. While the cost of handling and storage is consisting of the transportation of reels and the storage cost per cable. Lastly, the cost of capital is consisting of the loan provided to TKF by the TKH-group. An overview of this is provided in Figure 7.

Now that all inputs are identified, we will explain shortly how we calculate these costs. The loan of the TKH-group is calculated as a percentage over the cost price of the cable. The transportation of reels is determined by looking at the average time it takes to store a cable multiplied by the number of employees working on it times the labour cost. The storage cost per cable is calculated by looking at the space a reel of cable needs in inventory. We then multiply that number with the cost of the terrain and divide it by the length of the cable that fits on that specific reel. The depreciation of the reels is calculated by dividing the cost price of a reel by three. This is the depreciation of the reel per year, since TKF is depreciating the entire reel in three years of use. The insurance cost of the inventory is calculated by taking a percentage over the cost price of the cable. The machine cost is calculated by taking the calibration- and down-time and multiplying that with the machine tariff. The employee cost is calculated by taking the calibration- and down-time and multiplying that with the number of employees involved multiplied by the employee labour cost. The waste of raw materials per setup is calculated by determining the total amount of waste that is created by a process for a certain period and dividing that over the number of switches that have been made in the same period. Then we multiplied it with the cost price to calculate the average cost of raw material per switch. Lastly, we have the cable loss per setup. This cost is calculated by taking the over-length that is required by a certain process and multiplying that with the cost price of the material that needed over-length.

