Bachelor thesis

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Using dual-sourcing for ordering spare components

UNIVERSITY OF TWENTE.

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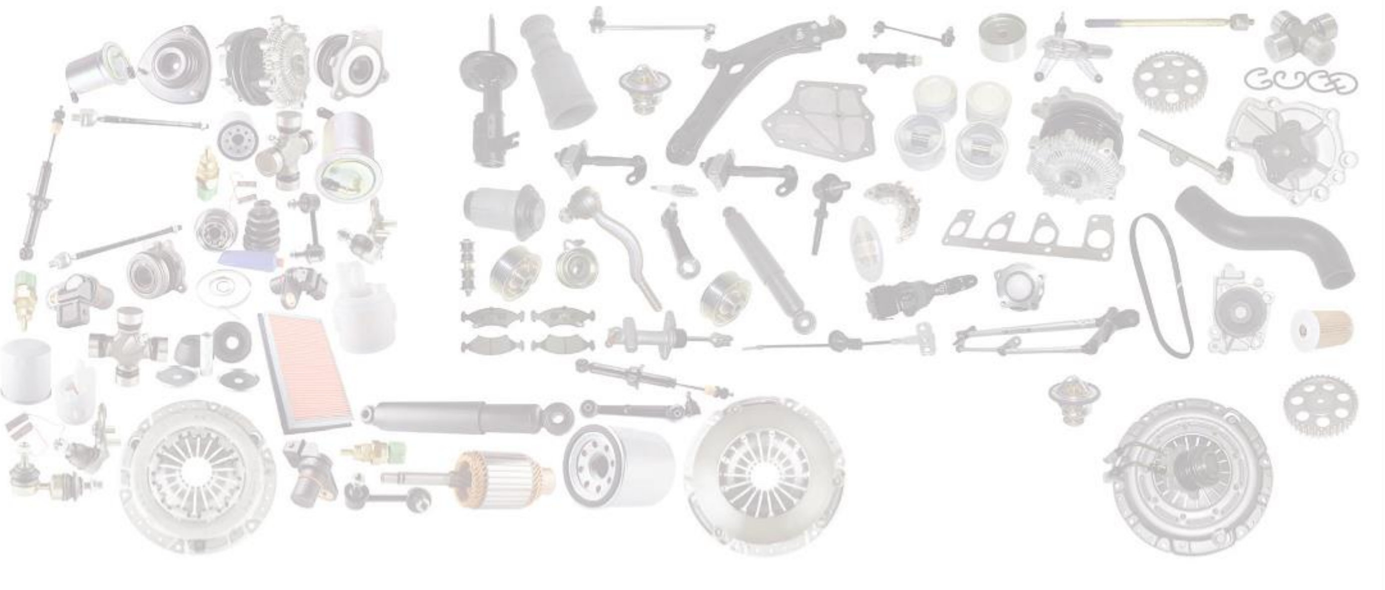

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Preface

This thesis is the final part of my bachelor study Industrial Engineering and Management at the University of Twente. I would like to use this preface to thank all persons who helped me to stay on track and get back on track to finalize this report.

Firstly, I would like to thank the employees of Pool Koudetechniek for their contribution to this research. The warm welcome and nice time at the office has helped a lot to fulfil this research. In particular, I want to thank Ruud Lubbers for his efforts on letting me into the company and guiding me during this thesis.

Secondly, I would like to thank my supervisor Engin Topan and second supervisor Ipek Seyran Topan. Their involvement and expertise helped me during this research. The guidance and feedback is much appreciated.

Christiaan Menningh, February 2020

Management summary

Pool Koudetechniek creates and maintains cooling installations. All installations are slightly different from each other and require slightly different components. To perform maintenance and repairs, Pool Koudetechniek has many spare components in its inventory and wants to find a way to reduce their inventory.

This research looks into a potential inventory management policy. By exploring dual-sourcing as an alternative way of ordering spare components, this research researches a dual-index policy (DIP) to change the current inventory management policy.

Using the historic purchasing data from a small group of spare components, the average demand of these spare components was determined. The demand is found to be Poisson distributed. This is used to model the demand in the DIP model. After analyzing the demand from historic data, the safety stocks and order-up-to levels are determined.

In order to compare the current policy and a proposed policy using DIP, a simulation model is created to simulate the inventory policy.

By using a Monte Carlo simulation, the current policy is compared against a DIP policy. Switching to DIP will increases the total costs and reduces the service levels. Therefore, Pool Koudetechniek is suggested to first test DIP on other types of spare components. Only then can be decided whether changing the inventory management system into a DIP is beneficial.

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Glossary

Refrigerant	A refrigerant is a substance or mixture, usually a fluid, used to transfer heat in a refrigeration cycle.
DIP	Dual-index policy. Used as a control mechanism or policy for an inventory system, characterized by using more than one supplier for the same items or components.
SLS	Special Logistic Services is a courier company specialized in field service logistics. Pool Koudetechniek uses the overnight delivery service of SLS when in urgent need of getting a spare component to a certain location.
Mechanic	A technician who uses tools to build or repair machinery. In this report mechanic refers to the employees of Pool Koudetechniek providing maintenance and reparations on behalf of the service department unless stated otherwise.
Syntess	ERP business software used by Pool Koudetechniek.
Factuurdatum	in this report, the Dutch word 'Factuurdatum' is sometimes used. This is the invoice date of when an spare component got used.
Aantal	In this report, the Dutch word 'Aantal' is sometimes used. This is the total amount of spare components that got used during a single month.
Ventielhuis	In this report, the Dutch word 'Ventielhuis' is sometimes used. This is the Dutch word for thermostatic expansion valve, one of the spare components used by Pool Koudetechniek.
Ventielhuis type	In this report, the Dutch word 'ventielhuis type' is sometimes used. These are the 11 different types of thermostatic expansion valves used for this research.

1 Introduction

In this chapter the company Pool Koudetechniek will be introduced. At this company, a research will be performed regarding inventory management. First, the company will be introduced and the current situation will be described. Then the reason of the research will be treated.

1.1 Company background

Pool Koudetechniek is a company specialized in cooling techniques. In the summer of 2018, Pool Koudetechniek moved to its new location in Hengelo.

To put it simply, Pool Koudetechniek installs fridges and freezers. More specifically, Pool Koudetechniek provides and maintains big freezing units for the professional market. Although Pool Koudetechniek has manufactured cooling components in the past, Pool Koudetechniek no longer does this work itself. Cooling components are being shipped as modules from manufacturers in Germany and Denmark and being installed by Pool Koudetechniek. An example of such a module is shown in Figure 1.

Figure 1 Example of a cooling module as purchased from a Danish supplier ("Industrial Advansor CO2")

A couple of examples of its work are the cooling cell in the kitchen of a sports canteen, the coolers inside trucks transporting food and warehouses of food producers. All cooling solutions Pool Koudetechniek creates are tailored to meet the costumers wishes and requirements.

1.2 Reason for research

The cooling business is booming and Pool Koudetechniek has been growing a lot lately. Pool Koudetechniek is getting more customers and installing many new installations. This resulted in Pool Koudetechniek moving to a its new, bigger location in Hengelo.

Business is going well for Pool Koudetechniek but they want to keep growing and improving. As they might have grown a bit too fast, they are now looking where they can improve their business. Pool Koudetechniek's inventory is one of the things the company feels it can improve on.

1.2.1 High inventory value

One of Pool Koudetechniek's operations (amongst others) is providing service and maintenance to cooling installations. This includes replacing certain components of an installation if the installation is not functioning properly. The operations of Pool Koudetechniek will be discussed in detail later (see Chapter 2.

Because of all the different sizes of installations and also the use of different refrigerants, the components used in cooling installations often differ. Depending on the size of the installation and the type of refrigerant, the installation might require a slightly different type of spare components.

This wide variety of different components results in Pool Koudetechniek to keep a lot of inventory. Currently, Pool Koudetechniek has many different types of components in its inventory to be able to replace broken components with spare components. These spare components have a high purchase price and the inventory value of Pool Koudetechniek keeps growing because of the many different spare components that are kept in stock. Pool Koudetechniek wishes to reduces the inventory value.

1.2.2 Uncertainty about the use of spare components

The cooling industry keeps developing, sometimes due to technical innovations and sometimes out of necessity. An example of this is refrigerant R22 which is being phased out ("Uitfasering HFK's"; "HCFC and CFC phase out"; "R22 phase down"). While R22 is widely used in cooling installations, it can no longer be used in new installations from January 1st 2015. Restricting the use of certain refrigerants is an example of forcing the industry to innovate and change. This results in a wide range of different refrigerants, which all need a different kind of component.

Consequently, there is some uncertainty about how long the installations and its components can still be used. Knowing the spare components are quite expensive and installation specific, Pool Koudetechniek does not want to keep a big inventory of these spare components anymore. Hence, the research on the inventory of spare components.

1.3 Research scope

As mentioned above, there are many different spare components involved in the situation of Pool Koudetechniek. To keep the research manageable, this research will not focus on the entire inventory. Instead, this research will only focus on a small group of spare components instead of focussing on thousands of spare components: the thermostatic expansion valves.

Pool Koudetechniek has two main type of operations: service, which is mostly repairs and maintenance to excisting cooling installations and projects where they create new cooling installations. Out of all the components used by Pool Koudetechniek, the research will only focus on the components used for service purposes. These are actual spare components. The same components are also used for projects but these are not taken into account. More information about the project department and the service department of Pool Koudetechniek will be revealed in section 2.1 and section 2.2.

As Pool Koudetechniek has two different types of operations, the project department and the service department, Pool Koudetechniek also uses two different type of mechanics: project mechanics and service mechanics. In this report, the term mechanic will be used to refer to a service mechanic unless stated otherwise. More information on the mechanics can be found in section 2.4.

All mechanics have a van with tools and spare components. Each van could be seen as a sub-warehouse on its own. However, this research will not look into inventory policies regarding these smaller warehouses but only focus on the bigger warehouse at the office location.

1.4 Research goal

Pool Koudetechniek wants to reduce inventory and lower the chances of having unused items left on the shelf.

At this moment, Pool Koudetechniek has a regular way of ordering spare components and a faster ‘emergency’ way. For this emergency delivery, Pool Koudetechniek uses the services of SLS, a courier company. SLS can deliver products overnight. Currently, this service is used when Pool Koudetechniek does not have a spare component in its inventory and has to be delivered at a mechanic as soon as possible. More information about this faster ‘emergency’ delivery will be discussed in section 2.6.

The goal of this research is to develop an order policy for a sample size of spare components. This order policy can be used by Pool Koudetechniek to lower the amount of spare components in its inventory and the costs associated with holding inventory. The main question to support the research goal is:

How can Pool Koudetechniek change its way of inventory management using emergency delivery for spare components to reduce overall costs while still maintaining the required service level?

1.5 Research questions

The main question cannot be answered right away. To help answer this main question, a couple of research questions have been formulated. These research questions each cover one particular part of the research.

1. What kind of inventory policies are there according to literature to keep inventory of spare components?
    a. What is expediting?
    b. What is dual-sourcing?
    c. What should the safety stock level be?
2. What is the current inventory policy of Pool Koudetechniek regarding spare components?
    a. What kind of spare components is Pool Koudetechniek using?
    b. How often are these different spare components used?
    c. How often are spare components ordered?
3. How is Pool Koudetechniek currently using the emergency delivery option?
    a. How often are the emergency delivery services used?
    b. Which spare components can and cannot be delivered using emergency delivery?
4. What does literature say about dual-index policies?
5. How can a model test the use of the emergency delivery option?
    a. What kind of model could simulate the current and new situation?
    b. Which information is required to build such a model?
    c. How can different situations be compared?
6. What recommendations can Pool Koudetechniek be given based on the test results?

