MASTER

Cost/benefit allocation using third-party logistics in a health care setting

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Cost/benefit allocation using third-party logistics in a health care setting

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I Abstract

In this master thesis project cost/benefit allocation in the context of third party logistics is investigated. This topic is researched at Bernhoven Hospital, where Jeroen Bosch Hospital may be considered as a partner in its outsourcing process. By means of a warehousing cost model pooling advantages are quantified. Insights into these matters may be beneficial at contract negotiations between both health care providers and the logistics service provider.

The report has been made suitable for publication. Appendices or other relevant information throughout this thesis have been labeled confidential and were masked in this version. For more information, please contact Bernhoven Hospital or Jeroen Bosch Hospital.

II Acknowledgements

This final report is the result of my graduation project for the Master of Science program Operations Management and Logistics, at the Eindhoven University of Technology (TU/e). The project took place from May 2010 till December 2010 within the department of Industrial Engineering and Innovation Sciences, research area of Operations, Planning, Accounting and Control. This thesis would not have been possible without the valuable contributions of many people.

First, I would like to thank my primary TU/e supervisor Marco Slikker for his guidance and support in this thesis. His thorough scope and constructive criticism proved extremely valuable for me. It reminded me to continuously reflect my research methodology with the overall project's goals. This way of coaching is highly appreciated.

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Finally, I acknowledge the contributions of people not directly involved in this project. I want to thank my loved ones for providing me the support and confidence for successfully finishing my Master Thesis Project.

Tom Boot

Eindhoven, December 2010

III Management Summary

Outsourcing of logistical operations is gradually gaining more attention among Dutch health care providers, mainly because of the sector's increased attention towards costs savings and focus on higher operational efficiencies. This holds for Bernhoven Hospital (BE) and Jeroen Bosch Hospital (JBZ) as well. This report describes a method used for gaining insights into the contractual framework between the logistics service provider Hospital Logistics (HL) and both concerning hospitals. For BE/JBZ a lot of obscurities surrounding this contract emerged. After preliminary problem analysis and validation, a problem definition was formulated:
With respect to the new outsourcing situation little insight exists in the cost structure and therefore in the fairness of HL's contract and its allocation mechanisms.

Research Scope
At BE/JBZ there are two types of products, this being inventory articles and purchase articles. Since HL will mostly deal with products that actually have to be kept on stock, this study is limited to the inventory articles. Where BE and JBZ both still have two hospital locations at this moment (respectively Veghel and Oss for BE, and GZG and Carolus for JBZ) research is conducted on the situation where for each party one location is accounted for. For BE this is the new hospital in Uden, which will be operational from the beginning of 2013. For JBZ this is the facility Willem-Alexander in 's-Hertogenbosch (operational from halfway 2011 onwards). This is done because the initial contractual framework provided by HL only deals with these 2 primary locations.

Methodology
In order to gain insight into the contractual framework of HL we pose to look at HL's cost structure. More specifically, this thesis will focus on the business activities transportation and inventory management (i.e. warehousing). This because literature review (among others: Cruijssen et al, 2005; Gerchak and Gupta, 1991) revealed significant cost reductions can be made with respect to these matters. In order to effectively asses this cost structure we firstly build a model for approximating expected annual warehousing costs. This warehousing model will allow us to quantify different settings. With 'settings' we mean for instance:

1. The setting where BE is operating a warehouse individually.
2. The setting where JBZ is operating a warehouse individually.
3. A multi party setting where a warehouse is being shared by BE/JBZ.
4. An extension to the BE/JBZ setting with an additional hospital.

These different settings thus imply different quantities of products, deliveries, orders etc. Consecutively, we have to cope with different (magnitudes in) input parameters, so that we will be able to assess any possible pooling advantages. When insight into these pooling advantages is gained, these can be used to effectively asses the flex rates (incentives for BE/JBZ which HL designed to cope with work load variation) as specified by HL. Next to that, the possibility of adding an additional party to the cooperation with HL is looked upon and quantified.

Results
As mentioned above we deal with four specific settings. The most interesting appear to be the third and fourth. Results from the third setting's analysis indicate that the theoretical pooling advantages with respect to warehousing would be [redacted]. This thus means that when two

products are considered to be 100% overlapping, cost savings of [redacted] (of this unit's yearly warehousing costs) can be realized. Note on this is that all costs are here considered to be 'green', i.e. easily adjustable. When elaborating on the extent of ease of realization we split this [redacted] (or [redacted] when based on HL's tariffs) into:

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Table III.1 Action analysis

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Figure III.1 Pooling advantages

In the table above, savings with respect to the green costs are the easiest attainable (consequently 'red costs' being the hardest to realize). When specifically benchmarking this insight with the flex rates HL specified for dealing with product overlap, we see an understatement of pooling potential from HL's point of view. Where HL quantifies total realizable savings at [redacted] (or [redacted] of its tariffs), we state that the savings on opportunity costs alone [redacted] of HL's tariffs) already are approximately twice this amount (see table III.1 for the absolute figure).

With respect to the issue of additional parties we again looked at multiple settings, each setting coping with a different sized additional party joining the cooperation. The results of these analyses indicated that it is indeed beneficial for BE/JBZ to actively look for additional parties. If a party which is [redacted] of BE/JBZ's combined size joins the warehouse, the theoretically feasible pooling advantages for BE/JBZ are [redacted]. See the figure below for the complete overview:

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Figure III.2 Overview of relative savings BE/JBZ

Note that the findings in the figure above are again based on calculations which assume all costs to be easily adjustable.

We benchmarked this finding with the contract, which poses a relative pooling advantage for BE/JBZ of [redacted]. When looking at the space costs, which are considered 'red' (using the typology of table III.1) by HL, we pose that the additional party incentive has to cope with these. Namely, if these fixed costs are neither accounted for in the flex rates nor this incentive, BE/JBZ continues to carry the entrepreneurial risks of HL. Since these risks decrease when more parties join the coalition, BE/JBZ should significantly be compensated for this. When only considering these fixed costs, we would expect HL's incentive to be [redacted] Note that this amount is based on the situation where the warehouse is *exactly* large enough, i.e. we do not deal with a warehouse that has overcapacity (as is the case at HL). When the fixed costs of this excess space are taken into account as well, we expect the incentive to be [redacted]. When considering the prevailing incentive of [redacted] for BE/JBZ as posed by HL we see [redacted]

With respect to transportation only some qualitative reasoning was elaborated upon. This because of the fact that not enough data was available to facilitate a thorough quantitative analysis. However, significant pooling advantages may be realized here at a later stage.
As for internal transportation, it is worth keeping track of HL's picking procedures when significant product overlap is indeed effectuated. Possible benefits that emerge here may be shared among HL and its clients.

Recommendations

The main recommendations towards BE/JBZ can be summarized by:

- Because of the discrepancy between the easily attainable savings [redacted] and the all-embracing figure HL provides [redacted] it is recommended for BE/JBZ to reopen the discussion concerning the specification of these rates.
- With respect to the flex rates, it is recommended to negotiate flex rates for both sterile and non-sterile products. This because sterile storage proved to be significantly more expensive.
- For the future it may be beneficial for BE/JBZ to request its suppliers for an overview of a product's dimensions. With this specific kind of information, BE/JBZ might facilitate better use of its internal storage space, as well as the space utilization in HL's warehouse.
- BE/JBZ should be aware of the significant supplier overlap it already has. It should also keep track of these figures in order to reopen discussion of its tariffs if this will prove necessary.
- BE/JBZ should be aware of the pooling potential realizable with the addition of a new party to the cooperation, and it should use this insight in its contract negotiations. Where HL poses to pay BE/JBZ [redacted] when an additional party of [redacted] BE/JBZ's size is added, we calculate an amount that should be at least [redacted] HL will most likely be reluctant to alter the amount, because then it will not be able to cover as large parts of its fixed costs as it does now. However, with this should be noted that the entrepreneurial risk should actually be shifted towards HL, not towards BE/JBZ (as clients) as appears to be the case now, since BE/JBZ covers significant amounts of these fixed costs.
- Larger parties are more beneficial for addition to the cooperation than smaller ones. BE/JBZ should take this into account when introducing HL to potential candidate hospitals. This insight is valid under the assumption that HL uses proportional allocation on the gains for its clients. This specific allocation mechanism posed by HL may be reconsidered. Other methods may prove to be more fair for BE/JBZ.
- Furthermore, this study revealed that additional parties with more product overlap may be considered more beneficial for addition to the cooperation. BE/JBZ should take this into account as well.
- Finally, it is recommended that BE/JBZ look at transportation pooling at a later stage. Significant pooling advantages with respect to routing may be obtained, especially in the case where more than 2 hospital locations are replenished by HL. Furthermore, it is worth keeping track of HL's picking procedures when significant product overlap is indeed effectuated.

IV List of abbreviations

AGV	Automated Guided Vehicle
BE	Ziekenhuis Bernhoven
CS	Cost Structure
CV	Coefficient of Variation
EOQ	Economic Order Quantity
FTE	Fulltime Equivalent
GZG	Groot Ziekengasthuis
HL	Hospital Logistics
IAZ	Inkoop Alliantie Ziekenhuizen
JBZ	Jeroen Bosch Ziekenhuis
PDF	Probability Density Function
PE	Portfolio Effect
POQ	Predetermined Order Quantity
RU	Release Unit
SS	Safety Stock
SR	Storage Room
TPL	Third-Party Logistics
SKU	Stock Keeping Unit
VAT	Value Added Tax (in Dutch: BTW)

V Table of contents

Chapter 1: Description of involved companies

This master thesis addresses issues concerning 3 main parties. This being: Bernhoven Hospital (section 1.1), Jeroen Bosch Hospital (section 1.2) and Hospital Logistics (section 1.3). Since the initial problem was highlighted and brought into attention by Bernhoven Hospital, this party will be viewed as the main client throughout this thesis.

1.1 Bernhoven Hospital

The history of Bernhoven Hospital (BE) can be found in two medium large Dutch cities. First of all in the city of Oss. In 1913 the Sint-Anne Hospital was formed out of a regional monastery. After a necessary relocation in 1961 due to capacity problems the hospital became a large player in the provision of regional health care. Nowadays this location of BE accounts for approximately 280 licensed hospital beds. Apart from the location in Oss, BE has an almost equally sized hospital in Veghel with approximately 270 licensed beds. In the year 1900 the Sint-Joseph Hospital is founded and (at first) serves as a local health care provider. After major expansion takes place in 1935 (and later on during 1980-1990), the hospital starts covering regions larger than just Veghel itself.

As of 2000 both the Sint-Anne Hospital in Oss and the Sint-Joseph Hospital in Veghel are merged into Bernhoven Hospital. These locations together provide 566 licensed hospital beds, more than 126 medical specialists and 2,250 employees. In the vicinity of Oss-Uden-Veghel, health care is provided to nearly 200,000 inhabitants. In 2013 the structure of Bernhoven as it is present today will change. As mentioned above, BE now consists of hospitals in Veghel and Oss. As of 2013 Bernhoven will move both locations' operations to one new location in Uden (see figure 1.1).


Figure 1.1 Bernhoven's new facility


Figure 1.2 Jeroen Bosch's new facility

1.2 Jeroen Bosch Hospital

For Jeroen Bosch Hospital (JBZ), the history of patient health care in 's-Hertogenbosch and surroundings starts around 1274. In that year the so called Groot Ziekengasthuis (GZG) was established. As far as the name Jeroen Bosch goes, this was obtained via a merger of the Bosch Medical Centre and the Carolus-Liduina Hospital. It was decided to name the new merger after one of the most well known painters of 's-Hertogenbosch: Jeroen Bosch.
Nowadays JBZ is comprised of 5 different locations. Three of which are in 's-Hertogenbosch, one in Boxtel and one in Zaltbommel. The hospitals in Boxtel (Liduina Hospital) and

Zaltbommel (Bommels Gasthuis) are not part of the cooperation with BE. Thus, this research limits itself to the other locations, which are: GZG, Carolus and Willem-Alexander. Willem-Alexander (see figure 1.2) will become a completely new hospital, large enough to replace Carolus and the GZG halfway 2011. Both of these locations will eventually be demolished. The old buildings of Willem-Alexander (as present before new construction began) will partly serve as office- and educational facilities. The region of care JBZ covers for today encompasses 360,000 habitants.

1.3 Hospital Logistics

Hospital Logistics (HL) is a third party logistics provider of Belgian origin which is specialised in facilitating outsourcing decisions in a health care setting. Since 13 years they provide these services in the Dutch health care industry as well. In collaboration with its customers they control administrative and logistical processes, previously executed by hospital personnel. The main goal in this is a long term partnership in which total cost of ownership is effectively reduced. More on HL and its frameworks will be discussed in section 2.1.2.

Chapter 2: Research design

In this chapter an overview of the posed research is presented. First section 2.1 will provide the context in which this study's problem is situated. Using this knowledge consecutively the problem statement (section 2.2), research questions (section 2.3), the project's scope (section 2.4) and positioning of the thesis (section 2.5) will be discussed. The concluding part of this chapter (section 2.6) will cover the report outline and give an overview of the interdependency between the chapters in this report and the project's methodology.

2.1 Problem context

This section will introduce the decision of both companies to outsource their inventory management, yielding a significant change in both company's business processes. First the current processes will be described, after this the new third-party logistics (TPL) setting will be sketched. This modelling of business processes will provide necessary insights in the contractual structure that will be discussed in section 2.2.3.

2.1.1 Current logistical situation

When looking at the current logistical processes we firstly notice the numerous product flows (as modelled in figure 2.1). In this figure we can distinguish 2 types of products.

- First, the so called *purchasing articles*, which are represented by the dashed lines. Purchasing articles can be sub-divided into 'regular-purchase' and 'scan-purchase'. 'Regular-purchasing' articles are products that are ordered directly from the suppliers in small quantities. This mainly concerns products that are needed in low or irregular frequencies. The 'scan-purchase' articles are products that indeed are scanned on a hospital's department using barcode scanners for inventory management, but are only used by 1 department. This makes these articles too expensive to keep in the hospital's central storage space, thus these articles are ordered directly at the supplier.
- Next to that, there are *inventory articles*, which are represented by the solid lines. These articles comprise the majority of the product flow. In general, products are ordered for each separate location. Doing this, yields frequent deliveries from suppliers to all hospitals. BE on its own orders these inventory articles from just over [redacted] suppliers.

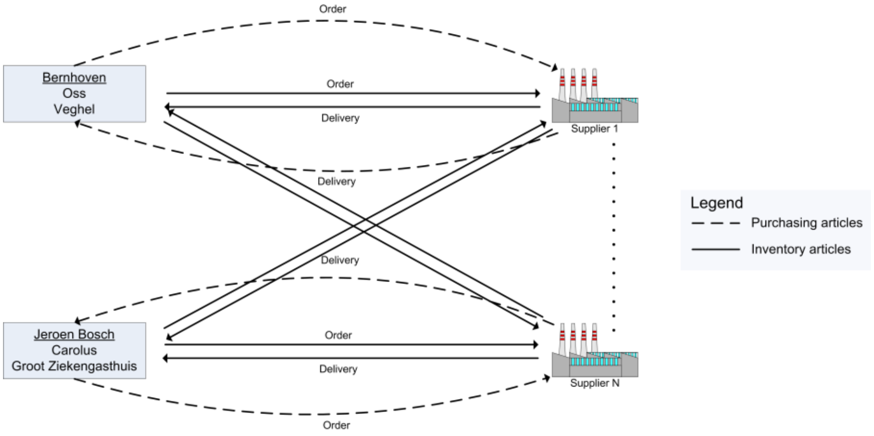

Figure 2.1 Model of current logistical situation

As can be seen in figure 2.1 the current logistical setting consists for both parties of two locations. This being: Veghel and Oss for Bernhoven, and Carolus and Groot Ziekengasthuis for Jeroen Bosch respectively. For BE holds: mostly, each location orders at the supplier (ranging 1 to N in figure 2.1) according to its own individual needs. Thus, since here no order consolidation over the different suppliers is carried out, numerous truck movements have to be taken care of. However, there are some cases in which BE itself uses order consolidation to make benefit of economies of scale in transportation, e.g. in the case of plaster. Oss and Veghel make their individual needs clear to BE's procurement department. After that, one order is sent to the plaster manufacturer. This because both locations themselves do not exceed minimum levels for free delivery. When plaster is delivered to Oss, internal transport makes sure Veghel receives its share.

On the other hand, at JBZ significant order consolidation over both weekdays and locations takes place. For illustrational purposes only a few connections are drawn. However, it is obviously also possible for Bernhoven to order purchasing articles (represented by the dashed lines) at supplier N.

2.1.2 Hospital Logistics' framework

As discussed in section 1.3, the main goal of HL and its customers is a long term partnership in which total cost of ownership is effectively reduced. HL effectuates this by using the framework as shown in figure 2.2 below.
First every hospital keeps track of internal supply requests for certain articles, arriving from hospitals' different departments. These requests are very likely to be formed using barcode scanners (or a similar internal inventory management system).

Second, the administrative department (see the orange square in figure 2.2) combines the several requests into one order and electronically sends this to HL (apart from this, it is optional to implement an internal inventory management system monitored by HL, this will not be the case for BE/JBZ). After HL received the order, its warehousing crew picks the articles requested for and delivers it to the concerning hospital. The hospital consequently only has to pay at the actual purchase of the articles and receives a bill consisting of two parts, one part for the goods that were purchased, and one for the service provided by HL.

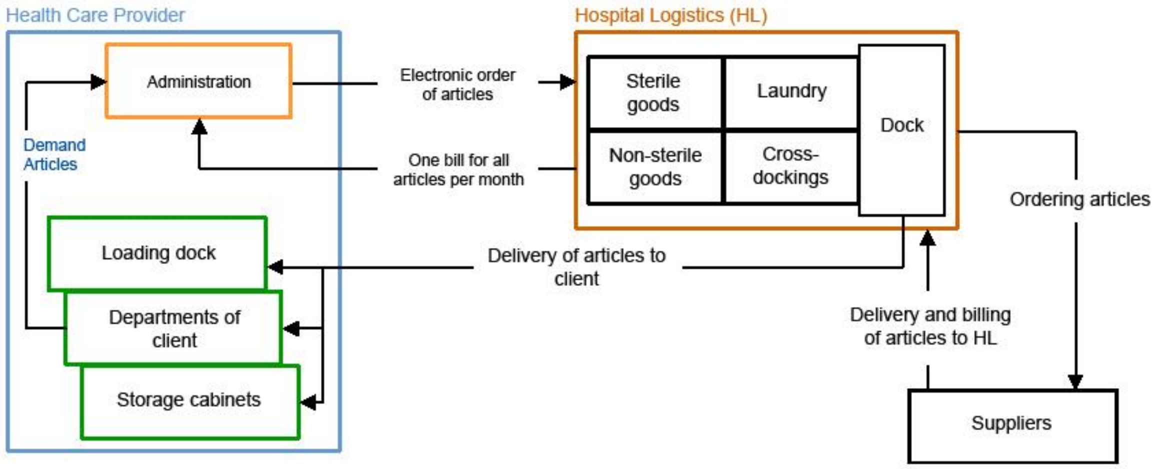

Figure 2.2 Hospital Logistics' framework

2.1.3 Preliminary HL situation for BE/JBZ

When looking at the preliminary HL situation we model the situation similar to section 2.1.1, but with HL as a new party. Both BE and JBZ have not yet transferred to their new locations in respectively Uden (early 2013) and 's-Hertogenbosch (halfway 2011). Here, we model this preliminary situation as well to gain insight into the transition phase. This step being the situation where Bernhoven and Jeroen Bosch each still have two locations (Veghel and Oss, Carolus and GZG respectively), but HL takes care of the inventory management. This transition phase will start for JBZ around October 2010 (till halfway 2011) and for BE around October 2011 (till early 2013).

When looking at the HL setting we see that it is highly probable that the number of truck movements (to each hospital) will be reduced. Each individual location (both for BE and JBZ) makes its individual needs known to HL. HL consequently delivers the products from stock. In this setting HL is supposed to plan [redacted] shipment(s) to each location per day. Apart from delivery, as mentioned above HL owns all of the stock it keeps and consequently makes its own procurement decisions. This results in the majority of truck movements to take place on HL's premises, instead of the hospitals'. In figure 2.3 the preliminary HL setting is modelled. Again, the dashed lines represent the purchasing articles, where the solid ones are the inventory items. As for the 'scan-purchase' articles we note that in the new setting these will become 'inventory items'. Thus the 'scan-purchase' typology is only relevant for the 'old' logistical situation. The 'regular-purchase' articles remain to exist (and are thus modelled as well in figure 2.3 below).

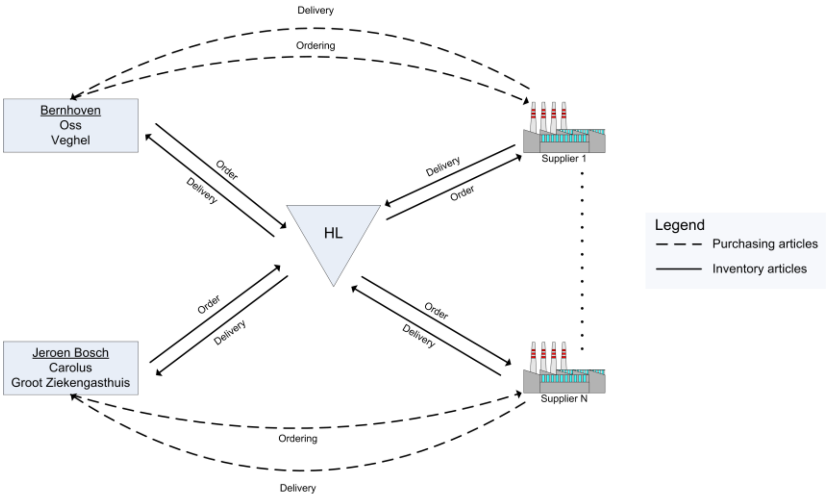

Figure 2.3 Model of the preliminary HL situation

However, since these articles (e.g. food / daily fresh products) will mostly be transported to BE/JBZ directly (thus without HL intervening), only this connection has been modelled. There is also a minor part that will go via HL, which has not been modelled.

More on this will be covered in section 2.4 where the scope of this study is discussed.

2.2 Problem statement

In this section we will come towards a problem definition. First the initial problem (as presented by BE) is discussed in 2.2.1. Second an analysis of this problem will take place (in section 2.2.2 with an elaboration in section 2.2.3). Based on this problem analysis, the problem definition will be formulated in section 2.2.4.

2.2.1 Initial problem

Hospital Logistics will facilitate storage for BE/JBZ's products and will take care of the transportation from its warehouse to the locations of BE and JBZ. However, BE/JBZ has very little insight in what impact certain parameters (on which the contract is based) have on (financial) performance. Apart from that it is not fully clear how (future) costs, but benefits as well, will develop. With benefits one might think of efficiency cost savings, more product overlap in BE and JBZ's assortment and the addition of extra hospitals to the coalition.

2.2.2 Problem analysis

Now the problem (as seen from BE/JBZ perspective) has been stated we will first look at its validity. In this section we will verify whether the issues as sketched above indeed are relevant and complete. It might be that some issues are interconnected or conflicting and impede a thorough study of the actual matters. For this analysis the contractual framework of Hospital Logistics will be used.

As stated above BE/JBZ has very limited insight in what impact certain parameters have on performance. This being both because of contractual difficulties, and because of lack of thorough contractual analysis by BE/JBZ as well. We can model this problem as follows (figure 2.4).

The problem as given appears to be twofold. On one side there is the cost structure as it is present in the supply chain. With this we mean the actual costs as incurred by the third-party logistics provider (i.e HL). These costs are comprised of inventory holding costs, opportunity costs, transportation costs, personnel costs etc. Thus, all costs related to the managing and keeping of inventory.

