Stock items on the run

A research into the new inventory system in the OR-complex of the Reinier de Graaf hospital

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March 2007

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Date: March 2007

Bachelor assignment *Industrial Engineering & Management*

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Summary/*Samenvatting*

This research studies the new inventory system of the Reinier de Graaf hospital in Delft (RdGG). In December 2006, the RdGG implemented a two-bin replenishment policy under periodic review in the OR-complex of the H building (OR H). The policy is used to supply all (disposable) stock items to the OR-complex. In this research, we evaluate the main problems of the current inventory system. We conclude that the demand for stock items in the OR-complex is stochastic. We therefore state that the RdGG needs an alternative, more reliable methodology for determining stock levels in an OR-complex. Given a two-bin replenishment policy under periodic review, we define an alternative methodology to be used when demand is stochastic. This methodology is based on inventory management literature. We test the methodology by simulating the replenishment in MS Excel, and compare the simulated stock levels with the current stock levels in OR H. The methodology supports the two-bin replenishment policy and minimizes inventory in the OR-complex of the RdGG. Implementing this methodology is expected to reduce inventory the storage rooms of OR H by 50% to 70%.

Samenvatting

Dit onderzoeksrapport beschrijft een onderzoek naar het nieuwe voorraadbeheersysteem van het OK-complex va het Reinier de Graaf ziekenhuis in Delft (RdGG). In december 2006 besloot de RdGG om het huidige bevoorradingssysteem te vervangen door een 'twee-pots' systeem met een verkorte herbevoorradingstijd. Dit bevoorradingssysteem wordt gebruikt om alle voorraadartikelen te leveren aan het OK-complex. Met de verkorte herbevoorradingstijd worden de artikelen in het OK-complex in het nieuwe bevoorradingssysteem vijf keer per week in plaats van twee keer per week herbevoorraad. In dit onderzoek beschrijven we de problemen die zich voordoen in het huidige bevoorradingssysteem. In onze analyse van het nieuwe systeem, bekijken we in hoeverre het nieuwe systeem de problemen van het huidige systeem oplost. Allereerst concluderen wij dat de vraag naar de voorraadartikelen stochastisch verloopt. Het is daarom noodzakelijk dat de RdGG een alternatieve, betrouwbaardere methodiek gaat gebruiken om de voorraadhoogtes per voorraadartikel te bepalen. Gegeven een twee-pots bevoorradingssysteem met een periodieke herbevoorrading, definiëren wij een alternatieve methodologie die de voorraad in een OK-complex moet minimaliseren onder stochastische vraag. Voor het definiëren van deze methodologie maken we gebruik van de literatuur over voorraadbeheersystemen. We testen onze methodologie aan de hand van een simulatie in Excel en vergelijken tenslotte onze verwachtte voorraadgrootte met de huidige voorraadgrootte. De nieuwe methodologie zal als aanvulling dienen op het twee-pots bevoorradingssysteem. Wanneer de methodologie wordt geïmplementeerd verwachten wij dat de voorraadgrootte in OK H kan worden teruggedrongen met 50% tot 70%.

Preface

This research is part of my bachelor programme *Industrial Engineering & Management* at the University of Twente. In December 2005, I decided to look for various research options in the Dutch health care. I was interested in doing a research into health care management and logistics. I contacted Eelco Bredenhoff, who presented me several interesting logistic management problems within the Reinier de Graaf hospital in Delft. In June 2006, we consulted David and Francisca within the Reinier de Graaf to globally formulate my research objective concerning the logistics of the operating rooms.

During the first two weeks of September, I was introduced into several departments of the Reinier de Graaf. I witnessed most of the operational problems at the main warehouse and the operating rooms. After this exciting period, we formulated the research assignment like it is written down in this thesis.

I thank the following people who participated in the formulation and supervision of my research:

From the University of Twente: Erwin Hans and Eelco Bredenhoff.

From the Reinier de Graaf hospital: David Lange and Francisca van der Pol.

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1 Introduction

In the Reinier de Graaf hospital, about 13,000 surgical procedures are performed per year. A wide range of materials is used during these surgical procedures. The replenishment of these materials might take place at different time intervals, and the materials might be stored at multiple locations. The central warehouse is located a few kilometres from the hospital. Despite these complexities, the hospital cannot afford delayed deliveries or early stock-out. Its inventory system should guarantee materials are available at the moment they are needed. How can this inventory system satisfy unpredictable demand and simultaneously minimize stock levels?

1.1 Research context: The 'Reinier de Graaf Groep'

The *Reinier de Graaf Groep* (RdGG) is a general hospital with medical facilities located in Delft, Voorburg, Naaldwijk, and Ypenburg. A total of 3,000 people are employed in the RdGG, including 165 doctors over 30 specialties. The *Reinier de Graaf Gasthuis* is located in Delft. It consists of two buildings: the Hippolyt (H) building, and the Bethel (B) building. In 2007, the construction of a new hospital starts, which substitutes the facilities of the H and B building into one new location.

In both the H and B building, an OR-complex is located: OR H and OR B respectively. Each OR-complex has four operating rooms (ORs). An additional OR-complex is located in Voorburg. Different specialties are allocated to every OR. The OR-complex holds all materials used during surgery, like the instruments, (bed)clothes, and a large variety of disposables.

We distinguish three types of material flows (see Figure 1):

The first flow consists of all disposable items used during surgery, like bandages, needles, and hand gloves. The main warehouse of the RdGG supplies these items. We call these items the *stock items*.

The second flow consists of all items that are customer specific, such as prostheses, and eye lenses. All customer specific items are ordered by the OR assistant. We call these items the *customer specific items*.

The third flow contains all surgical instruments. These instruments are packed in metal boxes called *instrument nets*. The instruments are cleaned, resorted, repacked, and sterilized by *CombiSter*, the central sterilization department of the RdGG. Unlike the previous two material flows of items for single use only, this is a permanent cycle of materials.

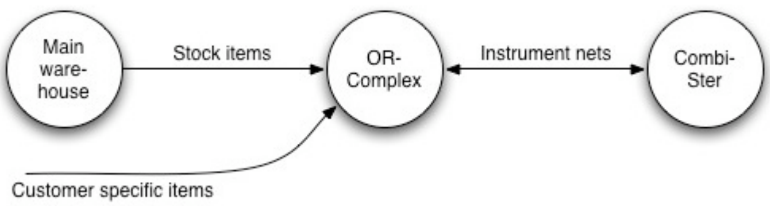

Figure 1: The three different types of material flows in the OR-complex.

2 Research objective

There is a range of operational problems involved with the three material flows described in section 1.1. The delivery of customer specific items is often unpredictable, despite the efforts made to ascertain a timely delivery. The instruments from CombiSter are sometimes incorrectly arranged within the nets, although the layout is carefully documented and prescribed. For some instrument nets, the layout is outdated and does not fit the type of surgical procedure. The nurses, the managers of the ORs, and the main warehouse are confronted with these problems. Although these problems are of great importance, we will focus on the flow of materials involving the stock items. More precisely:

This research studies the efficiency and effectiveness of the logistics of the stock items in OR H and OR B.

As stated in section 1.1, the main warehouse of the RdGG supplies all stock items. The stock items used in OR H and OR B are stored in their respective storage rooms. The transport department is responsible for periodically replenishing these storage rooms. The nurses withdraw stock items from the storage rooms to replenish the cabinets in the four ORs. This way, secondary stock build-up is created. The replenishment of these cabinets is a time consuming daily routine. Stock shortages in the storage rooms are frequently reported. Because the main warehouse has no information of the number of items withdrawn over a range of surgical procedures, the inventory levels in the OR-complex might not fit the real time use. These unknown levels of material use, lead to fluctuating demand at the main warehouse as well.