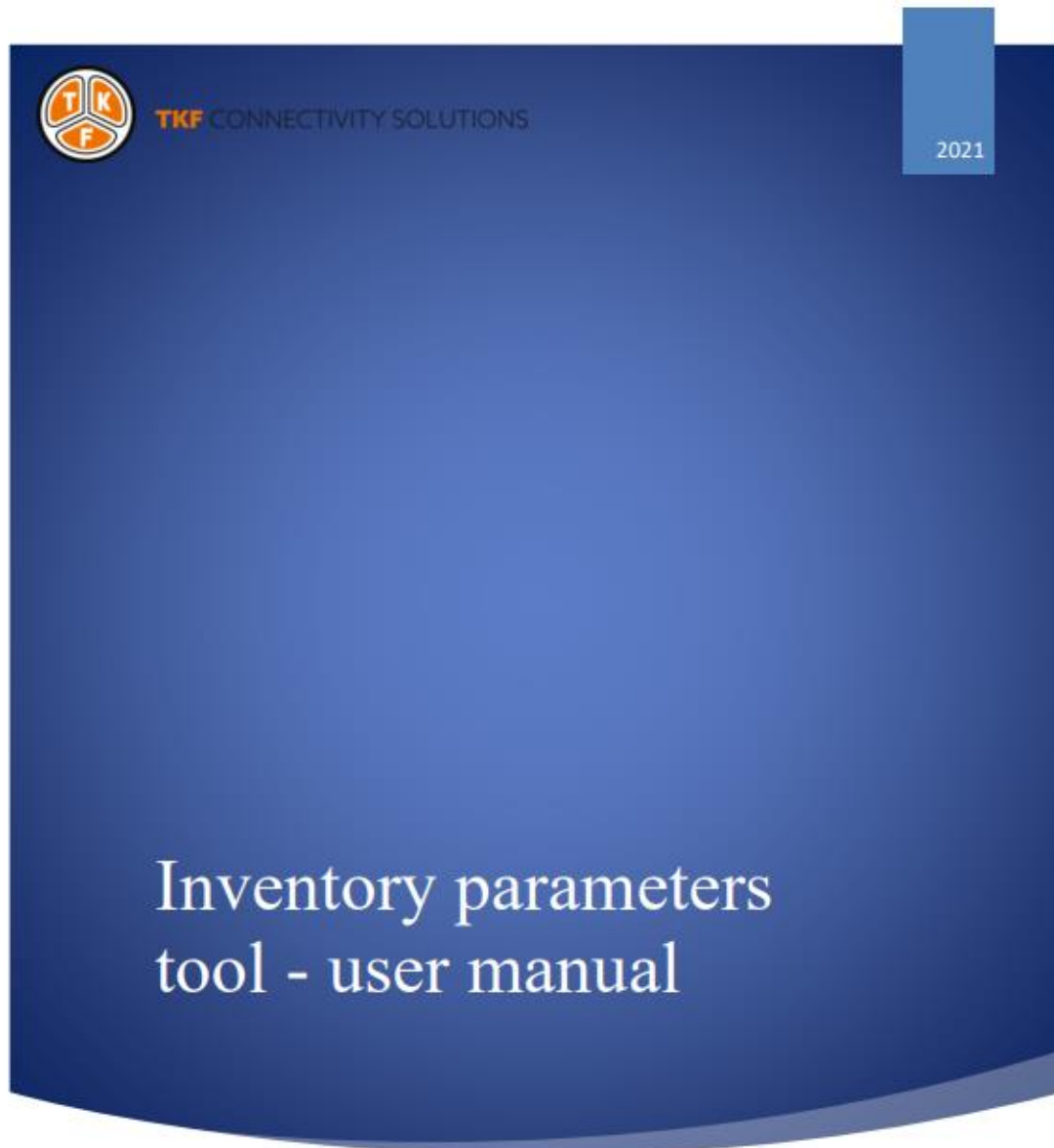
References

- Agrawal, N., & Smith, S. A. (1996). *Estimating Negative Binomial Demand for Retail Inventory Management with Unobservable Lost Sales*.
- Bijvank, M. (2014). Periodic review inventory systems with a service level criterion. In *Journal of the Operational Research Society* (Vol. 65, Issue 12, pp. 1853–1863). Palgrave Macmillan Ltd.
<https://doi.org/10.1057/jors.2013.160>
- Durlinger, P. P. J. (2014). *INVENTORY AND HOLDING COSTS A white paper approach for managers*.
- Harding, M. L. (2005). *What's Your Inventory Carrying Cost, and Why Don't You Know It?*
- Harms, C. L. (2001). *A comparison of inventory carrying cost in literature and in practice*.
<https://lib.dr.iastate.edu/rtd>
- Heerkens, H., & van Winden, A. (2021). *Solving Managerial Problems Systematically*. Routledge.
<https://doi.org/10.4324/9781003186038>
- Holsenback, J. E. (2007). A SURVEY OF INVENTORY HOLDING COST ASSESSMENT AND SAFETY STOCK ALLOCATION. In *Academy of Accounting and Financial Studies Journal* (Vol. 11, Issue 1).
- Mortici, C. (2010). A class of integral approximations for the factorial function. *Computers and Mathematics with Applications*, 59(6), 2053–2058.
<https://doi.org/10.1016/j.camwa.2009.12.010>
- Reel | Definition of Reel at Dictionary.com. (n.d.). Retrieved March 29, 2021, from
<https://www.dictionary.com/browse/reel>
- Reid, R., & Sanders, N. (2005). *Operations Management An Integrated Approach* (2nd ed.). John Wiley & Sons.
- Ross, G. J. S., & Preece, D. A. (1985). The Negative Binomial Distribution. *The Statistician*, 34(3), 323.
<https://doi.org/10.2307/2987659>
- Russell, G. (2017, September 2). *People & Profits: Do You Know Your Carrying Costs? | Farm Equipment*. <https://www.farm-equipment.com/blogs/6-opinions-columns/post/14452-people-profits-do-you-know-your-carrying-costs>
- Silver, E. A., Pyke, D. F., & Thomas, D. J. (2017). *Inventory and Production Management in Supply Chains Fourth Edition* (4th ed.). Taylor & Francis Group.
- TKH Group. (n.d.). *about us - TKH Group*. Retrieved March 29, 2021, from
<https://www.tkhgroup.com/en/about-us/>
- Twentsche Kabelfabriek. (n.d.). *Profile TKF - TKF (Twentsche Kabelfabriek)*. Retrieved March 29, 2021, from <https://www.tkf.nl/en/about-tkf/profile-tkf>
- UCSF. (n.d.). *Negative Binomial Distribution*. Retrieved May 26, 2021, from
https://valelab4.ucsf.edu/svn/3rdpartypublic/boost/libs/math/doc/sf_and_dist/html/math_toolkit/dist/dist_ref/dists/negative_binomial_dist.html
- Variance/Mean Ratio - Statistics.com: Data Science, Analytics & Statistics Courses. (n.d.). Retrieved May 26, 2021, from <https://www.statistics.com/glossary/variance-mean-ratio/>

Wagner, H. M., & Lundh, B. (1965). An Empirical Study of Exactly and Approximately Optimal Inventory Policies. In *Source: Management Science* (Vol. 11, Issue 7).
<https://about.jstor.org/terms>

Appendices

A. User manual tool



VERSIE 1: 15-06-2021
ZENTVELD, BRAM

TWENTSCHE KABELFABRIEK BV | Spinnerstraat 15 7481 KJ Haaksbergen

 member of the TKH Group <



Table of Contents

Hoofdstuk 1: Inleiding	2
Hoofdstuk 2: MTS-artikelen	2
Hoofdstuk 3: Inventory holding en setup cost model	3
Input	3
Opstartkosten.....	4
Gronstofkosten	4
Inventory holding kosten.....	5
Opslagkosten	6
Realiteit	6
Hoofdstuk 4: Realiteit MTS artikelen	6
Hoofdstuk 5: Limitaties Inventory holding en setup cost model	8
Hoofdstuk 6: Inventory parameters tool.....	9
Input	9
Demand	9
Optimale productie grootte.....	10
Demand distributie en bijhorende parameters.....	10
Voorraadparameters	10
Rode en groene lijn	11
Hoofdstuk 7: Inventory parameters voor alle MTS	11
Hoofdstuk 8: Limitaties inventory parameters tool.....	12
Hoofdstuk 9: Inzicht EOQ.....	13
Hoofdstuk 10: Berekeningtijden	13
Hoofdstuk 11: Overzicht tabbladen.....	14



Hoofdstuk 1: Inleiding

Beste lezer,

In deze handleiding leg ik jullie uit hoe jullie de inventory holding cost, setup cost, de optimale batchgrootte en voorraadsparameters kunnen berekenen met de tool. Dit is gedaan op de volgende manier:

- In hoofdstuk 2 wordt de scope van de artikelen uitgelegd die meegenomen worden als je het voor de MTS-artikelen gaat berekenen. Dit is namelijk niet voor alle artikelen en daarom belangrijk om te weten.
- In hoofdstuk 3 wordt het overzicht van het dashboard voor de inventory holding en setup cost gegeven. Aan de hand hiervan worden de functionaliteiten en details ervan beschreven. Verder wordt er beschreven hoe je sommige gegevens kan verversen in de inventory holding en setup cost model zodat de gegevens up-to-date zijn. De redenen waarom deze niet standaard verversen worden is omdat deze gegevens niet elke keer verversen hoeven te worden en dit significant veel berekentijd scheelt.
- In hoofdstuk 4 wordt beschreven hoe je de inventory holding en setup cost voor de MTS-artikelen in de scope kan berekenen. Hierbij krijg je ook een overzicht hoe dit er dan uit ziet.
- In hoofdstuk 5 worden de limitaties van de tool uitgelegd. Dit is belangrijk om te weten aangezien de tool dus nog niet het beste beeld van de werkelijkheid geeft. Met deze kennis kan je dan ook kritischer naar de uitkomsten van de tool kijken en weet je waar de tekortkomingen liggen.
- In hoofdstuk 6 wordt het dashboard van de inventory parameters tool gegeven. Aan de hand van dit overzicht worden alle functionaliteiten en details uitgelegd.
- In hoofdstuk 7 wordt beschreven hoe de inventory parameters voor de MTS-artikelen berekend kan worden. Hier worden dan ook de resultaten bij gegeven.
- In hoofdstuk 8 worden de limitaties van de inventory parameters tool beschreven zodat de gebruiker dit mee kan nemen bij de resultaten die verkregen worden.
- In hoofdstuk 9 wordt een visualisatie gegeven tussen wat de actuele productie grootte is en wat de tool voorstelt.
- In hoofdstuk 10 wordt een overzicht gegeven van alle berekentijden zodat gebruikers van de tool precies weten waar ze aan toe zijn voordat ze bepaalde delen laten runnen.
- In hoofdstuk 11 wordt een overzicht gegeven waar de dingen die in voorgaande hoofdstukken beschreven zijn, te vinden zijn in de tool.

Hopelijk veel plezier bij het lezen en mochten er vragen zijn kunnen jullie die altijd stellen via b.zentveld@tkf.nl.