Figure 2.4 Problem model

On the complete opposite side there is the behavior (of BE/JBZ) one might expect given a certain cost structure. With behavior we mean all kinds of decisions related to procurement and (internal) inventory management. However, in this setting the behavior of BE/JBZ is not directly related to the actual cost structure as present in the supply chain, but it is directly linked to the contractual framework of Hospital Logistics. Namely, given a certain cost structure (of the supply chain) and a certain demand (that of BE/JBZ), HL formed a contract in order to allocate commercial tariffs to BE/JBZ (see figure 2.4). Based on this contract, BE/JBZ shows certain behavior, e.g. in order to optimize its own operations. BE/JBZ decides how much they will buy from HL, when to order etc., knowing HL's tariffs and thus knowing

how to optimize its own financial performance (keeping the parameters of the contract and its corresponding values in mind).
Given the duality of the problem as modeled above, an analysis of both aspects will be provided.

2.2.3 Flex rates and behavioral aspect

Key issue in the two folded problem stated above are the so called flex rates. Flex-rates represent variable tariffs and are a way for BE/JBZ to alter the fixed amount HL charges both hospitals per year for its service. So when more (or less) articles are ordered by BE/JBZ, not only the amount of articles is reduced, but also the effort HL has to put into the cooperation. In order to deal with this increase (or decrease) of HL's effort (and thus costs) the flex rates are shaped. There are flex rates specified separately for Bernhoven and for Jeroen Bosch. More specifically, both hospitals have rates for so-called MORE-work and LESS-work. MORE-work flex rates are meant for allocating higher costs to the individual hospitals because of greater workload, where the opposite holds for the LESS-work rates. The specific values of these rates differ from each other because of certain costs HL has to make despite of the actual workload, i.e. fixed costs. These fixed costs (e.g. investments in plant and equipment) are incurred by HL even if BE/JBZ manages to reduce its number of articles. That is why an increase of [redacted] articles for BE/JBZ means they have to pay [redacted] per year more, where a decrease of [redacted] articles yields a saving of only [redacted] per year.

In appendix E a complete overview of these flex rates is provided. For illustrational purposes we will here consider only one rate, this being the LESS-work rate for Bernhoven (see table 2.1). This LESS-work flex rate is meant to be an incentive for Bernhoven to strive for efficiency improvements. With respect to the definition of an 'order line' in table 2.1 we note that there exists a difference between HL's viewpoint and Bernhoven's:

1. At Bernhoven, an order line is a request from the central warehouse to one of its suppliers for a replenishment order.
2. At HL, an order line is defined as a replenishment request from a hospital's department to the central warehouse (this is what Bernhoven calls 'releases' or in Dutch 'afgiftes').

For clarity reasons we pose to use Bernhoven's typology throughout this study and thus distinguish between order lines and releases.

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Table 2.1 LESS-work flex rate

As can be seen from this figure, the rate is influenced by three parameters. This being:

- # Articles: represents the number of unique articles which Bernhoven's assortment in HL's warehouse comprises.
- # Order lines inventory: represents the number of order lines Bernhoven has per year for so-called inventory-articles (i.e. highly frequent articles).
- # Order lines purchase: represents the number of order lines Bernhoven has per year for so-called purchase-articles (infrequently used articles, low volume). Note on this: it is not yet clear whether or not BE and JBZ will make significant use of HL's offer to also deal with the delivery of these articles.

- External transportation: represents the number of truck movements to Bernhoven's premises. The starting point is (as mentioned) [redacted] to the hospital per day.

Thus, the fixed amount [redacted] Bernhoven pays per year to Hospital Logistics for its *warehousing* service (for the remainder of this section represented by the constant *C*) can be lowered if Bernhoven will be able to leverage on the above stated parameters. Each parameter has a starting point (see table 2.1) on which the amount *C* was based. The threshold value is a value (calculated by multiplying the threshold percentage with the starting point) which functions as a minimum requirement for the LESS-work rate to apply. For example, if Bernhoven manages to reduce its number of unique articles in HL's assortment by [redacted], nothing changes to the amount *C*. If they reduce it by [redacted] articles (and thus exceed the threshold of [redacted]) the amount *C* reduces by [redacted] per year. This because for every reduction of [redacted] articles they save [redacted] per year (only leveraging on the LESS-work flex rate for # Articles, and thus under the assumption that the other parameters remain unchanged). Keeping this order of magnitude in mind we will have a look at possible savings for the BE/JBZ cooperation.

The number of articles BE and JBZ respectively have in HL's assortment is influenced by two aspects:
1. The number of unique articles of each hospital carries in HL's warehouse.
2. The number of articles which is overlapping in the assortments of BE and JBZ.

For these overlapping articles, HL specified that each respective article that is present in both BE's and JBZ's assortment is counted for [redacted]. Thus, if BE and JBZ have a common pool of [redacted] articles in HL's warehouse, both of them pay for [redacted] articles instead of [redacted]. Problem with this is that both BE and JBZ do not have insight in whether or not this is significantly worth putting effort into.

Next to this, there are other flex rates specified (i.e. the number of order lines and transportation). More on this will be covered later on.

2.2.4 Problem definition

Based on the above stated observations we define the problem as:

> *With respect to the new outsourcing situation little insight exists in the cost structure and therefore in the fairness of HL's contract and its allocation mechanisms.*

This problem definition thus primarily addresses the fairness of the contractual framework for BE/JBZ as provided by HL. Fairness being interpreted as the extent to which the tariffs towards BE/JBZ represent HL's actual incurred cost for each contractual topic, taking HL's own margin into account.

2.3 Research questions

In order to be able to provide a solution to the problem definition as mentioned in section 2.2.4 the following research questions are formulated:

What does HL's cost structure look like?

This research question will provide insight in HL's perceived cost structure. Thus, the scope of this question comprises only HL and BE/JBZ. The addition of parties will not be covered here. When insight into the cost structure has been gained, it will be discussed whether or not HL provides BE/JBZ with the right incentives and if these incentives are sufficiently strong to yield significant benefits for BE/JBZ.

Do the current contractual framework and its corresponding parameters give a good representation of HL's actual cost alterations?

In the contract the so-called flex rates are meant to be a way for HL to deal with volume changes caused by BE/JBZ. In this research question the contractual parameters will be checked for validity. When the framework for these parameters is clear, the specific value of them will be investigated. This being, are the amounts presented by HL 'fair'. Stated otherwise: is BE/JBZ sufficiently rewarded for the cost savings (e.g. that HL can facilitate because of inventory pooling) they realize at HL.

Next to the above mentioned flex rates (and their perceived fairness), which are used for coping with changes in work level, there are matters of indistinctness regarding any additional parties joining the coalition. There exists very little insight in whether (and how) HL's cost structure is affected by these additional parties.

What is the impact of additional suitable parties to HL's cost structure and how should this justly be allocated among HL and its customers?

Here the addition of more parties to the BE/JBZ coalition will be discussed. Insight will be provided in whether or not it will be significantly profitable for BE/JBZ to actively look for these extra parties. Next to that, the way HL's current contractual framework ([redacted] per year incentive for the BE/JBZ coalition) deals with this addition will be objectively evaluated by its fairness.

2.4 Project's scope

The project's scope is defined as the range of the research in this study. In this section we make a distinction between the scope seen from a supply chain perspective (see 2.4.1) and the individual company's cost structure perspective (see 2.4.2).

2.4.1 Supply chain perspective

The research will only be concerned with the three parties as indicated by the red square in figure 2.5. This being: Bernhoven Hospital, Jeroen Bosch Hospital and Hospital Logistics. With respect to HL's suppliers we assume there to be no supply chain difficulties, i.e. HL's suppliers are at any time able to supply HL's warehouse. HL's inventory is within scope of this study and will be considered. Furthermore, it will be assumed that HL effectuates rational inventory management. This means HL will keep stock using efficient stock keeping policies.

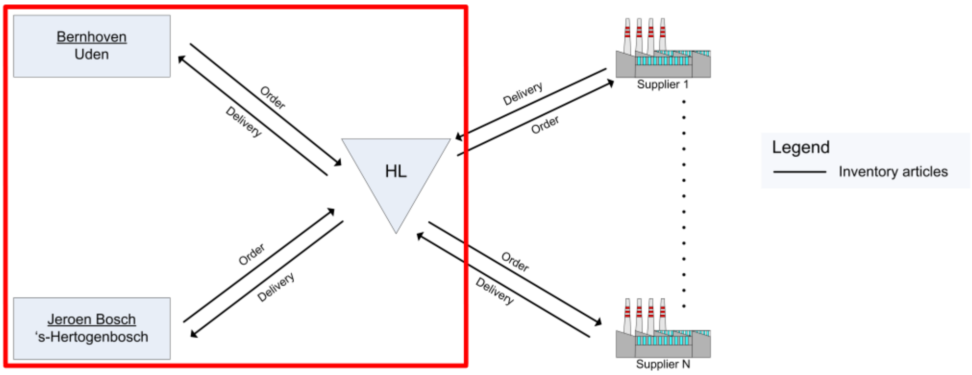

Figure 2.5 Scope of the project

Note further that figure 2.5 (opposed to figure 2.1 and 2.3) does not deal with purchase-articles. As mentioned earlier, there are two types of purchase articles. This being: 'scan-purchase' and 'regular-purchase' articles. These so called 'scan-purchase' articles will be taken under the denominator of inventory articles. The remaining 'regular-purchase' articles are out of scope. Namely, a large part of these are not taken care of by HL, and the delivery frequencies and quantities of the remaining (minor) share are non-significant.

With respect to the number of locations for each party as indicated in figure 2.5 we note that HL only delivers to Uden (BE) and 's-Hertogenbosch (JBZ). This because the contractual framework provided by HL was based on only 2 locations (one for each party).

2.4.2 Cost structure perspective

As already briefly mentioned in the 2.4 introductory, a thorough analysis of the research questions requires a narrower scope than just the high-level limitations as introduced in the previous section 2.4.1.
A company has a specific cost structure that is dependent on its level of business activity. (Note that we describe the details of a cost structure in much more detail in chapters 3 and 4, but because of its importance in this project's scope, it is useful to understand some of the aspects even at this early stage).
Within a company's cost structure, costs can be ascribed to the different cost drivers that comprise the organization. A cost driver being a factor which causes a change in the cost of an activity. These activities (e.g. inventory management, production, transportation) often carry multiple cost drivers. When examining a company's cost structure, one obviously wants to limit oneself to the cost drivers that matter. Whether or not to include a business activity (and its corresponding cost drivers) in an analysis is dependent on:

- Whether or not a business activity makes up a large portion of a particular company's budget. An activity seems not worth examining if only minor gains can be realized.
- Whether or not practice has shown the relevance of examining particular business activities (and its corresponding cost drivers).

- Whether or not a business activity would benefit from possible multi-party collaboration (and thus would facilitate pooling). Given the background of this study it makes sense to highlight activities that might be merged with other companies.

Based on these considerations this thesis will focus on the business activities transportation and inventory management (i.e. warehousing). Furthermore, as is also briefly mentioned in appendix D, literature review (Among others: Cruijssen, 2005; Gerchak and Gupta, 1991) revealed significant cost reductions can be made with respect to these matters. Thus, when considering Bernhoven Hospital one can roughly depict the scope of this project as the red square modeled in figure 2.6 below.

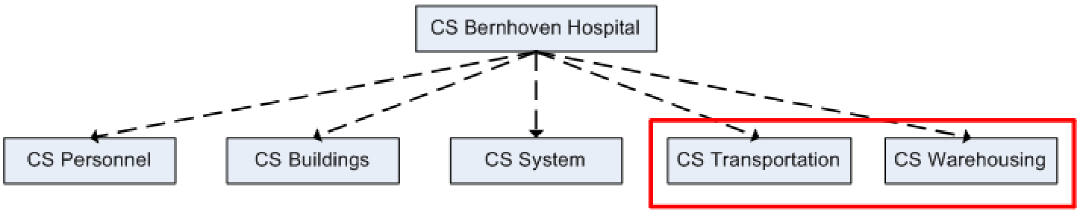

Figure 2.6 Scope cost structure Bernhoven Hospital ('Cost Structure' abbreviated to 'CS')

Note that the figure above is only a high level modeling of Bernhoven's cost structure and intended for introductory use. The distinction between the five different cost structures is not straightforward. These facets indeed are interdependent are correlated.

2.5 Positioning of thesis

For this study's approach we will partly use the so called regulative cycle (Van Strien, 1997) as modeled in figure 2.7. This cycle starts with a so called problem mess. A problem mess (step 1) comprises a pool of obscurities surrounding operational (business) processes. I.e. it is not yet clear where the causes of (operational) inefficiencies can be found. Out of this 'problem mess' a problem is defined (step 2) on which an analysis will be based (step 3). This analysis of the actual problem results in a plan of action (step 4), which is consecutively followed in order to cope with the problem, i.e. an intervention (step 5) takes place. After action has been taken (to solve the problem as indicated in step 2), the outcomes are evaluated (step 6). When these outcomes still bring about obscurities the whole cycle repeats itself till the business processes function properly.

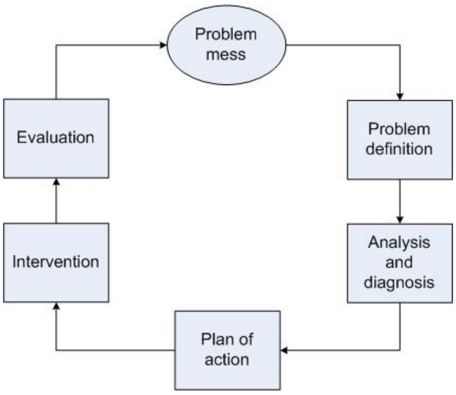

Figure 2.7 The regulative cycle (Van Strien, 1997)

More specifically, when using this cycle in the context of BE/JBZ, obscurities (which are part of the problem mess) about the contractual framework and its corresponding incentives resulted in a problem definition (see section 2.2.4). In defining this problem it was taken into account that it would be large enough that its solution contributes significantly to the performance of BE/JBZ, and small enough to be solved within the prevailing constraints in time and effort.
In the ‘analysis and diagnosis’ step, the cost structure of BE/JBZ and HL will be thoroughly investigated. These insights will result in the plan of action. Here a range of recommendations to be used by BE/JBZ in its contract negotiations with HL will function as the projects deliverables. The study will thus be positioned in the areas ‘analysis and diagnosis’ and ‘plan of action’. Any implementation will not take place.

2.6 Research methodology and report outline

Now the introduction and research design have been discussed, we will come to a thorough problem analysis. After a conceptual approach is introduced, the scientific modeling will be elaborated upon. Using this scientific model, the contractual framework for BE/JBZ as provided by HL will be assessed. This for BE, JBZ and BE/JBZ together. Using the results from these analyses, benchmarking of HL’s contract against the actual cost structure as present in the supply chain will take place, hereby keeping the scope in mind. Also, the possible benefits that may emerge when more parties join the BE/JBZ cooperation are discussed. Based on the outcomes of these analyses, recommendations will be made. In figure 2.8 a graphical representation on the interdependence between this study’s chapters is given.

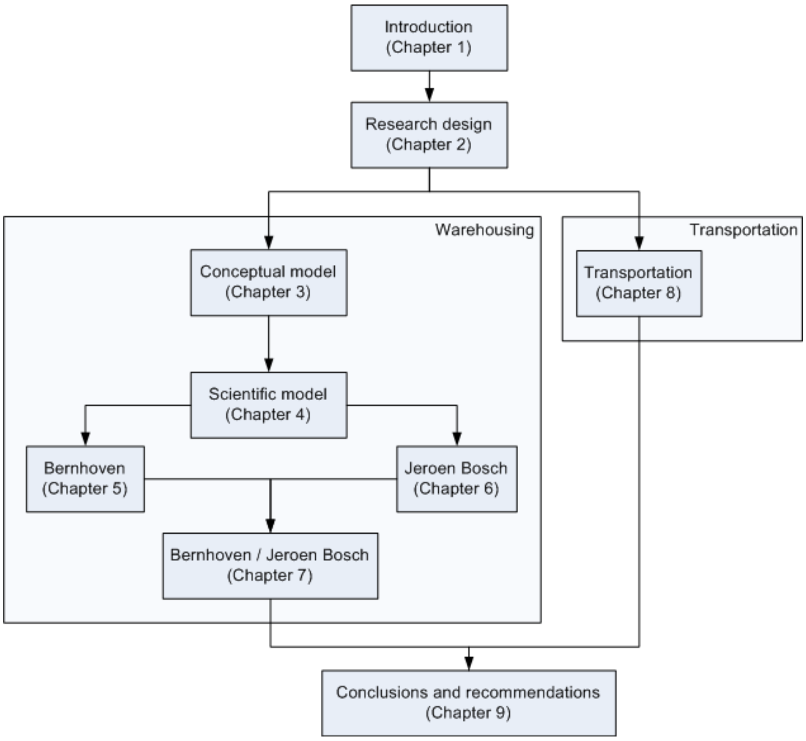

Figure 2.8 Report outline

Chapter 3: Conceptual model for warehousing

As discussed in the previous chapter, the focus of this study is primarily aimed at assessing any possible pooling advantages with respect to warehousing. In this chapter we conceptually address how this model should be shaped. In section 3.1 a general introduction is given, where section 3.2 addresses what the specific goal of the model should be. Furthermore, the model is decomposed in this section. Based on this decomposition, respectively the input parameters (section 3.3), decision variables (section 3.4), constraints (section 3.5) and outputs (section 3.6) are discussed.

3.1 Introduction to costing

3.1.1 Fixed and variable costs

Depending on a company's level of business activity, costs will react. As the activity level rises or falls, a particular cost may rise or fall as well, or it may remain constant. For planning purposes a manager must be able to anticipate which of these costs will change, and if so to what extent. To help make such distinctions, typically costs are categorized as variable or fixed (Garrison et al, 2003).
A variable cost is a cost that varies in direct proportion to changes in the level of activity (e.g. beds occupied, hours worked etc.). On the other hand, a fixed cost is a cost that remains constant, in total, regardless of changes in the level of activity. Note on this is that very few costs are completely fixed. Most will change if there is a large enough change in activity. Thus, when we say a cost is fixed, we mean it is fixed within a particular relevant range.
According to Garrison et al (2003) a company's cost structure is defined as the relative proportion of fixed, variable and mixed (i.e. semivariable) costs found in this particular organization.

3.1.2 Cost drivers

However, when talking about a cost structure in this study we extent the above introduced preliminary definition with the addition of the 'cost-drivers'-concept. As briefly mentioned in section 2.4.2 costs can be ascribed to the different cost drivers that are present in an organization. A cost driver being a factor which causes a change in the cost of an activity.

3.2 Model characteristics

In this section we will subsequently describe the goal of the model (section 3.2.1), what type of modeling strategy is chosen (section 3.2.2), how the model is decomposed (section 3.2.3), where finally we formulate a black box model (section 3.2.4), and elaborate on its interdependence with the remainder of this chapter.

3.2.1 Goal of the model

As can be read in chapter 2, the objective of this study is to asses, and evaluate different settings (and their corresponding cost structures). With 'settings' we mean for instance:

- The setting where BE is operating a warehouse individually.
- The setting where JBZ is operating a warehouse individually.
- A multi party setting where a warehouse is being shared by BE/JBZ.

For the sake of effective and transparent evaluation we introduce a total cost model for approximating warehousing costs in a specific time period, here: one year. The main functions any cost model should perform are (Kaplan and Cooper, 1998):

1. Valuation of inventory and measurement of the cost of goods and services sold for financial purposes.
2. Estimation of the costs of activities, products, services and customers.
3. Provide economic feedback to managers and staff in general about process efficiency.

Here, a cost model might thus be considered as a tool that a company can use in order to gain a proper understanding about the costs of running its warehouse, which is in line with our objective as mentioned above. Based on the data analyzed by the model the company obtains useful information for making decisions. Furthermore, based on this model, (which will be fed with each setting's specific input) the settings can be compared. For this comparison to be useful we need to minimize each setting's expected total costs (of warehousing) per year. Thus, we pose the objective of the total cost model to be:

Minimize the expected total warehousing costs per year.

When this objective is consecutively followed for each different setting, effective evaluation can take place. However, the model itself has still to be shaped. This will first be done conceptually in this chapter, where chapter 4 will elaborate on the scientific modeling.

3.2.2 Type of modeling strategy

Silver et al (1998) pose three possible modeling strategies:

- Detailed modeling and analytic selection of the values of a limited number of decision variables.
- Broader scope modeling, with less attempt at optimization.
- Minimization of inventories with very little in the way of associated mathematical models.

Detailed modeling is concerned with the development of a mathematical model that permits the selection of the values of a limited set of variables so that some reasonable measure of effectiveness can be optimized (Silver et al, 1998). Broader scope modeling (as mentioned) is not very well suited for optimization. Namely, with broader scope modeling the added realism in the model often prevents this. There may not even be a mathematically stated objective function (Silver et al, 1998). The third type of modeling is mostly about particular inventory philosophies like Just-In-Time and Optimized Production Technology.

The detailed modeling approach appears preferable for this study's purposes. This because the goal of this study is to evaluate different warehousing settings (and thus to asses their mutual differences).

3.2.3 Model decomposition

Now that the type of model and its corresponding modeling strategy are known, we elaborate on the model decomposition. We chose to minimize total yearly expected warehousing costs, based on minimization of expected yearly costs at *product level*. We focus on the product level because:

1. An allocation of costs to the product level facilitates comparison with HL's flex rates.

When products become overlapping this thus brings about new product assortments, modified order quantities, etc. When the corresponding costs are quantified and allocated to the individual products, we can effectively benchmark our findings with HL's flex rates (for more- or less products).
2. In line with the modeling strategy followed (section 3.2.2) we need to obtain a model suitable for optimization. Ascribing costs (only) to the product level positively influences the solvability of the optimization problem.

For each product under scope (more on scoping in chapter 5) the same procedure is followed. The remainder of this chapter covers this procedure for *one* of these products.

3.2.4 Black box model formulation

When elaborating on the previous three sections, we here introduce a so called black box model formulation (based on Limam, 2002). The black box (see figure 3.1) is the model that will be mathematically elaborated upon in chapter 4. Using its input parameters, this model 'decides' on its decision variables, taking its constraints into account. The result of this process yields the output of the model.

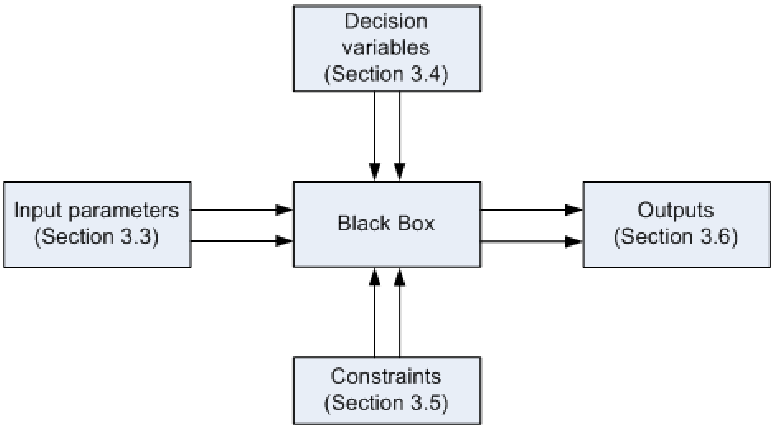

Figure 3.1 Black box model

When this deciding takes place, the model's objective is to minimize expected total warehousing costs per year. In the figure above, the interdependencies between the model and its influences are sketched. Furthermore, for each influence the corresponding section (where it is conceptually introduced) in this chapter is indicated. The details about the inputs, decision variables, constraints and outputs can be found in the scientific model (chapter 4). Now we conceptually introduce the model's input parameters in the following section.

3.3 Input parameters

Through empirical studies and deductive mathematical modeling, a number of factors have been identified that are important for warehousing (Silver et al, 1998). This study's relevant input parameters (recall: per product) can be grouped into:

- Cost factors.
- Demand patterns.
- Supply characteristics.