2 Current situation sketch

The company focuses on two distinctive operations. Pool Koudetechniek has a project department and a service department. Besides this, Pool Koudetechniek also runs a web shop to create extra revenue. This chapter will also include an overview of the mechanics' tasks and a description of the warehouse where Pool Koudetechniek stores its spare components.

2.1 Project department

The project department focusses on building new installations, renovating and upgrading existing installations. When building a new installation, this is done from scratch and almost all components necessary for a project are ordered specifically for this project. At Pool Koudetechniek's expedition, there are a few shelves labelled 'project a', 'project b', etc. Each ongoing project has its own shelve where small components for the projects are collected. The big modular components will be shipped to the customer's construction site directly.

When a project is in need of a component that cannot be delivered on time, Pool Koudetechniek will check if the specific component is in its own inventory. In that case they will take out this component from the warehouse and will it be placed on the shelve of the corresponding project.

2.2 Service department

The project department focusses on building new installations, the service department focusses on, as the name would suggest, the service afterwards. All of the service will be coordinated by the service department. There are two kinds of service provided by Pool Koudetechniek.

Naturally, a component of an installation could fail, or the installation could give an error. In these cases, Pool Koudetechniek can be contacted by the customer to repair the problems. Pool Koudetechniek does provide warranties on their installations but also when warranty has expired, Pool Koudetechniek will do repair work, sometimes involving replacing the failed component by a spare component.

Furthermore, Pool Koudetechniek provides periodic maintenance. This maintenance is scheduled in advance. Periodic maintenance is often scheduled in the periods before and after summer. The summer period is, obviously, the most important season for cooling installations to be functioning properly. This is also the period service mechanics are very busy doing repairs instead of performing scheduled maintenance.

2.3 Web shop

Pool Koudetechniek sells professional fridges and freezers. This equipment is a bit bigger and more expensive than the ones to be found in normal kitchens. These are shipped directly from Pool Koudetechniek's supplier in Denmark to the customer. The web shop of Pool Koudetechniek has been added fairly recent. As this web shop is mostly administrative work of Pool Koudetechniek, this research will not spend much time and effort on this part of Pool Koudetechniek's operations.

2.4 Mechanics

Both the project and the service department use mechanics. These mechanics are either project mechanics or service mechanics. Mechanics are appointed to the jobs of one department only. It could happen that one department needs an extra mechanic and the other department can spare one. In that case, a mechanic can be scheduled to do the other kind of job. Pool Koudetechniek has about ten project mechanics and ten service mechanics. Not all of the mechanics are living in Twente, some live in Noord-Brabant, Groningen or Limburg. This makes it easier for Pool Koudetechniek to cover the entire country with their services.

Each mechanic, both service and project, has a van to drive to the customers. In this van, the mechanic brings along all the tools and spare components they will need for their work. Some big tools are not in the van but can be brought from the Hengelo location by the mechanic. Besides the tasks they perform, there is no distinction between the van of a project mechanic and a service mechanic.

At the moment, there is no guideline or template on which spare components a mechanic should have in his van. Each mechanic decides on his own which spare components he likes to bring along, usually based on the mechanic's experience and preference. If the mechanic needs a specific spare component, this spare component can be ordered by the inventory manager and picked up at the Hengelo location by the mechanic.

2.5 Warehouse

At the Hengelo location Pool Koudetechniek has a small warehouse. In the current situation, many components are stored in the warehouse. This includes mounting materials like bolts, nuts and rolls of tape, many pipes of different lengths, materials, thickness and shapes, a range of electric material like wires, electromagnetic coils and switches and also refrigeration items like valves, filter driers and differential pressure switches.

Mechanics have spare components in their van. If mechanics run out or run low on spare components in their van, the mechanics can use the spare components from the warehouse to restock their van.

It is an open warehouse, meaning everyone can walk in. Mechanics can walk in themselves and grab the spare components they need themselves. If a mechanic grab the last item in stock, they have to write it down on a note for the inventory manager.

Due to the recent move to the new Hengelo location, not all items have been provided with a barcode. When a spare component has a barcode, this means the spare component has been registered as a stock item in Pool Koudetechniek's ERP software 'Syntess'. One of the reasons to focus on thermostatic expansion valves is all of these spare components are both in the warehouse present and are also registered in the ERP software.

2.6 Emergency shipment

In most cases, the mechanic's van will carry the spare components the mechanic needs. In the ideal situation, the mechanic can pick up the spare components he needs at the warehouse. Sometimes, the required spare component is not in stock. If ordering it the regular way takes too long, the inventory manager will order the spare component via SLS.

SLS is a courier specialized in fast delivery. One of SLS's services is a so-called 'innight delivery'. SLS can pick-up goods at the normal supplier and transport them overnight, guaranteeing delivery before 7 o'clock in the morning. Besides delivering at Pool Koudetechniek, SLS provides the option to deliver directly into the van of a mechanic, resulting in a mechanic who can start working with the right component immediately. Pool Koudetechniek can use the services of SLS as 'emergency' shipment.

The inventory manager will order the component that a mechanic needs and get it shipped via overnight delivery. SLS will pick up the component at the supplier in the evening. While the mechanic of Pool Koudetechniek is at home sleeping, SLS will use its distribution network to deliver overnight at the mechanic's home.

2.7 Current inventory policy

As mentioned in section 2.4, each service mechanic has his own van. In these vans, the service mechanic brings along his tools and several spare components he might need for his work. Because of this, the vans can be seen as small warehouse carry a sub-inventory of their own. The mechanics can restock their van using components from the warehouse at the Hengelo location.

In the current situation, many components are stored in the warehouse. Only one or two of each specialized and expensive component is being stored. The more simple components like bolts and nuts are being stored (and purchased) in larger amounts.

When the last one of a spare component gets taken out of the warehouse, this will be written down on a note by the mechanic for the inventory manager. That will be his signal to order new spare components. For the often used items like bolts and nuts, it can already be written down when the box is almost finishing.

Each day, the inventory manager will check the inventory of the warehouse manually. He checks the handwritten list of the spare components and also checks if there might be spare components finished or close to finishing. These spare components then will be ordered at the supplier via regular shipment so the inventory can get replenished.

3 Literature

In this research, several knowledge questions need answering. One question that needs to be answered is ‘what kind of inventory policies are there according to literature to keep inventory of spare components?’. A different question that needs answering is ‘what does literature say about ordering spare components?’. This chapter will first look into the different kinds of inventory policies. After this, a section will focus on safety stock. Then, DIP will be introduced and this chapter shall elaborate on how DIP can be applied on ordering spare components.

3.1 Inventory management

Inventory is a term used to describe the stockpiling of materials as they flow through processes or networks. Physical inventory is also sometimes called stock and can be any kind of physical components, parts, finished or semi-finished goods (Slack, Brandon-Jones, & Johnston, 2013).

Operations managers often have a dilemma about inventories. Inventories take up a lot of space and are costly on the one hand but on the other hand inventories do provide some form of security for a company. Keeping an inventory can smoothen the flow of materials, customers and information (Slack et al., 2013). For this reason, most companies keep an inventory of products. Keeping inventory makes it easier narrow the difference between supply and demand.

3.1.1 How much to order

Deciding how much items to order is an important question for operations managers. Every time a replenishment order is placed, the operation manager should determine how big the order should be in order to still have enough items in stock to meet demand. Deciding how much to order is sometimes called the volume decision (Slack et al., 2013).

To make the decision on how much to order, the two sets of costs have to be balanced: the cost of making a purchase or order and the costs associated with holding the stocks. Holding little to no inventory and only purchasing items when they are needed does not require much money. However it can lead to a situation where you have to make several purchases a day, which would be inconvenient.

The extreme opposite would be to make a purchases only once every few months and ordering all the items necessary up until the next purchase. This will reduce the time used on placing the orders and lower the purchasing costs. On the other hand, it will require a large amount of money each time which otherwise could be in the bank to earn interest or which could be used for other things. Next to it, it will require a lot of space to store all the purchased items. For most operation managers who manage physical inventories the main objective is to keep the level of inventory as low as possible whilst maintaining an acceptable level of customer service.

Safety stock is the amount of inventory that is ordered extra to satisfy demand that exceeds the expected demand during a certain period. It is used as a back-up because demand is uncertain (Chopra & Meindl, 2001).

3.1.2 When to order

One of the key questions for operation managers is when to place a new order. In many situations, items are being kept in stock to meet demand. Items are being sold directly from stock. Due to the demand, the inventory level will drop. When the existing inventory is reaching zero, new items will be ordered to replenish the inventory level. In the idealistic situation, the order of new items will arrive instantaneously and demand is steady and predictable. In that case, new items can be ordered exactly when the inventory level reaches zero.

However, in reality, deliveries will require some delivery time so orders will have to be placed before inventory runs out. The moment when the new order has to placed is called the re-order point. The re-order point (ROP) is the point at which stock will fall to zero minus the order lead time (Slack et al., 2013). In other words, there will still be enough items in stock to cover the period between placing the order and the moment of the order actually arriving. The inventory level at the moment of reordering is called the re-order level. The relation between the moment to reorder, the order lead time and demand is illustrated in Figure 2.

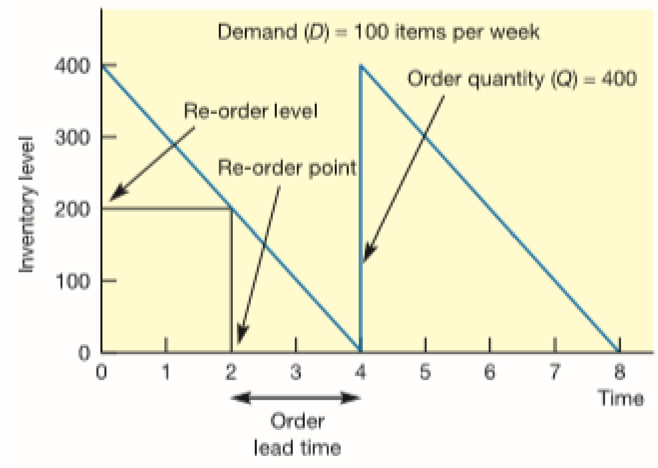

Figure 2 Re-order level and re-order point are derived from the order lead time and demand rate (Slack et al., 2013)

In practice, the situation is different as demand and order lead time are often not constant or predictable. Having the new order or items arrive exactly when the inventory level reaches zero is almost impossible with demand being unpredictable. To prevent a stockout, some extra items are kept in stock. These will still be in stock when the inventory level gets replenished. The amount of old stock that is still unused is called the safety stock. Its purpose is to be a buffer for any fluctuations the demand rate or the order lead time might have (Slack et al., 2013).

Figure 3 shows how the inventory level keeps decreases after the ROL has been reached at t_1 and before the replenishment order arrives. At t_2, the order lead time was bigger and the inventory level dropped, resulting in the safety stock being used.