For the new hospital, the ORs of the H and B building are located in a single OR-complex. The number of square meters reserved for inventory will be reduced. Combined with the problems described above, we claim the current system of inventory management cannot be maintained any longer. During this research, the RdGG decided to implement a new inventory system: a two-bin inventory system under periodic review. By replacing the inventory system in OR H, the RdGG hopes to solve the main problems of the current system. The RdGG successfully tested the two-bin system in the delivery rooms of the H building. Eventually, the current system will be replaced in OR B as well.

In this research, we refer to the two-bin system as the new inventory system implemented in OR H in December 2006. The previous inventory system in OR H – and thus, the present inventory system in OR B – is referred to as the *current* inventory system.

The main objective of this research is to assess the two-bin inventory system. To this end, the situations in the current and new system are compared. The two-bin inventory system should solve the main problems of the current inventory policy.

2.1 Problem definition

The following problem definition is based on the problem description and research objective:

How can the new inventory system solve the problems of the current inventory system?

Although the new inventory system is implemented in OR H, some of the main problems of the current system might not be solved. Therefore, special attention is required to solve these problems in the new system.

2.2 Research questions

To answer the problem definition, the following five research questions are formulated:

1. What are the current and new inventory policies?
2. What are the frequencies of replenishment orders placed?
3. What is the level of material demand?
4. What are the current and new stock levels?
5. How can the stock levels in the new inventory policy be minimized?

2.3 Research scope

The *hierarchical planning (HP)* model described by *Van Houdenhoven et al.* (2006) is used to define the scope of this research. The HP model distinguishes 4 managerial areas over 4 business-planning stages (see Table 1). According to the HP model, higher planning stages impose constraints on lower stages, and lower stages provide feedback information to higher stages. The managerial areas interact horizontally. Appendix A shows the complete HP model for the OR-complex.

		Managerial areas			
		Medical planning	**Resource planning**	**Material planning**	**Financial planning**
Planning stages	**Strategic planning**				
	Tactical planning				
	Operational offline				
	Operational online				

Table 1: The hierarchical planning model as used in Appendix A.

The HP model includes 4 managerial areas per business-planning stage. The shaded cells indicate the point of interest for this research.

Since this research focuses on the logistics of the stock items, the material planning is our major point of interest. The inventory system is defined in the strategic material planning stage. This inventory system thus imposes constraints on the tactical and operational material planning stages. For the RdGG, a relatively large number of planning activities are located in the operational online stage (see Appendix A). Probably, employees improvise planning activities that are not accounted for in the tactical or strategic stage. This indicates that an incomplete or inconsistent inventory system is defined. By redefining the inventory system at a strategic and tactical stage, we try to minimize the required operational online planning activities.

The ORs use an information system to register the actual material use and to verify the time-schedules of surgical procedures. At the time of this research, this information system was scarcely used. Therefore, no direct indication of the material use per surgical procedure can be obtained from this information system. We will estimate the material use per unit of time based on the available replenishment data.

This research focuses on the supply chain of the stock items from the main warehouse to the ORs. It will not propose a change in the physical construction of the current or new OR-complex. Given the time available for this research's, the operational costs of the current and new inventory systems will not be analyzed or compared.

2.4 Research design

The research design is structured corresponding the research questions formulated in section 2.2. In the following chapters, we answer these formulated questions. We conclude this research by answering the problem definition of section 2.1.

In section 2.3, we explained why this research focuses on the strategic and tactical material planning to reduce the operational material planning. We therefore split-up the analysis of the current and new inventory system in two parts:

1. An analysis of the inventory policy
2. An analysis of the implementation of the inventory policy (or the effects of the policy on operational planning)

This results in the following structure for chapters 3 and 4:

Chapter 3 describes the current inventory system: the *order-up-to-level* replenishment policy. We first introduce the layout of OR H and some frequently used terms. The current replenishment policy is presented in section 3.1. Next, the implementation is analysed based on the frequency of replenishment orders and the current stock levels. At the end of chapter 3, we state the main problems of the current inventory system and relate these problems to the stochastic material demand in OR H and OR B.

Chapter 4 presents the new inventory system of the RdGG: a two-bin or *order-point, order-quantity* replenishment policy. In this chapter, we describe the stock levels in this new policy and indicate how the new system deals with stochastic demand. We then show why the RdGG needs a more reliable methodology for minimizing stock levels under stochastic demand. In chapter 3 and 4 we thus answer research question 1 to 4.

In chapter 5, we subsequently continue with research question 5. We describe how to determine the stock level per stock item in a two-bin inventory system under periodic review. Therefore, we first introduce the two-bin inventory system under continuous review as described in the inventory management literature. When minimizing stock levels, we need a reliable estimator for the expected demand. Therefore, we present a method for calculation the average daily demand per stock item. This leads us to the formulation of a methodology for minimizing stock levels in the new inventory system.

In chapter 6, we test the formulated methodology of chapter 5. For a collection of stock items, we verify the average daily demand: we monitor the real-time demand and compare the results to our calculated averages. We verify the stock levels by a simulation of the replenishment cycle. The results of these two experiments are presented.

In chapter 7, we present the conclusion of this research concerning the defined methodology for minimizing stock levels in the two-bin inventory system. A discussion of the research is presented in chapter 8.

Figure 2 visualizes the research design as described in this section.

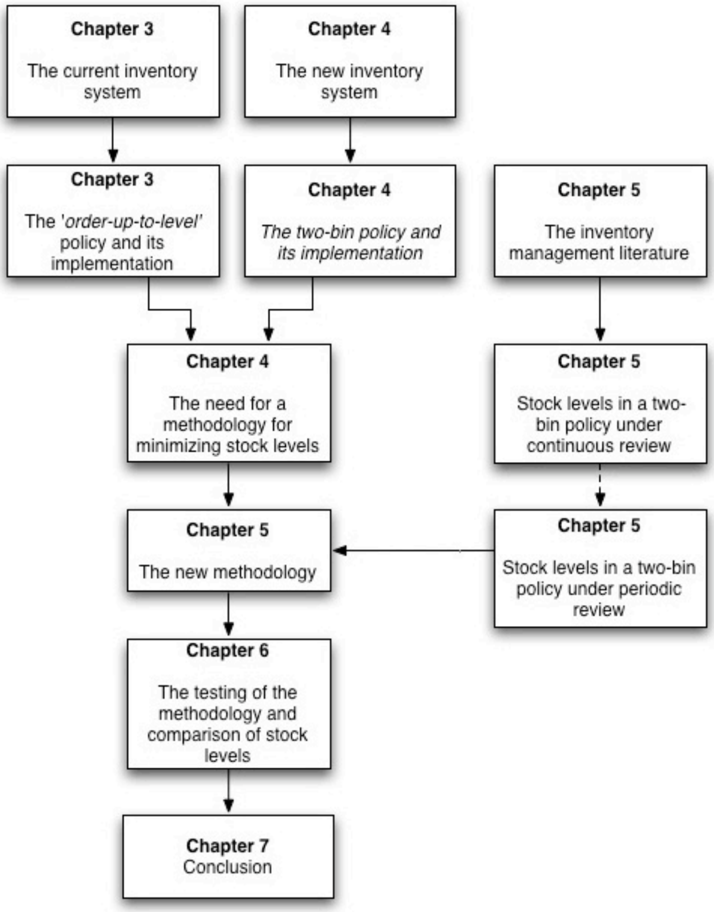

Figure 2: A graphical presentation of the research design.

3 The current inventory system: the 'Periodic-review, Order-up-to-level' System

In this chapter, we describe the replenishment policy and its implementation in OR H. Special notes are made when OR B differs from OR H. Figure 3 shows the layout of OR H. The map shows two stock locations: storage room 1 and 2. In these two storage rooms, most of the inventory is held. Figure 3 is presented to roughly indicate the layout of an OR-complex of the RdGG. We therefore not present the layout of OR B.