3.3.1 Cost factors

Managing warehousing costs is critical to the profitability of many firms (Roth and Sims, 1991). Depending on the type of firm (and thus warehouse), different costs are encountered. Using Roth and Sims (1991) we identified the costs that are relevant for this study:

- Ordering costs. Receiving merchandise involves unloading incoming shipments and checking them to verify the items and quantities noted on the bill. The costs for this activity often include the expense of warehouse- and office labor.
- Opportunity costs. Next to this cost driver, we take into account the cost of capital by introducing a measure to cope with opportunity costs.
- Space costs. The rent charged for the storage activity is based on costs incurred for the warehouse. These are typically allocated to products using a volume measure.

Note that the actual methods for calculating / estimating these cost factors are dealt with in the scientific model (chapter 4).

3.3.2 Demand patterns

There are basically two types of demand one can face: deterministic demand and stochastic demand. Deterministic demand implies that there is relatively no or little uncertainty concerning the level of demand throughout time. We speak of so called stochastic demand when uncertainty into the level of demand is introduced. For the stochastic description of a demand process, many probability density functions (PDF's) are available. When this description of the demand process is considered steady throughout time, we speak of so called stationary demand. We assume this to be the case and therefore pose the following assumption:

Assumption 3.1: The faced demand is stationary.

In the setting of a (s,Q) replenishment control system (see appendix F for a brief introduction and section 3.4.3 for an elaboration to this concept) and a service level as criterion, the numerical differences between respectively the Gaussian (i.e. Normal), Logistic, Gamma, Log-normal and Weibull distributions are negligible (Fortuin, 1980). Following these findings, the Normal distribution is chosen because this PDF is known to be extensively covered throughout literature.

However, in the context of the demand process at a health care provider some difficulties appear to emerge at first glance. Consider the example of Bernhoven Hospital (see appendix G for an elaboration on the demand process). Because of multiple stock points at Bernhoven, demand batching takes place. With this we mean: (continuous) patient demand is batched at the departments, and at the central warehouse. Since these departments' demand acts as input of this chapter's model, obviously we obtain intermittent demand. This thus means, departments do not order on a daily basis, which implies a daily demand distribution truncated at zero.

Furthermore, Burgin (1975) mentions as a disadvantage of the Normal distribution that it also exists for negative values of demand. However, we do chose to work with the Normal distribution because:

1. Our own field research reveals ordering at a Bernhoven's central warehouse takes place once or twice a week (at the most). This thus implies that the departments' (recall, which acts as the input for our model) demand over these multiple days is highly unlikely to remain zero.
2. Naddor (1978) suggests that the form of the probability distribution is far less important than its mean value and the standard deviation of the demand process, which are both relatively easy to derive.

Thus, we introduce the assumption:

Assumption 3.2: *Daily demand has a Normal distribution with known mean and standard deviation.*

3.3.3 Supply characteristics

The replenishment lead time is the time that elapses from the moment at which it is decided to place an order, until it is physically on the shelf and ready to satisfy customer demand (Silver et al, 1998). This lead time is indicated using the letter L and is usually comprised of:

- Order preparation time at the central warehouse.
- Order transit time from the warehouse to the supplier.
- Time at the supplier.
- Transit time back to the stock point.
- Time until the order receipt is processed and ready for use.

As can be seen many factors influence the lead time. This thus means that this L is usually subject to some uncertainty. Because one does not know how much time (usually expressed in days) will be between ordering and order receipt, demand over lead time will vary as well. Since demand over the lead time is essential when determining a reorder level (see section 3.4 for an elaboration) this might give some challenges. Because our own field research revealed lead times to be relatively constant, the benefits of coping with varying lead time demand are considered minimal. Therefore we assume fixed and constant lead times for each consecutive replenishment cycle. More on L can be found in the scientific model (chapter 4).

Assumption 3.3: *Replenishment lead times are fixed.*

3.4 Decision variables

In this section we derive the decision variables of the model. These variables follow from the choice we make regarding our replenishment control system (Silver et al, 1998). The framework as presented in this section is considered to be discrete with 1 period being equal to 1 day.

3.4.1 Introduction to inventory policies

An inventory policy is a way to make replenishment decisions. The main purpose of such an inventory policy is to resolve the following problems (Silver et al, 1998):

1. How often the inventory status should be determined.
2. When a replenishment order should be placed.
3. How large the replenishment order should be.

In the situation of stochastic demand the first issue is mostly dealt with using the aid of computers. This because monitoring your inventory status when demand is constantly varying is extremely labor intensive. Furthermore, the frequency with which you want to determine your inventory status is often related to how often a replenishment order can be placed. If an order can be placed only once a week, it would not make much sense to check your inventory status on a daily basis.

The second problem refers to the trade-off between ordering too early (and thereby being forced to stock your goods for a longer time period) and ordering too late, and hereby running out of stock (which could result in the loss of customer satisfaction).

The third (and final) problem deals with trying to find a balance between unit holding costs and fixed order costs. Replenishing with large orders yields less frequent ordering, but higher total holding costs (since stock has to be kept for a longer time period before it is sold). On the contrary, replenishing with small orders minimizes a company's total holding costs, but means more separate orders have to be placed in order to keep up with customer demand.

When resolving the above stated problems there are two critical things that have to be considered (Silver et al, 1998):

1. Can, or should, the stock status be reviewed continuously or periodically? (see section 3.4.2)
2. What form should the inventory policy take? (see section 3.4.3)

3.4.2 Reviewing the stock status

First we decide on the review period of the replenishment control system. A review interval (*R*) is the time that elapses between two consecutive moments at which we know the stock level (Silver et al, 1998). When considering a continuous review policy, the stock status is always known (mostly thanks to computerized inventory systems) and therefore *R*=0. A periodical system only determines the stock status every *R* days. Since we observed in practice that the health care providers under study determine inventory status of their products at specific time intervals, we pose:

Assumption 3.4: *The inventory status is reviewed periodically with a review interval of R days.*

3.4.3 Deciding on an inventory policy

With respect to the inventory policies we state that there basically are two types of ordering mechanisms, namely an 'Order-Point, Order-Quantity' or an 'Order-Point, Order-Up-To-Level' System. The more general terms for both concepts are respectively an (s,Q) and (s,S) system (see appendix F for the basics of these two systems). When the periodic reviewing parameter *R* is added we get (R,s,Q) and (R,s,S) systems.

The main advantage of the (R,s,Q) policy is that it is quite simple to implement, therefore errors are less likely to occur. The biggest disadvantage is that a proper (R,s,Q) policy may have trouble with large orders. If an order is larger than the *Q*, it might not be enough to raise the inventory position above *s*. A possible workaround with this is using a so called (R,s,nQ) policy, which allows multiples of *Q* to be ordered throughout time. Since we have not encountered this in the context of health care, and it poses not to be significantly better performing than a regular (R,s,Q) we do not look into this policy.

For the (R,s,S) policy, is has been shown that often the best (R,s,S) system produces a lower total of replenishment, carrying and shortage costs than any other system. However, this policy has some serious drawbacks (based on Silver et al, 1998):

- The computational effort to obtain the best values of the three control parameters is more intense than for any other system.
- Second, the variable order quantity as used in this system often means that suppliers are more likely to make errors.
- Last, variable order sizing often is not preferred in the first place, since suppliers rather work with fixed order quantities so they themselves can better predict customer demand.

Concluding, the (R,s,Q) policy is chosen because of its quite simple implementation, the fact that we pose to have many products in analysis (which would yield extremely high computational effort in the case of a (R,s,S) policy), and because of the fact that variable order sizes are typically not encountered or preferred by suppliers in the health care industry. This thus leads to the following two assumptions:

Assumption 3.5: *Order sizes are fixed and predetermined.*

Consequently,

Assumption 3.6: *The model is based on (R,s,Q) replenishment control.*

3.4.4 Overview of decision variables

The choice for the (R,s,Q) policy implies that the three decision variables of the model for each corresponding product *i* under analysis become:

1. The review interval R_i.
2. The reorder level s_i.
3. The order quantity Q_i.

Where each R_i is considered equal for each respective product under scope. Note that, the (R_i,s_i,Q_i) replenishment control system is extensively covered in chapter 4.

3.5 Constraints

Now the model's objective is stated (section 3.2.1) we first introduce a constraint it has to consider when deciding on its decision variables.

When demand is stationary (see assumption 3.1), there is a possibility of not being able to satisfy some of the demand directly out of stock. If demand is unusually large, a stock out may occur. On the other hand, if demand is lower than expected, a replenishment order may arrive earlier than needed and too much inventory is carried (which would result in unnecessary inventory carrying costs). To cope with these risks different methods of setting so called safety stocks (*SS*) may be considered.

There are basically two methods for setting safety stocks: based on shortage costs, or based on a predetermined service measure. In this study we chose to set safety stocks based on customer service. We do this because shortage costs are usually difficult to assign (De Kok et al, 1984). Furthermore, practice shows that service measures are more commonly used in a health care setting.
The two most frequently used service measures are the so called P_1 and P_2 measures (Silver et al, 1998):
P_1: Indicates the probability of no stock out in a replenishment cycle (i.e. cycle service level).
P_2: Indicates the fraction of demand satisfied directly from shelf (i.e. fill rate).

We chose to use the P_2 service measure, mainly because the P_1 measure has some negative implications which are not encountered at P_2. Consider the following examples:

- With using P_1: Consider the two parties, BE and JBZ, each working with product *i* and both using service measure P_1=90%. At BE product *i* is (directly by its supplier) replenished 50 times per year, where at JBZ it is 40 times per year. For BE we would expect (50*0.10) 5 stock outs per year, where JBZ would have 4. If BE and JBZ would go and work together, maintaining the same service measure P_1 of 90% could yield very bad results for JBZ, compared to the old situation of working alone. Namely, when BE and JBZ would be replenished for instance 50 times per year (what can be considered the minimum amount of replenishments in this new setting), JBZ will experience 5 stock outs per year. This is obviously worse than the old situation of 4. Thus since the number of replenishments increases for JBZ, the performance (in P_1) becomes worse. Thus when considering the total amount of stock outs per year, P_1 does not yield beneficial results.
- With using P_2: Consider the example above, but now with service measure P_2=90%. Both at BE and JBZ 90% of demand is satisfied directly from shelf. When working together and maintaining a measure P_2 of 90% for BE/JBZ together (and separately), nothing changes on each individual party's performance.

This example shows that the practical relevance of the P_1 measure in this study's context is relatively low, i.e. this service measure alone does not say much about actual performance (you need data on replenishments as well). We thus prefer to use P_2, where this ambiguity is not present.

So we pose to minimize the total expected warehousing costs (for each item under scope, more on this in chapter 4) subject to the constraint that there is a P_2% chance demand is satisfied directly from shelf (the mathematical derivation of the safety stock is addressed at the scientific model).

For the demand that cannot be met directly we note that in inventory control there are two possible ways of dealing with customer demand when an item is temporarily out of stock:

- Complete backordering.
- Complete lost sales.

We chose for complete backordering any unsatisfied demand because in this study's health care context it is not realistic to assume that demand (when out of stock) is lost. A hospital's departments cannot go elsewhere (other than the central warehouse) to satisfy their needs (see appendix G for an elaboration of the demand process at Bernhoven Hospital). We pose:

Assumption 3.7: *Demand that is not satisfied directly from shelf is backordered and filled as soon as an adequate-sized replenishment arrives.*

Because safety stock is defined as the average net stock (which equals the physical stock - backorders) just before a replenishment order arrives, its numerical value is influenced by our choice for backordering. More on this in chapter 4.

3.6 Outputs

As conceptually introduced in this chapter, the model will optimize the warehousing costs, whilst deciding on the decision variables (per product *i* under scope). The model's output can therefore be subdivided into both an aggregate and product level (where the aggregate is a summation of the different product solutions).

The output for each product *i* will be:

1. The total expected warehousing costs of product *i* per year. Broken down into:
   - Ordering costs.
   - Opportunity costs.
   - Space costs.
2. An optimal reorder level s_i.
3. An optimal reorder quantity Q_i.

The conceptual approach as presented in this chapter will be elaborated from a mathematical perspective in the following chapter.

Chapter 4: Scientific model for warehousing

Where chapter 3 introduces this study's warehousing model conceptually, this chapter elaborates on the scientific modeling. Furthermore, as indicated in the conceptual model, we calculate the expected annual warehousing costs by aggregating over multiple products. This chapter introduces a cost function for *one* product. Note that this chapter only deals with the mathematical modeling *methodology*, the actual *estimation* of parameter values and the use of *data* is covered in the subsequent chapters. The same holds for determining the specific amount of products under scope. Sections 4.1 and 4.2 will acts as introductory to this chapter. Sections 4.3 and 4.4 will elaborate in greater detail on the preliminary cost function as introduced in 4.1. Thereafter, the specific method for deriving input parameters (section 4.5) and optimization algorithm (section 4.6) are discussed. Finally, the model's outputs are stated in section 4.7.

4.1 Preliminary cost function

Typically, in a warehousing situation with (R,s,Q) replenishment control and a service measure method for setting safety stocks, total annual warehousing costs are comprised of (Silver et al, 1998):

- Ordering costs.
- Carrying costs.

Ordering costs are usually straightforward to calculate. This is typically done by multiplying the expected number of orders (per year) with a fixed cost per replenishment order. Different to this, but following a comparable approach, we pose to ascribe costs to the expected number of order *lines* per year (more on this is covered later on in this chapter). With the carrying costs some difficulties appear to emerge.

Note that in the above mentioned framework of Silver et al (1998) the opportunity costs and the space costs (as introduced in section 3.3.1) are taken under one denominator called 'carrying costs'. These carrying costs are typically calculated by multiplying a carrying charge with the average inventory level. For the opportunity costs this method seems straightforward (since opportunity costs are only incurred over the products that are actually paid for). For the space costs however, this has two negative implications in this study's setting:

1. With this specific approach, space costs for storing a unit are dependent on its monetary value, which is not in line with Roth and Sims (1991) as indicated in section 3.3.1., since they advise to use a volume measure.
2. The space costs are proportionally ascribed to the *average* inventory level.

We will address the first issue in section 4.5 where we elaborate on the method for deriving the input parameters.

With respect to the second issue we state that it seems counterintuitive to ascribe space costs to the *average* inventory level, since it implies shelf space for the particular product is completely variable / flexible. With this, it might be the case that space can be used on other products if needed. This kind of space allocation is highly advanced and not encountered during our field research.

We typically have to cope with the following inventory levels:
1. The inventory level just before the arrival of a replenishment order.
2. The inventory level just after the arrival of a replenishment order.

When using the average inventory, it is thus assumed that the product's shelf size is allowed to vary between the above mentioned levels 1 and 2. Because our field research showed this not to be realistic, we pose a different approach which will be elaborated in section 4.3.3.

Given the above mentioned issues, we thus obtain a cost function that is comprised of:
1. Order costs.
2. Opportunity costs, which are based on the average inventory.
3. Space costs, which are *not* based on the average inventory, but are calculated in a different manner (which will be elaborated in section 4.3.3).

Given the model's decisions variables (see section 3.4.4) we can thus model a preliminary cost function as:

$$TC(Q_i^*, s_i) = (A_i * O_i) + (ho_i * \bar{I}_i) + (hs_i * SP_i) \tag{4.1}$$

Additional notation:

$TC(Q_i^*,s_i)$	=	the expected total annual warehousing costs of product *i*, with an optimal order quantity Q_i^* and a reorder level s_i (€/year).
A_i	=	fixed costs per replenishment order of product *i* (€/order).
O_i	=	amount of orders per year for product *i* (orders/year).
ho_i	=	opportunity costs of product *i* (€/unit/year).
$\bar{I}_i$	=	average inventory of product *i* (units).
hs_i	=	space costs of product *i* (€/unit/year).
SP_i	=	required shelf space for product *i* (units).

In the following sections we will subsequently introduce methods for determining the ordering-, opportunity- and space costs. Consecutively, formula (4.1) will be gradually filled out and shaped for this study's purposes.

4.2 Mathematical introduction to the (R,s,Q) policy

Now we have stated the total cost model for approximating the warehousing costs, we introduce a mathematical approach to the chosen inventory policy.

4.2.1 Overview of sequence of events

When considering a general (R,s,Q) policy it is important to establish some preliminary ground rules for dealing with events. In the figure 4.1 we modeled an example where *R*=1 day and *L*=2 days.

Using this example, the sequence of events in this study is covered.

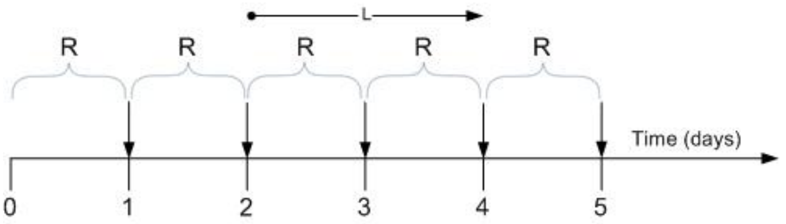

Figure 4.1 Sequence of events

We specify the sequence of events in figure 4.1 as follows. At the end of every day (since *R*=1) the inventory position (*Y*) is checked. If *Y* is less than the reorder level *s* a replenishment order of size *Q* is placed. In figure 4.1 we see that at the end of day 2 an order is placed. Since (in this example) we have a lead time of 2 (full) days, the order is in transit during days 3 and 4. This thus means *Y* is not increased with *Q* until the beginning of day 5.
In general we state that the sequence of events in an arbitrary period *t* is:

1. At the start of *t*: An order placed at the end of period *t*-(*L*+1) arrives at the central warehouse. Note that this implies that no demand occurs during the end of period *t* and the beginning of period *t*+1, i.e. the time that elapses between the end of period *t* and the beginning of *t*+1 is negligibly small.
2. During period *t*: the central warehouse faces customer demand.
3. At the end of period *t*: a replenishment order is placed if $Y(t)<s$.

4.2.2 Mathematical introduction

Below, a graphical representation of a general (R,s,Q) policy is given (based on De Kok, 2005). In this section we will introduce this policy and its key characteristics:

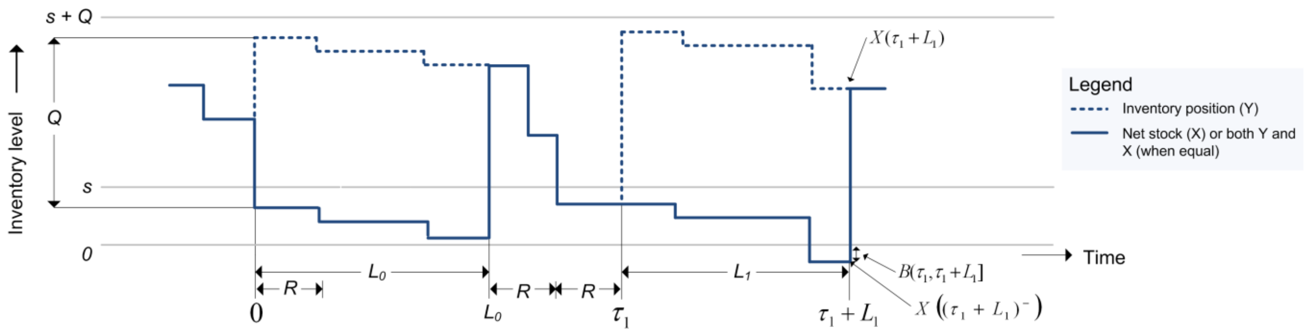

Figure 4.2 (R,s,Q) replenishment control

Additional notation:

X(t)	=	net stock at time t (units).
$X(t^-)$	=	net stock just before time t (units).
Y(t)	=	inventory position at time t (units).
$D(t_1,t_2]$	=	demand during the interval $(t_1,t_2]$, with $(t_1,t_2]=\{x \mid t_1 < x \le t_2\}$ (units).
$B(t_1,t_2]$	=	demand which cannot be met from shelf (i.e. is backordered) during the interval $(t_1,t_2]$, with $(t_1,t_2]=\{x \mid t_1 < x \le t_2\}$ (units).

τ_i	= i^{th} replenishment order moment after t=0 (i=1,2,3…).
τ_0	= 0, time at which the first replenishment order is placed.

Common corresponding assumptions:

1. As assumption 3.2 yields, $D(t_1,t_2]$ has a normal distribution with expectation $(t_2-t_1)\mu$ and variance $(t_2-t_1)\sigma^2$. Furthermore we face demand for 7 days a week and daily demand is considered to be independent and identically distributed throughout all days.
2. Delivery times are constant and set to *L*.
3. The reorder quantity is constant and equals *Q*, which is predetermined.
4. All demand which cannot be met from stock immediately is backordered.

General description:
We see in figure 4.2 (which provides a continuous description of the policy for gaining preliminary insights, and represents the case where the review interval is shorter than the replenishment lead time) that the (R,s,Q) system triggers a replenishment order of size *Q* when $Y(t)\leq s$. Note that the (R,s,Q) system uses the inventory position *Y* to trigger a replenishment order because if one would use the net-stock, and thus does not take the outstanding orders into account, it is theoretically possible that we order today, even though a replenishment order is due to arrive tomorrow. However, *Y(t)* is only checked every *R* days. We see that after the first replenishment order $Y(\tau_0+L)=X(\tau_0+L)>s$. We further see that $Y((\tau_0+L+R)^-)>s$ while $Y((\tau_0+L+R))<s$. Since the replenishment decision is made at the end of this reviewing period, we still face full demand for *R* days. Next to that, we cope with $\mathrm{D}(\tau_1,\tau_1+\mathrm{L}]$.
Thus typically, *s* has to be sufficient for fulfilling $\mathrm{D}(t,t+\mathrm{R}+\mathrm{L}]$ (Van der Vlist, 2007). Since we face stochastic demand, we have to cope with this uncertainty by setting *s* high enough, obviously not too high because this would result in unnecessary carrying of stock.

4.2.3 P_2 service measure

For any replenishment logic holds:

$$P_2=1-\frac{E\left(B(L_0,\tau_1+L_1]\right)}{D\left(D(L_0,\tau_1+L_1]\right)} \text{ (De Kok, 2005).} \quad (4.2)$$

See figure 4.2 for the graphical-, and section 3.5 for the conceptual support on this function. In this study we assume a fixed and constant value for P_2, for each individual product. We set P_2 to 98%. This is a generally accepted figure in warehousing. Recall that it thus means that there is a 98% chance that a department’s demand can be met immediately from shelf. Given this study’s health care setting (and thus the criticality of some of the products), one might expect a higher service level. However, 98% is acceptable because:

1. As mentioned in appendix G, Bernhoven’s departments use a two bin system. This thus implies that the probability that hospital staff runs out of products is far less than 2%.
2. Furthermore, it does not make much sense to set the service level much higher, since this would yield a tremendous increase in warehousing costs.

3. Finally, the contractual framework as proposed by HL also uses a fill rate of 98%. Setting our warehouse's service measure equal to this amount facilitates comparison issues.

4.3 Decomposition of cost function

In this section we will subsequently address the mathematical derivation of the order-, opportunity- and space costs. The first two costs are relatively straightforward to derive. For space costs however some difficulties appear to emerge (as mentioned in section 4.1).

4.3.1 Ordering costs

As mentioned before, the formula for determining ordering costs is relatively straightforward. Namely: the ordering costs are calculated by multiplying the fixed costs per replenishment order (€/order) of product i $\left(A_i\right)$ with the expected number of replenishment orders per year equal to:

$$\left[\frac{365 \cdot \mu_i}{Q_i^*}\right] \text{ (Silver et al, 1998).} \qquad (4.3)$$

Additional notation:

μ_i = mean daily demand for product i (units).

How the value of $\left(A_i\right)$ may be obtained, is discussed in section 4.5.1. Thus the annual ordering costs for product i become: $A_i\left[\frac{365 \cdot \mu_i}{Q_i^*}\right]$ (€/year). (4.4)

4.3.2 Opportunity costs

The opportunity costs (or cost of capital) are the costs of the money that is tied up in inventory. With this money, an alternative investment could have been made, which could yield monetary benefits.