Hoofdstuk 2: MTS-artikelen

Zoals beschreven in de inleiding worden niet alle MTS-producten meegenomen. Om die reden wordt in dit hoofdstuk geschreven welke er dan wel en niet bij zitten. Doordat er in sommige gedeeltes van de tool afdelingsspecifieke berekeningen zijn gemaakt die erg tijdrovend waren is ervoor gekozen om alleen de afdelingen Installatie en Multiconductor mee te nemen. De 40 kabels van energie vallen daarom af. Verder is dit ook het geval voor de 200 kabels die beheerd worden door expeditie. De tool zoals hij nu is opgebouwd was namelijk niet in staat om de berekeningen te voltooien die nodig zijn en door het tijdgebrek is dus de keuze gemaakt deze niet mee te nemen.



Hoofdstuk 3: Inventory holding en setup cost model

Dashboard setup en inventory holding cost (model)

Input

Artikelnr

Bereken setup & inventory cost

Ververstijd: ± 7 sec

Bereken setup cost

Ververstijd: ± 1 sec

Bereken inventory holding cost

Opstartkosten

Over-lengte kosten	69,20	[€]
Grondstof kosten	111,79	[€]
Opstartkosten materiaal	180,98	[€]

Machinekosten

398,06

[€]

Werknemerskosten

352,20

[€]

Opstartkosten insteltijd

750,26

[€]

Opstartkosten materiaal

180,98

[€]

Opstartkosten insteltijd

750,26

[€]

Totale opstartkosten

931,25

[€]

Inventory holding kosten

Kapitaalkosten (lening TKH groep, %)

[€]/meter

Verwerkingskosten

0,003

[€]/meter

Opslag kosten

0,007

[€]/meter

Verwerkings- en opslagkosten

0,010

[€]/meter

Verzekeringskosten (%)

[€]/meter

Haspelafschrijving

0,003

[€]/meter

Risico kosten

0,003

[€]/meter

Kapitaalkosten

0,0001

[€]/meter

Verwerkings- en opslagkosten

0,010

[€]/meter

Risico kosten

0,003

[€]/meter

Inventory holding kosten

0,01

[€]/meter

Informatie verversen (grondstofkosten)

Terugkrijgtijd grondstofkosten

182

[dagen]

MC Isolatielij 1-2-3 Totaal

41,95

[€/ ombouw]

MC Mantellijn 1-2

34,92

[€/ ombouw]

MC Mantellijn 3

40,26

[€/ ombouw]

IN Isolatielij 3-4-5 Totaal

77,91

[€/ ombouw]

IN Mantellijn 4-5-6, Hulpaderlijn

29,86

[€/ ombouw]

Ververs installatie grondstofkosten

Ververstijd: ± 10 min

Ververs MC grondstofkosten

Informatie verversen (opslagkosten)

Oppervlakte opslagterrein

33600

[m²]

Ruimprjs terrein

15

[€/m²/jaar]

Haspel op voorraad

8956

[aantal]

Oppervlakte inname haspels

9501,25

[m²]

Manoevreerruimte percentage t.o.v. totaal

71,72

[%]

Manoevreerruimte opslag t.o.v. haspelafmeting

353,64

[%]

Ververs voorraad info

Ververstijd: ± 1 min

Ververs haspel info

Ververstijd: ± 1 sec

Ververs QT info

Realiteit

Gemiddelde productie lengte

900,00

[meter]

Gemiddelde inventory holding kosten

12,20

[€]

Totale opstartkosten

931,245

[€]

Zoals gezien kan worden in bovenstaande afbeelding, bestaat de tool uit meerdere vlakken. De functionaliteiten en betekenis van die vlakken wordt daarom hier stuk voor stuk uitgelegd. Ook zullen we daarbij een uitleg geven van alle knoppen die ingedrukt kunnen worden.

Input

In het "Input" vlak linksboven vul je handmatig het artikelnummer in waarvan je de inventory holding en setup cost wilt berekenen. Indien dit niet een artikel uit de scope is of een foutief artikelnummer zal de tool je hier een melding van sturen. Dit gebeurt echter niet direct maar pas nadat je op de knop "bereken setup & inventory cost" hebt geklikt. Zoals de naam al zegt is dit de knop om beide berekeningen in een keer uit te voeren. De knoppen die naast deze "bereken setup & inventory cost" knop zitten zijn de knoppen die individueel één van deze componenten berekent. De reden dat dit erin zit is zodat je inventory cost en setup cost los kan berekenen zonder allebei voor de hele scope of voor een individueel product te doen aangezien je dit toch best wat tijd scheelt en niet altijd nodig is.

Input

Artikelnr

Bereken setup & inventory cost

Ververstijd: ± 7 sec

Bereken setup cost

Ververstijd: ± 1 sec

Bereken inventory holding cost



Opstartkosten

Dan gaan we door naar het vlak van de “opstartkosten”. Het “opstartkosten” vlak is verdeeld in 3 componenten. Het eerste gedeelte berekent de opstartkosten van het materiaal, het tweede gedeelte berekent de opstartkosten van de insteltijd en het derde gedeelte sommeert deze twee en geeft uiteindelijk de totale opstartkosten. Om wat specifieker op deze componenten in te gaan zie je in het “opstartkosten materiaal” component gedeelte dat deze opgedeeld is uit de over-lengte kosten en de grondstof kosten. De grondstof kosten worden hierbij berekend door te kijken naar de grondstoffen die weggegooid worden bij een ombouw. Dit is niet product specifiek berekent maar per afdeling. De reden hiervoor is omdat het afval van een afdeling pas weggegooid wordt als de bak vol is en niet per ombouw. Daarom konden we alleen voor een bepaald tijdsbestek kijken hoeveel er weggegooid werd en dit dan delen door het aantal ombouwen om zo een gemiddelde te berekenen. De uitkomsten van deze berekeningen kunnen echter in een ander vak gevonden worden. Dit staat in de volgende onderkop beschreven. De over-lengte kosten zijn de kosten die verbonden zijn aan de verliezen van half/ eindproducten tussen de verschillende qualified teams. Deze zijn in Navision te vinden en worden via deze manier opgehaald en berekent. De laatste component van de opstartkosten is de opstartkosten van de insteltijd. Hierin worden de machine kosten van het stilstaan en de manuren van het ombouwen meegerekend. Deze gegevens worden wederom uit Navision gehaald.