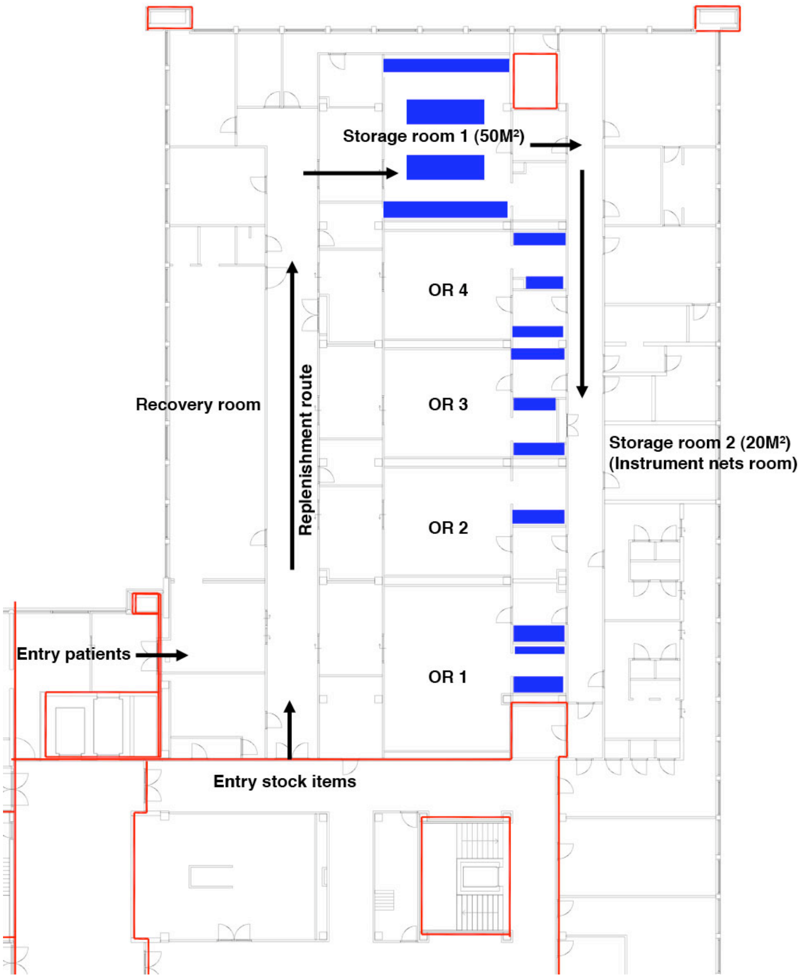

Figure 3: The layout of OR H.

The OR-complex is a sterile department. Access is only allowed when wearing appropriate clothing. Most of the stock items are stored in storage room 1. Due to a shortage of space, all disposable jackets and sheets are placed in another storage room. This room also stores the instrument nets. We will call this room **storage room 2.**

The blue areas indicate the location of cabinets. Large cabinets are placed in storage room 1 (50 m^2) and 2 (20 m^2). ORs 1 to 4 all have smaller cabinets used by the nurses for specific stock items that are withdrawn from the storage rooms.

Refer to Appendix C for a collection of frequently used terms and concepts in this research, like the definition of a stock item, the continuous and periodic review policies, and on-hand stock. Note that one unit of a stock item contains one or more pieces. A unit often corresponds to a supplier box. We will return on this difference in section 3.2.

An inventory system is characterized by a unique policy and a methodology for determining stock levels. In section 3.1 we first introduce the current *periodic-review, order-up-to-level* replenishment policy and the methodology currently used for determining stock levels. We then describe the implementation of the current policy in section 3.2. In section 3.3 we analyse the replenishment data of the current system. Finally, in section 3.4, we present the main problems of the current inventory system.

3.1 The 'Periodic-review, Order-up-to-level' policy

The current inventory policy is referred to as an *(R, S),* or *Periodic-review, Order-up-to-level* inventory system (see Silver et al., 1998). Every R units of time, on-hand stock is raised to the order-up-to-level S. The (R, S) policy is an example of a periodic review policy.

The stock clerk replenishes the storage rooms in OR H on Tuesday and Thursday morning. Replenishment in OR B takes place on Monday, Wednesday, and Friday morning. Therefore, the average replenishment time for OR H is between two and three working days, and for OR B less than two working days.

The stock clerk starts checking on-hand stock at 7:30^{AM}, finishes his checks around 8:00^{AM}, and then directly inputs all replenishment orders in the computer system. The computer system sends all these *scan orders* to the main warehouse. The main warehouse finally delivers all stock items around 12:00^{AM}. This makes the lead-time 4 hours, or half a working day.

Beside the regular *scan orders* placed by the stock clerk, the OR-assistant is authorized to place additional replenishment orders. As the current replenishment policy is sometimes unable to satisfy material demand, the RdGG decided the OR-assistant should be able to place these additional orders at any moment. We distinguish two types of additional orders that are placed by the OR-assistant:

1. High priority *urgent orders*: the main warehouse delivers all urgent orders during the same day.
2. Low priority *extra orders*: the delivery of extra orders only takes place on regular replenishment days.

The stock levels (S) per stock item are evaluated once a year. They are based on the average number of units ordered per week over the first 10 weeks of the year. Therefore, all registered scan, extra, and urgent orders of the particular stock item are averaged. To determine S, the calculated average is multiplied by 2. This methodology for determining the stock level S is illustrated in Equation 1. Theoretically, the stock levels should equal two times the average weekly demand.

Equation 1: $S = 2 \times \frac{number\ \ of\ \ units\ \ ordered}{10}$

In the next sections, we investigate why urgent and extra replenishment orders are placed by the OR-assistant. We show extra and urgent orders are placed very regularly and how this is related to the current methodology for determining stock levels.

3.2 Policy implementation

This implementation describes how the (daily) operational planning is influenced by the current policy. It therefore indicates the drawbacks of the current inventory system.

As indicated in section 3.1, the OR-assistant uses extra and urgent orders to anticipate on (possible) stock-out occurrences. There are currently 5 important situations that require the OR-assistant's anticipation:

1. The cabinets in the ORs are replenished during lead-time
2. On-hand stock is being matched to next week's material demand
3. The main warehouse runs out of stock
4. Replenishment errors are made by the stock clerk
5. The method used for determining the current stock levels

In most of these situations, the extra orders result in extra on-hand stock. We continue with a description of these situations:

The cabinets in the ORs are replenished during lead-time (1)

Secondary stock build-up is created in the ORs. By placing specific stock items — like jackets, sheets, hand gloves, aprons, and needles — in the cabinets of the ORs, the nurses can more easily reach for these items during surgery. Every day the nurses replenish these stock items in all four ORs. The stock items are withdrawn from the storage rooms.

Table 2 gives an indication of the extra stock created in OR H. The stock levels of 9 stock items – 5 types of hand gloves and 4 types of syringes – are shown. These items are stored in both the ORs and the storage rooms. Most of the +/-360 stock items located in the storage rooms are also stored in the ORs. As a result, the total number of pieces stored is a multiple of the number of pieces stored in the storage rooms.

Stock items		**Pieces per unit**	**OR 1**	**OR 2**	**OR 3**	**OR 4**	**Storage room**
		Number of pieces					
Hand gloves	Size 6	50	50	50	50	50	50
	Size 6,5	50	50	50	50	50	50
	Size 7	50	50	50	50	50	50
	Size 7,5	50	50	50	50	50	50
	Size 8	50	50	50	50	50	50
Syringes	2 ML	50			15	15	50
	5 ML	50			15	15	50
	10 ML	50			15	15	50
	20 ML	50			15	15	50

Table 2: Secondary stock locations in OR H.