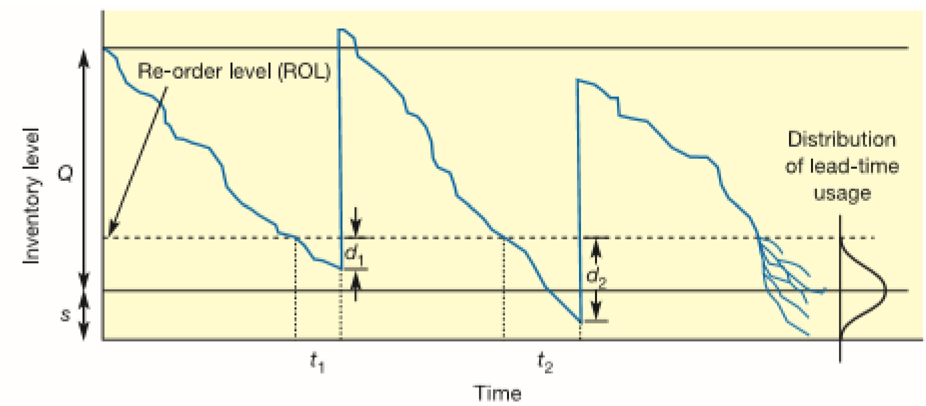

Figure 3 Safety stock (s) helps to avoid stock-outs when demand and/or order lead time are uncertain (Slack et al., 2013)

The situation described above reorders when the current inventory level drops below a certain level. To know when to replenish the inventory, the inventory level has to be reviewed all the time. Therefore, this approach of inventory management is called a continuous review approach (Slack et al., 2013).

Opposed to the continuous review approach there is the periodic review approach. This is an alternative and more simple approach. Where in the continuous review approach a replenishment order is placed at a predetermined reorder level will the orders in a periodic review approach be placed at a fixed and regular time interval. An example could be to look at the inventory level at the end of each month and then order a replenishment to bring the inventory back up to a predetermined level (Slack et al., 2013).

Figure 4 shows the inventory level in a periodic review approach. In this situation, the inventory level is reviewed at T_1, T_2 and T_3. At those three moments, the inventory level will have to be replenished up to the level Q_m so an order will be placed. This order does not arrive immediately but some delivery time is in place. The replenishment arrives after the order lead times t_1, t_2 and t_3 have passed. These replenishment moments can be recognized by the increasing inventory levels.

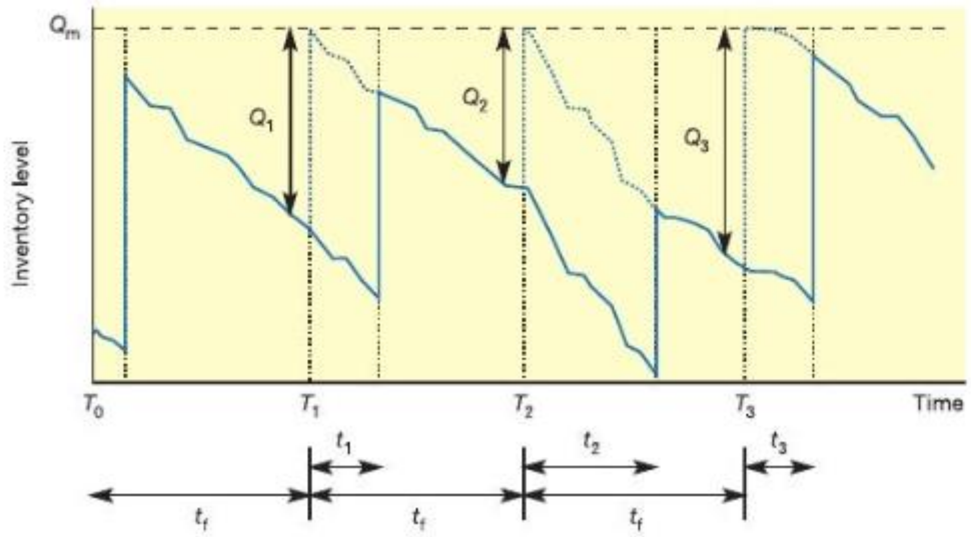

Figure 4 A periodic review approach to order timing with probabilistic demand and lead time

3.2 Dual sourcing

In many cases when looking to buy, the buyer will have several suppliers available. Each supplier wields their own delivery or order costs and their own delivery time, also called lead time. When a company has to decide which available supplier to go into business with, this problem is called vendor selection (Arts, Van Vuuren, & Kiesmüller, 2011).

There is also different approach to utilize having more than one supplier. The majority of the materials can be ordered from the cheaper supplier. In most cases, this cheaper supplier will have a longer lead time. If the demand peaks, the replenishment orders can be placed at the faster supplier. The cheaper and slower supplier is preferred for routine orders, therefore tis supplier is often called regular supplier. Similarly, faster but expensive suppliers are often called emergency supplier. This approach, when deciding when to use one emergency and when to use regular supplier, is called dual sourcing (Arts et al, 2011). According to Klosterhalfen, Kiesmüller and Minner (2011), companies relying on multiple suppliers for their material procurement can be frequently encountered. Dual-sourcing can be used as a policy, a certain approach or procedure for material procurement. A policy like such is called a dual-index policy, or DIP.

3.3 Dual-index policy

The DIP specifies two order-up-to levels, one for a regular situation using a basic supplier or shipment, and one order-up-to level for an emergency supplier or shipment. The order-up-to level can be denoted as S_e and S_r and is the amount of items up to which should be reordered (Klosterhalfen et al, 2011).

After a certain period *n*, the emergency inventory level is reviewed to find the emergency inventory position:

$$\mathrm{I}\,P_n^e = I^n + \sum_{i=n-l^r}^{n-1} Q_i^r + \sum_{i=n-l^e}^{n-1} Q_i^e$$

Simply put, the current emergency inventory level equals the sum of the quantities that were ordered and the inventory level I^n of the previous reviewed moment. If this inventory position is not at the level it should be, an emergency order $Q_n^e$is placed to raise the inventory position to its order-up-to level S_e. The emergency quantity order Q_n^e can be found using:

$$Q_n^e = S_e - I\,P_n^e$$

After the emergency order is placed, the regular inventory position is reviewed as well, which includes the emergency order. The summation of Q_n^e goes until *n* instead of *n-1*:

$$\mathrm{I\,P_n^r = I^n} + \sum_{\mathrm{i=n-l^r}}^{\mathrm{n-1}} \mathrm{Q_i^r} + \sum_{\mathrm{i=n-l^e}}^{\mathrm{n}} \mathrm{Q_i^e} = I\,P_n^e + Q_n^e + \sum_{i=n+1-l}^{n-1} Q_i^r$$

After the emergency level and reviewing the current inventory position, a regular order Q_n^r can be placed to raise the regular inventory position up to its order-up-to level S_r:

$$Q_n^r = S_r - I\,P_n^r$$

If the current inventory is 1 and the order-up-to level is 5, this means there should be ordered 4 more items to bring the inventory up to the level of 5. First the emergency inventory gets updated, after that, the replenishment order for the regular inventory gets placed.

4 A DIP model for Pool Koudetechniek

This chapter will focus on implementing the relevant models mentioned in Chapter 3 into practice. To execute this research, a DIP model has been created for Pool Koudetechniek. In this chapter, the creation and purpose of this model will be explained.

4.1 DIP model

To make an estimation on how dual-sourcing will influence the order policy for Pool Koudetechniek, this research will mimic this potential situation. This is done by creating a model to simulate reality. A model or simulation is "an approximate imitation of the operation of a process or system" ("Simulation", 2019). Using this model, the potential benefits of using DIP can be explored.

For creating this DIP model, the formulas of Arts et al. (2011) will be followed. This means the inventory position will be based on the inventory position of the previous period. However, as Kemeny and Schnell (1976) described, the changes from one period to the next are "a probabilistic matter". In order to determine this probabilistic matter, the distribution of demand of the spare components has to be determined. For this step, enough historic demand data of the spare components has to be collected.

The model requires several input variables to do its calculations. Amongst these variables, there are the lead time (L), review period (R), L+R, the mean demand during the period L+R (also referred to as *mu* μ), the variance of the demand during period L+R (also referred to as *sigma* σ) and the cycle service level (CSL). The safety stock can be calculated by multiplying *sigma* and norm. inv. of CSL (Chopra & Meindl, 2001; Winston & Goldberg, 2004).

Based on the data from the created histograms, the total demand of each spare component for a period of 7 years was found. With this data, the monthly and daily mean and standard deviation were calculated. Using the formulas from Chopra and Meindl (2001) and Winston and Goldberg (2004), the expected demand during period L+R, the safety stock level and the base stock level were derived for both the regular order and the emergency order.

4.2 Data collection

As mentioned in section 1.3, it has been decided to focus on thermostatic expansion valves only. Twelve different types of these type of valves were present in Pool Koudetechniek's warehouse so only these types have been taken into account. Other type of thermostatic expansion valves which has been used in the past but were not in the inventory have been neglected.

All purchasing orders and working slips from June 2012 till July 2019 were searched for these twelve spare components. Only eleven of these twelve types of spare components has been used by the service department, the other component is leftover after a project was finished.

In order to analyze the data of the spare components has been transformed into histograms. Each spare component got an overview of how often the component was used over the course of a month. An example can be find below in Figure 5, all histograms are listed in Appendix 10.2. Based on these histograms, it was assumed the demand of the spare components is Poisson distributed.

A Poisson Process is a model for a series of discrete event where the *average time* between events is known, but the exact timing of events is random. The arrival of an event is independent of the event before (Koehrsen, 2019)

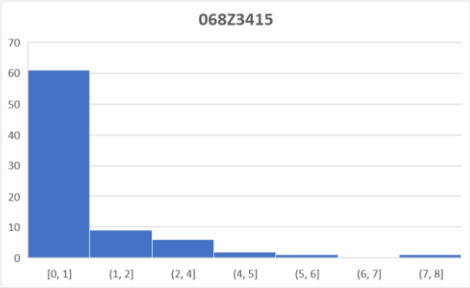

Figure 5 Histogram of monthly demand for spare component 068Z3415

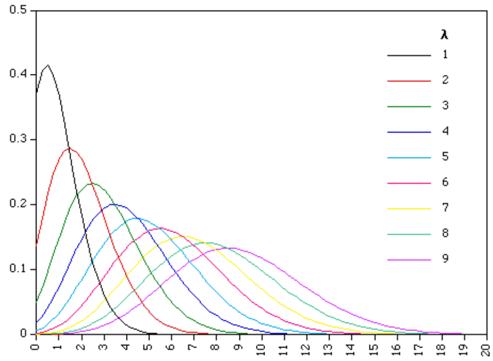

Figure 6 Examples of Poisson distribution with different mean values

4.3 Data analysis

To verify the assumption of the demand being Poisson distributed, several statistical tests are performed using SPSS. In this report the most important ones are listed. At first, the data is tested on normality. After rejecting normality, the data distribution is tested as being Poisson distributed.

4.3.1 Normality test

The tests of normality will check whether the data is distributed normally or not. There are several normality tests. Razali and Wah (2011) did a power comparison on the Kolmogorov-Smirnov test, Shapiro-Wilk test, Lilliefors test and Anderson-Darling test. They conclude the Shapiro-Wilk test is the most powerful normality test. SPSS does not offer the Anderson-Darling test but does offer the Kolmogorov-Smirnov test and the Shapiro-Wilk test. The Kolmogorov-Smirnov test has a Lilliefors significance correction.