Opstartkosten			
Over-lengte kosten		69,20	[€]
Grondstof kosten		111,79	[€]
Opstartkosten materiaal		180,98	[€]
Machinekosten		398,06	[€]
Werknemerskosten		352,20	[€]
Opstartkosten insteltijd		750,26	[€]
Opstartkosten materiaal		180,98	[€]
Opstartkosten insteltijd		750,26	[€]
Totale opstartkosten		931,25	[€]

Grondstofkosten

Zoals beschreven in het “opstartkosten” vlak worden de grondstofkosten per gemiddelde berekend over een bepaalde tijdsperiode. Aangezien dit over een zo groot mogelijke periode gebeurt worden uitzonderingen minder meegenomen en komt er dus een betere gemiddelde waarde uit. Echter zorgt een grotere tijdsperiode natuurlijk voor meer gegevens en kost dit meer tijd om het te berekenen. Standaard wordt deze berekentijd daarom op een half jaar gezet. Als je de tool dan runt volgens de twee knoppen eronder zal dit resulteren in 10 min berekentijd per afdeling. Dit hoeft je dus niet elke keer te doen, aangezien het niet van de ene op de andere dag significant zal gaan verschillen. Maar het af en toe bijwerken is wel verstandig zodat de nieuwste situatie meegenomen wordt.



Informatie verversen (grondstofkosten)			
Terugkijktijd grondstofkosten		182	[dagen]
MC Isolatielijijn 1-2-3 Totaal		41,95	[€/ ombouw]
MC Mantellijn 1-2		34,92	[€/ ombouw]
MC Mantellijn 3		40,26	[€/ ombouw]
IN Isolatielijijn 3-4-5 Totaal		77,91	[€/ ombouw]
IN Mantellijn 4-5-6, Hulpaderlijijn		29,86	[€/ ombouw]
Ververs Installatie grondstofkosten	Ververstijd: ± 10 min	Ververs MC gronstofkosten	

Inventory holding kosten

De "inventory holding kosten" zijn verdeeld over 4 componenten. In de bovenste component wordt de kapitaalskosten van de voorraad berekent. Het is belangrijk dat dit meegenomen wordt omdat het op voorraad leggen van artikelen betekent dat er geld gebruikt wordt dat niet meer geïnvesteerd kan worden en hier zit natuurlijk een kostenpost aan verbonden. Dan gaan we door naar het "verwerkings- en opslagkosten" component. In dit component wordt de verwerkingskosten en opslagkosten berekent. De verwerkingskosten zijn momenteel gebaseerd op de tijd die het duurt om een haspel te verwerken en op voorraad te liggen maal het uurtarief van de werknemers die dit doen maal het aantal werknemers. De opslagkosten waren wat lastiger te berekenen en hiervoor werden daarom ook meerdere berekeningen gemaakt. De uitkomsten van deze tussenberekeningen kan gezien worden in het "opslagkosten" vlak. Dit wordt in de volgende onderkop besproken. Als laatste hebben we de "risico kosten" component. In dit component worden de verzekeringskosten en de haspelafschrijving berekent.

Inventory holding kosten			
Kapitaalskosten (lening TKH group, %)			[€/meter]
Verwerkingskosten		0,003	[€/meter]
Opslag kosten		0,007	[€/meter]
Verwerkings- en opslagkosten		0,010	[€/meter]
verzekeringskosten (%)			[€/meter]
Haspelafschrijving		0,003	[€/meter]
Risico kosten		0,003	[€/meter]
Kapitaalskosten		0,0001	[€/meter]
Verwerkings- en opslagkosten		0,010	[€/meter]
Risico kosten		0,003	[€/meter]
Inventory holding kosten		0,01	[€/meter]



Opslagkosten

De opslagkosten worden berekend door te kijken naar het totale aantal haspels die op voorraad liggen en dit te vermenigvuldigen met de maat van deze specifieke haspels. Als je dit getal dan vergelijkt met het terrein dat hiervoor in gebruik genomen wordt kan je een opslagpercentage berekenen voor de paden en manoeuvreerruimte die nodig is. Als je dit dan vervolgens erbij op telt heb je de totale oppervlakte die een bepaalde type haspel nodig heeft en als je dan gaat kijken wat de terrein kosten hiervan zijn heb je een prijs per haspel. Dit rekenen we dan terug per meter door het te delen door het maximaal aantal meter dat op een haspel past. Aangezien het aantal haspels in voorraad regelmatig wisselt kan je de ruimte die het inneemt en de manoeuvreerruimte daarom verversen door opnieuw de bijhorende ExSIONs te runnen. Dit kan gedaan worden met de 3 knoppen in het “opslagkosten” vlak.

Informatie verversen (opslagkosten)				
Oppervlakte opslagterrein		33600	[m ²]	
Huurprijs terrein		15	[€/m ² /jaar]	
Haspels op voorraad		8956	[aantal]	
Oppervlakte inname haspels		9501,25	[m ²]	
Manoeuvreerruimte percentage t.o.v. totaal		71,72	[%]	
Manoeuvreerruimte opslag t.o.v. haspelafmeting		353,64	[%]	
Ververs voorraad info	Ververstijd: ± 1 min	Ververs haspel info	Ververstijd: ± 1 sec	Ververs QT info

Realiteit

Het laatste vlak is het “realiteit” vlak. Het “realiteit” vlak is toegevoegd om de huidige situatie te kunnen bekijken zodat we deze later kunnen vergelijken met de suggesties van het model. Een belangrijke toevoeging voor dit vak is daarom de gemiddelde productielengte zodat we de totale inventory holding cost van een productie grootte kunnen berekenen.

Realiteit			
Gemiddelde productie lengte		900,00	[meter]
Gemiddelde inventory holding kosten		12,20	[€]
Totale opstartkosten		931,245	[€]

Hoofdstuk 4: Realiteit MTS artikelen

In hoofdstuk 3 zijn de functionaliteit van de tool per artikel besproken, maar omdat het meestal interessanter is om het over de MTS-artikelen te bepalen is er ook een functie in de tool gemaakt om alles automatisch te berekenen. Verder zijn hier visualisaties aan toe gevoegd om er een beter inzicht in te geven. De onderstaande afbeelding kon net niet binnen de screenshot van het hele dashboard, dus daarom ontbreekt hij daar. Echter is deze wel op het dashboard te vinden. Wanneer deze knop ingedrukt wordt gaat de tool voor de MTS-artikelen de realiteit berekenen zodat er een duidelijke situatie geschetst kan worden.