Some stock items are stored in the cabinets of the ORs as well as in the storage rooms. The number of pieces gives an indication of the on-hand stock that is maintained.

All these stock items are withdrawn from the storage room at a random moment during the replenishment time. If the items are withdrawn during lead-time, the scan orders are outdated the moment they are processed in the main warehouse. This way, the replenishment does not entirely fit the material needs of the OR-complexes and the risk of shortages increases. As a result, the OR-assistant places extra or urgent orders to prevent inventory shortages.

On-hand stock is matched to next week's material demand (2)

Most surgical procedures are scheduled one to four weeks in advance. Around 85 percent of all procedures performed over a one-week period, is known one week in advance. Sometimes, the OR-assistant tries to match on-hand stock to next week's material demands, especially when the OR-complex is confronted with absentees during for example the holiday periods. This way, the risk of shortages is reduced.

The main warehouse runs out of stock (3)

Sometimes, the main warehouse runs out of stock for specific stock items. These items, although included in the scan orders, cannot be delivered to the OR-complexes. The OR-assistants are not informed of these incomplete deliveries: they have to find out themselves by checking the delivery lists included in each 12 o'clock delivery. When the assistants notice incomplete deliveries, they decide whether a substitute item is necessary. If this is the case, an extra or urgent order is placed for this substitute item.

Replenishment errors made by the stock clerk (4)

The fourth situation concerns the stock clerk: the stock clerk checks for which stock items on-hand stock needs to be raised. He sometimes overlooks shortages or, when he does find a shortage, orders incorrect numbers of units. This way, not all stock items are topped-up to their specific stock level S. Although numbers cannot state the frequency, it is a commonly known fact that errors are made. The results of these man-made errors are extra or urgent orders placed by the OR-assistant.

In section 3.1, we described the stock clerk is responsible for replenishing both storage rooms. In reality, the replenishment in OR H is implemented slightly different: the OR-assistant scans the stock items in storage room 2.

The method used for determining the current stock levels (5)

The final situation is the result of the current stock levels in the storage rooms: extra and urgent orders are placed as the result of sudden stock-out occurrences. Equation 1 shows how the value of S is calculated. After the stock levels have been calculated, they are presented to the OR-assistant. The OR-assistant sometimes adjusts the stock levels based on his experience and prediction of the material demand. Regardless of this adjustment is made, stock-outs still occur. Apparently, the stock levels are (still) not able to entirely satisfy the material demand.

There is another situation that does not result in additional orders, but does create stock build-up: for some stock items, one unit is defined as a single supplier's box. The supplier's box contains multiple pieces. As a result, a replenishment order for a small number of pieces – that is, less than the number of pieces per box – cannot be placed. Take for example, the hand gloves and syringes from Table 2: for these stock items, the number of pieces ordered always is a multiple of 50 pieces. Therefore, S always is a multiple of these box contents and stock levels are not minimized.

Because the inventory system does not allow replenishment of single pieces for several stock items, a lot of (supplier) boxes are stored in the (sterile) storage rooms. By hospital regulations, the un-sterile boxes are not allowed inside the storage rooms. Keeping stock items in boxes in the storage rooms also creates even greater shortages of space (see Appendix D for an illustration). In the near future, the RdGG plans to replenish most of the stock items as single pieces instead of supplier boxes.

Because most of the stock items need sterile handling when stored as single pieces, the main warehouse needs to expand its sterile storage space.

To indicate how many extra and urgent orders are placed, we next analyze the replenishment data. Because all replenishment orders are registered by a computer system, the replenishment data could be extracted from the computer database of the RdGG.

3.3 The frequencies of replenishment

In this section, we present the frequencies by which replenishment orders were placed during the first four months of 2006. We also present the number of units ordered during this period. The frequency of replenishment indicates the pattern of material demand. There might be a direct relation between the level of replenishment and the activity levels of the ORs. We therefore compare these two elements. Because we have no reliable data available of the exact material use in he ORs, we estimate the level of material use by focussing on the number of surgical procedures. The number of surgical procedures per unit of time will roughly indicate the level of material use in the ORs. This is especially the case for all commonly used stock items.

We defined a single replenishment order as an order for one or more units of a single stock item. A replenishment order can thus be a scan, extra or urgent order. The data used in this section corresponds to the first four months of 2006.

Table 3 shows the replenishment data of the first four months of 2006. It shows the average number of scan, extra, and urgent orders placed per week, as well as the number of units ordered per week.

	OR B	**OR H**
Number of different stock items stored in OR-complex	+/-360	+/-360
Average number of orders placed per week:		
Scan order	223±29	103±18
Extra order	6±4	4±4
Urgent order	6±6	1±2
Average number of units ordered per week:		
Scan order	1716±257	1533±390
Extra order	59±38	50±56
Urgent order	80±113	13±16
Average number of surgical procedures per week	159±17	198±27

Table 3: The replenishment data of OR B and OR H (January to and including April 2006)

The table shows the number of orders placed and the number of units ordered over the first four months of 2006 (average ± standard deviation). For comparison, the total number of stock items in the storage rooms and the number of surgical procedures are included.

Table 3 shows that the same number of stock items is stored in both OR-complexes. Although the average number of surgical procedures in OR B is relatively low, the number of units ordered per week is relatively high. This can be explained by the different specialities located in OR B and OR H: the surgical procedures in OR B are more complicated and more time-consuming.

In OR B, the *number of urgent orders* and the *number of units* included in *urgent orders* are relatively high. The average number of extra orders is almost equal in both OR B and OR H, as is the average number of extra units ordered.

Also, in section 3.2, we described how the replenishment responsibility is implemented in OR H: not the stock clerk, but the OR-assistant scans all stock items in storage room 2. We found no extra and urgent orders were placed for these stock items in OR H compared to OR B.

There are two possible explanations for these differences between OR B and OR H: the OR-assistant of OR H anticipates on fluctuating demand by holding extra on-hand stock (1), or creates higher stock levels (2). Though we cannot fully state what causes this difference between OR B and OR H, option 2 is most plausible[1]. To support this statement, we sum all stock levels in OR B and OR H concerning all +/- 360 stock items (see Table 4).

	OR B	**OR H**
The sum of all stock levels: $\sum S$	9,160	17,479

Table 4: The sum of all stock levels in OR B and OR H (units) concerning all +/- 360 stock items.

Although the same number of stock items is stored in both OR B and OR H, OR H holds a lot more units in inventory.

Table 4 shows that the sum of all stock levels in OR H is almost twice the sum of all stock levels in OR B. We therefore expect that a lot more inventory is hold in OR H. This might thus explain why OR H seems more stable.

Figure 4 and Figure 5 show the number of orders and the number of surgical procedures in OR B and OR H respectively. There is no clear relation between the number (or type) of orders placed and the activity level in the ORs. Comparing Figure 4 and Figure 5 confirms that a lot more urgent orders are placed in OR B.

[1] In the process of writing this report, we received another explanation for the large number of urgent orders in OR B: although the ORs in OR H are scheduled 1 to 4 weeks in advance, the ORs in OR B are scheduled less than 1 week in advance. Because of this short-term schedule in OR B, the OR-assistant is unable to completely match on-hand stock to next weeks demand. As a result, stock-outs occur more often, and thus more urgent orders are placed.