For the normality test of this research, the type of thermostatic expansion valves got crossed with the dates of these components being used. The outcome of the normality tests as seen in Figure 7 shows the data are significantly different from a normal distribution. Therefore, the null hypothesis of a normal distribution and it is concluded there is probably a non-normal distribution.

In a second normality test, see Figure 8, the histogram got tested on normality. Are the used amount of components per ventielhuis type independent from each other?

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Ventielhuis type	,218	128	,000	,879	128	,000
Factuurdatum	,099	128	,004	,916	128	,000

a. Lilliefors Significance Correction

Figure 7 Outcome normality tests ventielhuis and factuurdatum

Tests of Normality[b]

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Ventielhuis type	Statistic	df	Sig.	Statistic	df	Sig.
Aantal	1	,353	4	.	,744	4	,034
	2	,307	29	,000	,514	29	,000
	3	,367	5	,026	,684	5	,006
	4	,283	15	,002	,768	15	,001
	5	,209	29	,002	,783	29	,000
	7	,492	6	,000	,496	6	,000
	8	,367	5	,026	,684	5	,006
	9	,443	8	,000	,601	8	,000
	10	,492	6	,000	,496	6	,000
	11	,351	20	,000	,507	20	,000

a. Lilliefors Significance Correction

b. Aantal is constant when Ventielhuis type = 6. It has been omitted.

Figure 8 Outcome normality test Aantal

4.3.2 Poisson regression

As a final test, a generalized linear model is created to investigate the possibility of a Poisson distribution and a Goodness of Fit test is performed. This test is performed over all 128 spare components and is found in Figure 9

The first data output to look into is the Pearson Chi-Square test. A value of 1 indicates equidispersion whereas values greater than 1 indicate overdispersion and values below 1 indicate underdispersion. The value of 1.077 is unlikely to be a serious violation of this assumption.

Goodness of Fit[a]

	Value	df	Value/df
Deviance	92,484	116	,797
Scaled Deviance	92,484	116	
Pearson Chi-Square	124,886	116	1,077
Scaled Pearson Chi-Square	124,886	116	
Log Likelihood[b]	-198,141		
Akaike's Information Criterion (AIC)	420,282		
Finite Sample Corrected AIC (AICC)	422,995		
Bayesian Information Criterion (BIC)	454,507		
Consistent AIC (CAIC)	466,507		

Dependent Variable: Aantal
Model: (Intercept), Ventielhuis type, Factuurdatum[a]

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

Figure 9 Poisson Goodness of Fit test

4.4 Monte Carlo model

The type of model used for this research is a Monte Carlo simulation, which can be seen as a series of "computational algorithm that rely on repeated random sampling to obtain numerical results" ("Monte Carlo method", 2019). One of the benefits of a Monte Carlo simulation is the large amount of repetitions. By doing the same process over and over again, a big sample size gets created of which the average is more reliable than if the same process is only run once.

The model used for this research is a Monte Carlo simulation created in Excel. Using the functions of Excel, the model can quickly calculate the Poisson distributed demand with many repetitions, in this model 150,000 repetitions. The model generates a daily demand and based on the current inventory, an item will either be used from the warehouse, reordered using regular shipment or reordered using emergency shipment. Due to the many repetitions, the average inventory positions can be seen as a fairly accurate estimation.

As can be seen in Figure 10, Poisson distributed demand is generated on the left of the model. Using the daily average demands, this model generates a Poisson distributed, random demand *D* in Column *O* over 150,000 periods (days).

In the current model, the regular leadtime equals 7 days. This means that whenever a component needs to be ordered, it will take 7 days for delivery. To simulate this in the model, in every period, it will appear at P6 during the next period. From here it will slowly count down until it reached the inventory. The way a spare component moves diagonally from one period to the next, as seen in Figure 10, is an example of a Markov chain. The inventory position for the next period is being influenced by the current inventory position.

Spare components which are ordered with the emergency shipment have a leadtime of only one day. This means when a components is ordered, it should be seen as being in P1. However, as with the next period it is in the current inventory already, therefore it is stated in under the current inventory derived by *Ib* in Figure 10.

G18 =V17

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1															E[D]		E[I]	E[B]		E[Xe]		E[Xr]
2	Average	Poisson		Regular	Emergenc	Period							Inventor	Backorder	0,0274		1,880621	0		0,014279		0,013121
3	daily			Base	y Base								y	beginning	Demand	Ib-Bb-D						
4	lambda	x	P(X=x)	Sr	Se	t	P6	P5	P4	P3	P2	P1	Ib	Bb	D	I-B	I	B	IPe	Xe	IPr	Xr
5	0,03	0	0	1,986748	1,430768	1	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
6		0,97286	1			2	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
7		0,999628	2			3	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
8		0,999997	3			4	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
9		1	4			5	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
10		1	5			6	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
11		1	6			7	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
12		1	7			8	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
13		1	8			9	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
14		1	9			10	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
15		1	10			11	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
16		1	11			12	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
17		1	12			13	0	0	0	0	0	0	1,986748	0	1	0,986748	0,986748	0	0,986748	0,44402	1,430768	0,55598
18		1	13			14	0,55598	0	0	0	0	0	1,430768	0	0	1,430768	1,430768	0	1,430768	0	1,986748	0
19		1	14			15	0	0,55598	0	0	0	0	1,430768	0	0	1,430768	1,430768	0	1,430768	0	1,986748	0
20		1	15			16	0	0	0,55598	0	0	0	1,430768	0	0	1,430768	1,430768	0	1,430768	0	1,986748	0
21		1	16			17	0	0	0	0,55598	0	0	1,430768	0	0	1,430768	1,430768	0	1,430768	0	1,986748	0
22		1	17			18	0	0	0	0	0,55598	0	1,430768	0	0	1,430768	1,430768	0	1,430768	0	1,986748	0
23		1	18			19	0	0	0	0	0	0,55598	1,430768	0	0	1,430768	1,430768	0	1,986748	0	1,986748	0
24		1	19			20	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
25		1	20			21	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0
26						22	0	0	0	0	0	0	1,986748	0	0	1,986748	1,986748	0	1,986748	0	1,986748	0

Figure 10 Monte Carlo simulation using Markov chains

4.4.1 Decision making

In the model, there are two inventories, one for each delivery option. This model will decide whether to go with the regular delivery or the emergency delivery. There are two types of base stock levels: one regular stock and one emergency stock. This base level can easily be calculated by adding the safety stock and the daily mean (Winston & Goldberg, 2004).

If the daily demand can be met using the regular stock, the regular stock will be used. If demand cannot be met, this will be seen as a backorder, using the emergency shipment. After the demand has been met, the policy will do a replenishment order to get the inventory back to the base level. As explained in section 3.3, the DIP will first reorder the emergency inventory and then the regular inventory will be raised to the order-up-to level.

4.5 Cost calculation

As a final step, this research will make a cost calculation to compare how well a dual-index policy would do. At its results, this model shows the average daily demand of a spare component, how often items have been (back)ordered and the ratio regular orders and emergency orders. Using this data, an annual cost formula can be created.

The total annual costs for this part of the operations can be seen as the sum of three distinct parts: the costs for holding inventory, the 'penalty' costs for not meeting demand thus having backorders, and the costs for placing orders. The holding cost per item per year are assumed to be 25% of the retail price.

This results in the cost formula to be as seen in Figure 11. The holding cost part of the formula consists of the expected daily demand E[D] multiplied by the holding cost percentage [B97] multiplied by the retail price of the spare component [E96]. The backorder costs part of the formula consists of the expected daily amount of backorders E[B], multiplied by 365,25 and multiplied with the price of using the emergency shipment. The final part of the total annual cost formula is the part on order costs. The order costs consists of the expected amount of regular orders E[Xr] multiplied by 365,25 multiplied by the order cost at the regular supplier.

SOM | =Q2*'Input & Output'!$B$97*'Input & Output'!E96+(T2*42,5*365,25)+(V2*15*365,25)

	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD
1	E[D]		E[I]	E[B]		E[Xe]		E[Xr]	E[Xe+Xr]	Backorder rate	Realised service lvl					
2	0,0178		1,497995	0		0,010488		0,007312	0,0178	0,00%	100,00%					
3	Demand	Ib-Bb-D														
4	D	I-B	I	B	IPe	Xe	IPr	Xr		Total costs						
5	0	1,559665	1,559665	0	1,559665	0	1,559665	0		=Q2*'Input & Output'!$B$97*'Input & Output'!E96+(T2*42,5*365,25)+(V2*15*365,25)						

Figure 11 Total cost formula

5 Results

This chapter will go over the results from this research. By using the model, a dual-index policy can be simulated for 150,000 days. By changing the different base stock levels in the DIP model, the outcomes of the model will change.

A few aspects of the outcome are very important, especially two of them. These two aspects are the total annual cost for a particular spare component using that particular set of base stock levels and the backorder rate of the spare component. The backorder rate shows the percentage of orders that cannot be delivered at the scheduled time but that will be delivered at a later date by using a particular set of base stock levels. From the backorder rate, the direct opposite can be derived namely the realized service level.

5.1 Results using DIP

Using the theory from section 4.1 and the historic data, the average demand were determined. After this, the expected demand over a certain time period was calculated to estimate the recommended base stock level. These results can be found below in Figure 12.

	A	B	068Z3383	068Z3385	068Z3403	068Z3414	068Z3415	068Z3416	068Z3418	068Z3420	068Z3421
85	Total demand		11,00	49,00	7,00	33,00	67,00	2,00	7,00	9,00	11,00
86	Monthly mean		0,14	0,61	0,09	0,41	0,84	0,03	0,09	0,11	0,14
87	Monthly St. Dev		0,82	1,15	0,36	1,09	1,44	0,22	0,32	0,50	0,47
88	Total demand per day		0,36	1,61	0,23	1,08	2,20	0,07	0,23	0,30	0,36
89	Daily mean		0,00	0,02	0,00	0,01	0,03	0,00	0,00	0,00	0,00
90	Daily St. Dev		0,15	0,21	0,07	0,20	0,26	0,04	0,06	0,09	0,08
91											
92	Cycle service level	95%									
93	Review period R (days)	7									
94	Lead time regular	7									
95	Lead time emergency	1									
96	Purchasing price		€ 27,51	€ 44,10	€ 38,50	€ 27,51	€ 44,10	€ 27,51	€ 27,51	€ 26,46	€ 44,10
97	Holding cost	25%									
98	Ordering costs regular	€ 15,00									
99	Ordering costs emergency	€ 42,50									
100											
101											
102	**Regular ordering**										
103	Lead time (days)		7	7	7	7	7	7	7	7	7
104	Review period (days)		7	7	7	7	7	7	7	7	7
105											
106	L+R=		14	14	14	14	14	14	14	14	14
107	MU L+R		0,063	0,282	0,040	0,190	0,385	0,011	0,040	0,052	0,063
108	Sigma L+R		0,555	0,777	0,244	0,741	0,974	0,151	0,220	0,339	0,317
109	Norm.S.Inv		1,644854	1,644854	1,644854	1,644853627	1,644854	1,644854	1,644854	1,644854	1,644854
110	Safety stock		0,912154	1,27794	0,401973	1,218112851	1,601532	0,247879	0,361209	0,557598	0,521562
111	Base stock		0,975	1,560	0,442	1,408	1,987	0,259	0,401	0,609	0,585

Figure 12 Extracted data from historic usage

By adjusting the base stock levels and entering these levels in the DIP model, the expected total costs and amount of backorders are determined. The results are different per spare component and are dependent on the set base stock levels. For each type of spare component, the results for several combinations of base stock levels are found in below in Figure 13 till Figure 23.