TKF CONNECTIVITY SOLUTIONS

Overzicht realiteit verversen	
Ververs Realiteit MTS	±30 sec
Inventory holding cost berekenen voor alle MTS	±6 min
Setupcost berekenen voor alle MTS	±34 min

Resultaten hiervan, kunnen gezien worden in onderstaande afbeeldingen. De eerste afbeelding laat zien hoe de data neergezet wordt en de andere afbeeldingen laten de visualisaties van de resultaten zien. De afbeeldingen hieronder zijn momenteel ter indicatie, maar er zijn er nog meer.

Art. nr.	Beheer door afdeling	Setupcost	Inventory holding cost	gemiddelde productie lengte	Portfolio code	Portfolio omschrijving	Inventory holding cost per meter
	INSTALLATIE	1904,2744	1400,894069	2590,545455 SHIP		Scheepskabel	0,573909496
	INSTALLATIE	2213,6174	899,5431754	1251,033333 SHIP		Scheepskabel	0,719040134
	INSTALLATIE	1614,9373	562,9841674	1759,666667 SHIP		Scheepskabel	0,319637962
	INSTALLATIE	1905,9037	446,7555233	852,1000007 SHIP		Scheepskabel	0,524258388
	INSTALLATIE	1629,9172	807,4137973	1977,625 SHIP		Scheepskabel	0,408274469
	INSTALLATIE	2031,5266	508,4079865	809,6 SHIP		Scheepskabel	0,584645799
	INSTALLATIE	2009,9522	1374,907049	2125,043478 SHIP		Scheepskabel	0,647001844

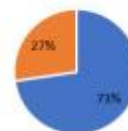
ZONDER FILTER

MULTICONDUCTOR + INSTALLATIE

gemiddelde setup	1263,612085
gemiddelde inventory	474,8312063
Totaal setup + inventory	1738,443291
gemiddelde lengte	4468,411427
setupcost per meter	0,282787766
Inventory holding cost per meter	0,156186921
Totaal setup + inventory per meter	0,438974687

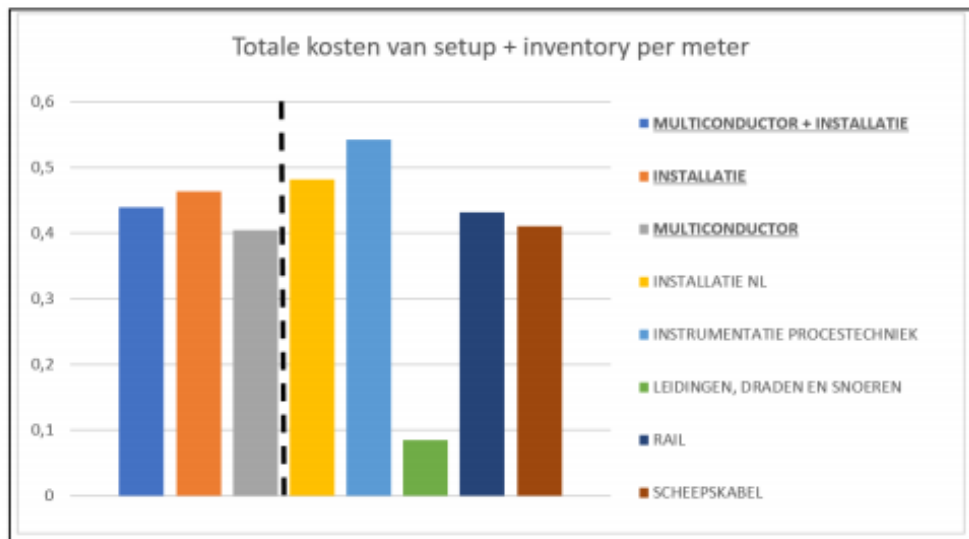
Multiconductor + Installatie

■ gemiddelde setup ■ gemiddelde inventory





TOTAAL SETUP+INVENTORY PER METER (OVERZICHT)



Hoofdstuk 5: Limitaties Inventory holding en setup cost model

Omdat de tool momenteel nog niet alles zo realistisch mogelijk nabootst, zijn er momenteel nog wat limitaties. Deze zijn belangrijk voor de gebruiker zodat de gebruiker hier dan ook rekening mee kan houden bij de interpretatie van de resultaten. De eerste limitatie van de tool is dat het alle artikelen individueel bekijkt en berekent. Hierdoor houdt het geen rekening met zaken zoals maximum productiecapaciteit. De tweede limitatie is dat er geen limiet staat op het lenen van kapitaal. Echter is dit in de praktijk wel het geval want TKH wordt er niet blij van als we te veel op voorraad leggen aangezien zij dat dan niet kunnen investeren en dan lopen ze dus geld mis. De derde limitatie is dat de kabelafschrijving van 33.3% per jaar niet meegenomen wordt. Aangezien dit een best wel grote impact op de inventory holding cost gaat hebben zou deze wel geïmplementeerd moeten worden want nu wijst het teveel op te grote productie grootte.



Hoofdstuk 6: Inventory parameters tool

Dashboard voorraadparameters (heuristic)