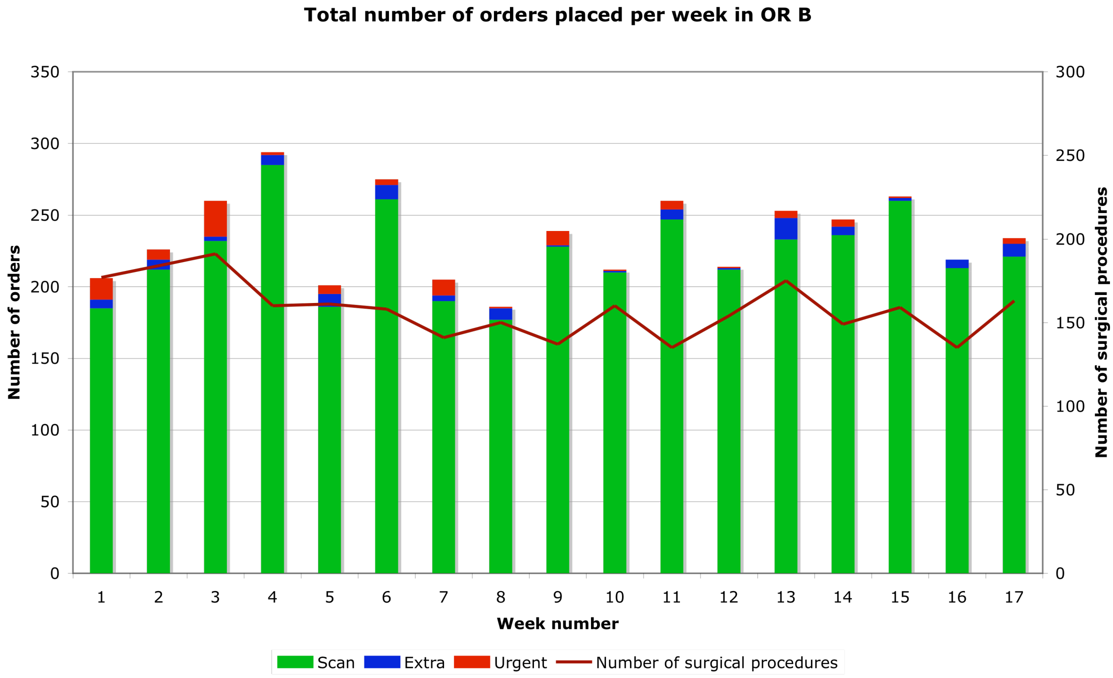

Figure 4: The total number of orders placed per week in OR B (January to and including April 2006)

The green line indicates the number of surgical procedures performed. There is no clear relation between the replenishment and activity levels in OR B.

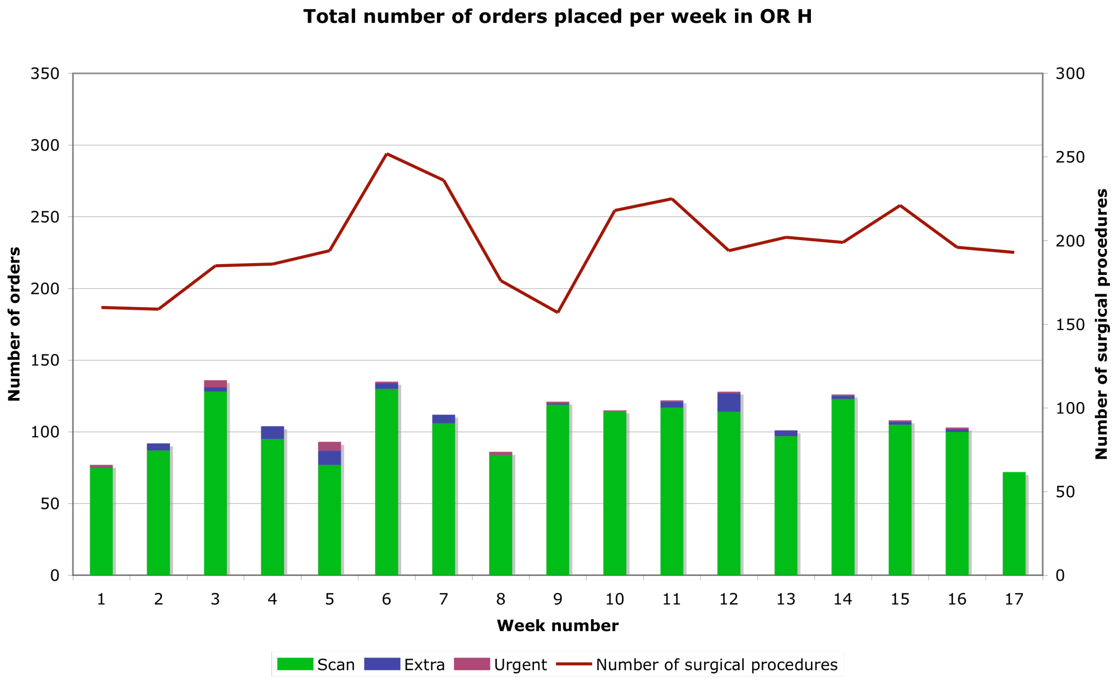

Figure 5: The total number of orders placed per week in OR H (January to and including April 2006)

There is no clear relation between the replenishment and activity levels in OR H.

During the analysis of the replenishment data, we found that about 70 of all +/-365 stock items stored in OR H were not replenished. Apparently, these stock items are not frequently used. In OR B, all +/-365 stock items were replenished at least once.

Figure 6 and Figure 7 show the number of units ordered per week. There is no clear correspondence between the number of units ordered does and the number of surgical procedures per week.

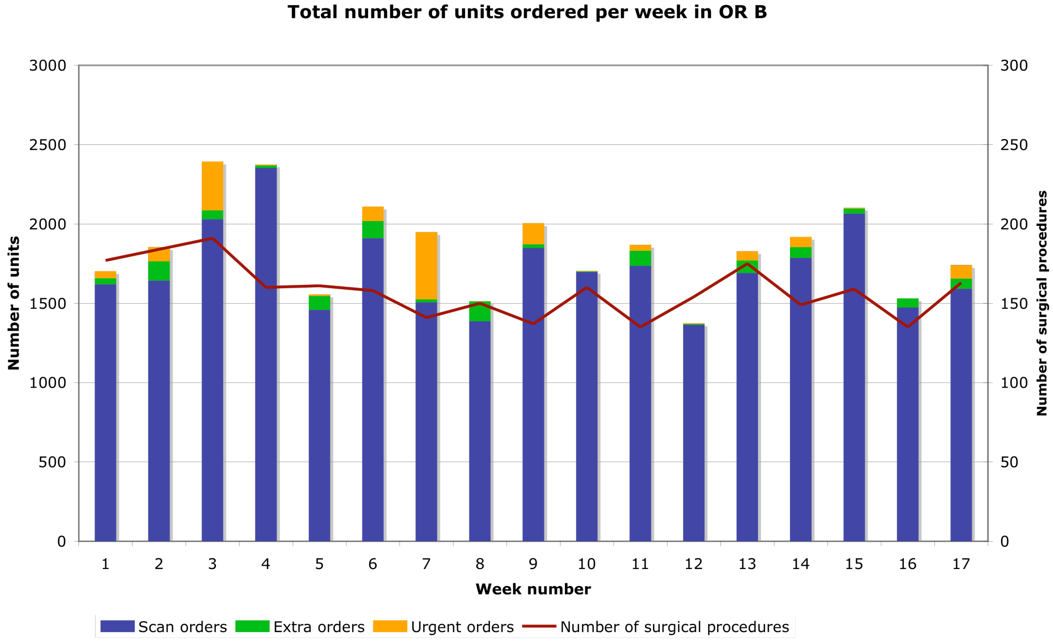

Figure 6: The number of units ordered per week in OR B (January to and including April 2006)

The number of units ordered and the activity level in OR B do not correspond.