In the current situation, Pool Koudetechniek only uses 1 type of base stock. To simulate the current situation, the model used only the regular base stock and the emergency base stock was set to zero for this test. The regular base stock was set to either one or two.

068Z3383			
Base stock lvl		Total expected annual costs	65,79654102
Regular	0,97539788	Backorder rate	3,12%
Emergency	0,725662884	Realised service lvl	96,88%
Base stock lvl		Total expected annual costs	72,3377625
Regular	0	Backorder rate	100,00%
Emergency	0	Realised service lvl	0,00%
Base stock lvl		Total expected annual costs	34,3886771
Regular	1	Backorder rate	3,76%
Emergency	0	Realised service lvl	96,24%
Base stock lvl		Total expected annual costs	78,3558177
Regular	0	Backorder rate	0,004347826
Emergency	1	Realised service lvl	0,995652174
Base stock lvl		Total expected annual costs	79,28670085
Regular	1	Backorder rate	0,001428571
Emergency	1	Realised service lvl	0,998571429
Base stock lvl		Total expected annual costs	38,48236615
Regular	2	Backorder rate	0,00%
Emergency	0	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	83,8884387
Regular	0	Backorder rate	0,00%
Emergency	2	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	39,8684927
Regular	2	Backorder rate	0
Emergency	1	Realised service lvl	1

Figure 13 Model results 068Z3383

068Z3385			
Base stock lvl		Total expected annual costs	249,0352417
Regular	1,559665214	Backorder rate	0,50%
Emergency	1,127017742	Realised service lvl	99,50%
Base stock lvl		Total expected annual costs	305,90905
Regular	0	Backorder rate	100,00%
Emergency	0	Realised service lvl	0,00%
Base stock lvl		Total expected annual costs	140,982746
Regular	1	Backorder rate	10,94%
Emergency	0	Realised service lvl	89,06%
Base stock lvl		Total expected annual costs	332,645039
Regular	0	Backorder rate	1,09%
Emergency	1	Realised service lvl	98,91%
Base stock lvl		Total expected annual costs	316,615575
Regular	1	Backorder rate	1,02%
Emergency	1	Realised service lvl	98,98%
Base stock lvl		Total expected annual costs	132,8094825
Regular	2	Backorder rate	0,89%
Emergency	0	Realised service lvl	99,11%
Base stock lvl		Total expected annual costs	338,186598
Regular	0	Backorder rate	0,00%
Emergency	2	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	156,3034975
Regular	2	Backorder rate	0,06%
Emergency	1	Realised service lvl	99,94%

Figure 14 Model results 068Z3385

068Z3403			
Base stock lvl		Total expected annual costs	43,71954198
Regular	0,442219802	Backorder rate	55,95%
Emergency	0,326861272	Realised service lvl	44,05%
Base stock lvl		Total expected annual costs	43,3612625
Regular	0	Backorder rate	100,00%
Emergency	0	Realised service lvl	0,00%
Base stock lvl		Total expected annual costs	25,9294325
Regular	1	Backorder rate	1,83%
Emergency	0	Realised service lvl	98,17%
Base stock lvl		Total expected annual costs	52,75253
Regular	0	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	54,92442
Regular	1	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	35,73191583
Regular	2	Backorder rate	0,22%
Emergency	0	Realised service lvl	99,78%
Base stock lvl		Total expected annual costs	67,13500333
Regular	0	Backorder rate	0,00%
Emergency	2	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	33,53122583
Regular	2	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%

Figure 15 Model results 068Z3403

068Z3414			
Base stock lvl		Total expected annual costs	169,0623587
Regular	1,407845911	Backorder rate	0,36%
Emergency	1,029225655	Realised service lvl	99,64%
Base stock lvl		Total expected annual costs	208,7342875
Regular	0	Backorder rate	100,00%
Emergency	0	Realised service lvl	0,00%
Base stock lvl		Total expected annual costs	93,9574695
Regular	1	Backorder rate	9,07%
Emergency	0	Realised service lvl	90,93%
Base stock lvl		Total expected annual costs	216,0368831
Regular	0	Backorder rate	0,40%
Emergency	1	Realised service lvl	99,60%
Base stock lvl		Total expected annual costs	226,691694
Regular	1	Backorder rate	0,71%
Emergency	1	Realised service lvl	99,29%
Base stock lvl		Total expected annual costs	85,9254688
Regular	2	Backorder rate	0,30%
Emergency	0	Realised service lvl	99,70%
Base stock lvl		Total expected annual costs	225,7069409
Regular	0	Backorder rate	0,00%
Emergency	2	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	97,4280997
Regular	2	Backorder rate	0,15%
Emergency	1	Realised service lvl	99,85%

Figure 16 Model results 068Z3414

068Z3415			
Base stock lvl		Total expected annual costs	315,9660251
Regular	1,986747745	Backorder rate	0,14%
Emergency	1,430767706	Realised service lvl	99,86%
Base stock lvl		Total expected annual costs	426,6789625
Regular	0	Backorder rate	100,00%
Emergency	0	Realised service lvl	0,00%
Base stock lvl		Total expected annual costs	197,2328135
Regular	1	Backorder rate	16,06%
Emergency	0	Realised service lvl	83,94%
Base stock lvl		Total expected annual costs	427,1666845
Regular	0	Backorder rate	1,27%
Emergency	1	Realised service lvl	98,73%
Base stock lvl		Total expected annual costs	436,2669695
Regular	1	Backorder rate	1,19%
Emergency	1	Realised service lvl	98,81%
Base stock lvl		Total expected annual costs	173,860575
Regular	2	Backorder rate	1,38%
Emergency	0	Realised service lvl	98,62%
Base stock lvl		Total expected annual costs	454,630762
Regular	0	Backorder rate	0,00%
Emergency	2	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	209,550365
Regular	2	Backorder rate	0,19%
Emergency	1	Realised service lvl	99,81%

Figure 17 Model results 068Z3415

068Z3416			
Base stock lvl		Total expected annual costs	13,97027032
Regular	0,259378318	Backorder rate	74,12%
Emergency	0,193950014	Realised service lvl	25,88%
Base stock lvl		Total expected annual costs	11,6940875
Regular	0	Backorder rate	100,00%
Emergency	0	Realised service lvl	0,00%
Base stock lvl		Total expected annual costs	11,1393286
Regular	1	Backorder rate	1,75%
Emergency	0	Realised service lvl	98,25%
Base stock lvl		Total expected annual costs	20,42835615
Regular	0	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	18,2560815
Regular	1	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	17,8098536
Regular	2	Backorder rate	0,00%
Emergency	0	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	27,6161811
Regular	0	Backorder rate	0,00%
Emergency	2	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	18,8959751
Regular	2	Backorder rate	0
Emergency	1	Realised service lvl	1

Figure 18 Model results 068Z3416

068Z3418			
Base stock lvl		Total expected annual costs	44,61192178
Regular	0,97539788	Backorder rate	59,95%
Emergency	0,725662884	Realised service lvl	40,05%
Base stock lvl		Total expected annual costs	43,7752125
Regular	0	Backorder rate	100,00%
Emergency	0	Realised service lvl	0,00%
Base stock lvl		Total expected annual costs	21,7266625
Regular	1	Backorder rate	1,75%
Emergency	0	Realised service lvl	98,25%
Base stock lvl		Total expected annual costs	54,9779131
Regular	0	Backorder rate	0,002155172
Emergency	1	Realised service lvl	0,997844828
Base stock lvl		Total expected annual costs	51,5642928
Regular	1	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	30,1916387
Regular	2	Backorder rate	0,00%
Emergency	0	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	59,16588435
Regular	0	Backorder rate	0,00%
Emergency	2	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	29,68479255
Regular	2	Backorder rate	0
Emergency	1	Realised service lvl	1

Figure 19 Model results 068Z3418

068Z3420			
Base stock lvl		Total expected annual costs	58,3764678
Regular	1,559665214	Backorder rate	39,52%
Emergency	1,127017742	Realised service lvl	60,48%
Base stock lvl		Total expected annual costs	56,504175
Regular	0	Backorder rate	100,00%
Emergency	0	Realised service lvl	0,00%
Base stock lvl		Total expected annual costs	26,306475
Regular	1	Backorder rate	1,90%
Emergency	0	Realised service lvl	98,10%
Base stock lvl		Total expected annual costs	60,3021246
Regular	0	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	63,6123575
Regular	1	Backorder rate	0,18%
Emergency	1	Realised service lvl	99,82%
Base stock lvl		Total expected annual costs	33,5473443
Regular	2	Backorder rate	0,00%
Emergency	0	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	71,3651908
Regular	0	Backorder rate	0,00%
Emergency	2	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	33,4022569
Regular	2	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%

Figure 20 Model results 068Z3420

068Z3421			
Base stock lvl		Total expected annual costs	69,12485867
Regular	0,442219802	Backorder rate	42,02%
Emergency	0,326861272	Realised service lvl	57,98%
Base stock lvl		Total expected annual costs	70,992425
Regular	0	Backorder rate	100,00%
Emergency	0	Realised service lvl	0,00%
Base stock lvl		Total expected annual costs	37,2309465
Regular	1	Backorder rate	2,74%
Emergency	0	Realised service lvl	97,26%
Base stock lvl		Total expected annual costs	80,002138
Regular	0	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	84,655768
Regular	1	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	46,9332555
Regular	2	Backorder rate	0,00%
Emergency	0	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	95,887596
Regular	0	Backorder rate	0,00%
Emergency	2	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	48,596185
Regular	2	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%

Figure 21 Model results 068Z3421

068Z3429			
Base stock lvl		Total expected annual costs	45,80397649
Regular	1,407845911	Backorder rate	60,13%
Emergency	1,029225655	Realised service lvl	39,87%
Base stock lvl		Total expected annual costs	43,257775
Regular	0	Backorder rate	100,00%
Emergency	0	Realised service lvl	0,00%
Base stock lvl		Total expected annual costs	22,99897475
Regular	1	Backorder rate	1,61%
Emergency	0	Realised service lvl	98,39%
Base stock lvl		Total expected annual costs	47,11639355
Regular	0	Backorder rate	0,52%
Emergency	1	Realised service lvl	99,48%
Base stock lvl		Total expected annual costs	45,9784437
Regular	1	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	29,28653745
Regular	2	Backorder rate	0,00%
Emergency	0	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	61,64848395
Regular	0	Backorder rate	0,00%
Emergency	2	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	29,95891345
Regular	2	Backorder rate	0,00%
Emergency	1	Realised service lvl	100,00%

Figure 22 Model results 068Z3429

068Z3430			
Base stock lvl		Total expected annual costs	173,1216606
Regular	1,986747745	Backorder rate	0,28%
Emergency	1,430767706	Realised service lvl	99,72%
Base stock lvl		Total expected annual costs	207,6994125
Regular	0	Backorder rate	100,00%
Emergency	0	Realised service lvl	0,00%
Base stock lvl		Total expected annual costs	91,041763
Regular	1	Backorder rate	8,01%
Emergency	0	Realised service lvl	91,99%
Base stock lvl		Total expected annual costs	223,5414315
Regular	0	Backorder rate	0,44%
Emergency	1	Realised service lvl	99,56%
Base stock lvl		Total expected annual costs	216,8195215
Regular	1	Backorder rate	0,45%
Emergency	1	Realised service lvl	99,55%
Base stock lvl		Total expected annual costs	93,148091
Regular	2	Backorder rate	0,31%
Emergency	0	Realised service lvl	99,69%
Base stock lvl		Total expected annual costs	227,84386
Regular	0	Backorder rate	0,00%
Emergency	2	Realised service lvl	100,00%
Base stock lvl		Total expected annual costs	100,659046
Regular	2	Backorder rate	0,05%
Emergency	1	Realised service lvl	99,95%

Figure 23 Model results 068Z3430

6 Conclusion

In chapter 5, the effects of eight different combinations of base stock levels are shown for eleven types of thermostatic expansion valves. In this chapter, the report will conclude its findings.