Run tool

Laatste maand met verkoopdata		2021-04
Artikelnr	Input	
Q Service level	Kans om niet uit voorraad te raken tijdens een periode	96 [%]
T Afname periode	Periode om de demand over te berekenen	14 [maanden]
R Review period length	1 dag voor alle MTS producten (scope)	1 [dagen]
L Leadtime	Bufferklasse	22 [dagen]
K Setupcost	Berekent met model uit andere dashboard	1864,274375 [€]
h Inventory holding cost per jaar	Berekent met model uit andere dashboard	0,672069496 [€/meter]
n Inventory holding cost per dag	Inventory holding cost/265	0,001572519 [€/meter]
D Afname over de periode	Som van aantal	20467 [meter]
μ _h Gemiddelde afname per dag (n=1)	Afname van de periode/(aantal maanden*(dagen in een maand))	0,480599217 [100meter]
Δ Wilhoor's tot size formule	Afgerond naar het dichtstbijzijnde hele getal; $\lceil \sqrt{2K\mu h} \rceil$	10673 [meter]
σ _h spreiding per dag (n=1)		2,908456824 [100meter]
VMR Variance-to-mean ratio	$\text{VMR} = \sigma^2 / \mu$	17,60854623
Distributie type	VMR = 0 Constant random variable, 0 < VMR < 1 binomial, VMR = 1 Poisson en VMR > 1 Negative binomial distribution	Negative binomial distribution
D _h slingskansen experiment in nR periode [neg. Binomial]	$p^*2 = (p^*)/(1-p^*2) \& \mu = (p^*)/(1-p) \rightarrow p = 1 - (\mu/p^*2)$	0,943209401
F _h aantal van mislukkingen tot einde experiment [neg. Binomial]	$p^*2 = (p^*)/(1-p^*2) \& \mu = (p^*)/(1-p) \rightarrow r = (\mu^*1-p)/p$	0,028924837
D _{hL} slingskansen experiment in nR _L periode [neg. Binomial]	$p^*2 = (p^*)/(1-p^*2) \& \mu = (p^*)/(1-p) \rightarrow p = 1 - (\mu/p^*2)$	0,997930844
F _{hL} aantal van mislukkingen tot einde experiment [neg. Binomial]	$p^*2 = (p^*)/(1-p^*2) \& \mu = (p^*)/(1-p) \rightarrow r = (\mu^*1-p)/p$	0,027349669
D _{hK} slingskansen experiment in nR periode [neg. Binomial]	$p^*2 = (p^*)/(1-p^*2) \& \mu = (p^*)/(1-p) \rightarrow p = 1 - (\mu/p^*2)$	0,971604701
F _{hK} aantal van mislukkingen tot einde experiment [neg. Binomial]	$p^*2 = (p^*)/(1-p^*2) \& \mu = (p^*)/(1-p) \rightarrow r = (\mu^*1-p)/p$	0,0202079465
S _h startwaarde reorder point		1600 [meter]
S _h startwaarde order up-to level		12300 [meter]
S _h verbeterde reorder point		0 [meter]
S _h verbeterde order up-to level		0 [meter]
RL Rode Lijn		1600 [meter]
OL Groene Lijn		12300 [meter]

#	Maand	Aantal
1	2021-04	1579
2	2021-03	2363
3	2021-02	863
4	2021-01	243
5	2020-12	3665
6	2020-11	927
7	2020-10	992
8	2020-09	2018
9	2020-08	1253
10	2020-07	1339
11	2020-06	463
12	2020-05	1456
13	2020-04	1385
14	2020-03	2286

In bovenstaande afbeelding is het overzicht van de voorraadparameters dashboard te zien. Net zoals bij de setup en inventory holding cost dashboard is dit dashboard opgebouwd uit vlakken. Deze vlakken worden in dit hoofdstuk stuk voor stuk beschreven.

Input

De input waardes die door de gebruiker ingegeven moeten worden voor het berekenen van de voorraadparameters zijn: het artikel nummer, het beoogde servicelevel, de afname periode waarover de demand bekeken wordt, en de review periode lengte. De 3 laatstgenoemde zijn standaard al door de tool ingevuld om het voor de gebruiker makkelijker te maken maar mochten deze om een of andere reden anders moeten kunnen deze aangepast worden. Nadat de gebruiker dit allemaal naar wens ingevuld heeft kan er op de knop "Run tool" gedrukt worden. Vanaf dat moment gaat de tool beginnen met het berekenen van de voorraadparameters.

Artikelnr	Input
Q Service level	Kans om niet uit voorraad te raken tijdens een periode
T Afname periode	Periode om de demand over te berekenen
R Review period length	1 dag voor alle MTS producten (scope)

Demand

Als het artikelnummer ingevuld is gaat de tool automatisch de demand van dit specifieke terughalen uit de historische data. Dit wordt in de tabel aan de rechter kant van de tool ingevuld. Daarnaast laat de tool dan ook de laatste maand waarover de tool momenteel aan data beschrijft zodat de gebruiker kan beoordelen of deze gegevens recent genoeg zijn of deze ververs moeten worden



Optimale productie grootte

In het volgende vlak worden de tussenberekeningen en de berekening voor de optimale productie grootte berekent. Hiervoor wordt eerst de uitkomst van de setup en inventory holding cost tool opgehaald en deze daarna naar de juiste grootheden gezet. Verder wordt de gemiddelde afname per dag uit de demand data gehaald en de lead time uit de database gehaald. Daarna wordt de optimale productie grootte berekent.

L	Leadtime	Bufferklasse	22	[dagen]
K	Setupcost	Berekent met model uit andere dashboard	1854,274375	[€]
h	Inventory holding cost per jaar	Berekent met model uit andere dashboard	0,573969496	[€/meter]
h	Inventory holding cost per dag	Inventory holding cost/365	0,001572519	[€/meter]
D	Afname over de periode	Som van aantal	20457	[meter]
μ_d	Gemiddelde afname per dag ($t=1$)	Afname van de periode/ (aantal maanden*dagen in een maand)	0,480399217	[100meter]
Δ	Wilson's lot size formule	Afgerond naar het dichtstbijzijnde hele getal: $\sqrt{2K\mu/h}$	10673	[meter]

Demand distributie en bijhorende parameters

Om uiteindelijk de voorraadparameters te kunnen berekenen, is het nodig om een demand voorspelling te maken. Hiervoor moet je dus kijken welke distributie de demand het beste past om op deze manier de beste voorspelling te kunnen maken. Hiervoor gebruiken we de variantie-gemiddelde test en dit is te zien in het bovenste vlak van onderstaande afbeelding. De uitkomst hiervan was dat de negatieve binomiale distributie het beste paste. Daarom berekenen we in het onderste vlak de parameters van deze distributie die nodig zijn voor het bereken van de voorraadparameters. De eerste parameter van de negatieve binomiale distributie is r_t . De r_t staat voor het aantal van mislukkingen tot einde van het experiment met t periodes. De p_t is dan de slagingskans van het experiment met t periodes. Zoals al gezien kan worden zijn hier meerdere periodes (t) voor gebruikt. Dit komt door de manier waarom de voorraadparameters berekend is. De variaties hiervoor zijn $t = \text{review periode lengte}$, $t = 2 * \text{review periode lengte}$, en $t = \text{review periode lengte} + \text{lead time}$.