To take this cost of best alternative use into account we derived an amount per unit (€/unit), given by: ho_i. The method for deriving this value is discussed in section 4.5.2.

With the opportunity costs of one unit, we determine the total amount of capital tied up in inventory. The amount of capital tied up in inventory has a positive correlation with the average inventory level. This because only over the products that are paid for, opportunity costs are incurred. Namely, no alternative investments can be made with the capital invested in these products. As mentioned, we typically deal with two inventory levels:

1. The inventory level just before the arrival of a replenishment order.
2. The inventory level just after the arrival of a replenishment order.

Note that in the first case we store: $(s_i - \mu_{L_i+R_i})$ (4.5)

Where in the second we have to store: $(s_i - \mu_{L_i+R_i}) + Q_i^*$ (4.6)

This thus yields an average inventory of $(s_i - \mu_{L_i+R_i}) + \frac{Q_i^*}{2}$ (Silver et al, 1998) (4.7)

Additional notation:

$\mu_{L_i+R_i}$ = mean demand during $L_i + R_i$ (units).

Thus the annual opportunity costs, which are taken over the average inventory level of product *i* become:

$$ho_i\left[(s_i - \mu_{L_i+R_i}) + \frac{Q_i^*}{2}\right] \text{ (€/year).} \tag{4.8}$$

4.3.3 Space costs

As indicated in section 4.1 we decide to derive the space costs in a different manner. First, we look at two common methods and their corresponding drawbacks:

1. Space costs ascribed to the average inventory $(s_i - \mu_{L_i+R_i}) + \frac{Q_i^*}{2}$. (Silver et al, 1998)

   When using this approach (as mentioned in section 4.1), space costs are ascribed to the average inventory, and thus flexible shelf sizes are assumed, (which is not realistic in this study's setting).
2. Space costs ascribed to the level $(SS_i + Q_i^*)$. (Benjumea, 2010)

Additional notation:

SS_i = Safety stock of product *i*.

Now, consider the example where products are maintained on separate shelves, and a specific shelf size is allocated to each item. The determination of this shelf size is straightforward when no demand uncertainty is incurred, since you know exactly how large the demand will be. In the case of a standard (s_i, Q_i^*) policy, with no lead time (and thus a reorder level s_i of 0) and a demand rate that is both constant and deterministic, you obviously want a shelf size large enough to store Q_i^*.

When both stochasticity and a leadtime / review period are introduced, it becomes less straightforward. One might suggest a shelf size of $(s_i + Q_i^*)$. However, this implies that $\mu_{L_i+R_i}$ would be zero, which is highly unlikely in this study's setting. So if this method is followed, too much space is allocated to a product, which would thus result in an overstatement of the warehousing costs. The method posed by Benjumea (2010) where the shelf space is set equal to $(SS_i + Q_i^*)$ where $SS_i = s_i - \mu_{L_i+R_i}$ results in a shelf space that is adequate in 50% of the cases, as will be shown below.

We introduce a method to determine a shelf size which will be large enough to store our replenishment order in 95% of the cases. We chose 95% because we find a 5% chance of not being able to store a replenishment order acceptable. In the cases that this might occur, the goods may be stored in alternative locations. Practice shows there is always some room available in front of the shelf (in the hallway) or at goods receipt. This may seem odd at first glance. Namely, (occasionally) storing some goods in for instance the hall way reduces the effective size of working aisles. This might negatively influence labor productivity. However with this a simple consideration between the extra labor- and space costs has to be made. If one would want to make sure nothing is stored in the aisles at any moment in time, one has to allocate a shelf space of $(s_i + Q_i^*)$, but face an increase in necessary warehousing space as well.

Recall from assumption 3.2 that this warehousing model assumes Normal distributed demand. In the figure 4.3 below we see the Normal distribution and the probabilities associated with it.

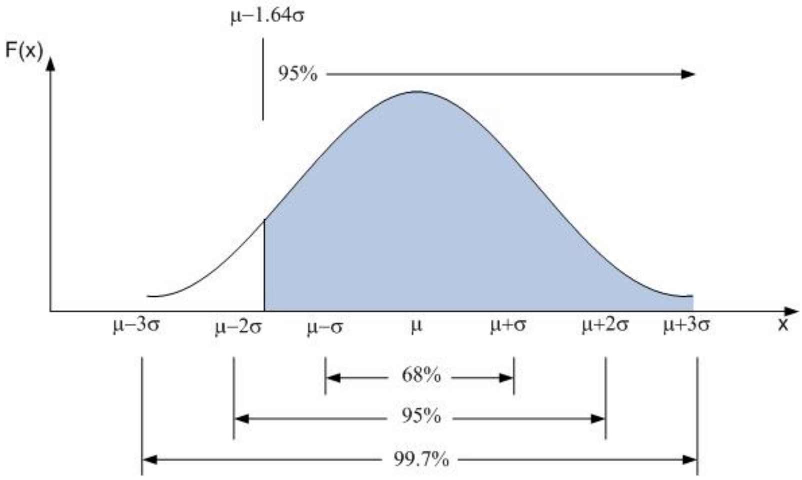

Figure 4.3 Distribution of demand during L_i+R_i with its corresponding μ and σ

We want to be able to store Q_i^* in 95% of the cases. We stated that $(s_i + Q_i^*)$ would result in a shelf that would be too large. Consecutively, we diminish $(s_i + Q_i^*)$ with a particular factor, such that the 95% restriction is maintained. Now, if we calculate the shelf size via $Q_i^* + s_i - CF$, we want to determine this correction factor *CF* such that:

$$P(D_i < CF) = 0.05 \tag{4.9}$$

Additional notation:

$P(E)$	=	the probability of an event E.
D_i	=	stochastic demand during $L_i + R_i$ with its known $\mu_{L_i+R_i}$ and $\sigma_{L_i+R_i}$.
$\sigma_{L_i+R_i}$	=	standard deviation of demand during $L_i + R_i$ (units).
CF	=	correction factor used with shelf size determination.

We thus obtain a chance of 5% that the demand during $L_i + R_i$ is smaller than *CF*. If the demand is smaller than *CF*, we are left with more units on the shelf than anticipated and

consecutively we cannot store Q_i^*. If demand is larger than anticipated, this obviously poses no problems since in this case enough shelf space is cleared to store Q_i^*.
If we would take *CF* equal to $\mu_{L_i+R_i}$ we would not be able to store Q_i^* in 50% of the cases (Benjumea, 2010). This because (as can be seen from figure 4.3) there is a 50% chance that demand during $L_i + R_i$ is smaller than $\mu_{L_i+R_i}$. We want to obtain a *CF* such that the highlighted area in figure 4.3 equals 0.95 (and thus the white area 0.05).

We solve:

$$P(D_i \leq CF) = P\left(\frac{D_i - \mu_{L_i+R_i}}{\sigma_{L_i+R_i}} \leq \frac{CF - \mu_{L_i+R_i}}{\sigma_{L_i+R_i}}\right) = P\left(Z \leq \frac{CF - \mu_{L_i+R_i}}{\sigma_{L_i+R_i}}\right) = \Phi\left(\frac{CF - \mu_{L_i+R_i}}{\sigma_{L_i+R_i}}\right) = 0.05 \quad (4.10)$$

Using a cumulative standard Normal distribution table (Montgomery, 2003) we find:

$$CF = \mu_{L_i+R_i} - 1.64\sigma_{L_i+R_i} \quad (4.11)$$

This thus implies demand during $L_i + R_i$ is larger than $\mu_{L_i+R_i} - 1.64\sigma_{L_i+R_i}$ in 95% of the cases. However, the above derivation is based on a standard Normal distribution (see appendix I), following assumption 3.2 we deal with a Normal distribution with its corresponding $\mu_{L_i+R_i}$ and $\sigma_{L_i+R_i}$. We thus have to cope for the fact that it is possible that $1.64\sigma_{L_i+R_i}$ is larger than $\mu_{L_i+R_i}$, and thus *CF* would become negative. A preliminary analysis showed that this indeed is the case for (especially) slow moving products. Since it does not make sense to allocate more shelf size to a product *i* than $(s_i + Q_i^*)$, we rewrite formula (4.11) into:

$$CF = \left(\mu_{L_i+R_i} - 1.64\sigma_{L_i+R_i}\right)^+ \quad (4.12)$$

Where:

x^+ = max(0,x)

We thus obtain as the necessary shelf size in order to store Q_i in (at least) 95% of the cases.

$$Q_i^* + s_i - CF = Q_i^* + s_i - \left(\mu_{L_i+R_i} - 1.64\sigma_{L_i+R_i}\right)^+ \quad (4.13)$$

The annual space costs of product *i* are thus calculated by

$$hs_i\left[Q_i^* + s_i - \left(\mu_{L_i+R_i} - 1.64\sigma_{L_i+R_i}\right)^+\right] \quad (4.14)$$

Where the parameter hs_i will be elaborated in section 4.5.3.

4.4 Complete cost function

When combining the cost functions of the previous section we can rewrite formula (4.1) into:

$$TC(Q_i^*, s_i) = A_i\left[\frac{365 \cdot \mu_i}{Q_i^*}\right] + ho_i\left[\left(s_i - \mu_{L_i+R_i}\right) + \frac{Q_i^*}{2}\right] + hs_i\left[Q_i^* + s_i - \left(\mu_{L_i+R_i} - 1.64\sigma_{L_i+R_i}\right)^+\right] \quad (4.15)$$

Now the total cost function has been modeled, we need to elaborate on the methodology for estimating the input parameters. This will be done in the subsequent section. The actual parameter *values* are calculated by using the next section's framework, and are covered in chapter 5.

4.5 Method for deriving input parameters

Where the previous section elaborated on the mathematical modeling with respect to the ordering-, opportunity- and space costs, this section discusses the method for estimating the parameters used in section 4.3. This thus being the three parameters as stated in the warehousing cost function of formula (4.15). First we pose an essential assumption.

Usually, a replenishment order is comprised of multiple order lines. However, since our total cost function minimizes at the individual product level (i.e. no multi-article ordering is considered), we have to limit the scope to one product at the time. Therefore we pose:

Assumption 4.1: An order is comprised of precisely one order line.

We are aware of the fact that this assumption might result in an overstatement of ordering costs. More on this will be covered later on in this study.

Using this specific methodology, subsequently (relative) pooling advantages may be quantified as well. In this section we will calculate the relevant costs per *order line*, which by assumption 4.1 become equal to the costs per *order* of product *i*.

4.5.1 Ordering costs (A_i)

One of the most obvious ordering costs are the (external) costs one has to pay to a supplier for each consecutive order line placed. However, next to that, as elaborated in section 3.3.1, ordering costs often include warehouse- and office labor. In this section we will present a method for approximating these three costs.
For each order line of product *i* we state there are fixed costs A_i. This fixed charge is calculated by:

$$A_i = SC_i + PC + HC \text{ (€/order line).} \quad (4.16)$$

Additional notation:

SC_i = product *i*'s supplier's (i.e. external) costs per order line of product *i* (€/order line).

PC	=	procurement costs per order line (€/order line).
HC	=	handling costs per order line (€/order line).

Note that formula (4.16) implies that only the supplier's costs are product dependent. The other two factors are general approximations for a typical order. We will now elaborate on this and justify this methodology.

4.5.1.1 Supplier's costs (SC_i)

For each order line the central warehouse places, it has to pay a certain amount to the supplier (of product *i*) to cover its costs (e.g. for handling, transportation etc.). The fixed supplier's charge of each article is predetermined and known by the health care provider.

There are two notes with respect to this charge:

1. This figure may not be relevant for each individual supplier. When considering the situation at Bernhoven Hospital, we see that there are numerous suppliers which do not charge anything for their shipments. This because of the contractual agreements Bernhoven has with these suppliers that bring about free shipments. More on this is covered in the next chapter.
2. Often the charge is only applicable if an order does not surpass some threshold value (i.e. minimum order amount). Field research revealed that on average these order costs are incurred in [redacted] of the cases (throughout all suppliers), that is why it is necessary to correct the charge for this probability.

Because this situation would yield relatively complex modeling issues we pose the following assumption to benefit the solvability of our optimization problem:

Assumption 4.2: *The supplier's costs are fixed, dependent on the specific supplier, but independent of the order quantity or type of product.*

Keeping the above mentioned notes into account we approximate this charge by:

[redacted] (4.17)

Additional notation:

FSC_i	=	fixed charge per order at the supplier of product *i* (€/order).
OL_i	=	average number of order lines from the warehouse at the supplier of product *i* (order lines/order).

4.5.1.2 Procurement costs (PC)

Next to the supplier's charge, it takes time (and thus costs money) to issue and process a replenishment order. One might think of different staff-departments assisting in the ordering process. Typically the departments that appear to be most important with this are procurement and financial administration (based on Van de Poel, 1991). Procurement is concerned with the issuing of a replenishment order, while financial administration handles the payment of the invoices. Both these activities require resources, which have to be accounted for. That is why we introduce a so called procurement charge.

Preliminary analysis at Bernhoven's procurement department and financial administration revealed that data on personnel and materials (i.e. operational costs) to be widely available. With respect to housing no tariffs for both departments are given. This does not pose any limitations to this study, since the model's goal is not primarily to give a pinpoint number on costs, but instead to account for costs that actually do vary with the number of order lines. Our field inquiries confirmed that it is reasonable to assume that the amount of office space does indeed not significantly vary with the workload. This seems not straightforward since additional employees have to be housed as well. However, office space is mostly predetermined and fixed, i.e. if additional employees have to be housed it is not uncommon to just rearrange the existing office layout such that extra room is created. In practice it is namely often very difficult to either find existing, or built new office space.

Assumption 4.3: *Office space needed for procurement and financial administration is not dependent on the amount of order lines and is thus considered fixed.*

Other overhead costs are assumed to be less prone to variation in the amount of order lines and therefore we pose:

Assumption 4.4: *The only overhead costs that are not considered fixed (when altering the number of issued order lines) are: operational costs for financial administration and procurement costs.*

Also this assumption is in line with the goal of the cost model. Since we try to quantify possible pooling effects, costs that appear to be relatively inelastic to changes in inventory level / amount of orders are of less importance.

Now, the costs per order line for both departments are approximated by (based on Van de Poel, 1991):

$$PC = \frac{\left(E[PD]*T_{PD}\right)+\left(E[FA]*T_{FA}\right)}{E[OY]} \text{ (€/order line).} \qquad (4.18)$$

Additional notation:

$E[PD]$	=	expected yearly costs of the warehouse's procurement department (€/year).
$E[FA]$	=	expected yearly costs of the warehouse's financial administration department (€/year).
T_{PD}	=	percentage of time procurement officers at the warehouse allocate to ordering (%).
T_{FA}	=	percentage of time the financial administration allocates to handling of invoices (%).

$E[OY]$ = expected yearly amount of order lines at the warehouse (order lines).

4.5.1.3 Handling costs (HC)

When the goods have been ordered, they are shipped to the central warehouse. Here, employees inspect and process the order. Obviously, the processing time is highly dependent on the characteristics of a product (e.g. dimensions, weight). However, the costs of the employees' activities besides the actual unloading (e.g. order picking) have to be accounted for as well. The same holds for the supporting material (e.g. pallet trucks). Again we use the method of absorption costing (Garrison, 2003).

We obtain the handling charge by:

$$HC = \left(\frac{\left(E[FTE]*CFTE\right) + E[OC]}{E[OY]} \right) \text{ (€/order line).} \tag{4.19}$$

Additional notation:

FTE = expected number of FTE's (i.e. fulltime equivalent) used by the warehouse for handling (and receipt) of goods (FTE).

$CFTE$ = the costs per FTE at the warehouse (€/FTE).

$E[OC]$ = expected other operational costs at the warehouse (€/year).

$E[OY]$ = expected yearly amount of order lines at the warehouse (order lines).

Next to the FTE costs at a warehouse, other costs are incurred which are correlated with the workload / amount of personnel. One might think of material costs, software licenses, training etc, these costs are accounted for by adding E[OC].

4.5.2 Opportunity costs (ho_i)

The opportunity costs (or cost of capital) are the costs of the money that is tied up in inventory. With this money, an alternative investment could have been made, which could yield monetary benefits. The opportunity costs per unit are calculated by:

$$ho_i = v_i * r \text{ (€/unit) (Silver et al, 1998).} \tag{4.20}$$

Additional notation:

v_i = is the unit variable costs (here: the cost price) of one unit of product i (€/unit).

r = a specific rate set to account for the cost of best alternative use (set by Bernhoven).

4.5.3 Space costs (hs_i)

As mentioned in 4.3.3 we calculate a unit's space costs using a volume measure. We estimate the costs of stocking one unit of product i to be (based on Benjumea, 2010):

$$hs_i = c \cdot 1.2 \frac{Vb_i}{b_i} \text{ (€/unit/yr).} \quad (4.21)$$

Where:

$$c = \begin{cases} c_{sterile} & \text{if kept in sterile storage} \\ c_{non-sterile} & \text{if kept in non-sterile storage} \end{cases}$$

Additional notation:

$c_{sterile}$	=	price per cubic meter for sterile storage in the warehouse (€/m^3/year).
$c_{non-sterile}$	=	price per cubic meter for non-sterile storage in the warehouse (€/m^3/year).
b_i	=	number of units of product *i* per box (units/box).
Vb_i	=	is the volume of one box of article *i* (m^3).

We pose to use a correcting factor of 1.2 (i.e. 20%) on the volume of a box, since it is not realistic to assume that boxes on a shelf fit like a puzzle. Our field research reveals that for this reason (nearly) every shelf deals with some extent of dead space. To account for this, we pose to use this factor which has been recommended by Bernhoven's employees. With respect to the figure *c* we deal with two values, one for sterile storage conditions and one for non-sterile.

4.5.4 Demand characteristics

As mentioned before, the model for warehousing will be used for *i*=1…N products under scope (N is specified in chapter 5). For each individual product the daily mean and standard deviation are calculated via:

$$\mu_i = \frac{\sum_{i=1}^{N} x_i}{N}, \ \sigma_i = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \mu_i)^2}{N}} \text{ (Montgomery, 2003)} \quad (4.22), (4.23)$$

Additional notation:

x_i	=	one release from the central warehouse to a specific department.

The corresponding mean and standard deviation during $L_i + R_i$ are:

$$\mu_{L_i+R_i} = (L_i + R_i) \cdot \mu_i, \ \sigma_{L_i+R_i} = \sqrt{L_i + R_i} \cdot \sigma_i \quad (4.24), (4.25)$$

4.6 Optimization algorithm

4.6.1 Introduction

Given this study's setting of using (R,s,Q) replenishment control with a P_2 service measure, we note the following (Silver et al, 1998): in most situations, the two decision variables, *s* and *Q*, are not independent. This thus means the best value of *Q* depends on the *s* value, and vice versa. In this study we use this insight when setting up the optimization algorithm. We pose to follow a sequential framework (Silver et al, 1998) which eventually appears to facilitate simultaneous optimization. This has to do with the fact that we will deal with a so called predetermined order quantity (section 4.6.2) and consecutively look at the minimal warehousing costs whilst deciding on the best pair of s_i and Q_i^*.

4.6.2 Determine Q_i^*

It is common practice to use the Economic Order Quantity (EOQ) for optimizing the order quantity in a (R,s,Q) system (note that the EOQ formula's corresponding assumptions are given in appendix H). Some might appear to be far removed from reality, but still the EOQ formula yields a near optimal solution (Among others Zheng, 1992 and Axsäter, 1996).

When dealing with a situation where costs depend on volume considerations as well as the value of the inventory, the best replenishment quantity would be (Silver et al, 1998):

$$EOQ_i = \sqrt{\frac{2A_iD_i}{2hs_i + ho_i}} \text{ (units/order)} \tag{4.26}$$

Additional notation:

EOQ_i	=	the economic order quantity for product *i* (units/order).
D_i	=	demand rate of product *i* (units/year).

Note that this is a modification of the standard EOQ formula. The derivation of this modified formula can be found in appendix H.

Now we have an optimal order quantity for product *i*, we use this figure to approach the most cost effective order quantity that is actually feasible, named Q_i^*. Namely, it is obviously not possible to order for instance 3 surgical masks at the supplier when these are sold in boxes of 20.

To bring about that Q_i^* is a multiple of a predetermined order quantity (POQ_i), we first pose the following method:

First define:

$$Q_i^1 = rounddown\left(\frac{EOQ_i}{POQ_i}\right) * POQ_i \text{ (units)} \tag{4.27}$$

$$Q_i^2 = roundup\left(\frac{EOQ_i}{POQ_i}\right) * POQ_i \text{ (units)} \tag{4.28}$$

Additional notation:
POQ_i = Predetermined order quantity of product *i* (units).

With both of these order quantities we resume calculations. To determine whether Q_i^1 or Q_i^2 is best, we look at which one yields the lowest result in formula (4.15). Thus Q_i^* is given either by Q_i^1 or Q_i^2 depending on their corresponding total costs.

Note that because of the rounding of EOQ_i (into Q_i^1 and Q_i^2) and the fact that we resume calculations with both feasible quantities, we effectively deal with simultaneous (instead of sequential) setting of s_i and Q_i^*.

4.6.3 Determine the safety factor k_i

In the context of (R,s,Q) replenishment control (with P_2 as service measure and a Normal distributed demand) we need a so called safety factor, before we can determine the reorder level s_i (an introduction to the Normal distribution is given in appendix I). This safety factor is a measure to cope with the variability in demand by weighing the standard deviation of demand. Since we deal with complete backordering, this safety factor is chosen such that:

$$G_u(k_i) = \frac{Q_i^*}{\sigma_{L_i+R_i}}(1-P_2) \text{ (Silver et al, 1998)} \tag{4.29}$$

See that we can easily derive the right hand side of the formula. Using a lookup table (Silver et al, 1998) we can determine the value k_i such that $G_u(k_i)$ equals this amount, where:

$$G_u(k_i) = \int_{k_i}^{\infty}(u_0 - k_i)\frac{1}{\sqrt{2\pi}}\exp\left(\frac{-u_0^2}{2}\right)du_0 \tag{4.30}$$

Formula (4.30) is a special function of the unit Normal (mean 0, standard deviation 1) variable (see appendix I), and is used in finding the expected shortages per replenishment cycle.

4.6.4 Determine s_i

When both Q_i^* and the (product dependent) safety factor k_i are determined, we obtain the reorder level s_i by:

$$s_i = \mu_{L_i+R_i} + k_i\sigma_{L_i+R_i} \tag{4.31}$$

For practical reasons we obviously want an integer value for s_i. To ensure a service measure of at least P_2, we round s_i to the next higher integer, if not already an integer.

4.7 Outputs

As already introduced with the preliminary model formulation (section 4.1) the total cost model is constructed using three components: ordering-, opportunity- and space costs.

These cost-components are dependent on the values of the decision variables which are chosen by the model. Consecutively the final output per product under scope is:

- The optimal order quantity Q_i^*.
- The reorder level s_i.
- The expected total warehousing costs per year for product *i*, split into:
    - Ordering costs.
    - Opportunity costs.
    - Space costs.

Chapter 5: Bernhoven

Now the warehousing framework has been modeled (both conceptually and analytically) we will start with the actual data analysis. This chapter will address the setting where Bernhoven Hospital is the only health care provider in the warehouse. Its warehousing costs are approximated using the preceding chapter's framework. Key figures used in this chapter are chosen such that they facilitate benchmarking with HL's framework, i.e. where available we thus use the data Bernhoven sent to HL (and by which HL thus formed its contract). Section 5.1 will discuss the product delineation where section 5.2 consecutively provides an overview of this sample data. After determining the product independent input parameters in section 5.3 the analysis for one product is elaborated upon (section 5.4). This section is subsequently followed by the optimization algorithm (section 5.5) as introduced in the previous chapter. Section 5.6 gives the optimization results for one product, where 5.7 discusses the aggregate.