6.1 Ideal base stock level

One of the first things to notice are total costs in the scenarios using the exact base stock level. Even though it is not possible in the real world to use a fractional regular base stock level for a spare component, theoretically this should be the best solution. However, the DIP model uses the ideal base stock level for either the regular or the emergency level. To find the combination with the lowest costs or the lowest backorder rate, base stock levels close to the 'ideal' levels have been tried out. In most cases this results in an alternative better than the 'ideal' levels.

6.2 Backorder costs

Looking at the backorder rate and total costs, there seems to be some causality. The higher the backorder rate of a product, no matter which of the scenarios, the higher the total costs are. Although Pool Koudetechniek felt the inventory levels have to decrease to save money, having to place backorders seems to lead to higher costs instead. Having a low regular base stock level and no emergency stock seems to be the option with the least amount of costs for these slow moving spare components.

6.3 Realized service level versus backorder rate

There is a big difference in the realized service levels. In most cases, both for the type of scenario and the type of spare component, the backorder rate is lower than 10%. When the backorder rate is not at 10% or lower, the backorder rate is often close to 100%. It seems like the different scenarios are either going for close to no backorders or using backorders all the time, there is no option in the middle except when using the exact base stock levels.

All spare components which score relatively high on service level have something in common compared to all spare components which have a relatively high backorder rate. All components with a relatively high realized service level, also have a relatively high expected demand when compared to the items which have a low expected demand and need to use the emergency option more often. This would suggest that, depending on the scenario and type of spare component, a decision could be made to either focus on having an inventory and provide a high service level or to discard the inventory at all and take the backorder costs for granted.

6.4 Two base stock levels compared to current situation

DIP has proven its worth in some cases (Arts et al, 2011). Subjectively or unconsciously, it even sounds like a normal solution. Based on the scenarios and spare components used in this research, DIP has proven using a second (emergency) base stock level is a more expensive alternative. This can be seen at Figure 23, where using a regular base level of 2 leads to fewer costs (€93) than using both a regular and emergency base stock level of 1 (€216), even though the total inventory is the same. This emergency base stock is more expensive because once the inventory drops, the model restocks this stock up to its base stock level using the more expensive emergency shipment.

7 Recommendation

Pool Koudetechniek was considering reducing their inventory cost by using an emergency shipment option more often. This report looked into the option of changing the inventory management policy of Pool Koudetechniek and researched how viable implementing a dual-index policy is. Based on this sample set of 11 different thermostatic expansion valves, it has to be concluded switching to using the emergency shipment frequently and having an emergency base stock is *not* recommended. Staying in the current situation and using only one type of 'regular' shipment provides lower costs.

The results also show the spare components with a lower demand also carry relatively lower penalty cost. If Pool Koudetechniek decides to decrease the amount of spare components, these slow moving spare components are most interesting to look into financially speaking.

8 Discussion

This report is based on data collected at Pool Koudetechniek but also includes some estimations. These estimations might differ from reality and therefore, this report might not fully represent the real situation.

An example of estimations is the total cost formula. For this formula, an estimation has been done for the holding cost. The costs for holding one spare component in stock for one year were not known. In order to create a total cost formula, the holding costs were estimated to be 25% of the retail price of the spare component.

A second estimate done for this total cost formula was the cost of placing an order. To make creating the model more easy, the model calculates the order cost per spare component. In reality, it is more logical to combine multiple spare components in one order so the order costs will be paid only once.

8.1 DIP model

The DIP model can be seen as one of the results of this research. At the recommendations, it is not recommended to use the DIP. However, this advice is based on a small sample size of only 11 spare components, all being from the same group. This model could be re-used to check whether or not other spare components could benefit from DIP.

9 References

Arts, J., Van Vuuren, M., & Kiesmüller, G. (2011). Efficient optimization of the dual-index policy using Markov chains. *Iie Transactions, 43*(8), 604-620.

CFC, HCFC, HFC and HFO: All replacement solutions! (n.d.). Retrieved July 4, 2019, from https://climalife.dehon.com/cfc-hcfc-hfc-and-hfo-all-replacement-solutions

Chopra, S., & Meindl, P. (2001). Supply chain management: strategy. *Planning and Operation, 15*(5), 71-85.

HCFC and CFC phase out. (n.d.). Retrieved July 4, 2019, from https://www.danfoss.com/en/about-danfoss/our-businesses/cooling/refrigerants-and-energy-efficiency/hcfc-and-cfc-phase-out/

Industrial Advansor CO2. (n.d.). Retrieved July 18, 2019, from https://www.hillphoenix.com/industrial-refrigeration/industrial-advansor-co2-refrigeration-system/

Kemeny, J. G., & Snell, J. L. (1976). *Markov Chains*. Springer-Verlag, New York.

Klosterhalfen, S., Kiesmüller, G., & Minner, S. (2011). A comparison of the constant-order and dual-index policy for dual sourcing. *International Journal of Production Economics, 133*(1), 302-311.

Koehrsen, W. (2019, August 20). The Poisson Distribution and Poisson Process Explained. Retrieved from https://towardsdatascience.com/the-poisson-distribution-and-poisson-process-explained-4e2cb17d459

Markov chain Monte Carlo. (2019, December 29). Retrieved from https://en.wikipedia.org/wiki/Markov_chain_Monte_Carlo.

Monte Carlo method. (2019, December 30). Retrieved from https://en.wikipedia.org/wiki/Monte_Carlo_method.

R22 phase down. (n.d.). Retrieved July 4, 2019, from https://www.danfoss.com/en/about-danfoss/our-businesses/cooling/refrigerants-and-energy-efficiency/hcfc-and-cfc-phase-out/r22-phase-down/

Razali, N. M., & Wah, Y. B. (2011). Power comparisons of shapiro-wilk, kolmogorov-smirnov, lilliefors and anderson-darling tests. *Journal of statistical modeling and analytics*, *2*(1), 21-33.

Simulation. (2019, December 26). Retrieved from https://en.wikipedia.org/wiki/Simulation.

Slack, N., Brandon-Jones, A., & Johnston, R. (2013). *Operations management*. Harlow: Pearson.

Uitfasering HFK's. (n.d.). Retrieved July 4, 2019, from https://www.uniechemie.nl/koelgassen/uitfasering

Winston, W. L., & Goldberg, J. B. (2004). *Operations research: applications and algorithms* (Vol. 3). Belmont^ eCalif Calif: Thomson/Brooks/Cole.