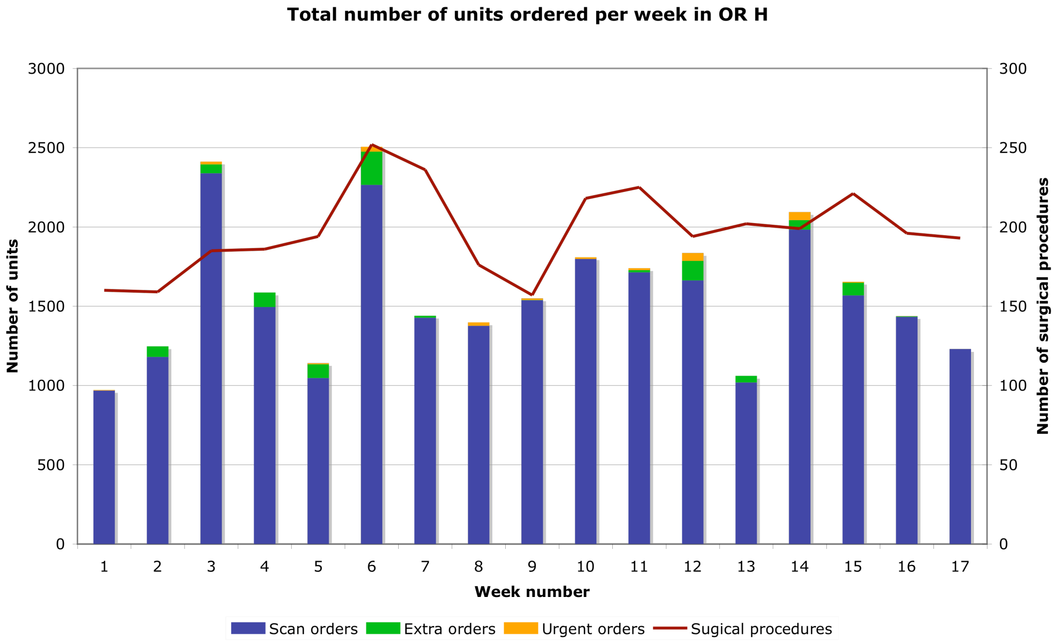

Figure 7: The total number of units ordered per week in OR H (January to and including April 2006)

The number of units ordered and the activity level in OR H does not correspond.

From Figure 6 and Figure 7 it becomes clear that especially OR H has large fluctuations in the number of units ordered per week. In both OR B and OR H, these fluctuations are not the result of a particular range of products: the fluctuation is present in both frequently and infrequently used stock items. We support this statement by plotting the *number of pieces ordered per week* in OR H of the hand gloves (Figure 8) and the 'curettage set' (Figure 9). The hand gloves are a frequently used stock item used by all specialties during all surgical procedures. The curettage set is an infrequently used stock item used by the gynaecology specialty during curettage procedures only. The number of curettage procedures performed per week is relatively stable.

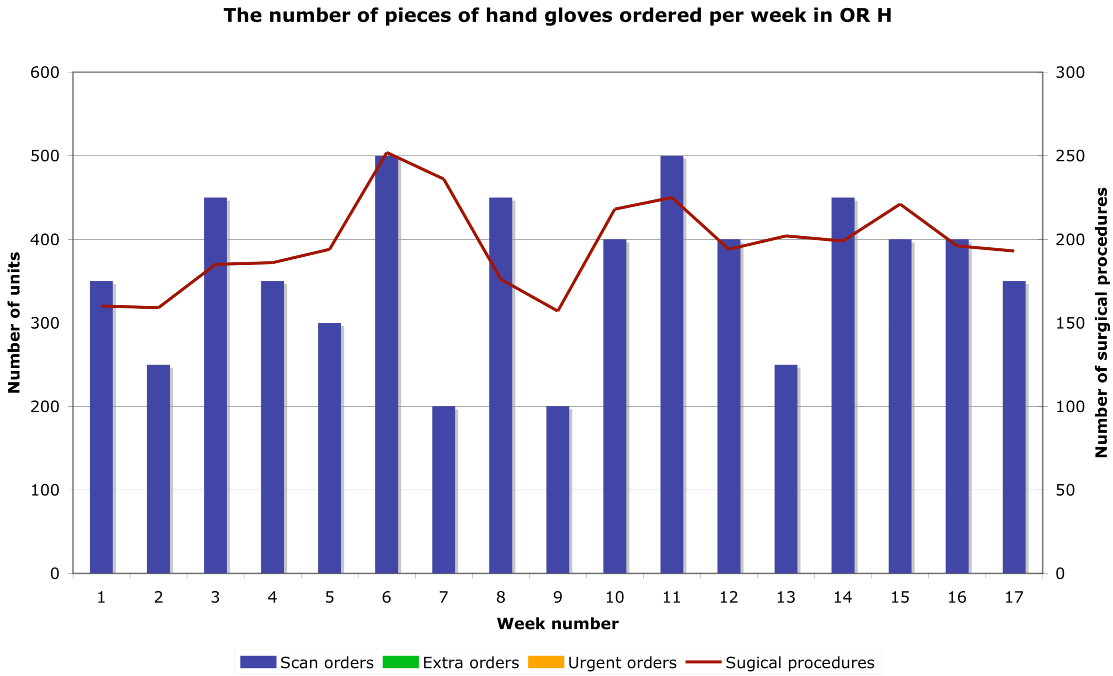

Figure 8: The number of pieces of hand gloves ordered per week in OR H (January to and including April 2006)

Although hand gloves are used during every surgical procedure, the number of pieces ordered does not correspond to the activity level in the ORs.

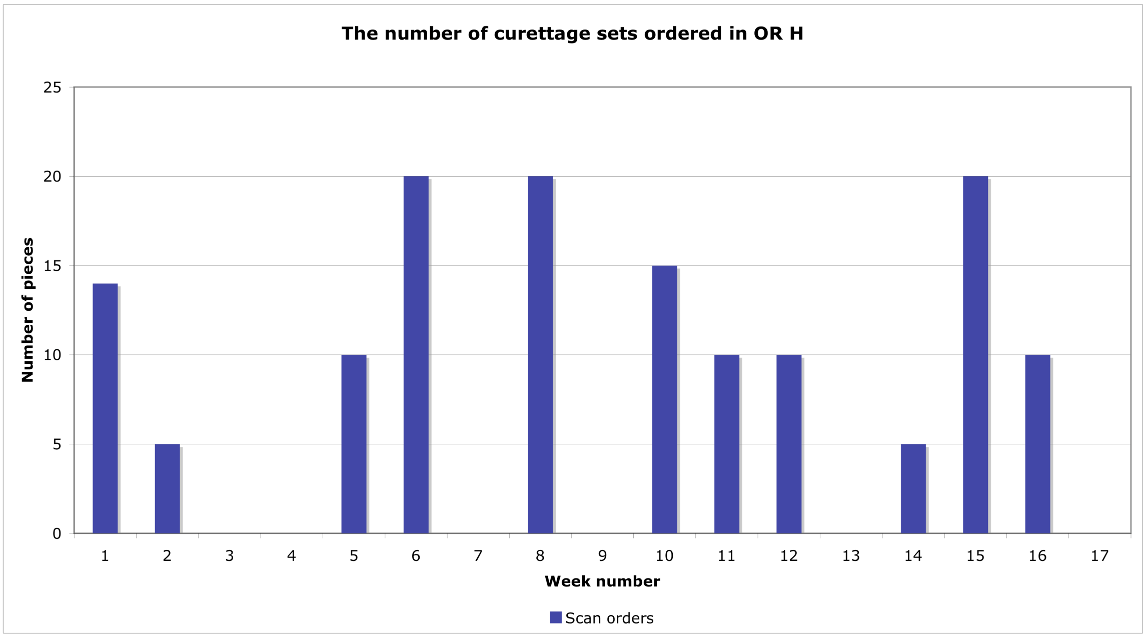

Figure 9: The number of pieces of curettage sets ordered per week in OR H (January to and including April 2006)

There is a large fluctuation in the number of pieces of curettage sets ordered per week, although the number of curettage procedures per week is relatively stable.