p_R	slagingskans experiment in $t=R$ periode (neg. Binomial)	$\sigma^2 = (p^*r)/((1-p)^2) \& \mu = (p^*r)/(1-p) \rightarrow p = 1 - (\mu/\sigma^2)$	0,943209401
r_R	aantal van mislukkingen tot einde experiment (neg. Binomial)	$\sigma^2 = (p^*r)/((1-p)^2) \& \mu = (p^*r)/(1-p) \rightarrow r = (\mu^*[1-p])/p$	0,028924817
p_{2R}	slagingskans experiment in $t=2R$ periode (neg. Binomial)	$\sigma^2 = (p^*r)/((1-p)^2) \& \mu = (p^*r)/(1-p) \rightarrow p = 1 - (\mu/\sigma^2)$	0,997530844
r_{2R}	aantal van mislukkingen tot einde experiment (neg. Binomial)	$\sigma^2 = (p^*r)/((1-p)^2) \& \mu = (p^*r)/(1-p) \rightarrow r = (\mu^*[1-p])/p$	0,02734969
p_{2R}	slagingskans experiment in $t=2R$ periode (neg. Binomial)	$\sigma^2 = (p^*r)/((1-p)^2) \& \mu = (p^*r)/(1-p) \rightarrow p = 1 - (\mu/\sigma^2)$	0,971604701
r_{2R}	aantal van mislukkingen tot einde experiment (neg. Binomial)	$\sigma^2 = (p^*r)/((1-p)^2) \& \mu = (p^*r)/(1-p) \rightarrow r = (\mu^*[1-p])/p$	0,028079485

Voorraadparameters

Doordat het algoritme die uiteindelijk de optimale rode en groene lijn berekent twee scenario's tegen elkaar afweegt, zijn deze tussen uitkomsten voor inzicht van de gebruiker allebei op het dashboard geprint. Dit zorgt ervoor dat de gebruiker daarmee kan zien wat de uitkomsten ervan zijn. Het is ook mogelijk dat het tweede scenario 0 voor beide waarde heeft. Dit is geen fout, maar is dan omdat het criteria van het algoritme gehaald is en dan hoeft hij niet verder te kijken om zo de berekeningstijd te optimaliseren.

S_0	startwaarde reorder point	1600	[meter]
S_0	startwaarde order-up-to-level	12300	[meter]
S_1	verbeterde reorder point	0	[meter]
S_1	verbeterde order-up-to-level	0	[meter]



TKF CONNECTIVITY SOLUTIONS

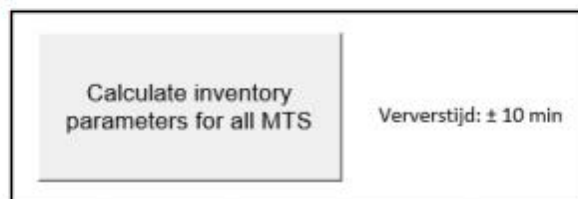
Rode en groene lijn

Voor de laatste stap van het algoritme, weegt de tool de kosten van beide oplossingen tegen elkaar af en print hij de goedkoopste. Dit wordt dan in het onderste vak van de tool geprint.

RL	Rode Lijn	1600	[meter]
GL	Groene Lijn	12300	[meter]

Hoofdstuk 7: Inventory parameters voor alle MTS

Aangezien het totaal voor TKF weer belangrijker is dan een individueel artikel, hebben we ook weer een knop toegevoegd om het voor de MTS-artikelen in totaliteit te berekenen. Deze is in onderstaande afbeelding te vinden.



Na het runnen van deze tool krijg je de resultaten net zoals onderstaande afbeeldingen. In de eerste afbeelding wordt dan de huidige suggestie gegeven en de resultaten hiervan. In de tweede afbeelding zie je dan de top 50 kabels waar de grootste percentuele winst te behalen valt indien je de huidige situatie wijzigt naar de EOQ. De reden waarom dit toegevoegd is, omdat je hiermee dan goed kan kijken welke kabels je wel of niet naar EOQ zet, zodat je de maximale besparing pakt met het minimale flexibilitetsverlies.

Results (Nu)		
average EOQ	21317	[meters]
average prod length	4518	[meters]
Flexibility loss	471,8238158	[%]
Savings (on average)	0,475643802	[€/meter]
Costprice (on average)	3,757380645	[€/meter]
Savings (percentage)	12,6589198	[%]



Largest difference (top 50)						
Art. nr.	Difference(% costprice)	EOQ	Avg prod. Length	EOQ - Avg prod length	mean demand (jaar)	# of years stock
	274,7750643	10546	1063	9483	1329	7,937849462
	236,4948454	12761	900	11861	2571	4,962611111
	98,60367253	11536	633	10903	706	16,33333333
	67,29934924	24951	2103,035714	22847,96429	9749	2,559301917
	59,11159263	10974	1297,6	9676,4	2822	3,889125152
	56,54559344	4591	1243,166667	3347,833333	447	10,26085568
	55,46487904	20683	3206,633333	17476,36667	7443	2,77901263
	55,31182318	7068	1069,75	5998,25	1328	5,323434474
	55,1010938	2649	633	2016	259	10,23344371
	54,06421753	24893	4442,5	20450,5	6909	3,603205128
	49,72356089	4346	752,25	3593,75	854	5,090696118
	48,76557453	19963	2293,454545	17669,54545	10808	1,847106564
	48,48148969	48152	4304,4	41847,6	27142	1,700372639
	48,23255814	21631	2889,444444	18741,55556	10155	2,130173602
	47,63886376	10538	2076	8462	2805	3,757436838
	47,46535029	3094	500	2594	64	48,12888889
	45,45132952	7592	1463,6	6128,4	1268	5,988731125
	44,71285324	18438	3033,5	15404,5	8628	2,136995628
	44,67935166	6391	1968,68	4422,32	2433	2,627260982
	43,75499943	6771	2416,2	4352,8	945	7,161831369
	43,17137229	77237	6994,0625	70242,9375	67080	1,151416219
	42,82061935	1992	500	1492	227	8,769811321
	41,85145123	12022	1971,571429	10050,42857	5963	2,01605098
	40,81657378	7607	1341	6266	2805	2,712357376
	39,39788446	11345	2178,333333	9166,666667	3671	3,090318313
	38,51262269	6353	1180,75	5172,25	1917	3,313291611
	37,40988671	14217	1723,285714	12493,71429	4915	2,89265783
	37,17026379	2981	1199,571429	1781,428571	236	12,64666667
	36,09721229	8827	2064,333333	6762,666667	2415	3,655721216
	36,05307736	13136	3949	9187	7485	1,75487614
	36,00741943	23088	5075,333333	18012,66667	8218	2,809345015
	35,65370138	13558	1833,8	11724,2	7487	1,815618304
	35,53959903	8265	2001,5	6263,5	1713	4,826076076
	35,4133382	8091	500	7591	932	8,68399264
	34,95756052	15607	3033	12574	4526	3,448516414
	34,92837309	5764	872,5	4891,5	1937	2,975516224
	34,76869363	5638	1992,5	3645,5	236	23,91878788
	34,66847091	7075	1950	5125	1132	6,248422912
	34,22159888	15293	3456	11837	4414	3,464433657
	33,94673499	7046	1992,5	5053,5	1159	6,080128205
	32,81907433	7077	1728,580645	5348,419355	1624	4,356992084
	32,68895855	25377	4454,75	20922,25	13243	1,916278317
	32,25493054	10182	2579,857143	7602,142857	2939	3,464275299
	31,5970386	10246	3250	6996	1809	5,662561187
	31,28782456	15501	2313,4	13187,6	7643	2,028092408
	31,02035048	10202	3454	6748	2330	4,379077753
	30,29131986	28638	4433,571429	24204,42857	20964	1,366056096
	30,25063362	9581	1576	8005	3335	2,872740512
	30,20509926	8237	1190,5	7046,5	3419	2,409083312
	29,68680289	15842	3053	12789	4457	3,554294872