10 Appendix

10.1 Monthly spare component demand November 2012 - June 2019

068Z3383		068Z3385		068Z3403		068Z3414		068Z3415		068Z3416		068Z3418		068Z3420		068Z3421		068Z3429		068Z3430	
Month	Amount	Month	Amount	Month	Amount	Month	Amount	Month	Amount	Month	Amount	Month	Amount	Month	Amount	Month	Amount	Month	Amount	Month	Amount
nov-12	0,00	nov-12	0,00	nov-12	0,00	nov-12	0,00	nov-12	0,00	nov-12	0,00	nov-12	1,00	nov-12	0,00	nov-12	0,00	nov-12	0,00	nov-12	0,00
dec-12	0,00	dec-12	2,00	dec-12	0,00	dec-12	0,00	dec-12	3,00	dec-12	0,00	dec-12	0,00	dec-12	0,00	dec-12	0,00	dec-12	0,00	dec-12	0,00
jan-13	0,00	jan-13	0,00	jan-13	0,00	jan-13	0,00	jan-13	0,00	jan-13	0,00	jan-13	0,00	jan-13	0,00	jan-13	0,00	jan-13	0,00	jan-13	0,00
feb-13	0,00	feb-13	0,00	feb-13	0,00	feb-13	0,00	feb-13	0,00	feb-13	0,00	feb-13	0,00	feb-13	0,00	feb-13	0,00	feb-13	0,00	feb-13	0,00
mrt-13	0,00	mrt-13	2,00	mrt-13	0,00	mrt-13	4,00	mrt-13	0,00	mrt-13	0,00	mrt-13	0,00	mrt-13	0,00	mrt-13	0,00	mrt-13	0,00	mrt-13	0,00
apr-13	0,00	apr-13	0,00	apr-13	0,00	apr-13	0,00	apr-13	0,00	apr-13	0,00	apr-13	0,00	apr-13	0,00	apr-13	0,00	apr-13	0,00	apr-13	0,00
mei-13	0,00	mei-13	2,00	mei-13	0,00	mei-13	0,00	mei-13	4,00	mei-13	0,00	mei-13	0,00	mei-13	0,00	mei-13	0,00	mei-13	0,00	mei-13	0,00
jun-13	0,00	jun-13	1,00	jun-13	2,00	jun-13	0,00	jun-13	0,00	jun-13	0,00	jun-13	0,00	jun-13	3,00	jun-13	0,00	jun-13	0,00	jun-13	0,00
jul-13	0,00	jul-13	0,00	jul-13	2,00	jul-13	3,00	jul-13	0,00	jul-13	0,00	jul-13	1,00	jul-13	1,00	jul-13	2,00	jul-13	1,00	jul-13	0,00
aug-13	0,00	aug-13	0,00	aug-13	1,00	aug-13	0,00	aug-13	0,00	aug-13	0,00	aug-13	0,00	aug-13	0,00	aug-13	0,00	aug-13	0,00	aug-13	0,00
sep-13	0,00	sep-13	2,00	sep-13	0,00	sep-13	0,00	sep-13	0,00	sep-13	0,00	sep-13	2,00	sep-13	0,00	sep-13	0,00	sep-13	1,00	sep-13	0,00
okt-13	0,00	okt-13	0,00	okt-13	0,00	okt-13	0,00	okt-13	0,00	okt-13	0,00	okt-13	0,00	okt-13	0,00	okt-13	0,00	okt-13	0,00	okt-13	0,00
nov-13	0,00	nov-13	2,00	nov-13	0,00	nov-13	0,00	nov-13	2,00	nov-13	0,00	nov-13	0,00	nov-13	0,00	nov-13	0,00	nov-13	0,00	nov-13	1,00
dec-13	0,00	dec-13	1,00	dec-13	0,00	dec-13	0,00	dec-13	1,00	dec-13	0,00	dec-13	0,00	dec-13	0,00	dec-13	0,00	dec-13	0,00	dec-13	0,00
jan-14	0,00	jan-14	0,00	jan-14	0,00	jan-14	0,00	jan-14	0,00	jan-14	0,00	jan-14	0,00	jan-14	0,00	jan-14	0,00	jan-14	0,00	jan-14	1,00
feb-14	0,00	feb-14	0,00	feb-14	0,00	feb-14	0,00	feb-14	2,00	feb-14	0,00	feb-14	0,00	feb-14	0,00	feb-14	0,00	feb-14	0,00	feb-14	0,00
mrt-14	0,00	mrt-14	0,00	mrt-14	0,00	mrt-14	0,00	mrt-14	0,00	mrt-14	0,00	mrt-14	0,00	mrt-14	0,00	mrt-14	0,00	mrt-14	0,00	mrt-14	0,00
apr-14	0,00	apr-14	2,00	apr-14	0,00	apr-14	0,00	apr-14	0,00	apr-14	0,00	apr-14	0,00	apr-14	1,00	apr-14	0,00	apr-14	0,00	apr-14	0,00
mei-14	0,00	mei-14	1,00	mei-14	0,00	mei-14	0,00	mei-14	0,00	mei-14	0,00	mei-14	0,00	mei-14	0,00	mei-14	0,00	mei-14	0,00	mei-14	0,00
jun-14	0,00	jun-14	2,00	jun-14	0,00	jun-14	0,00	jun-14	0,00	jun-14	0,00	jun-14	0,00	jun-14	0,00	jun-14	0,00	jun-14	0,00	jun-14	0,00
jul-14	0,00	jul-14	1,00	jul-14	0,00	jul-14	0,00	jul-14	0,00	jul-14	0,00	jul-14	0,00	jul-14	0,00	jul-14	0,00	jul-14	0,00	jul-14	0,00
aug-14	0,00	aug-14	3,00	aug-14	0,00	aug-14	0,00	aug-14	4,00	aug-14	0,00	aug-14	0,00	aug-14	0,00	aug-14	0,00	aug-14	0,00	aug-14	2,00
sep-14	0,00	sep-14	0,00	sep-14	0,00	sep-14	0,00	sep-14	0,00	sep-14	0,00	sep-14	0,00	sep-14	0,00	sep-14	0,00	sep-14	0,00	sep-14	0,00
okt-14	0,00	okt-14	0,00	okt-14	0,00	okt-14	0,00	okt-14	0,00	okt-14	0,00	okt-14	0,00	okt-14	0,00	okt-14	0,00	okt-14	0,00	okt-14	0,00
nov-14	0,00	nov-14	0,00	nov-14	0,00	nov-14	0,00	nov-14	0,00	nov-14	0,00	nov-14	0,00	nov-14	0,00	nov-14	0,00	nov-14	0,00	nov-14	0,00
dec-14	0,00	dec-14	0,00	dec-14	0,00	dec-14	0,00	dec-14	0,00	dec-14	0,00	dec-14	0,00	dec-14	0,00	dec-14	0,00	dec-14	0,00	dec-14	0,00
jan-15	0,00	jan-15	1,00	jan-15	0,00	jan-15	1,00	jan-15	0,00	jan-15	0,00	jan-15	0,00	jan-15	0,00	jan-15	0,00	jan-15	0,00	jan-15	0,00
feb-15	0,00	feb-15	1,00	feb-15	0,00	feb-15	0,00	feb-15	8,00	feb-15	0,00	feb-15	0,00	feb-15	0,00	feb-15	3,00	feb-15	0,00	feb-15	0,00
mrt-15	0,00	mrt-15	0,00	mrt-15	0,00	mrt-15	0,00	mrt-15	3,00	mrt-15	0,00	mrt-15	0,00	mrt-15	0,00	mrt-15	0,00	mrt-15	0,00	mrt-15	0,00
apr-15	0,00	apr-15	0,00	apr-15	0,00	apr-15	0,00	apr-15	0,00	apr-15	0,00	apr-15	0,00	apr-15	0,00	apr-15	0,00	apr-15	0,00	apr-15	0,00
mei-15	0,00	mei-15	0,00	mei-15	0,00	mei-15	0,00	mei-15	0,00	mei-15	0,00	mei-15	0,00	mei-15	0,00	mei-15	0,00	mei-15	0,00	mei-15	0,00
jun-15	0,00	jun-15	0,00	jun-15	0,00	jun-15	5,00	jun-15	0,00	jun-15	0,00	jun-15	0,00	jun-15	0,00	jun-15	0,00	jun-15	0,00	jun-15	0,00
jul-15	0,00	jul-15	0,00	jul-15	0,00	jul-15	2,00	jul-15	1,00	jul-15	0,00	jul-15	0,00	jul-15	0,00	jul-15	0,00	jul-15	0,00	jul-15	2,00
aug-15	0,00	aug-15	0,00	aug-15	0,00	aug-15	0,00	aug-15	0,00	aug-15	0,00	aug-15	0,00	aug-15	0,00	aug-15	0,00	aug-15	0,00	aug-15	0,00
sep-15	0,00	sep-15	0,00	sep-15	1,00	sep-15	0,00	sep-15	1,00	sep-15	0,00	sep-15	0,00	sep-15	0,00	sep-15	0,00	sep-15	0,00	sep-15	0,00
okt-15	0,00	okt-15	0,00	okt-15	0,00	okt-15	0,00	okt-15	0,00	okt-15	0,00	okt-15	0,00	okt-15	0,00	okt-15	0,00	okt-15	0,00	okt-15	0,00
nov-15	0,00	nov-15	0,00	nov-15	0,00	nov-15	2,00	nov-15	2,00	nov-15	0,00	nov-15	0,00	nov-15	0,00	nov-15	0,00	nov-15	1,00	nov-15	0,00
dec-15	0,00	dec-15	0,00	dec-15	0,00	dec-15	0,00	dec-15	0,00	dec-15	0,00	dec-15	0,00	dec-15	0,00	dec-15	0,00	dec-15	0,00	dec-15	0,00
jan-16	0,00	jan-16	0,00	jan-16	0,00	jan-16	0,00	jan-16	2,00	jan-16	0,00	jan-16	0,00	jan-16	0,00	jan-16	0,00	jan-16	0,00	jan-16	0,00
feb-16	0,00	feb-16	0,00	feb-16	0,00	feb-16	0,00	feb-16	3,00	feb-16	0,00	feb-16	0,00	feb-16	0,00	feb-16	0,00	feb-16	0,00	feb-16	0,00
mrt-16	0,00	mrt-16	0,00	mrt-16	0,00	mrt-16	0,00	mrt-16	1,00	mrt-16	0,00	mrt-16	0,00	mrt-16	0,00	mrt-16	0,00	mrt-16	0,00	mrt-16	0,00
apr-16	0,00	apr-16	2,00	apr-16	0,00	apr-16	0,00	apr-16	3,00	apr-16	0,00	apr-16	0,00	apr-16	0,00	apr-16	0,00	apr-16	1,00	apr-16	0,00
mei-16	0,00	mei-16	1,00	mei-16	0,00	mei-16	0,00	mei-16	0,00	mei-16	0,00	mei-16	0,00	mei-16	0,00	mei-16	0,00	mei-16	0,00	mei-16	1,00
jun-16	0,00	jun-16	1,00	jun-16	0,00	jun-16	1,00	jun-16	5,00	jun-16	0,00	jun-16	0,00	jun-16	0,00	jun-16	0,00	jun-16	0,00	jun-16	0,00
jul-16	0,00	jul-16	0,00	jul-16	0,00	jul-16	0,00	jul-16	0,00	jul-16	0,00	jul-16	0,00	jul-16	0,00	jul-16	0,00	jul-16	0,00	jul-16	2,00
aug-16	0,00	aug-16	0,00	aug-16	0,00	aug-16	0,00	aug-16	0,00	aug-16	0,00	aug-16	0,00	aug-16	0,00	aug-16	0,00	aug-16	0,00	aug-16	1,00
sep-16	0,00	sep-16	1,00	sep-16	0,00	sep-16	0,00	sep-16	0,00	sep-16	0,00	sep-16	0,00	sep-16	0,00	sep-16	0,00	sep-16	0,00	sep-16	0,00
okt-16	0,00	okt-16	0,00	okt-16	0,00	okt-16	0,00	okt-16	1,00	okt-16	0,00	okt-16	0,00	okt-16	0,00	okt-16	0,00	okt-16	0,00	okt-16	0,00
nov-16	0,00	nov-16	0,00	nov-16	0,00	nov-16	0,00	nov-16	0,00	nov-16	0,00	nov-16	0,00	nov-16	0,00	nov-16	0,00	nov-16	0,00	nov-16	0,00
dec-16	0,00	dec-16	1,00	dec-16	0,00	dec-16	0,00	dec-16	2,00	dec-16	0,00	dec-16	0,00	dec-16	0,00	dec-16	0,00	dec-16	0,00	dec-16	2,00
jan-17	0,00	jan-17	0,00	jan-17	0,00	jan-17	0,00	jan-17	1,00	jan-17	0,00	jan-17	0,00	jan-17	0,00	jan-17	0,00	jan-17	0,00	jan-17	0,00
feb-17	0,00	feb-17	0,00	feb-17	0,00	feb-17	0,00	feb-17	1,00	feb-17	0,00	feb-17	0,00	feb-17	0,00	feb-17	0,00	feb-17	0,00	feb-17	1,00
mrt-17	0,00	mrt-17	0,00	mrt-17	0,00	mrt-17	0,00	mrt-17	2,00	mrt-17	0,00	mrt-17	0,00	mrt-17	0,00	mrt-17	0,00	mrt-17	0,00	mrt-17	0,00
apr-17	0,00	apr-17	0,00	apr-17	0,00	apr-17	0,00	apr-17	0,00	apr-17	0,00	apr-17	0,00	apr-17	0,00	apr-17	0,00	apr-17	0,00	apr-17	1,00
mei-17	0,00	mei-17	0,00	mei-17	0,00	mei-17	1,00	mei-17	2,00	mei-17	0,00	mei-17	0,00	mei-17	0,00	mei-17	1,00	mei-17	0,00	mei-17	1,00
jun-17	0,00	jun-17	0,00	jun-17	0,00	jun-17	0,00	jun-17	0,00	jun-17	0,00	jun-17	0,00	jun-17	0,00	jun-17	0,00	jun-17	0,00	jun-17	0,00
jul-17	0,00	jul-17	3,00	jul-17	0,00	jul-17	1,00	jul-17	0,00	jul-17	0,00	jul-17	0,00	jul-17	0,00	jul-17	1,00	jul-17	0,00	jul-17	0,00
aug-17	0,00	aug-17	0,00	aug-17	0,00	aug-17	0,00	aug-17	0,00	aug-17	0,00	aug-17	0,00	aug-17	0,00	aug-17	0,00	aug-17	0,00	aug-17	0,00
sep-17	0,00	sep-17	0,00	sep-17	0,00	sep-17	1,00	sep-17	0,00	sep-17	0,00	sep-17	1,00	sep-17	0,00	sep-17	1,00	sep-17	0,00	sep-17	0,00
okt-17	0,00	okt-17	0,00	okt-17	0,00	okt-17	0,00	okt-17	2,00	okt-17	0,00	okt-17	0,00	okt-17	0,00	okt-17	0,00	okt-17	0,00	okt-17	0,00
nov-17	0,00	nov-17	0,00	nov-17	0,00	nov-17	0,00	nov-17	1,00	nov-17	0,00	nov-17	0,00	nov-17	0,00	nov-17	0,00	nov-17	0,00	nov-17	0,00
dec-17	0,00	dec-17	1,00	dec-17	0,00	dec-17	0,00	dec-17	0,00	dec-17	0,00	dec-17	0,00	dec-17	0,00	dec-17	0,00	dec-17	0,00	dec-17	0,00
jan-18	0,00	jan-18	0,00	jan-18	0,00	jan-18	0,00	jan-18	0,00	jan-18	0,00	jan-18	0,00	jan-18	0,00	jan-18	0,00	jan-18	0,00	jan-18	0,00
feb-18	0,00	feb-18	0,00	feb-18	0,00	feb-18	6,00	feb-18	0,00	feb-18	0,00	feb-18	0,00	feb-18	3,00	feb-18	0,00	feb-18	0,00	feb-18	0,00
mrt-18	0,00	mrt-18	1,00	mrt-18	0,00	mrt-18	0,00	mrt-18	0,00	mrt-18	0,00	mrt-18	0,00	mrt-18	1,00	mrt-18	0,00	mrt-18	0,00	mrt-18	0,00
apr-18	0,00	apr-18	0,00	apr-18	0,00	apr-18	0,00	apr-18	0,00	apr-18	0,00	apr-18	0,00	apr-18	0,00	apr-18	0,00	apr-18	0,00	apr-18	0,00
mei-18	0,00	mei-18	0,00	mei-18	0,00	mei-18	0,00	mei-18	0,00	mei-18	0,00	mei-18	0,00	mei-18	0,00	mei-18	0,00	mei-18	0,00	mei-18	8,00
jun-18	0,00	jun-18	0,00	jun-18	0,00	jun-18	0,00	jun-18	0,00	jun-18	0,00	jun-18	0,00	jun-18	0,00	jun-18	0,00	jun-18	0,00	jun-18	0,00
jul-18	0,00	jul-18	0,00	jul-18	0,00	jul-18	1,00	jul-18	1,00	jul-18	0,00	jul-18	0,00	jul-18	0,00	jul-18	0,00	jul-18	0,00	jul-18	0,00
aug-18	0,00	aug-18	1,00	aug-18	0,00	aug-18	1,00	aug-18	3,00	aug-18	0,00	aug-18	0,00	aug-18	0,00	aug-18	0,00	aug-18	0,00	aug-18	0,00
sep-18	0,00	sep-18	0,00	sep-18	0,00	sep-18	0,00	sep-18	0,00	sep-18	0,00	sep-18	0,00	sep-18	0,00	sep-18	0,00	sep-18	0,00	sep-18	0,00
okt-18	1,00	okt-18	0,00	okt-18	0,00	okt-18	0,00	okt-18	0,00	okt-18	0,00	okt-18	0,00	okt-18	0,00	okt-18	0,00	okt-18	0,00	okt-18	0,00
nov-18	0,00	nov-18	1,00	nov-18	0,00	nov-18	0,00	nov-18	1,00	nov-18	0,00	nov-18	0,00	nov-18	0,00	nov-18	0,00	nov-18	0,00	nov-18	0,00
dec-18	0,00	dec-18	0,00	dec-18	0,00	dec-18	0,00	dec-18	0,00	dec-18	0,00	dec-18	0,00	dec-18	0,00	dec-18	0,00	dec-18	0,00	dec-18	0,00
jan-19	0,00	jan-19	1,00	jan-19	0,00	jan-19	0,00	jan-19	3,00	jan-19	0,00	jan-19	0,00	jan-19	0,00	jan-19	0,00	jan-19	0,00	jan-19	1,00
feb-19	1,00	feb-19	0,00	feb-19	0,00	feb-19	0,00	feb-19	0,00	feb-19	0,00	feb-19	0,00	feb-19	0,00	feb-19	0,00	feb-19	0,00	feb-19	0,00
mrt-19	2,00	mrt-19	1,00	mrt-19	1,00	mrt-19	2,00	mrt-19	0,00	mrt-19	0,00	mrt-19	0,00	mrt-19	0,00	mrt-19	1,00	mrt-19	1,00	mrt-19	1,00
apr-19	7,00	apr-19	8,00	apr-19	0,00	apr-19	2,00	apr-19	2,00	apr-19	2,00	apr-19	1,00	apr-19	0,00	apr-19	1,00	apr-19	2,00	apr-19	3,00
mei-19	0,00	mei-19	2,00	mei-19	0,00	mei-19	0,00	mei-19	0,00	mei-19	0,00	mei-19	1,00	mei-19	0,00	mei-19	0,00	mei-19	0,00	mei-19	2,00
jun-19	0,00	jun-19	1,00	jun-19	0,00	jun-19	0,00	jun-19	0,00	jun-19	0,00	jun-19	0,00	jun-19	0,00	jun-19	1,00	jun-19	0,00	jun-19	2,00