Figure 9 shows a large fluctuation in the number of pieces of curettage sets ordered per week. Unfortunately, we could not extract the exact number of curettage procedures performed per week from the computer database. In general, the number of curettage procedures performed per week is relatively stable. This was verified based on the operating rooms' weekly schedule. We thus conclude that there is no direct relation between the number of curettage procedures and the number of pieces of curettage sets ordered.

Considering the data presented, there is no clear correspondence between the activity levels in the ORs (or the number of surgical procedures) and the replenishment activities. Both OR B and OR H show large fluctuations in the *number of orders placed* and the *number of units ordered* per week. Apart from this resemblance between OR H and B, the replenishment of OR H seems more reliable: fewer urgent orders are required. As mentioned before, OR H holds more units of stock compared to OR B (when considering the sum of all stock levels), even though the same number of stock items is stored in both OR-complexes.

The replenishment orders reflect the material use in the ORs. Based on the frequencies of replenishment activities, we state the material use in OR B and OR H is unpredictable. Equation 1 showed how the current stock levels are calculated based on the average weekly demand. Since demand fluctuates heavily in both OR-complexes, we stress that the average weekly demand is an unreliable estimator for the material use. We conclude this chapter by stating the main problems of the current inventory system.

3.4 The main problems of the current inventory system

In the previous sections, we described why additional replenishment orders are placed by the OR-assistant and we analyzed the frequency by which these orders are placed. We concluded that the material demand in the ORs fluctuates heavily and is unpredictable. We described the methodology for determining the stock level S per stock item. In this methodology, the material use is estimated by the average weekly demand. The OR-assistant indicates whether the calculated stock levels should be altered. Due to the unpredictability of demand, the average weekly demand is an unreliable estimator for the material use. As a result, the stock levels cannot cope with the fluctuating material demand of the ORs.

Section 3.1 listed 5 situations that require extra or urgent orders, being:

1. The cabinets in the ORs are replenished during lead-time
2. On-hand stock is being matched to next week's material demand
3. The main warehouse runs out of stock
4. Replenishment errors are made by the stock clerk
5. The method used for determining stock levels

These 5 situations are the result of two main problems concerning the current inventory system:

1. The current (R, S) replenishment policy can not cope with the stochastic material demand in the ORs, and
2. The methodology used to minimizing stock levels is unreliable.

Although preventing secondary stock build-up in the ORs might reduce the fluctuating material demand in the storage rooms, this is no option on the short term. We therefore conclude the current inventory system, concerning the replenishment policy and the methodology for minimizing stock levels, cannot be maintained. In the next chapter, we analyze the new inventory system and conclude whether this new system solves these problems.

4 The new inventory system: the 'Order-point, Order Quantity' System

In the course of this research, an alternative inventory policy was successfully tested in the delivery rooms of the H building. Therefore the RdGG decided to implement this inventory policy in OR H as well. The new policy was eventually implemented in the final weeks of this research.

The inventory policies we present in this research can be placed in a broader perspective of inventory management. The production and the inventory management literature distinguish two major types of production systems. We first describe these two production systems based on *Reid and Sanders (2002)*:

1. Production *push* systems: push systems are used on the assumption that it is better to anticipate for future production. The system produces products in advance to be able to satisfy future demand when it occurs. The products are stored in anticipation of demand. This way, stock build-up is created. To minimize stock build-up, push systems can best be used when demand is deterministic.
2. Production *pull* systems: in pull systems, production is triggered by demand. The production starts when a customer places an order for a product. Demand is thus satisfied directly from production, and not from inventory. This minimizes stock build-up. Pull systems best suit situations where demand is stochastic.

The principles of the push and pull production system apply to inventory management as well. In inventory push systems, materials are stored to anticipate on future production. In inventory pull systems, materials are supplied to the production line the moment they are needed. Pull system thus minimize stock build-up of materials alongside the production line.

When we compare the ORs to a production line, the materials can either be supplied according a push or pull system. In the RdGG a pull system is used to supply the ORs. Both the current and new inventory policy are examples of pull systems. Because of the stochastic material demand in the ORs, pull systems are the best option for supplying stock items to the ORs (Silver et al., 1998).

The new inventory policy is a *two-bin* inventory system. The two-bin policy is a physical form of the *Order-point, Order-quantity System*. The next section describes the replenishment policy for this inventory system. In section 4.2, we present the implementation of the new policy. We conclude this chapter by reflecting on the main problems of the current inventory system.

4.1 The two-bin replenishment policy

The new inventory policy is an *(s, Q)* inventory policy, physically implemented by using 2 bins to store a stock item. A standard number of units *Q* is ordered whenever the stock item's on-hand stock drops below its indicated level *s*. In a (s, Q) policy, s refers to the order-point and Q to the order-quantity. The two-bin policy of the RdGG differs from the standard (s, Q) policy as described in the inventory management literature. We will first present the policy as described by Silver et al. (1998) and Winston (1993) (see Figure 10).

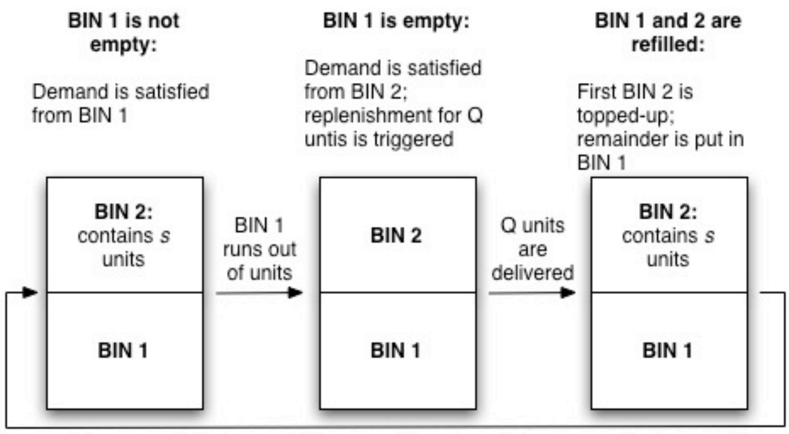

Figure 10: The two-bin policy as described by Silver et al. and Winston.

Description of one cycle of the (s, Q) policy for a single stock item

As long as bin 1 contains units, demand is satisfied from it. When bin 1 runs out of units, a replenishment order for Q units is placed. During lead-time, demand is satisfied from bin 2. When the replenishment order arrives, bin 2 is topped up to its stock level s, and the remainder is put in bin 1.

The RdGG made three important alterations to the standard (s, Q) model:

1. Although the inventory management literature describes the (s, Q) policy as a policy under continuous review, the RdGG implements the policy under periodic review. The review time is raised from 2 to 5 times per week: the on-hand stock level is checked every morning from Monday to Friday.
2. The RdGG implements a Kanban system. A Kanban system signals the stock clerk when replenishment is needed: whenever a nurse or the OR-assistant withdraws the last unit from bin 1, he or she places the barcode of the stock item inside the cabinet door. The barcode inside the cabinet door signals the stock clerk replenishment for the stock item is needed. This simplifies the operational activities of the stock clerk: he now only has to check the cabinet doors for barcodes, and does not have to count the on-hand stock levels during each replenishment cycle.
3. The RdGG simplified the replenishment policy as well. In the two-bin policy of the RdGG, bin 1 and bin 2 contain the same number of units (s). When the first bin runs out of units, demand is satisfied from bin 2 and a replenishment for s units is triggered. The empty bin is refilled up to its stock level s. Here, the reorder-point s equals the standard order-quantity Q. As a result, the stock clerk does not have to count on-hand stock when delivery takes place. All Q (or s) units are placed in the empty bin. See Figure 11 for an illustration.