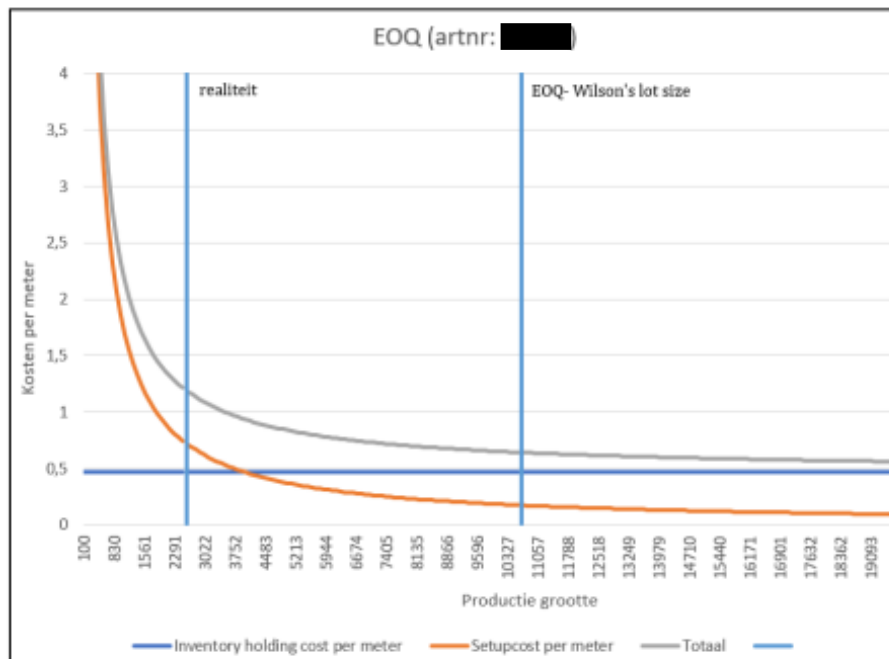
Hoofdstuk 8: Limitaties inventory parameters tool

Doordat de tool doorrekent met de gegevens van de inventory holding en setup cost, gelden alle limitaties van de vorige tool ook voor deze. Echter komt hier nog bij dat de berekentijden dermate lang werden als de optimale productie grootte omhooggingen dat we een stapgrootte toe moesten voegen. Deze stapgrootte is 100 meter voor alle productie grootte onder en gelijk aan de 20 km, 1000 meter als de productie grootte groter dan 20 km is maar kleiner dan 30 km, en 2000 meter als de productie grootte groter dan 30 km is. De limitatie hiervan is dus dat hij niet de exacte uitkomst geeft maar dit is in de praktijk ook lang niet nodig.



Hoofdstuk 9: Inzicht EOQ

Aangezien het verschil tussen de huidige gemiddelde productie grootte en de optimale productie grootte moeilijk te visualiseren is, hebben we ook een afbeelding toegevoegd die hier inzicht in brengt. Deze is hieronder te zien.



Hoofdstuk 10: Berekentijden

In dit hoofdstuk is een overzicht gegeven van alle berekentijden van de tool. Dit is handig om overzichtelijk te hebben omdat je zo goed kan zien hoelang het duurt om bepaalde gegevens te verversen en te berekenen.

Functie	Berekeningstijd
Berekenen van de setup en inventory holding cost (per artikel)	7 secondes
Berekenen setup cost	1 seconde
Berekenen inventory holding cost	1 seconde
Ververs installatie grondstofkosten	10 minuten
Ververs multiconductor grondstofkosten	10 minuten
Ververs voorraad info	1 minuut
Ververs haspel info	1 seconde
Ververs qualified team info	1 seconde
Ververs realiteit MTS (setup en inventory holding cost) met bestaande gegevens	30 secondes



TKF CONNECTIVITY SOLUTIONS

Inventory holding cost berekenen voor de MTS-artikelen	6 minuten
Setup cost berekenen voor de MTS-artikelen	34 minuten
Run tool (inventory parameters)	7 secondes – 2 minuten (afhankelijk van artikel)
Berekenen inventory parameters voor de MTS-artikelen	10 minuten

Hoofdstuk 11: Overzicht tabbladen

In dit hoofdstuk wordt beschreven waar de dashboards en functionaliteiten die beschreven werden in voorgaande hoofdstukken in de tool te vinden zijn. In onderstaande afbeelding is de volgorde van de tabbladen in de tool te zien. Deze worden in de tabel gelinkt aan de hoofdstukken.

Dashboard Heuristic	Dashboard Setup & Inv	Exsion	Realiteit MTS	Inzicht EOQ	Inventory Parameters MTS
Tabblad	Hoofdstuk				
Dashboard Heuristic	Hoofdstuk 6				
Dashboard Setup & Inv	Hoofdstuk 3				
Exsion	-				
Realiteit MTS	Hoofdstuk 4				
Inzicht EOQ	Hoofdstuk 9				
Inventory Parameters MTS	Hoofdstuk 7				