5.1 Delineation of products under scope

The goal of this section is to determine the amount (and type) of products we will use to approximate Bernhoven's warehousing costs. How JBZ's assortment relates to BE's, is addressed in the next chapter. We pose to delineate the product assortment under scope because of obvious time constraints. BE's assortment is comprised of [redacted] (i.e. inventory) articles. An analysis of all these articles is not viable. Here we describe our methodology for the delineation.

5.1.1 Typical classifications

When considering Bernhoven's assortment of [redacted] articles, you can look at each individual product in many different ways. One can for instance classify products based on whether they are (based on Benjumea, 2010):

1. Sterile / non-sterile.
2. Fast moving / slow moving.
3. Large / small in volume.
4. High unit value / low unit value.
5. Perishable / non-perishable.
6. Critical to hospital needs / non-critical.

Keeping these classifications in mind, we want to obtain a sample of products that is representative for Bernhoven's complete assortment. Recall that the nature of the product is very much of influence on its storing costs. For instance, the yearly costs of storing a euro of toilet paper are much higher than for storing a euro of disinfectant. For exactly this reason we posed (in the previous chapter) to use a volume measure for ascribing space costs, instead of a method based on the unit variable costs.

Keeping this in mind, it is thus intuitive to obtain a sample which is primarily representative with respect to space costs issues. A product's space costs are influenced by respectively its volume, and the way the product has to be stored.

At Bernhoven (and all other health care providers) there typically are two types of articles:
1. SKU's which have to be stored under sterile conditions.
2. SKU's which can be stored in a non-sterile room.

Storing a product under sterile conditions is obviously more expensive than under regular ones. This because of costs for air treatment systems and other sorts of additional requirements.

Next to the volume measure and the storage requirements (which both are elements of the space costs), we deal with opportunity costs (as elaborated in the previous chapter's cost model). In order to obtain a sample that is representative with respect to this issue as well, we take the unit value into account (to what extent will be elaborated later on). We do this both for sterile and non-sterile products. By choosing a product set that consists of both cheap, and expensive products we facilitate generalizability. Using the above insights we thus pose to delineate the product assortment based on (in descending order of importance):
1. The storage requirements (sterile or non-sterile) / volume of the product.
2. Unit value.

This methodology brings about one obstacle. Bernhoven does not keep track of a product's dimensions in its database. It does however on whether it's sterile or not, and what the corresponding unit value is. Because of this obstacle we pose to use a quantitative and qualitative approach.
- A quantitative one for determining the proportion of sterile and non-sterile products.
- A qualitative one for determining which products are high in volume and whether they are high or low in unit value. Recall that with this reasoning the volume measure has the primary focus. With respect to the unit value we do not pose a strict proportion since we observed that this is highly correlated with a unit's volume. Typically, small products may be considered to be cheaper than larger ones.

5.1.2 Storage requirements

Because (as elaborated in chapter 2) JBZ will be considered as well, we benchmarked the proportion of sterile and non-sterile items in all three settings. This because we want to obtain a sample that is representative in all settings, not just BE's.

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Figure 5.1 Product assortments

From the above figure 5.1 we see that the proportions of sterile and non-sterile items at both BE and JBZ are approximately [redacted]. BE has [redacted] sterile, where JBZ has [redacted]. Since we want to obtain a sample which is representative for the complete assortment we want to obtain a proportion which is approximately [redacted], we assume:

Assumption 5.1: Bernhoven's assortment is comprised of [redacted] *sterile, and* [redacted] *non-sterile products.*

Since Bernhoven will act as the base of this study, this ratio is thus subsequently applicable for each additional party under study.

5.1.3 Volume considerations

With respect to volume considerations we used a qualitatitive approach. Since Bernhoven does not have any information on its product's dimensions, we used insights from Bernhoven's employees at the central warehouse (in Veghel) to determine which products are voluminous, and which are not. These products were subsequently measured. We chose to use one location since combining the locations Veghel and Oss (and thus their corresponding product assortments, warehouse layouts etc.) would yield unnecessary difficulties. For practical reasons Veghel is considered to be the preferred location.

We pose the following assumption for further specification of our sample with respect to the volumes of the products in Bernhoven's assortment:

Assumption 5.2: Bernhoven does not carry more typically 'large' products than 'smaller' ones.

With this we bring about that the assortment is not (positively or negatively) skewed volume wise. We thus assume each volume between the smallest and the largest product in the assortment is equally probable. Following this insight we want to obtain approximately equal proportions of typically 'smaller' products, and 'larger' ones. This for both sterile and non-sterile products.

5.1.4 Sample size

With respect to the determination of the actual size of the sample we have to find a balance between obtaining a sample that is not only representative, but feasible as well (given this study's time constraints). We pose to use a total sample size of 100 products. Given the above mentioned proportions we thus obtain:

- Sterile products: [redacted]. Of which:
  - Smaller ones: [redacted].
  - Larger ones: [redacted].
- Non-sterile products: [redacted]. Of which:
  - Smaller products: [redacted].
  - Larger products: [redacted].

What is considered to be a 'smaller' or 'larger' product is based on qualitative reasoning (of Bernhoven's warehousing employees) as mentioned in the previous section.

5.2 Overview of data obtained

All data obtained is extracted from Bernhoven's database tool called Villa and based on the demand at Veghel in the year 2009. The selected 100 products as mentioned in appendix K are all suitable for analysis. However, after an initial analysis we replaced several products in the sample because:

- No unit value was given. Some products are not individually charged to Bernhoven because of (service) contractual agreements between BE and the corresponding supplier.

This is for example the case for several types of toners. Analysis of these products is not straightforward and these thus had to be replaced.
- The product was not used anymore at this current date.
- The number of observations per product was insufficient. There were several products which appeared to be extreme slow movers (1 release per year). These were replaced for similar products with a somewhat higher moving speed.

At Bernhoven there are several types of so called release units (or in Dutch: 'afgifte eenheden'). Some products are released to the departments in boxes, others per piece, again others per can. For the remainder of this study we define the term 'unit' as 1 release unit (RU) of the corresponding product (see appendix K).

For each of the 100 suitable products we gathered the following product data:
1. Article number.
2. Daily demand per department in the year 2009 (units/day).
3. Required storage conditions: either sterile or non-sterile.
4. Product description.
5. Predetermined order quantity (units/order).
6. The type of release unit (e.g. box, piece, can).
7. Unit price (€/unit).
8. Volume per release unit (m^3/unit).
9. The supplier with its:
    - Lead time (days).
    - Fixed costs per replenishment order, SC_i (€/order).
    - Minimum order amount (€/order).
    - Average number of order lines per order (order lines/order).

The acquired data had to be checked for errors and outliers, this in order to facilitate thorough analysis. Outliers are observations that do not follow the statistical distribution of the bulk of the data, and consequently may lead to erroneous results with respect to the analysis. Namely, if negative- and extreme large values were not removed, this would result in an erroneous mean and an overstatement of the standard deviation. In order to follow the same methodology for each subsequent product under scope we used the method as described in appendix J. The product- and supplier data obtained can be found in respectively appendix K and L.

5.3 Estimation of product independent input parameters

Where the preceding chapter 4 introduced the *methodology* for estimating the relevant input parameters, this section will elaborate on the actual *values*. This will subsequently be done for all three relevant parameter groups.

5.3.1 Ordering costs (A_i)

As mentioned in section 4.5.1 the ordering costs are calculated via:

$$A_i = SC_i + PC + HC \qquad (5.1)$$

Now we will address subsequently the procurement- and handling costs (the supplier's cost is product dependent and addressed in the following section).

Bernhoven's procurement department and financial administration have operational costs of respectively [redacted] and [redacted] per year. Using the allocation of FTE's at both departments we obtained estimates on the parameters T_{PD} and T_{FA}. The time Bernhoven's procurement department allocates to ordering is approximately [redacted] FTE (out of the [redacted] FTE at this department). This thus yields [redacted] of the time (i.e. T_{PD}=[redacted]). For financial administration this is [redacted] FTE (out of the [redacted] FTE at this department). This thus translates to T_{FA}=[redacted]. The fact that it takes financial administration somewhat more time to deal with ordering can be explained by the fact that an order can bring about multiple invoices which have to be accounted for. From BE's database we extracted the total number of order lines in 2009 for both Veghel ([redacted]) and Oss ([redacted]).

When allocating all relevant costs to the amount of order lines (based on the absorption costing method) we thus obtain:

[redacted] (5.2)

Now we calculate the handling charge. As was mentioned in chapter 4, this charge is comprised of salary costs and other operational costs. At Bernhoven the warehousing costs for Veghel and Oss are [redacted] and [redacted] respectively. Of these figures there are [redacted] salary costs for Veghel ([redacted] FTE) and [redacted] for Oss ([redacted] FTE). We thus obtain:

[redacted] (5.3)

Later on the interdependence between the above derived costs and the total warehousing costs will be elaborated.

5.3.2 Opportunity costs (ho_i)

The fixed rate that is used to account for opportunity costs is used throughout all products under scope and set to [redacted] (provided by Bernhoven). Furthermore, by doing this we set the rate equal to what HL specified in its contract and facilitate comparison issues.

5.3.3 Space costs (hs_i)

The most important parameter we have to estimate in order to quantify space costs is obviously the price per m^3 in the warehouse. However, industry wide no single TPL provider provides a tariff per m^3. Space costs are always accounted for using a m^2 rate.

Preliminary analysis by Bernhoven among TPL providers revealed that the prevailing m^2 tariff is typically ranging between [redacted] and [redacted]. This figure is all-embracing and includes issues as rent, security, insurance and cleaning. When benchmarking this figure against the prevailing price per m^2 for storage in a hospital ([redacted] as indicated by BE), these figures can be easily assessed.

We use the open book calculation provided by HL, and verified and approved for by both JBZ and BE to approximate storage costs. We do this for both sterile- and non-sterile storage, where this distinction is not typically being made in industry. We obtain as *general* m^2 prices (see appendix M section M.1):
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Table 5.1 Estimation of general m^2 prices/yr

However, we pose to resume calculations based on effective warehousing space used, thus without taking room for hallways, goods receipt and storage of equipment into account. Therefore we correct the figures of table 5.1 based on a m^2 usage of [redacted] (see appendix M section M.2) and obtain the following assumption:

Assumption 5.3: [redacted] *of the sterile- and non-sterile warehousing space can be used for storage.*

We obtain as effective m^2 prices:
- For sterile storage: [redacted] per m^2 per year.
- For non-sterile storage: [redacted] per m^2 per year.

Furthermore, since we pose to calculate storage costs in m^3 use instead of m^2 usage, we have to consider the average storage height in the warehouse. Usually a warehouse has certain areas for general storage racks and bulk products. Since bulk racks can range as high as 6 meters (or higher), we obviously encounter difficulties in obtaining a *general* storage height.

As can be seen in the pictures in appendix M (taken at HL's warehouse in Oss) we deal with a similar layout. In figure M.1 on the left we see bulk storage, in the center the clean room for sterile storage and on the right hand side the typical storage racks (as in figure M.2). We base our calculations on the sterile storage room and the typical storage racks. For this we assume the storage rack to be maximally [redacted] meters high. With this we consequently pose:

Assumption 5.4: *A storage rack in the warehouse is maximally* [redacted] *meters high.*

We thus obtain as m^3 prices for sterile and non-sterile storage respectively [redacted]/m^3/yr and [redacted]/m^3/yr.

5.4 Analysis for one product

The remainder of this chapter will elaborate on the analysis of *one* of the 100 products, where the last section provides an overview of the aggregated results. The layout of the remainder of this chapter follows the same sequence as chapter 4.

5.4.1 Product details

The product which will be elaborated upon in detail has article number 000230057, and is a specific type of infusion system. After outlier removal (see appendix J) we obtained the following data (from appendix K):
- *SR*: 2 (i.e. it is a sterile product).
- Description (in Dutch): INFUUSSYSTEEM A25001.

- Supplier: 000311.
- Number of observations: 879.
  (This figure corresponds to the number of releases minus data errors and outliers).
- Mean daily demand: 46.21 (units/day).
- Standard deviation of daily demand: 42.12 (units/day).
- Coefficient of variation: 0.91.
- Release unit: STUK.
- Value per unit: [redacted](€/unit).
- Volume per unit: 0.000665 (m^3).
- Lead time: 6 (days).
- Predetermined order quantity: [redacted] (units/order).

Using appendix L we obtain as additional information for supplier number 000311:
- Name: B. BRAUN MEDICAL B.V.
- Average order lines per order, OL_i: [redacted](order lines/order).
- There [redacted] fixed supplier's charge, FSC_i: [redacted] (€/order).

5.4.2 Estimation of product dependent input parameters

Now all the product *independent* input parameters and the related product information are known, we elaborate on the estimation of the product *dependent* input parameters.

As mentioned above, the supplier's charge in this case is equal to [redacted] For the infusion system the order costs we thus obtain are:

[redacted] (5.4)

Given formula (4.20) and that the value of one unit is equal to [redacted] we obtain opportunity costs of:

[redacted] (5.5)

Since the infusion system is a product which has to be stored under sterile conditions we obtain as space costs (given the unit volume from appendix K):

[redacted] (5.6)

5.5 Optimization

5.5.1 Determine Q_i^*

Following formula (4.26) we obtain an economic order quantity of 892.74 units. Subsequently taking the predetermined order quantity of 800 (see appendix K) into account we obtain:

- $Q_i^1 = rounddown\left(\frac{EOQ_i}{POQ_i}\right) * POQ_i = rounddown\left(\frac{892.74}{800}\right) * 800 = 800.$ (5.7)

- $Q_i^2 = roundup\left(\frac{EOQ_i}{POQ_i}\right) * POQ_i = roundup\left(\frac{892.74}{800}\right) * 800 = 1600$. (5.8)

5.5.2 Determine the safety factor k_i

As mentioned in the preceding chapter we resume calculations for both feasible order quantities, we subsequently obtain:

- For Q_i^1: $G_u(k_i) = \frac{Q_i^*}{\sigma_{L_i+R_i}}(1-P_2) = \frac{800}{\left(\sqrt{6+1}\cdot 42.12\right)}(1-0.98) = 0.144$. (5.9)

  Using the lookup table (Silver et al, 1998) we find $G_u(0.69) = 0.1453$ and $G_u(0.70) = 0.1429$. For guaranteeing at least 98% P_2 service we chose $k_i = 0.70$.

- For $Q_i^2 : G_u(k_i) = \frac{Q_i^*}{\sigma_{L_i+R_i}}(1-P_2) = \frac{1600}{\left(\sqrt{6+1}\cdot 42.12\right)}(1-0.98) = 0.287$. (5.10)

  For Q_i^2 we find $G_u(0.24) = 0.2904$ and $G_u(0.25) = 0.2863$. For guaranteeing at least 98% P_2 service we chose $k_i = 0.25$.

5.5.3 Determine s_i

- For Q_i^1 we obtain:

  $s_i^1 = \mu_{L_i+R_i} + k_i^1\sigma_{L_i+R_i} = (6+1)\cdot 46.21 + 0.70\cdot\left(\sqrt{6+1}\cdot 42.12\right)$=402. (5.11)

- For Q_i^2 we obtain:

  $s_i^2 = \mu_{L_i+R_i} + k_i^2\sigma_{L_i+R_i} = (6+1)\cdot 46.21 + 0.25\cdot\left(\sqrt{6+1}\cdot 42.12\right)$=352. (5.12)

5.6 Outputs

As mentioned in chapter 4, we look at the output figures, using formula (4.15), in order to determine which feasible order quantity will be taken. We thus obtain two figures for each corresponding product. For the infusion system this becomes:

For Q_i^1, we obtain as ordering costs via formula (4.13):

[redacted] (5.13)

Via formula (4.8) the opportunity costs are: (5.14)

[redacted]

Formula (4.14) yields as space costs:

[redacted] (5.15)

When we follow the same procedure for Q_i^2 we obtain total warehousing costs of:

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Table 5.2 Costs overview of order sizes

Since we pose to minimize total warehousing costs per year we will choose Q_i^1 (800) as the optimal (and feasible) order quantity, and a reorder level of 402, for this type of infusion system.

5.7 Aggregated results for BE

Where the preceding section described our methodology for one product (the specific type of infusion system), we repeated this sequence for all other items in the sample. The results from these analyses can be found in appendix N.

When looking at these figures we can easily distinguish between opportunity and space costs. If we for instance consider the first product (i=1) we see the opportunity costs are far greater than the space costs. The reason for this can be found when looking at the product's data in appendix K. Here we see that the unit value of this product is [redacted] where the demand and unit volume are both relatively low.

On the other hand, when we consider product i=62 (shoe covers), we note opportunity costs which are a tiny fraction of the space costs. This can be explained by the fact that the unit value [redacted]) is extremely low compared to its volume.
Thus, given the sample size of these 100 products we obtain the following warehousing costs:

1. Ordering costs: [redacted].
    - Supplier's charge: [redacted].
    - Procurement charge: [redacted].
    - Handling charge: [redacted].
2. Opportunity costs: [redacted].
3. Space costs: [redacted].

This yields a total amount of [redacted] per year. This translates for Bernhoven to an average amount for stock keeping of [redacted] per product per year. Now we have obtained a cost figure for the BE setting, we will subsequently elaborate on the JBZ- and BE/JBZ settings in respectively chapters 6 and 7.

Chapter 6: Jeroen Bosch

Where the previous chapter elaborated on the situation where Bernhoven is the only health care provider in the warehouse, this chapter will consider the same methodology but for JBZ alone instead. We pose to use the same methodology as in chapter 5, taking the relative size differences between JBZ and BE into account. A method for coping with these size differences is introduced in sections 6.1 and 6.2. Using the insights from these sections an analysis is executed which is elaborated in section 6.3.

6.1 Analysis of coefficients of variation

Before we actually start our analysis for JBZ we look at whether it is allowed to generalize among health care providers. As one can imagine, each individual party has its own products and suppliers (mere article overlap between BE and JBZ is known to be around [redacted]%). However, in order to obtain results that can be used throughout all settings we pose to make consequent use of the same 100 products as used in the sample for BE. It is namely not feasible within this study's obvious time constraints to do a separate analysis for JBZ or additional parties (and their corresponding product assortments).

We thus pose to use the demand patterns of BE and adjust these for JBZ's size. To determine whether or not this methodology can be justified we will first conduct a preliminary analysis for 10 random products. Using product descriptions for both BE and JBZ (since article numbers obviously are not the same at both health care providers) 10 products were matched.

For each of these 10 products the demand was analyzed. For BE the data obtained ranges from January 2009 till December 2009, where JBZ only provided data from April 2009 till March 2010. This discrepancy between intervals does not pose any limitations to this analysis since demand variability for these products at both health care providers is known to have been relatively constant throughout both years.

Thus, using the demand for each individual product we subsequently calculated the product's mean and standard deviation of daily demand. Using formula (6.1) the coefficient of variation (CV) is calculated via:

$$CV_i = \frac{\sigma_i}{\mu_i} \tag{6.1}$$

We pose to use the coefficient of variation because the standard deviation of demand must always be understood in the context of a product's mean demand. Using formula (6.1) we can asses a product's demand variability for BE and JBZ, independently of their respective sizes. We can use this insight when adjusting Bernhoven's demand to the JBZ level. See appendix O for the 10 products and their corresponding CV's for both BE and JBZ.

When the values from appendix O are graphically represented, figure 6.1 below is obtained.

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Figure 6.1 Coefficient of variation overview

At first glance it appears reasonable to assume that for BE and JBZ the CV's for the corresponding products above may be considered equal. To confirm whether or not this presumption is statistically valid, we conduct an Analysis of Variance (ANOVA). An ANOVA is a well known method from statistics which can be used to assess whether two means significantly differ from each other. In this case we thus want to assess whether the mean CV for JBZ is significantly different from BE's. The outcome of the ANOVA states that there is not a statistically significant difference between the mean CV from BE to JBZ at the 95.0% confidence level. It is thus allowed to assume JBZ and BE have the same (relative) demand variability, based on the sample above.

Note that this finding is valid for the products above that may be considered as products for 'general hospital use'. Namely, all these products are relatively commonly used throughout health care providers. With respect to products that are related to a specific hospital's specialism (e.g. cardiology / radiology etc.) other findings may be obtained. Namely, where one hospital might frequently use one particular type of pacemaker, the other might not use it at all (when this kind of treatment is not covered at this health care provider). For this reason we pose:

Assumption 6.1: *The health care providers under study are considered to have the same specialisms.*

Given assumption 6.1, for the remainder of this study we will elaborate on the warehousing figures we obtain when considering the multiple settings as introduced in chapter 3. As for JBZ, we will first adjust Bernhoven's demand patterns to take its corresponding size difference into account.

6.2 Size differences between BE and JBZ

Using the insights from section 6.1 (that led to assumption 6.1) we assume JBZ uses the exact same products as in the sample we used for BE in chapter 5. Consider the overview (on which HL based its contract) in table 6.1:

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Table 6.1 Annual releases BE and JBZ accounted for by HL

The ratios above are calculated for gaining insight into both health care providers. Although calculating size differences based on the number of releases without taking the released amount into account appears very crude at first glance, these figures indeed appear to be good approximations for relative size differences (as internal case studies already indicated). We thus see the ratio JBZ/BE for non-sterile goods is around [redacted], where it for sterile is [redacted].

Taking these ratios into account, next to the fact that for each of the 100 products under scope the CV of JBZ has to remain equal to the CV of BE we pose for each product *i*:

$$CV_{i,BE} = \frac{\sigma_{i,BE}}{\mu_{i,BE}} = CV_{i,JBZ} = \frac{\sigma_{i,JBZ}}{\mu_{i,JBZ}} = \frac{M \cdot \sigma_{i,BE}}{M \cdot \mu_{i,BE}} \tag{6.2}$$

Where: *M* equals [redacted] for non-sterile goods and [redacted] for sterile goods.

Additional notation:

$CV_{i,H}$ = coefficient of variation of product *i*, at health care provider *H*
Where *i*=1…100 and *H*=BE, JBZ.

$\mu_{i,H}, \sigma_{i,H}$ = respectively the mean and standard deviation of daily demand for product *i* at health care provider *H*.

Concluding, this method can be summarized in assumption 6.2:

Assumption 6.2: JBZ has [redacted] *times BE's demand for non-sterile and* [redacted] *for sterile goods.*

Now the mean and standard deviation of daily demand for JBZ are known, we analyze each of the 100 products in the sample. For this analysis the same product independent input parameters (see section 5.3) will be used as estimated in chapter 5. Furthermore, also the product dependent input parameters are considered equal for each consecutive product. This obviously apart from the mean and standard deviation as mentioned and derived above.

6.3 Aggregate results for JBZ

Following the same methodology as in the preceding chapter we obtain the results as noted in appendix P. We see that the corresponding costs for JBZ in the warehouse (for the 100 products under scope would become):

1. Ordering costs: [redacted].
    - Supplier's charge: [redacted].
    - Procurement charge: [redacted].
    - Handling charge: [redacted].
2. Opportunity costs: [redacted].
3. Space costs: [redacted].

This yields a total amount of [redacted] per year. This translates for Jeroen Bosch to an average amount for stock keeping of [redacted] per product per year.

Chapter 7: BE/JBZ and flex rates

Where the separate analyses of both BE and JBZ are considered in respectively chapters 5 and 6, this chapter elaborates on possible pooling effects that may emerge when the two parties would be sharing the warehouse. After introducing a method for aggregating both health care providers' demand in section 7.1, possible pooling advantages regarding product overlap are discussed in section 7.2. The insights gained here are used to evaluate HL's flex rates (section 7.3). The posed incentives for adding additional parties to the cooperation are addressed in section 7.4.

7.1 Warehousing costs for BE/JBZ

In this section we elaborate on the method of how the demand for both BE and JBZ should be aggregated. This aggregation consecutively takes place for each one of the 100 products in the sample. When considering the aggregated demand for each respective product under scope we use:

$$\mu_{i,BE/JBZ} = \mu_{BE} + \mu_{JBZ} \tag{7.1}$$

$$\sigma_{i,BE/JBZ} = \sqrt{\sigma_{i,BE}^2 + \sigma_{i,JBZ}^2} \tag{7.2}$$

We use the method above because we assumed the daily demand of BE and JBZ to be equally distributed. When aggregating these two independent demands, one can simply add the corresponding means. With the standard deviation however, one has to do calculations using its variance as posed in formula (7.2).