Figure 24 Monthly spare component demand November 2012 - June 2019

10.2 Histograms of monthly spare component demand

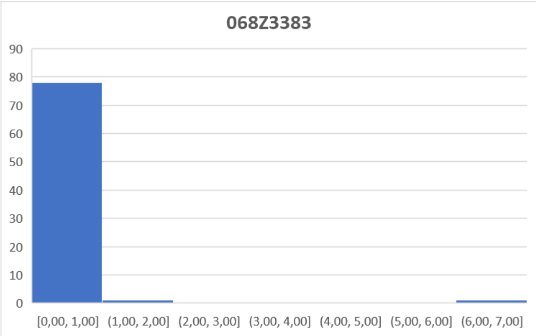

Figure 25 Histogram of monthly demand for spare component demand 068Z3383

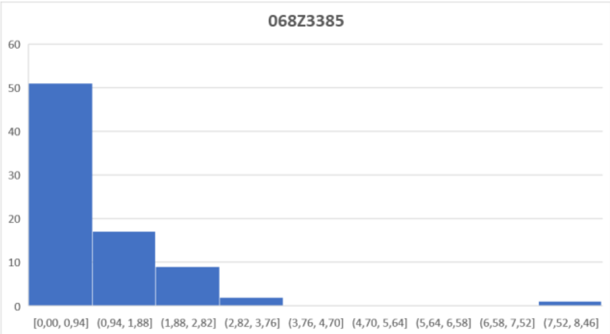

Figure 26 Histogram of monthly demand for spare component demand 068Z3385

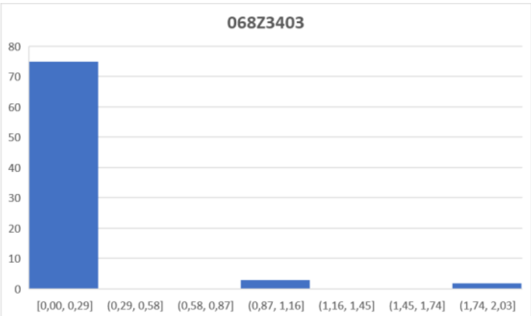

Figure 27 Histogram of monthly demand for spare component demand 068Z3403

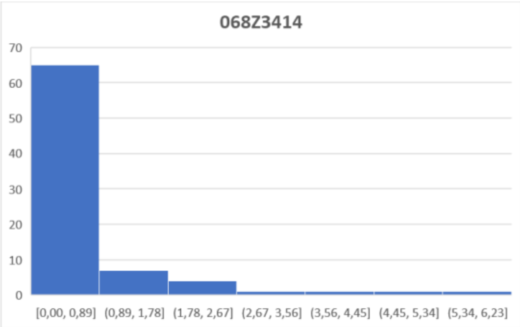

Figure 28 Histogram of monthly demand for spare component demand 068Z3414

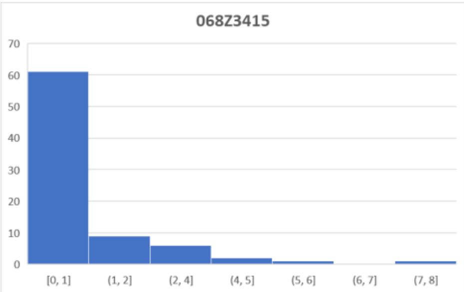

Figure 29 Histogram of monthly demand for spare component demand 068Z3415

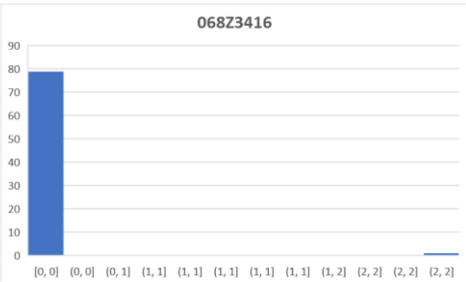

Figure 30 Histogram of monthly demand for spare component demand 068Z3416

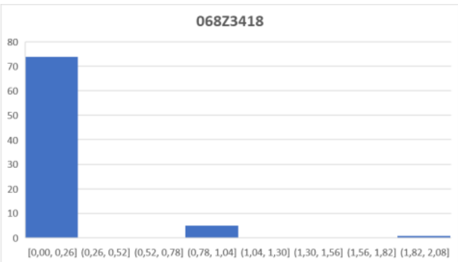

Figure 31 Histogram of monthly demand for spare component demand 068Z3418

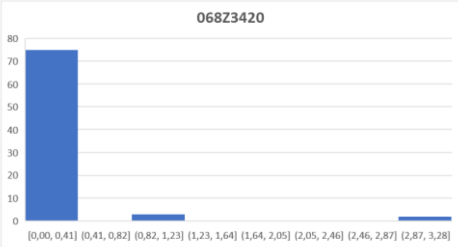

Figure 32 Histogram of monthly demand for spare component demand 068Z3420

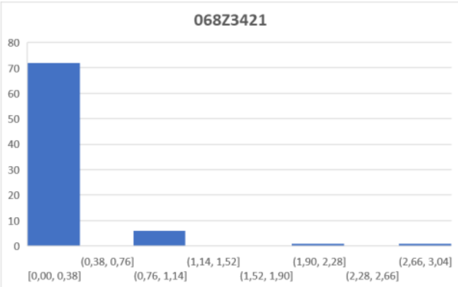

Figure 33 Histogram of monthly demand for spare component demand 068Z3421

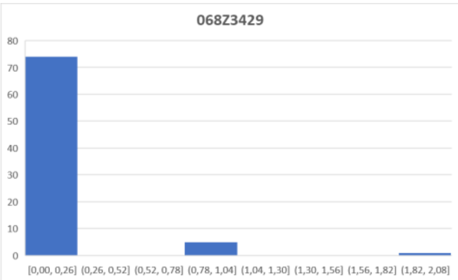

Figure 34 Histogram of monthly demand for spare component demand 068Z3429

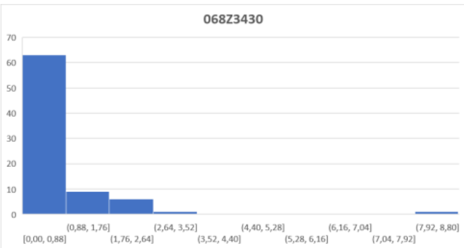

Figure 35 Histogram of monthly demand for spare component demand 068Z3430

10.3 Ideal base stock levels

Results per component	068Z3383	068Z3385	068Z3403	068Z3414	068Z3415	068Z3416	068Z3418	068Z3420	068Z3421	068Z3429	068Z3430
Base stock regular	0,975	1,560	0,442	1,408	1,987	0,259	0,401	0,609	0,585	0,401	1,388
Base stock emergency	0,726	1,127	0,327	1,029	1,431	0,194	0,296	0,451	0,430	0,296	1,015

Figure 36 Ideal base stock levels for regular and emergency shipment per spare component type

POOL Koudetechniek