Now the aggregated demand per unit is obtained, the actual data analysis will take place. Again the warehousing model of chapter 4 is used. The parameters used throughout chapters 5 and 6 (apart from the mean and standard deviation) remain unchanged.

Following the same sequential methodology as extensively covered in chapter 5, we obtain the results as noted in appendix Q. We see that the corresponding costs for BE/JBZ in the warehouse (for the total of 100 products under scope) become:

1. Ordering costs: [redacted].
   - Supplier's charge: [redacted].
   - Procurement charge: [redacted].
   - Handling charge: [redacted].
2. Opportunity costs: [redacted].
3. Space costs: [redacted].

Summation of the above figures yields a total amount of [redacted] per year. This translates for BE/JBZ to an average amount for stock keeping of [redacted] per product per year. In the following section we will discuss the implications of this figure, particularly in relation to the cost figures obtained in the preceding two chapters.

7.2 Theoretical pooling advantages

Using the outcomes for each corresponding setting, we obtain as relevant figures:

Confidential.
Table 7.1 Costs per setting

Note that in the last row of table 7.1, the cost savings for the BE/JBZ cooperation (compared to when both health care providers are operating the warehouse individually) are stated, this in an absolute and relative format. When the absolute figures are divided by 100, the pooling advantages per product are obtained. Now, we first elaborate on the total costs figure and its corresponding implications.

In the setting where BE and JBZ are combined, in theory we would thus be able to realize a total relative pooling advantage of:

[redacted]. (7.3)

Again, these are the relative advantages Bernhoven and Jeroen Bosch would have, compared to the setting where each is operating the warehouse individually. However, note that this figure is based on a product overlap of [redacted]. Of these [redacted] savings, we see that approximately [redacted] can be ascribed to savings in ordering costs (of which [redacted] to the supplier's charge, [redacted] to the procurement charge and [redacted] to the handling charge), [redacted] to savings in opportunity costs and [redacted] to savings in space costs.

Using the above insights into the pooling advantages that would be theoretically feasible for BE/JBZ, we elaborate on the methods HL posed for coping with pooling advantages, i.e. the flex rates.

7.3 Flex rates

In this section we will discuss the flex rates HL offered to BE/JBZ to effectuate (and cope with) efficiency savings at both health care providers. First an overview of these figures is given, there after these rates are compared to the findings we obtained in the previous section.

Note: Where the previous chapters dealt with figures obtained from this study's warehousing model, the remainder of this section will consider the actual amounts (i.e. tariffs) as introduced by HL. This in order to effectively benchmark against the prevailing flex rates.

7.3.1 Overview

Now look back at appendix E. Here we see that HL formed the so called flex rates for both BE and JBZ. Following the method from section 2.2.3 Bernhoven (and thus JBZ as well) would save [redacted] per year (excluding VAT) if BE would manage to get its [redacted] articles overlapping with JBZ. Note that this is under the assumption that the amount of releases (or what HL calls 'bestellijnen' does not change. This seems intuitive since BE's demand is likely to remain the same irrespective of whether BE will use its specific own product, or a similar product which is being shared with JBZ. In appendix R table R.1 we see that Bernhoven has to pay a total amount of [redacted] per year to HL. However, this figure is all-embracing. When diminishing this figure with HL's costs for transportation we obtain relevant warehousing costs of: [redacted]. For JBZ we obtain [redacted].

The above mentioned [redacted] effectuated by the product overlap thus corresponds to: [redacted] of BE's amount.

When using the method of absorption costing on HL's warehousing rates for both health care providers (appendix R), we see that BE and JBZ respectively have to pay HL:
- BE: [redacted]
- JBZ: [redacted]

Note further from appendix E that HL provides a discount to BE, for each product less in its assortment, of [redacted] per product per year (disregarding the threshold value of [redacted] articles). Next to that, as mentioned in section 2.2.3 each product which BE has in common with JBZ, is counted for [redacted]. This way, HL wants to reward both BE and JBZ equally for their effort put into the effectuated product overlap. Since each product which BE has less in its assortment decreases BE's yearly amount by [redacted] (see appendix E at the LESS-work flex rates in table E.1) and product overlap is allocated for [redacted] to Bernhoven, BE thus effectively saves [redacted] per year per overlapping product.

7.3.2 Benchmarking

Assume that at this moment both BE and JBZ do not have any product overlap in HL's warehouse. BE is thus billed for [redacted] products, where JBZ pays for [redacted] products. Now consider a specific type of injection needle. BE is known to use needle A, where JBZ uses needle B. Needles A and B are interchangeable (i.e. they serve the same purpose), and are of the exact same quality. Consider furthermore from section 7.3.1 the average costs that HL charges BE and JBZ for keeping one product in its warehouse. Assume the costs of keeping both respective needles on stock are given by these average figures. Thus, BE pays [redacted] per year for needle A, where JBZ pays [redacted] per year for needle B.

Now, BE decides to switch from needle A to needle B. Using the insights from section 7.2 we would expect the subsequent pooling advantages for this overlapping product to be:

[redacted] (7.4)

Using the insights from our analyses in chapter 5 and 6 we can say that the amount of [redacted] is thus comprised of costs saved because:
1. Needle A's shelf space (when used by BE/JBZ) is less than the sum of needle A+B. So there should be fewer costs for rent, cleaning, utilities etc.
2. HL saves on order costs since no orders for needle B have to be issued any more. These savings are shown to exceed the increase in ordering costs for needle A.
3. HL saves on interest costs since the monetary value of the new needle A's inventory is less than the old inventory levels of needles A and B combined.

Furthermore, when assuming that the relative savings as obtained in our analysis are applicable for HL's situation as well (see table 7.1) we obtain as pooling advantages:

1. Ordering: [redacted].
    - Supplier's charge (SC): [redacted].
    - Procurement charge (PC): [redacted].
    - Handling charge (HC): [redacted].
2. Opportunity: [redacted].
3. Space: [redacted].

See figure 7.1 below for a graphical representation of these pooling advantages.

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Figure 7.1 Pooling advantages

However, the in figure 7.1 mentioned pooling advantages are not all equally easy to obtain. In order to distinguish between the ease of realization we use an action analysis (Garrison et al, 2003). An action analysis is a report showing what costs have been assigned to (in this case) a product, and how difficult it would be to adjust these costs if changes in the activity occur.

Where cost changes can be adjusted, possible savings might be accounted for. In the action analysis we deal with three color-coded types of costs (in descending order of ease of adjustment):

- Green costs.
- Yellow costs.
- Red costs.

The green costs are thus the easiest to adjust. Because of this relative ease of adjustment, this category is the one that is most likely to transform these cost adjustments into actual savings.

When considering the costs from figure 7.1 we make the following distinction:

- Green costs: Supplier's charge, opportunity costs. Both costs are easy to adjust. No significant investments were made with respect to these matters, so changes in these costs can easily be adjusted.
- Yellow costs: Procurement charge, handling charge. These costs are somewhat more difficult to adjust than the ones mentioned above. This because of the fact that labor (which mainly comprises both charges) is often fixed to some extent. Where TPL providers may have temporary workers, often a large part is under contract and thus cannot easily be adjusted.
- Red costs: Space costs. The costs HL has for operating its warehouse may be considered fixed. Whether or not BE/JBZ facilitates product overlap, HL still has to cope with operational costs for the building, cleaning, security and insurance. These fixed costs are thus very difficult to adjust.

Figure 7.1 and the distinctions made above yield the following overview:

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Table 7.2 Action analysis

Table 7.2 provides an overview of the extent to which the different savings might be realized. When benchmarking these figures with HL's flex rates we note the following:

Assume that the flex rates only concern the green costs (yellow costs are more difficult to assess and should be used for qualitative insights here). We would expect the savings per overlapping product thus to be [redacted].

Recall that the discount for BE/JBZ for an overlapping product was [redacted]. Furthermore note in appendix R, figure R.1 that HL suggests to divide cost savings on a [redacted] basis. With this we thus mean, [redacted] of a realized discount is a benefit for HL, where the other [redacted] is for its customers (in this case thus BE/JBZ). Assuming the same holds for the posed flex rate, HL thus estimates the total cost savings per overlapping product to be [redacted] per year. This translates to: [redacted] of its rates.

The easiest realizable savings as quantified by our model are thus already significantly higher than the [redacted] as used by HL. The potential savings on opportunity costs alone are approximately twice this amount, [redacted]

7.4 Incentives related to additional parties

Next to the product related incentives discussed above, HL constructed an incentive for BE/JBZ when additional parties join them in the warehouse. This incentive effectuates a decrease in yearly costs of [redacted] (excl. VAT) for BE/JBZ (see appendix R, table R.2). This for the setting where the additional party is [redacted] of the combined size of BE/JBZ.

In order to be able to benchmark this figure with our warehousing model we conducted an analysis ourselves with several theoretical settings (including the one posed by HL). In this analysis the additional party's size ranges between [redacted].
For each corresponding setting we accounted for the increase in product demand (again based on the sample of 100 products from chapter 5) via:

$$\mu_{i,S_j} = (\mu_{BE} + \mu_{JBZ}) \cdot (1 + j) \tag{7.5}$$

$$\sigma_{i,S_j} = \sqrt{(1 + j)(\sigma_{i,BE}^2 + \sigma_{i,JBZ}^2)} \tag{7.6}$$

Additional notation:

S_j = setting $\text{BE/JBZ} + \text{j}(\text{BE/JBZ})$.
Where: [redacted]

$\mu_{i,S_j}, \sigma_{i,S_j}$ = respectively the mean and standard deviation of daily demand for product *i* at setting S_j.

Again, using the warehousing model from chapter 4, each consecutive setting is analyzed. Note that in table 7.3 below the results of these analyses are stated. For each setting we thus deal with three parties sharing the warehouse: BE, JBZ and j(BE/JBZ).

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Table 7.3 Analysis of the savings potential on additional parties

Note further that the settings where BE/JBZ is joined by a party larger its size are for illustrational purposes only. It is namely questionable whether BE/JBZ would want a party larger than itself to join the cooperation, this because of political issues affecting the influence of BE/JBZ.

We will consider the methodology for the setting j=([redacted]). In table 7.3 is stated that this study's warehousing model (recall: based on the sample of 100 products) yields total expected warehousing costs per year of [redacted]. This would thus be the costs associated with setting j=([redacted]) if the additional party can facilitate [redacted] pooling advantages and cost adjustments can be effectuated.

If the additional party would yield no pooling advantages at all, the costs would become: [redacted]. This results in a theoretically achievable pooling advantage of [redacted]. These pooling gains are distributed [redacted] among HL and its clients (appendix R, figure R.1). The clients in this case thus are: [redacted]. The gains for BE/JBZ thus become [redacted]

Note that in this case gains are allocated proportionally among BE/JBZ and the additional party. The contract with HL is shaped in this way at the current date. In order to effectively benchmark against HL's prevailing flex rates we use the same method and thus pose:

Assumption 7.1: Gains for HL's clients are proportionally allocated among them.

These savings of [redacted] correspond to [redacted] of BE/JBZ's base rate (i.e. the rate they pay for the *warehousing* in the BE/JBZ situation), based on our model. When the same method is followed for each subsequent setting, we see that the relative pooling advantages gradually become less increasing. This is intuitive since for the first portion of overlapping products more relative gains (e.g. because of material- / space- or order sharing) can be effectuated. However, when considering the percentages, it is highly beneficial for BE/JBZ to plead for a larger party to join the cooperation instead of a typically smaller one (consider figure 7.1 as well). In the figure 7.2 below we obtain a graphical representation of the findings from table 7.3.

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Figure 7.2 Savings potential for BE/JBZ

The results as displayed are the savings that can be made when all costs are considered 'green'. As mentioned before, this is not realistic since not every cost is equally likely to change when an activity changes. Where the flex rates are shaped to cope with green costs, we pose that the fixed incentive (of [redacted]) is created to meet BE/JBZ in the reallocation of mainly red costs (i.e. space in this study's setting).

Where BE/JBZ is known to effectively carry large amounts of HL's fixed costs, we expect these to alter significantly when additional parties are added, and HL can thus spread these costs amongst more parties. When splitting the total savings potential for BE/JBZ (for the setting j=[redacted]) we obtain:

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Table 7.4 Savings potential for BE/JBZ

Here we thus see that when the additional party is considered, [redacted] of the total savings ([redacted] of the base rate) are because of savings on space.

Note: Now we have quantified possible pooling advantages in our warehousing model we extrapolate these findings to HL's tariffs.

HL poses an incentive of [redacted] for BE/JBZ. The amount BE/JBZ pays to HL for *warehousing* per year is (appendix R, table R.1): [redacted]. This relates to a relative incentive of [redacted]

When all costs are considered green, we would expect the total savings for BE/JBZ to become: [redacted]. Note that this figure is based on [redacted] pooling advantages. However, this is not realistic to assume. We do pose that the fixed costs BE/JBZ carries for space are to be shared with the additional party. When thus assuming that space costs for BE/JBZ can be adjusted we expect the savings for BE/JBZ to be [redacted] of the [redacted]

Thus assuming that HL wants to cover its fixed costs by largely ascribing these to its customers, we expect the incentive to be approximately twice the amount as it is specified at this current date. Note that this figure does not cope with the semi-variable costs which can partly be spread among its clients as well.

Next to that we note that these savings on fixed costs are calculated using the situation where the warehouse is *exactly* large enough. With this we mean that for each setting, the warehouse is large enough to store the products under scope, i.e. we do not deal with a warehouse that has overcapacity (as is the case at HL). When the fixed costs of this excess space are taken into account as well, we expect the incentive to be significantly higher.

Chapter 8: Transportation

In this chapter we will elaborate on the matter of transportation. For this topic a more qualitative reasoning is followed. This because of the fact that data necessary for a quantitative analysis of this topic was not available. For the remainder of this chapter the focus will be on the setting (in line with chapter 2) where Bernhoven has one location (in Uden) and Jeroen Bosch is located at Willem-Alexander. Section 8.1 will address the issues that hampered thorough analysis of this topic, where section 8.2 provides qualitative insights.

8.1 Practical issues

At first the situation accounted for in the contract between BE/JBZ and HL was as follows. For both BE and JBZ, HL would sent a trailer [redacted] to the corresponding hospital locations. This trailer would thus only contain materials for either BE or JBZ. Apart from these hospital specific deliveries, [redacted] would replenish both BE and JBZ in one combined tour. Now, some critical issues related to these routings have changed.

1. HL did not acquire a trailer with a loading capacity of [redacted] roll cages, but a smaller truck that can store [redacted] roll cages per tour instead. This was done because of the fact that for the preliminary HL situation (where thus JBZ has GZG and Carolus as hospitals that need to be replenished, and BE has respectively Veghel and Oss) the trailer was not considered suitable for delivery to GZG. This because GZG is located in the center of 's-Hertogenbosch and thus very difficult to replenish with larger vehicles.
   Given the negative implications of this vehicle's dimensions, the decision whether or not to acquire one for the setting Willem Alexander / Uden was postponed as well. This obviously hampers thorough analysis since the loading capacity of a vehicle is crucial in routing optimization.
2. The above mentioned loading capacities are based on the standard HL roll cages. However, for both health care providers holds that they aspire to use so called Automated Guided Vehicles (AGVs). However, the implementation dates of this concept and whether or not this aspiration is actually carried out are not specifically defined. The decision whether or not to make use of an AGV in the replenishment cycle automatically yields a choice for a particular roll cage design. Namely, the AGV has to be placed under the roll cage, where after this cage is lifted and automatically driven to the concerning hospital's department. Roll cages suitable for AGV handling have other dimensions. This factor introduces thus another obscurity to the determination of the vehicle's loading capacity.

Where this section elaborates on the practical issues that hampered thorough quantitative analysis in transportation, the next section will discuss (in a qualitative manner) possible research topics that are worth looking into when the above lacked data is indeed obtained.

8.2 Qualitative analysis

The above mentioned issues do not mean no significant gains may be realized in transportation. Our literature review (see appendix D, section D.4) revealed that order sharing is profitable in terms of overall transport efficiency. Cost savings generally are between 5 and 15%, Cruijssen and Salomon (2004). With respect to this order sharing it is (as mentioned in section 8.1) crucial what specific type of vehicle is chosen for the delivery. If this is known, BE/JBZ might do an independent analysis on pooling advantages in transportation. With these figures, the contract with HL might be benchmarked and optimized.

With the addition of new health care providers to the cooperation with HL, possibilities for pooling advantages in transportation significantly increase. Recall that the setting of this study is:

- Bernhoven has one hospital location in Uden.
- Jeroen Bosch has one hospital location in Den Bosch.
- Hospital Logistics has the central warehouse in Oss.

The routing with these three locations is relatively straightforward. If possible a combined tour is carried out (e.g. HL-BE-JB-HL). The exact sequence at which the hospitals are replenished is for order sharing of less importance. As long as the vehicle is loaded to its maximum feasible capacity. When 3 (or even 4) hospital locations need to be replenished, the actual routing is less trivial and a so called vehicle routing problem emerges (Toth and Vigo, 2002). The vehicle routing problem calls for the determination of a set of routes, each performed by a single vehicle that starts and ends at its own depot. With this all requirements of the hospital's locations are fulfilled, all the operational constraints are satisfied and the global transportation costs are minimized.

With respect to possible pooling advantages one can also elaborate on internal transportation. When additional parties join HL's warehouse it might be beneficial to consider order-picking of multiple hospitals on a simultaneous basis. With this we mean that orders for two equal departments (e.g. radiology) from two separate hospitals are picked at the same time, instead of sequentially. This is only beneficial of significant product overlap exists between those departments. Namely, then the probability that each picking location visited for hospital A can be used for hospital B as well, increases. Consequently, two picks can be made by visiting one location, instead of visiting two separate ones (if products do not overlap or picking is done sequentially).

Concluding we can state that it is recommended for BE/JBZ to look into these matters. Thorough analysis might yield important insights in the optimal vehicle's size (given the number of locations / the use of AGVs and whether or not accessibility restrictions are present). With respect to internal transportation it is worth keeping track of HL's picking procedures when significant product overlap is indeed effectuated. Possible benefits that emerge here may be shared among HL and its clients.

Chapter 9: Conclusions and recommendations

This chapter elaborates on the conclusions that can be drawn after thorough analysis of the problem setting and its corresponding obscurities. An overview of the findings will be presented in section 9.1. This will be done by reflecting on this study's goals and posed research questions. In section 9.2 the findings will be consecutively noted and shaped into specific recommendations for Bernhoven and Jeroen Bosch. Subsequently, section 9.3 elaborates on the limitations of this study. Finally, possible future research directions are highlighted from a scientific perspective in section 9.4.

9.1 Conclusions

This study aimed to address problems related to the allocation of costs and benefits in a health care setting. The health care providers under study (Bernhoven and Jeroen Bosch) encountered numerous obscurities in the forming of a contract with their logistics service provider, Hospital Logistics. This section will elaborate on the findings by first looking at the problem statement:

> *With respect to the new outsourcing situation little insight exists in the cost structure and therefore in the fairness of HL's contract and its allocation mechanisms.*

The goal of the problem statement was thus primarily to assess the fairness of HL's contract. Fairness being interpreted as the extent to which the tariffs towards BE/JBZ represent HL's actual incurred cost for each contractual topic, taking HL's own margin into account. We will address these issues here by using the research questions. The first one being:

What does HL's cost structure look like?

The goal of this question was to gain insight in how the warehousing costs of HL are shaped. In order to cope for its costs (which consist of ordering-, opportunity- and space costs) HL charges BE and JBZ respectively [redacted] and [redacted] per product per year. In order to asses these costs and how these would change, we conducted analyses using our own warehousing model. This model was fed with parameters for four settings. First for the setting where Bernhoven would be the only health care provider in the warehouse, second for Jeroen Bosch alone, third for the two combined and finally for the case of extension with an additional hospital. All corresponding settings were based on a sample of 100 products, which were thoroughly analyzed. The insights obtained from the third setting (BE/JBZ) highlighted that cost savings of [redacted] are theoretically feasible when inventory pooling is considered. Using HL's cost structure this translated to a theoretically feasible savings amount of [redacted] per overlapping product per year, this when each costs is considered 'green'. However, not every cost allocated to the product level (as done in our model) is equally easy to adjust when activity changes. In order to gain insight into this, an action analysis was carried out. Consequently, the potential savings amount of [redacted] was split.

The savings (in decreasing ease of realization) become:

- Supplier's charge [redacted] and opportunity costs [redacted]
- Procurement charge [redacted] and handling charge [redacted]
- Space costs [redacted]

Do the current contractual framework and its corresponding parameters give a good representation of HL's actual cost alterations?

Using the cost structure as found via the preceding research question we conducted a benchmark with HL's prevailing flex rates. HL effectively acknowledges a savings potential of [redacted] (or [redacted] of its tariff) per overlapping product per year. Half of the amount is a benefit for HL, where the other half is shared between BE and JBZ. When we consider only the easiest attainable savings (on the supplier's charge and opportunity costs) we obtain a figure of [redacted] With this we have to note that the supplier's charge is highly influenced by the methods used in our warehousing model. Namely, we ascribed supplier's costs to an individual order line (instead of per order). This because multi-article ordering was not considered. The used method may overstate the savings on ordering costs (of which the supplier's charge is part). Namely, the supplier's charge might become less relevant when orders are comprised of multiple order lines, and thus BE/JBZ exceeds the minimum threshold value for free delivery more easily. Other figures on the savings might thus be obtained. However, when leveraging on just the opportunity costs we see that these savings alone ([redacted] of HL's tariff) are already approximately twice HL's flex rate.

What is the impact of additional suitable parties to HL's cost structure and how should this justly be allocated among HL and its customers?

In order to answer this research question we again used the warehousing model. Now we analyzed different settings. Each setting coping with a different sized additional party joining the cooperation. The results of these analyses indicated that it is indeed beneficial for BE/JBZ to actively look for additional parties. If a party which is ([redacted]) of BE/JBZ's combined size joins the warehouse, the theoretically feasible pooling advantages for BE/JBZ would become [redacted] However, this percentage is based on the assumption that all costs are considered 'green'.

When looking at the space costs (which are considered fixed by HL) we pose that the additional party incentive has to cope with these. Namely, if these fixed costs are neither accounted for in the flex rates nor this incentive, BE/JBZ continues to carry the entrepreneurial risks of HL. Since these risks decrease when more parties join the coalition, BE/JBZ should significantly be compensated for this.

When only considering these fixed costs, we would expect this incentive to be [redacted] Note that this amount is based on the situation where the warehouse is *exactly* large enough, i.e. we do not deal with a warehouse that has overcapacity (as is the case at HL). When the fixed costs of this excess space are taken into account as well, we expect the incentive to be significantly higher. When considering the prevailing incentive of [redacted] for BE/JBZ as posed by HL we see a discrepancy that may be accounted for.

9.2 Recommendations

In this section we will consecutively state the recommendations for BE/JBZ. Using the insights from this study and the recommendations below, might prove beneficial in future contract negotiations.

9.2.1 Product flex rates

HL effectively poses cost savings from product overlap to be [redacted] per product per year, where we calculate the savings on opportunity costs alone to be already approximately [redacted] this amount. It is therefore recommended for BE/JBZ to reopen the discussion concerning the specification of these rates. This may prove beneficial. Namely, HL poses an incentive of [redacted] which is to be distributed [redacted] among HL and its clients. For BE, this thus yields [redacted] per product less in the assortment of BE, or [redacted] per overlapping product. This seems to be an understatement of realizable savings. Where HL may be reluctant to alter this amount, the action analysis might provide valuable insights at contract negotiations. However, with this should be noted that the entrepreneurial risk should actually be shifted towards HL, not towards BE/JBZ as appears to be the case now, since BE/JBZ covers large amounts of HL's fixed costs. BE/JBZ should significantly be compensated for the carrying of these risks, this either by the flex rates, or the additional party incentive (see section 9.2.2).

With respect to the flex rates, it is recommended to negotiate flex rates for both sterile and non-sterile products. This since sterile storage proved to be significantly more expensive, mainly because of the costs for the clean room. BE/JBZ should reflect on the extent it wishes to pay HL's fixed costs. With respect to this issue significant gains may be realized. Furthermore, sterile products on average have a higher lead time than non-sterile products (since it occurs they have to be sterilized at the supplier before shipment). A larger lead time thus implies higher (safety) stocks. This brings about higher costs for sterile products (compared to non-sterile ones) as well.

Furthermore, in the future it may be beneficial for BE/JBZ to request its suppliers for an overview of a product's dimensions. With this specific kind of information, BE/JBZ might facilitate better use of its internal storage space, especially taking the new hospital locations into account. Next to that, HL might be better able to optimize its warehouse operations. This again might yield monetary gains since HL poses to distribute long term cost savings on a [redacted] basis.

With respect to the ordering costs of a product we note the following. In our sample we assumed products (and thus suppliers) to be [redacted] overlapping. Where this is a theoretical implication, this insight may already prove beneficial at this current date. Namely, analysis among inventory articles between BE and JBZ revealed significant overlap in its suppliers. It might prove beneficial to look into this and quantify the pooling advantages at this current date. This because HL will be able to realize larger orders (when more supplier overlap is effectuated) and thus consecutively incur fewer ordering costs. BE/JBZ should keep track of these figures in order to reopen discussion of its tariffs if this is necessary.

9.2.2 Additional party incentives

Where HL poses to pay BE/JBZ [redacted] (excl. VAT) when an additional party of [redacted] BE/JBZ's size is added, we consider this [redacted] to be an understatement of actual incurred gains. The theoretically feasible gains are [redacted], which would translate to an amount of [redacted]. HL has to significantly compensate BE/JBZ for the fixed costs they carry. When only considering these costs we expect the incentive for BE/JBZ to become at least [redacted]. BE/JBZ should be aware of this potential and use this in its contract negotiations.

Since this study indicated that larger parties are more beneficial for addition to the cooperation than smaller ones, BE/JBZ should take this into account when introducing HL to potential candidate hospitals. With this however, it is questionable whether BE/JBZ would want a party larger than itself to join the cooperation, this because of political issues concerning the effective influence of BE/JBZ.
Recall that the insight above is valid under the assumption that HL uses proportional allocation on the gains for its clients. This specific allocation mechanism posed by HL may be reconsidered. Other methods may prove to be more fair for BE/JBZ.

Furthermore, this study revealed that additional parties with more product overlap may be considered more suitable for addition to the cooperation. BE/JBZ should take this into account as well. Next to that, they should not only look at the existing extent of product overlap, but to the potential on realizing this in the future as well. With respect to this it is recommended to look at hospitals with shared suppliers, shared specialisms or which are part of the 'Inkoop Alliantie Ziekenhuizen' (IAZ).

9.2.3 Transportation

Since no thorough analysis on transportation could be conducted, it is recommended that BE/JBZ look at this at a later stage. Significant pooling advantages with respect to routing might be obtained, especially in the case where more than 2 hospital locations are replenished by HL. Furthermore, it is worth keeping track of HL's picking procedures when significant product overlap is indeed effectuated.

9.3 Limitations of this study

This study has some limitations which will be discussed in this section. First of all, we mention the product scope. Because of obvious time constraints we had to delineate the products under study. Where we decided to look into 100 products, it is arguable whether or not this figure is high enough for objective generalizability.

Next to that, this study highlights the quantitative modeling with respect to the services of a logistical service provider. Any qualitative advantages in inventory pooling or outsourcing are not considered.

Furthermore, where data about actual use at a hospital's department is ample, it is very difficult to obtain figures related to costing. The parameter values obtained in this study are subject to estimation errors. However, since we used the same costing parameters throughout all different settings, the *relative* figures obtained are not prone to this error. A thorough and all-embracing study for the cost parameters is recommended, but was not feasible in this study's time constraints.

Finally, the optimization model does not deal with multi-article ordering. This method was not considered in order to benefit the solvability of the optimization problem. Instead this approximation method (based on the amount of order lines) was used. For this reason an overstatement of savings on ordering costs might be obtained. Namely, the supplier's charge might become less relevant when orders are comprised of multiple order lines, and thus BE/JBZ exceeds the minimum threshold value for free delivery more easily. With this different results on potential savings might be obtained.

9.4 Future research directions

This first issue to which future research should be directed is the subject of the thesis in general. Health care logistics is a relatively new concept in the Netherlands. Where qualitative research is ample, the quantitative approach is less extensively covered. Literature especially lacks practical applications or thorough case studies. Another aspect is the allocation of gains among a TPL provider and its clients. The definition of perceived fairness is hard to assess and account for when total costs are mainly considered to be fixed.

References

Aptel, O., Pourjalali, H., (2001). “Improving activities and decreasing costs of logistics in hospitals. A comparison of U.S. and French hospitals”. *The International Journal of Accounting* 36 (2001), p. 65-90.

Axsäter, S., (1996). “Using the deterministic EOQ formula in Stochastic Inventory Control”. *Management Science* 42 (6), p. 830-834.

Bartlett, C., Ghoshal, S., (2000). “Managing across boundaries: the collaborative challenge. Text, Cases and Readings in Cross-Border Management”. Irwin/McGraw-Hill, Boston, p. 403-502.

Benjumea, N.S., (2010). “Finding out opportunities in Franciscus Ziekenhuis: The influence of a Third-Party logistics service within the supply chain”. *Master Thesis of Industrial Engineering, Eindhoven University of Technology*.

Boot, J.M., Knapen, M.H.J.M, (2005). “De Nederlandse Gezondheidszorg”. Bohn Stafleu van Loghum.

Burgin, T.A., (1975). “The Gamma Distribution and Inventory Control”. *Operational Research Quarterly* 26 (3), p. 507-525.

Coyle, J.J., Bardi, E.J., Langley, C.J., (2003). “The Management of Business Logistics-A Supply Chain Perspective”. South-Western Publishing, Mason.

Cruijssen, F., Cools, M., Dullaert, W., (2005). “Horizontal cooperation in logistics: Opportunities and impediments”. *Transportation Research Part E* 43 (2007), p. 129-142

Cruijssen, F., Salomon, M., (2004). “Empirical study: Order sharing between transportation companies may result in cost reductions between 5 to 15 percent”. *CentER Discussion Paper* 80, Faculty of Economics and Business Administration, Tilburg University, The Netherlands.

Dai, S. H., Wang, M.O., (1992). “Reliability analysis in engineering applications”. Van Nostrand Reinhold, New York.

De Kok, A.G., Tijms, H. C., Van Der Duyn Schouten, F.A., (1984). “Approximations for the single-product production-inventory problem with compound poisson demand and service-level constraints”. *Advances in Applied Probability* 16, p. 378-401.

De Kok, A.G., (2005). “Analysis of stock control models for one location with one product”. Reader commissioned by the Department of Industrial Engineering and Innovation Sciences, Eindhoven University of Technology.

Dyer, J., Singh, H., (1998). “The relational view: cooperative strategy and sources of interorganizational competitive advantage”. *The Academy of Management Review* 23 (4), p. 660-679.

European Union, (2001). “Commission notice: guidelines on the applicability of Article 81 of the EC Treaty to horizontal cooperation agreements”, (2001/C 3/02).

Evers, P.T., (1995). “Expanding the square root law: an analysis of both safety and cycle stocks”. *The Logistics and Transportation Review* 31, p. 1-20.

Field, A., (2005). “Discovering Statistics Using SPSS”. SAGE Publications, London.

Fortuin, L., (1980). “Five popular probability density functions: a comparison in the field of stock-control models”. *Journal of Operational Research Society* 31, p. 937-942.

Garrison, R., Noreen, E., Seal, W., (2003). “Management Accounting, European Edition”. McGraw-Hill, Berkshire.

Gerchak, Y., and Gupta, D., (1991). “On apportioning costs to customers in centralized continuous review inventory systems”. *Journal of the Operations Management* 10, p. 546-551.

Jarett, P.G., (1998). “Logistics in the health care industry”. *International Journal of Physical Distribution and Logistics Management* 28, p. 741-742.

Kaplan, R. S., Cooper, R., (1998) “Cost and Effect: Using Integrated Cost Systems to Drive Profitability and Performance”. Harvard Business School Press, Boston.

Krajewska, M.A., Kopfer, H., Laporte, G., Ropke, S., Zaccour, G., (2007). “Horizontal cooperation among freight carriers: request allocation and profit sharing”.

Lieb, R.C., (1992). “The use of third-party logistics services by large American manufacturers”. *Journal of Business Logistics* 13 (2), p. 29-42.

Limam, S., (2002). “Simulation of Operational Processes”. Reader commissioned by the Department of Industrial Engineering and Innovation Sciences, Eindhoven University of Technology.

Marasco, A., (2007). “Third-party logistics: A literature review”. *Int. J. Production Economics* 113 (2008), p. 127-147.

Montgomery, D.C., Runger, G.C., (2003). “Applied statistics and probability for engineers”. John Wiley & Sons, New York.

Naddor, E., (1978). “Sensitivity to distributions in inventory systems”. *Management Science* 24, p. 1769-1772.

Nicholson, L., Vakharia, A., Erenguc, S., (2002). “Outsourcing inventory management decisions in healthcare: Models and application”. *European Journal of Operational Research* 154 (2004), p. 271-290.

Ordeshook, P.C., (1986). “Game theory and Political Theory”. Cambridge University Press, Cambridge.

Osborne, M.J., Rubinstein, A., (1994). “A Course in Game Theory”. MIT Press, Cambridge.

Parkhe, A., (1993). “Strategic alliance structuring: a game theoretic and transaction cost examination of interfirm cooperation”. *The Academy of management Journal* 36 (4), p. 794-829.

Roth, H. P., Sims, L.T., (1991). “Costing for Warehousing and Distribution”, *Management Accounting* 73 (2), p. 42-45.

Silver, E.A., Pyke, D.F., Peterson, R., (1998). “Inventory Management and Production Planning and Scheduling”. John Wiley & Sons, Hoboken.

Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., (1999). “Designing and Managing the Supply Chain: Concepts, Strategies, and Cases”. McGraw-Hill.

Skjoett-Larsen, T., (2000). “Third party logistics - From an interorganizational point of view”. *International Journal of Physical Distribution and Logistics Management* 30 (2), p. 112-127.

Slikker, M., (2009). “Game theory with application to supply chain management”. Reader commissioned by the Department of Industrial Engineering and Innovation Sciences, Eindhoven University of Technology.

Toth, P., Vigo, D., (2002). “The Vehicle Routing Problem”. University City Science Center, Philadelphia.

Tyan, J., Wang, F., Du, T., (2003). “An evaluation of freight consolidation policies in global third party logistics”. *Omega* 31 (1), p. 55-62.

Van de Poel, E. Y. (1991). “Centraal voorraadbeheer in het A.Z.R.” *Master Thesis Econometrics Erasmus University Rotterdam.*

Van der Vlist, P. (2007). “Synchronizing the Retail Supply Chain”, *Dissertation at Rotterdam Erasmus University, The Netherlands.*

Van Strien, P.K. (1997). “Towards a Methodology of Psychological Practice”. *Theory and Psychology* 7 (5), p. 683-700

Zheng, Y.S., (1992). “On properties of stochastic inventory systems”. *Management Science*, 38 (1), p. 87-103.

Zinn, W., Levy, M., and Bowersox, D.J., (1989). “Measuring the Effect of Inventory Centralization/Decentralization on Aggregate Safety Stock: The ‘Square Root Law’ Revisited.” *Journal of Business Logistics* 10, p. 1-13.

Appendix A: List of figures

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Appendix D: Literature review

D.1 Outsourcing and TPL

Nowadays, numerous companies look at options to improve and streamline both their internal and external processes. This holds for all branches of industry, i.e. health care as well. There are many ways of achieving this. Outsourcing part of a company's activities is for example one of the possibilities. This section will cover the reasons these companies, more specifically health care providers, may have when considering outsourcing or making use of a TPL-provider's (i.e. third-party-logistics) services.

When looking at the reasons Dutch health care providers may have for outsourcing their logistical operations we can distinguish two main arguments.

- Section D.1.1 will cover a literature review which highlighted significant benefits for concerning parties in the case of using outsourcing principles (among others: Nicholson et al, 2004; Jarett, 1998; Aptel and Pourjalali, 2001).
- Next to that, section D.1.2 elaborates on the fact that the Dutch health care industry is subject to significant changes which affect all health care providers (Boot and Knapen, 2005).

D.1.1 Generic literature

Traditionally, supply chains in the healthcare environment have been very reliant on hospital personnel to monitor and order supplies. Receiving, sending and storing of goods requires a significant amount of space within hospitals. Furthermore, the frequent deliveries of supplies cause jams. This both inside (within the logistics department) and outside the hospital (i.e. truck movements on its premises). Often hospitals are confronted with supply chain inefficiencies because of overstocking and aging of products, and waste. Recent trend has shifted these logistical challenges towards companies specialised in the above mentioned TPL concept.

According to Lieb (1992) TPL involves 'the use of external companies to perform logistics functions that have traditionally been performed within an organization. The functions performed by the third party can encompass the entire logistics process or selected activities within that process'. Coyle et al (2003) state that: TPL involves an external organisation 'that performs all or part of a company's logistics functions'. These 'broad' definitions appear to suggest that TPL includes any form of outsourcing of logistics activities previously performed 'in-house'. However, key element with this is that TPL is, next to the provision of a broad range of services, also about a long-term duration, joint efforts to develop cooperation, the customization of the logistics solution and a fair sharing of benefits and risks (Marasco, 2007). This thus implies that TPL incorporates mainly strategic and not just tactical dimensions (Skjoett-Larsen, 2000).

Furthermore, in a health care setting outsourcing inventory decisions are primarily driven by three factors:

- Inventory investments in this industry are substantial (among others Aptel and Pourjalali, 2001).

- Healthcare providers focus on quality of service both from an internal and external perspective. It has been argued that the move towards outsourcing of inventory can lead to improved internal performance as assessed through service levels (Jarett, 1998).
- Further, improving internal service levels also positively impacts patient care and this, in turn, should lead to increases in the external measures of customer satisfaction (Nicholson et al, 2004).

D.1.2 The Dutch health care industry

When looking at the changing environment of the Dutch health care we can identify two significant reasons for the increasing use of third party logistics in this industry. First of all, Boot and Knapen (2005) mention that starting around 1980 the Dutch government increasingly formed its (health care) policy around the so-called market forces (in Dutch: 'marktwerking'). This means that policy is aimed at maintaining or restoring market relationships. Key issue in this is influencing a nation's scarcities, i.e. preventing unwanted monopoly- or cartel constructions. The effectiveness of this policy can be found in the interest that the different parties (e.g. insurance companies and health care providers) have in delivering (cost-) effective and high quality health care. This holds for insurance companies because of mutual competition and the freedom its customers have in switching between the different insurance providers. When they conclude adverse agreements (in comparison with competitors) with health care providers they will evidently lose market share. The same holds for the actual health care providers.

Thus quality and cost-effectiveness become increasingly more important in the Dutch health care setting. To this point can be added that the way Dutch Hospitals have to finance their expansion (or building of new locations / facilities) has changed dramatically. These days (opposed to several years back) hospitals have to finance this themselves, i.e. without any governmental help.

Keeping this in mind, the different parties explore options in reducing costs and improving customer (i.e. patient) satisfaction. This coincides with an increase in the expertise and opportunities (e.g. because of technological developments) of TPL-providers which offer inventory management services. Because of these forces a number of Dutch and Belgian (we see the same trend emerging in this country as well) hospitals decided to outsource their inventory management. This being for instance (among others) in the Netherlands: Gelre Hospital and Groene Hart Hospital, and in Belgium: UZ Leuven and AZ Diest.

D.2 Strategic alliances

Where the previous section highlights the reasons health care providers have in outsourcing their logistical operations, this section elaborates on the questions why they might do this *jointly* (i.e. in a multi party setting).

The driving force behind the formation of alliances is each participant's expectation of a net positive value to the expected alliance outcomes (Parkhe, 1993). By cooperating, partners can generate so-called relational rents (Dyer and Singh, 1998). Relational rents are about supernatural profit jointly generated in an exchange relationship that cannot be generated by either firm in isolation and can only be created through the joint contributions of the specific alliance partners (Dyer and Singh, 1998). In a logistics context relational rents can be both 'hard' and 'soft'. E.g. when forming an alliance the combined bargaining power accumulates and thus economies of scale can be achieved (i.e. 'hard' rents), but mutual learning effects occur as well (i.e. 'soft' rents). Especially in a logistical setting, alliances can be very fruitful (Cruijssen, 2005).

Bartlett and Ghosal (2000) mention three ways in which strategic alliances allow participating firms to reap the benefits of scale economies of learning: by pooling their resources and concentrating on core activities, by sharing and leveraging the specific strengths and capabilities of the other participating firm, and by trading different or complementary resources to achieve mutual gains and eliminate the high cost of duplication. More specifically, keeping above stated reasons in mind, health care providers might decide to *jointly* evaluate their reasons for outsourcing their logistical operations because of:

- Economies of scale in bargaining with a third party logistics provider. When contacting a company specialized in TPL it is beneficial to have a significant company size. Namely, larger sized customers generally are more interesting for TPL's than smaller ones. This because with larger volumes the TPL itself can better exploit its own economies of scale, and thus work more cost effective, and is consequently more probable to maintain a higher profitability. E.g. two health care providers combined obviously consume larger orders and thus are more interesting for the TPL than one of these parties considered on its own. This implies that the TPL is more willing to discuss (for both health care providers) favourable terms, which could result in generated costs savings on behalf of those.
- Learning effects. When for instance two health care providers have no prior experience in the field of outsourcing logistical operations, it could be wise to combine insights from both organizations in evaluating possibly suitable options. By forming an alliance, expertise from within both hospitals can be aggregated, which facilitates mutual discussion and could yield new solutions that are beneficial for both parties.

D.3 Inventory centralization

Inventory centralization (or consolidation) of several uncertain demands is known to reduce cost through risk or statistical economies of scale (among others: Eppen, 1979; Zinn et al, 1989). However, an important question that arises when several customers are served from the same centralized stock is to allocate the inventory costs among them. If that is not done rationally, some customers may end up with higher allocated costs than if they were served from a dedicated stock point, despite the overall benefit of consolidation.

D.3.1 Safety and cycle stock

The effect of consolidating inventories into fewer locations has two distinct components: the safety stock and the cycle stock (Evers, 1995). Cycle stock being the portion of inventory available (or planned to be available) for the normal demand during a given period and is formed by items arriving infrequently but in large quantities to meet frequent (but small-quantity) demand. It is also called working stock or lot size stock. Next to that, safety stock comprises all inventory held as buffer against a mismatch between forecasted and actual demand, and unforeseen circumstances. The safety stock component corresponds to the so called portfolio effect (Zinn et al, 1989).

D.3.2 Portfolio effect

The percent reduction in aggregate safety stock made possible by centralizing inventories is also known as the portfolio effect (Zinn et al, 1989). The portfolio effect (PE) is independent of specific values of the standard deviation of demand in locations being considered for centralization or decentralization of inventories. It is instead, a function of two variables: sales correlation of past sales between two stocking locations and 'Magnitude', which is the quotient of standard deviation of sales between two stocking locations.
The underlying principle explaining the portfolio effect is based on risk-pooling. Zinn et al (1989) quantify the PE as:

$$PE = 1 - \frac{SS_a}{\sum_{i=1}^{N} SS_i}, \text{ for } 0 \leq PE \leq 1 \qquad \text{(D.1)}$$

Notation:

SS_a	=	aggregate safety stock for a given product if inventory is consolidated.
SS_i	=	safety stock for a given product at location *i*.

The bounds of the PE are 0 and 1. The closer the PE is to the upper bound, the greater the percent reduction in aggregate safety stock if inventories are consolidated. Obviously, when PE is 0, there is no reduction in aggregate safety stock as a result of consolidation.
Concluding, we can say that the portfolio effect is maximized whenever the sales correlation between two inventory locations is highly negative and the Magnitude small. The opposite is also true. The PE is minimized when sales correlation between two stocking locations is highly positive (regardless of the Magnitude).

D.4 Transportation

Fierce competition in global markets, the introduction of products with shorter life cycles and the heightened expectations of customers have forced shippers and third party logistics providers to invest in developing stronger and mutually beneficial relationships with each other (Cruijssen et al, 2005).

The most common and best-studied type of *vertical* cooperation involves shippers hiring TPL-providers to perform all or part of their materials management and product distribution function (Simchi-Levi et al, 1999). Tyan et al (2003) describe the supply chain advantages of consolidation of logistics flows by TPL's. The increased economies of scale make it for example possible to acquire large equipment that would have been too expensive for the individual shipper.

Next to the above mentioned *vertical* cooperation there exists so called *horizontal* cooperation, which is defined by the European Union (2001) as coordinated practices between companies operating at the same level(s) in the market. Through close collaboration, the partnering TPL's aim at increasing productivity, e.g. by optimizing vehicle capacity utilization, reducing empty mileage and cutting costs of non-core activities to increase the competitiveness of their logistics networks. With this order sharing, companies mutually share order data for simultaneous planning, such that in the long run total market demand for transportation capacity better matches with supply. By doing this all kinds of cost advantages emerge. Cruijssen and Salomon (2004) only consider the operational costs with this respect. They illustrate order sharing in the context of the transportation of flowers in The Netherlands and show that it is profitable in terms of overall transport efficiency. Cost savings generally are between 5 and 15% and are sometimes even higher. Taking into account the thin profit margins in road transportation, these cost savings are considerable. Their results also show that order sharing is more profitable when a large number of transportation companies participate. This insinuates an incentive for cooperation and integration.

Another issue in (horizontal) cooperation is the aspect of gain sharing (i.e. benefit allocation). This because savings from order sharing can per definition only be generated when a group of companies cooperate, there is a clear need for a fair allocation mechanism of these savings among the participating companies. This mechanism may be of crucial importance for the success of an order sharing initiative. In coping with this issue we take a look at the field of cooperative game theory.

D.5 Cooperative game theory

Cooperative game theory primarily deals with joint profits that can be obtained by groups of players if they coordinate their actions (Slikker, 2009). In some situations these joint profits are freely transferable between the players whereas in other situation they are not.
Krajewska et al (2007) propose a framework for profit sharing using concepts from cooperative game theory, more specifically using the Shapley value. To define a cooperative game, two ingredients are needed:

- A set $P = \{1,..., p\}$ of players (in this framework the TPL-providers).
- A characteristic function $v(S)$ which assigns to each possible coalition of players $S(S \subseteq P)$ a numerical value. This value can be interpreted as a measure of a player's individual power (i.e. payoff) of the coalition.

This characteristic function must satisfy two conditions:

$v(\varnothing) = 0$ and (D.2)

$v(S \cup T) \geq v(S) + v(T)$ with $\forall S,T \subseteq P$ where $S \cap T = \varnothing$ (D.3)

The first property states that an empty coalition has zero value, where the second (called superadditivity) states that when two coalitions start working together they can at least achieve the same payoff as when working separately.

A vector $x = (x_1,..., x_p)$ is called an imputation if it satisfies:

$x_i \geq v(\{i\}), \forall i \in P$ (D.4)

$$\sum_{i=1}^{p} x_i = v(P) \tag{D.5}$$

An imputation is a set of players' outcomes. Its definition refers to individual (D.4) and group rationality (D.5). Individual rationality means that a player will not accept an outcome which is not at least equal to what he could obtain by acting alone as measured by his characteristic function value. Group rationality states that the total cooperative gain, when the grand coalition forms, is fully shared.

From a negotiation perspective, the set of imputations (denoted by X) can be seen as the set of feasible agreements. This set is seldom a singleton and therefore one needs other properties to predict the final issue of the game. This is precisely the objective pursued by the different solution concepts of cooperative games. The set of solutions include the kernel, the bargaining set, the stable set, the core, the Shapley value and the nucleolus (see among others Slikker (2009), Osborne and Rubinstein (1994) or Ordeshook (1986) for an introduction to these concepts).

Appendix E: Flex tables

Confidential.

Table E.1 Flex table Bernhoven

Confidential.

Table E.2 Flex table Jeroen Bosch

Appendix F: Introduction to replenishment control

F.1 (s,Q) systems

A (s,Q) system is a continuous review policy. When the inventory position (represented by the dashed line in figure F.1, or the solid one where both coincide) drops below the reorder point *s*, a replenishment order (with lead time *L*) of size *Q* is placed.

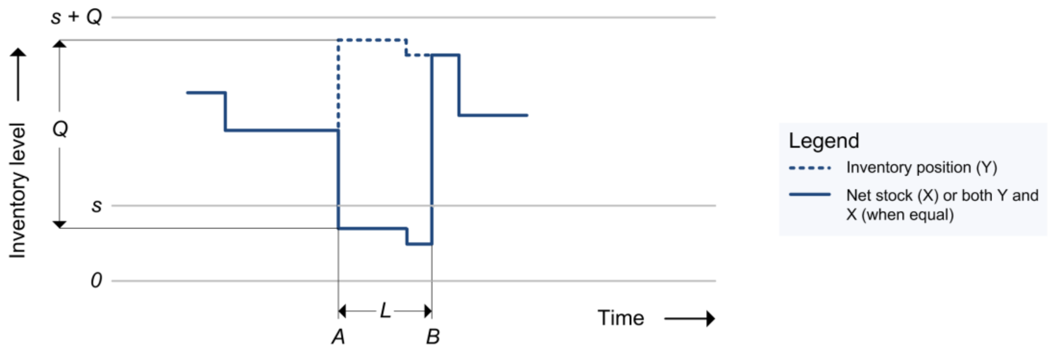

Figure F.1 (s,Q) system

When letting go of a fixed replenishment quantity *Q* one can use the so-called (*s*,*S*) system.

F.2 (s,S) systems

Just as the (s,Q) system, the (s,S) system is a continuous review policy. When the inventory position drops below the reorder point *s*, a replenishment order is placed (with lead time *L*). Opposed to the (s,Q) system, this replenishment order does not have a fixed size. The name of this policy (i.e. Order-Up-To-Level) already indicates this. The order has a variable size large enough to raise the inventory position to a predetermined (Order-Up-To-Level) *S*.

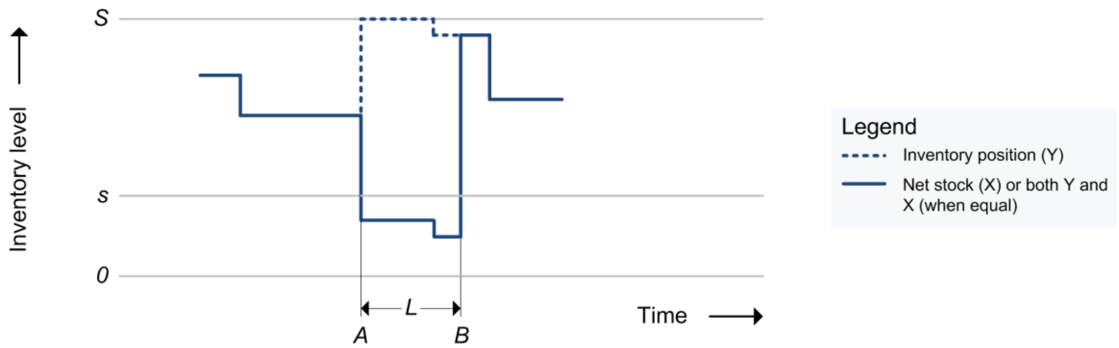

Figure F.2 (s,S) system

This (s,S) system is often referred to as a min-max system. This because *Y* (except for a short drop below the reorder point *s*) is always between the minimum value of *s* and the maximum value of *S*.

Appendix G: Demand process at Bernhoven Hospital

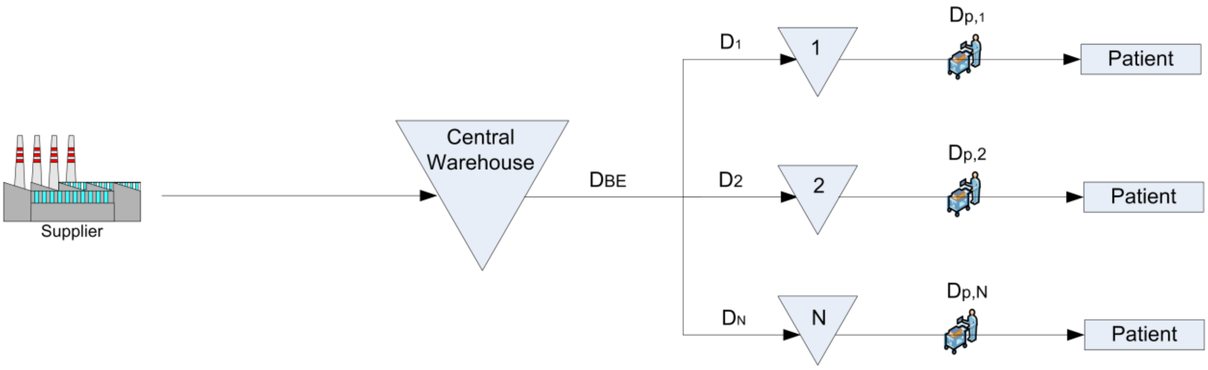

Figure G.1 Demand process at Bernhoven Hospital (for one product)

Notation:

i	=	department, where i=1…N.
p	=	one patient at a department i, where p=1…M.
$D_{p,i}$	=	demand of patient p which is met by department i.
D_i	=	aggregated patient demand at department i.
D_{BE}	=	aggregated department demand at central warehouse.

With:

$$D_i = \sum_{p=1}^{M} D_{p,i} \quad \text{(G.1)}$$

$$D_{BE} = \sum_{i=1}^{N} D_i = \sum_{i=1}^{N}\sum_{p=1}^{M} D_{p,i} \quad \text{(G.2)}$$

Starting on the right hand side of the figure we see that the departments' (e.g. nursery, radiology etc.) patients create demand for a particular product. This demand is met from each department's own individual stock.

Each department carries its own individual stock in several cabinets. These cabinets are subdivided into individual bins, that each holds products. For each product, 2 bins (of equal predetermined size) are used. Whenever one bin is empty, the hospital staff picks the products from the other bin.

Consecutively, these departments are replenished by the central warehouse. In this central warehouse, the demand of the N departments is aggregated (D_{BE},). Based on this demand, inventory management takes place and replenishment orders are generated for the supplier.

Appendix H: Modified EOQ formula

H.1 Assumptions

1. The demand rate is constant and deterministic.
2. The order quantity need not be an integral number of units, and there are no minimum or maximum restrictions on its size.
3. The unit variable costs do not depend on the replenishment quantity.
4. The cost factors do not change with time.
5. The item is treated entirely independent of other items.
6. The replenishment lead time is of zero duration.
7. No shortages are allowed.
8. The entire order quantity is delivered at the same time.
9. The planning horizon is very long, i.e. all parameters will continue at the same values for a long time.

H.2 Derivation

In this section we will elaborate on the modified EOQ formula as used in the model for warehousing. First the general EOQ formula (and its corresponding drawbacks for this study) will be discussed (based on Silver et al, 1998). Thereafter a modification is made to the standard formula, in order to meet this study's requirements.

H.2.1 Standard EOQ formula

First note that the inventory level for a standard EOQ formula is shaped like a so called saw tooth curve, as sketched in figure H.1.

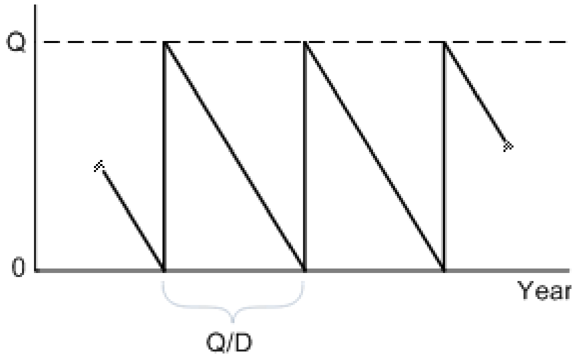

Figure H.1 Behavior of inventory level

Each time a replenishment order of size Q is placed, order costs of size A are incurred next to the amount of Qv for acquiring the actual products (each unit having a value of v euros). So the replenishment costs per year are:

$$C_r = (A + Qv) \cdot \frac{D}{Q} = \frac{AD}{Q} + Dv \text{ (€/year)} \tag{H.1}$$

Note that Dv does not depend on Q and therefore cannot influence the optimal order quantity Q, i.e. Dv is omitted in further calculations. Given that the costs of keeping one unit in inventory are equal to rv where r are the costs of having one euro in inventory per time unit (€/€/yr) and the average inventory equal to ($Q/2$), the total relevant costs are:

$$TRC(Q) = \frac{AD}{Q} + \frac{Q}{2} vr \text{ (€/year)} \tag{H.2}$$

Optimization yields: $$EOQ = \sqrt{\frac{2AD}{vr}} \tag{H.3}$$

H.2.2 Modified EOQ formula

Note that this study's cost function is given by:

$$TC(Q_i^*, s_i) = A_i \left[\frac{365 \cdot \mu_i}{Q_i^*} \right] + ho_i \left[\left(s_i - \mu_{L_i+R_i} \right) + \frac{Q_i^*}{2} \right] + hs_i \left[Q_i^* + s_i - \left(\mu_{L_i+R_i} - 1.64\sigma_{L_i+R_i} \right)^+ \right] \tag{H.4}$$

Since preliminary analysis revealed this function to be convex, the minimum can be found by using the necessary condition that the slope of the curve is zero at the minimum. Thus taking the first derivative over Q_i^* yields:

$$\frac{dTC(Q_i^*, s_i)}{dQ_i^*} = -A_i \left[\frac{D_i}{Q_i^{*2}} \right] + \frac{ho_i}{2} + hs_i \text{ where } D_i = 365 \cdot \mu_i \tag{H.5}$$

Rewriting the formula gives:

$$-A_i \left[\frac{D_i}{Q_i^{*2}} \right] + \frac{ho_i}{2} + hs_i = -A_i D_i + Q_i^{*2} \left[\frac{ho_i}{2} + hs_i \right] \tag{H.6}$$

And thus:

$$Q_i^* = \sqrt{\frac{A_i D_i}{hs_i + \frac{ho_i}{2}}} = \sqrt{\frac{2 A_i D_i}{2hs_i + ho_i}} \tag{H.7}$$

To guarantee that we deal with a minimum we have to check whether the second derivative is positive, we see that this holds for any value $Q_i^* > 0$.

$$\frac{d^2 TC(Q_i^*, s_i)}{dQ_i^{*2}} = \frac{2 A_i D_i}{Q_i^{*3}} \tag{H.8}$$

Now the modified EOQ formula has been derived, we compare the standard EOQ formula (H.3) with the modified one (H.7), and note the factor '2' in front of the space costs in the denominator. Furthermore, space costs and opportunity costs are modeled as two separate parameters.

H.2.3 Coping with a predetermined box size

In the section above, the method for determining the theoretical optimal order quantity is given. Recall the second assumption: "The order quantity need not be an integral number of units, and there are no minimum or maximum restrictions on its size". However, as mentioned in section 4.6.2, we deal with predetermined order quantities. We thus obtain the following interdependence:

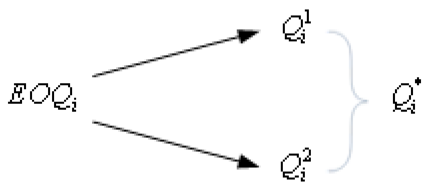

Figure H.2 Interdependence between order quantities

Since we round EOQ_i in two ways with which we resume calculations we thus bring about that Q_i^* is either larger or smaller than EOQ_i. This method is allowed because the minimum costs are obtained with an order quantity that lies in the interval $[Q_i^1, Q_i^2]$ where EOQ_i yields the theoretical minimum. Since $Q_i^1 \leq EOQ_i$ and $Q_i^2 \geq EOQ_i$ we explore all relevant possibilities for a costs minimizing order quantity that is practically feasible.

Appendix I: Introduction to the Normal distribution

A random variable *X* with probability density function (pdf)

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \quad \text{where } -\infty < x < \infty \quad \text{(Montgomery, 2003)} \tag{I.1}$$

is a Normal random variable with parameters μ, where $-\infty < \mu < \infty$, and σ >0.

Furthermore,

$$E(X) = \mu = \int_{-\infty}^{\infty} xf(x)dx \text{ and} \tag{I.2}$$

$$V(X) = \sigma^2 = \int_{-\infty}^{\infty} (x-\mu)^2 f(x)dx = \int_{-\infty}^{\infty} x^2 f(x)dx - \mu^2 \tag{I.3}$$

and the notation $N(\mu,\sigma^2)$ is used to denote the distribution.

Notation:

$E(X)$ = expectation of *X*.

$V(X)$ = variance of *X*.

In the situation where $\mu = 0$ and $\sigma = 1$ we obtain the so called standard Normal distribution.

Appendix J: Outlier removal

1. For each individual product under scope the releases per day (in 2009) from the central warehouse to the departments are obtained.
2. These releases are analyzed for outliers and negative values. We constructed a so called outlier plot. This plot displays respectively the absolute released amount (on the left Y-axis), the standardized released amount (on the right Y-axis) and the corresponding row number of the release (on the X-axis). We describe the analysis below for product 000230057 (a specific type of infusion system).

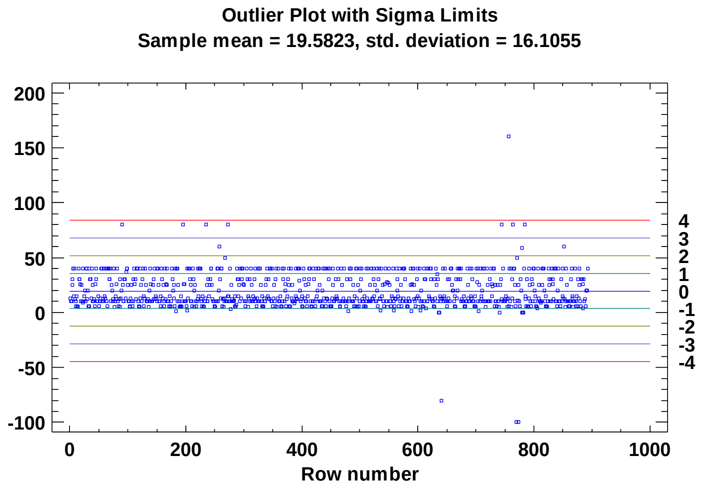

Figure J.1 Outlier plot for article 000230057

3. In the figure above we thus see 3 negative values which are firstly removed. These values are removed because otherwise they would distort the mean and standard deviation. The negative values may be the result of administrational reversals. However, since these are not clearly linked to corresponding (positive) releases these cannot be corrected and thus have to be removed. The negative values are:

Amount	Row	Date
-80	641	22-9-2009
-100	770	12-11-2009
-100	773	13-11-2009

4. When these negative values are removed we look at the updated outlier plot again. To evaluate and select appropriate data for analysis we used the 'Three-Sigma Rule' by Dai and Wang (1992). This rule uses the fact that 99.7% (see figure 4.3 in chapter 4) of all values of a normally distributed parameter fall within three standard deviations of the mean. Points beyond this range are usually reason for concern (Field, 2005). We thus pose to remove any value that is not in the interval $\mu \pm 3\sigma$. Larger samples are more likely to have values outside this interval than smaller sized samples.

   It is however not viable to individually asses each value outside of this interval and because we chose to consequently follow a same methodology for each consecutive product we here thus remove the following releases:

Amount	Row	Date
80	90	6-2-2009
80	195	19-3-2009
80	235	6-4-2009
80	272	21-4-2009
80	745	3-11-2009
160	757	6-11-2009
80	764	10-11-2009
80	784	19-11-2009

5. After that, the remaining 879 cases are exported back to Microsoft Excel and allocated to each corresponding release date. Using these filtered release data, the mean and standard deviation of *daily* demand are calculated (see appendix K).

Appendix K: Products under scope at Bernhoven

Confidential.

Table K.1 Product's under scope (Veghel, 2009)

Appendix L: Suppliers under scope at Bernhoven

Confidential.

Table L.1 Supplier's under scope (Veghel, 2009)

Appendix M: HL's tariffs for storage

In this appendix we will elaborate on the amount BE/JBZ has to pay to HL for storage. We first derive a general m^2 price (section M.1). This being the price per m^2, coping with so called 'dead space'. 'Dead space' refers to the space that has to be reserved for hallways and for instance goods receipt. Using this general amount, we approximate the costs per m^2 of effective storage space (in section M.2), i.e. the space reserved for keeping the actual products.

M.1 General m^2 price

Confidential.

Table M.1 HL's tariffs for housing (in Dutch)

The above figure M.1 deals with warehouse usage of [redacted] (of which [redacted] non-sterile, and [redacted] sterile storage) and an office space use of [redacted]. Office space is not considered in the calculation of warehousing m^2 costs, since we considered this to be fixed in our warehousing model.
The warehousing space costs consist of multiple topics. First of all there is the rent. HL charges [redacted] as rent to BE/JBZ (see table M.1, [redacted]). The costs for [redacted] are ascribed to the storing space of [redacted] (using the method of absorption costing) and are assumed to be positively correlated to this m^2 usage. and (just like the other figures) concern the total space necessary. With this we thus also mean space for hall ways, goods receipt etc.
Where HL does not distinguish between sterile-/non-sterile storage costs, we pose to do so. For sterile storage HL built a so called clean room in the warehouse (see the center of figure M.1, and the left hand side of figure M.2), costing [redacted] per year.

Confidential.

Figure M.1 Bulk storage and clean room

Confidential.

Figure M.2 Storage racks

Ascribing these costs to [redacted] (see table M.1) yields an additional charge for sterile storage of [redacted] per m^2. We thus obtain as general m^2 prices:

Confidential.

Table M.2 Estimation of general m^2 prices/yr

M.2 Effective m^2 price

Since we pose to calculate with the effective storage space (this thus being the shelf space without hallways etc.) we have to correct table M.2 for this. Based on the visit to HL's warehouse (see also figures M.1 and M.2) we assume [redacted] of the floor space can be used for effective storage (verified at, and approved by Bernhoven), this both for sterile and non-sterile storage. The remaining half is allocated to matters as hallways, goods receipt and storage of equipment. The effective m^2 prices thus become:

- For sterile storage: [redacted] per m^2 per year.
- For non-sterile storage: [redacted] per m^2 per year.

Appendix N: Analyses results Bernhoven

Confidential.

Table N.1 Analyses results BE (Based on Veghel, 2009)

Appendix O: Coefficients of variation

Confidential.

Table O.1 Overview coefficients of variation

Confidential.

Table O.2 ANOVA Table

Where:

$$SS_{Between} = \sum_{i=1}^{a} \frac{y_i^2}{n} - \frac{y_{..}^2}{N}, \; MS_{Between} = \frac{SS_{Between}}{Df} \text{ (Montgomery, 2003)} \quad \text{(O.1), (O.2)}$$

$$SS_{Within} = SS_{Total} - SS_{Between}, \; MS_{Within} = \frac{SS_{Within}}{Df} \quad \text{(O.3), (O.4)}$$

$$SS_{Total} = \sum_{i=1}^{a}\sum_{j=1}^{n} y_{ij}^2 - \frac{y_{..}^2}{N}, \; F - ratio = \frac{MS_{Between}}{MS_{Within}} \quad \text{(O.5), (O.6)}$$

In the notation above we have 2 levels for *a* (JBZ, BE) and 10 observations per level (so *n=10*), $y_{i.}$ represents the total of the observations under the *i*th treatment, and $y_{..}$ the grand total of all observations. The ANOVA table decomposes the variance of CV into two components: a between-group component and a within-group component, where the groups are respectively JBZ and BE (under the denominator 'Hospital'). The F-ratio, which in this case equals 0.07, is a ratio of the between-group estimate to the within-group estimate. Since the P-value of the F-test is greater than or equal to 0.05, there is not a statistically significant difference between the mean CV from one level of Hospital to another at the 95.0% confidence level.

Appendix P: Analyses results Jeroen Bosch

Confidential.
Table P.1 Analyses results JBZ

Appendix Q: Analyses results BE/JBZ

Confidential.
Table Q.1 Analyses results BE/JBZ

Appendix R: BE/JBZ contractual figures

Confidential.
Table R.1 Budget overviews BE, JBZ and BE/JBZ

Confidential.
Figure R.1 BE/JBZ's contract about incentives

Confidential.
Table R.2 HL's incentives for additional parties

Appendix S: Scientific poster

Master Thesis Project, December 2010
MSc Program in Operations Management and Logistics

TU/e Technische Universiteit Eindhoven University of Technology

Cost/Benefit allocation using third-party logistics in a health care setting

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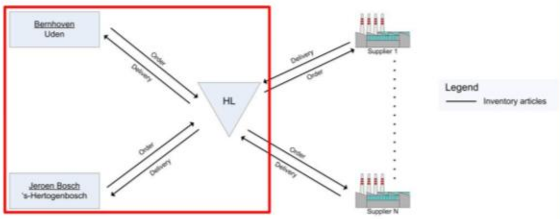
Introduction / Background

Outsourcing of logistical operations is gradually gaining more attention among Dutch health care providers, this holds for Bernhoven Hospital (BE) and Jeroen Bosch Hospital (JBZ) as well. A logistical service provider (LSP), Hospital Logistics (HL) facilitates this for BE/JBZ.

Since this is a relatively new field, a lot of contractual obscurities emerged at both health care providers. The main research question of this study addresses the **problem**:

With respect to the new outsourcing situation little insight exists in the cost structure and therefore in the fairness of HL's contract and its allocation mechanisms.

Research Method



The red square situation will be modeled based on:
- Warehousing.
- Transportation.

Warehousing costs model:
- For 100 products under scope.
- Each based on (R,s,Q) replenishment control.
- Subject to P_2 service measure constraint of 98%.

Warehousing costs and corresponding possible pooling advantages are quantified in different settings:
1. BE alone in the warehouse.
2. JBZ alone in the warehouse.
3. BE/JBZ in the warehouse.
4. The extension with an additional party, varying in size.

Results

Product overlap:
When BE/JBZ would be sharing the warehouse, theoretical pooling advantages are x%. These are split into:

Relative:
- Ordering costs: x%.
  - ✓ Supplier's charge (SC): x%.
  - ✓ Procurement charge (PC): x%.
  - ✓ Handling charge (HC): x%.
- Opportunity costs: x%.
- Space costs: x%.

Based on HL's tariffs:
[redacted]

Action analysis results in ease at which savings might be realized (descending): Opportunity, SC, PC, HC, Space.

Additional party:
Savings for BE/JBZ:
[redacted]

Theoretically feasible pooling advantages of x% when the cooperation is extended with a hospital (x) of BE/JBZ's size and all costs are considered adjustable (x% when only considering allowance for space costs).

Conclusion

- Product overlap not sufficiently accounted for. Even easiest attainable savings (on opportunity costs) are only covered x%.
- Room for contract negotiations on incentive with addition of party. Pooling advantages acknowledged by HL are x%, where this study's posed minimum is x%.
- Transportation pooling could yield significant benefits, recommended to BE/JBZ for future study when data will become available.
- Future scientific research should be directed towards (quantitative) case studies on LSP's in health care.

/ Department of Industrial Engineering and Innovation Sciences

Figure S.1 Scientific poster