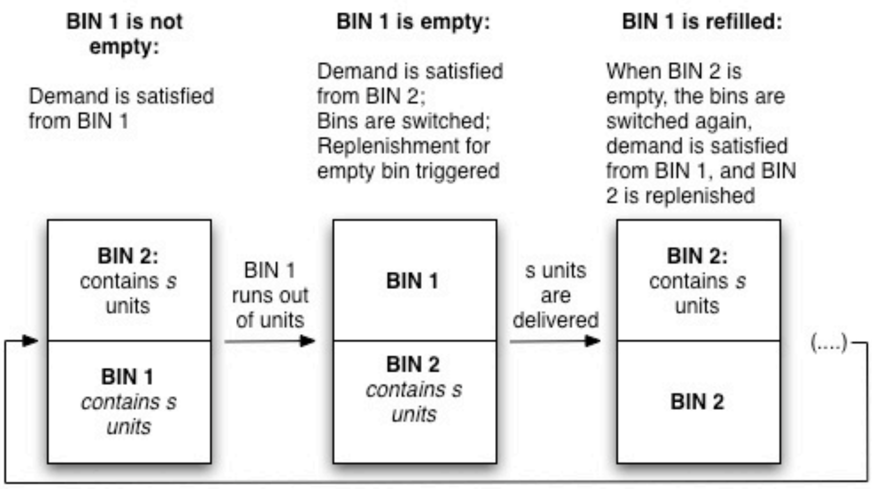

Figure 11: The two-bin replenishment policy of the RdGG

Compared to Figure 10, only one bin gets replenished during a replenishment cycle. The reorder-point (s) equals the standard number of units ordered (Q).

When bin 1 contains units, demand is satisfied from it. When bin 1 runs out of units, bin 1 and 2 are switched from location and replenishment is triggered for Q units. Bin 2 is than used until it runs out of units. In the mean time, the Q units delivered are placed in bin 1. When bin 2 runs out of units, the bins are switched again, replenishment is triggered, and demand is satisfied from bin 1. The Q units are placed in bin 2. Now, the cycle starts all over again. One of the major advantages of this alternative two-bin system, is that is guarantees the first-in-first-out principle. This system is especially useful in the context of the RdGG, since a lot of sterile stock items are stored in the OR-complex.

4.2 Policy implementation

We monitored the replenishment activities in the new two-bin policy for 2 weeks. The new policy raised the regular scan activities of the stock clerk from 2 to 5 times per week. By decreasing the review time, the monitoring of on-hand stock is intensified. This way, the fluctuations in material demand in the ORs are easier to cope with and probably less extra and urgent orders are required. Table 5 shows the comparison of the number of orders placed and the number of units ordered in OR H in the current (R, S) and the new two-bin inventory system.

	OR H	
Two-bin policy:	**Average number of orders placed per week:**	**Average number of units ordered per week:**
Scan order	144±8	3,886±293
Extra order	3±0	41±34
Urgent order	0	0
(R,S) policy:		
Scan order	103±18	1,533±390
Extra order	4±4	50±56
Urgent order	1±2	13±16

Table 5: Comparison of the number of orders placed in the new and current inventory policy.

The number of extra orders is significantly reduced. The last three rows are extracted from Table 3.

From Table 5, we conclude that the average number of scan orders increased. This is the result of daily replenishment in the two-bin policy. We conclude the number of extra orders reduced significantly. Based on the two weeks of monitoring, we cannot conclude whether the number of urgent orders reduced significantly.

When considering the average number of units ordered (as shown in Table 5) we see that the number of units per scan order increased drastically. This can be explained as follows: in section 3.2, we explained why the RdGG plans to replenish all stock items as single pieces instead of supplier boxes. To allow for this replenishment of single pieces, the units of the particular stock items need to be converted (i.e. from pieces per box to single pieces). During the implementation of the two-bin policy, the units of some stock items were converted to single pieces. For these stock items, one unit now equals one piece instead of multiple pieces. Take for example one unit of a stock item that previously contained 10 pieces, and suppose this stock item had a stock level of 4 units. Because of the unit conversion, this stock item is now registered with a stock level of 40 units (4x10 pieces). As a result, one unit now corresponds to one single piece of the stock item. For a single replenishment order, on the average, more units will now be ordered. Finally, in Table 5 we show that the number of units per extra and urgent order decreased significantly.

The reduction in the number of extra orders could indicate that the OR-assistant's anticipation on next weeks demand decreased as a result of the new replenishment policy. However, the OR-assistant might still anticipate on next weeks material demand: he could just place the barcode inside the cabinet door instead of placing an extra order by computer, when he estimates an extra order is needed. Placing the barcode inside the cabinet door in the case of an extra order, results in the order not being registered as an extra order but as a regular scan order.

The operational activities of the stock clerk are simplified compared to the (R, S) policy. This is an operational benefit for the logistics department. Whether this simplification reduces operational costs is unclear, because we have no data available for comparing operational costs of the (R, S) policy with the two-bin policy.

When the two-bin policy was implemented, new stock levels had to be determined. Because of daily replenishment, in theory, the stock level per bin could be reduced to an average use per working day. During weekends however, there is a risk of intensive material use in the ORs. The RdGG therefore decided not to base the new stock levels per bin on the average use per working day: the stock levels *S* of the (R, S) policy were divided by 3, resulting in an average use per 3 working days

($\frac{2\ weeks}{3} \approx 3\,working\ days$). The OR-assistant then indicated whether the newly calculated stock levels were correct.

4.3 The evaluation of the main problems

In chapter 3, we stated the two main problems of the (R, S) inventory policy. We now return to these problems and indicate whether the new inventory system solves them.

Problem 1: ***"The current (R, S) replenishment policy can not cope with the stochastic material demand in the ORs"***

The new replenishment policy simplifies the replenishment activities for the stock clerk. Probably fewer errors will be made when checking on-hand stock. It is however, at this moment, unclear whether the new policy will decrease operational costs for the transport department and the main warehouse. Although the average number of pieces per order will decrease in the new policy, the frequency of replenishment activities is raised. Because of the decreased review time, the new two-bin policy can cope better with the stochastic material demand in OR H.

Problem 2: ***"The methodology used to minimize stock levels is unreliable"***

The current stock levels of the (R, S) policy are used for determining the new stock levels. According to the RdGG, every bin should be able to satisfy demand for 3 working days. As usual, the recalculated stock levels were presented to the OR-assistant. Small adjustments were made based on his indications.

Since the two-bin policy was implemented with the goal of minimizing inventory, we now calculate the reduction of inventory after the implementation. During this research, we did not find a reduction in the number of cabinets (or square meters) used. In order to quantify the reduction of inventory, we compare the current and new stock levels in three subsequent comparisons:

1. Calculating the *stock level change* per stock item as defined by $\frac{s-S}{S} \times 100\%$
2. Since two-bins are reserved per stock item in the two-bin system: calculating the *total stock change* per stock item as defined by $\frac{2s-S}{S} \times 100\%$
3. Comparing the sum of the stock levels: $\sum s$ and $\sum 2s$ to $\sum S$

In comparison 1 and 2 respectively, we expect an average change of -66% and -33%, since $s \approx \frac{1}{3} S$. In comparison 3, we compare the sum of the new stock levels to the sum of the current stock levels.

<u>Comparison 1:</u>

We compare the stock levels of 358 stock items stored in OR H in the current and new inventory system:

- 72 Stock items had a current stock level of 1 unit. These stock items already had there stock levels minimized. Consequently, in the two-bin inventory system, these stock items also have a stock level of 1 unit.
- For the remaining 286 stock items ($S > 1$ unit), we analyze the stock level change by calculating: $\frac{s-S}{S} \times 100\%$. We categorized all these 268 stock items based on their stock level change. See Table 6 for this categorization.

Stock level change	Number of stock items	Average change of stock level
-100% or smaller -80% to -100% -60% to -80% -40% to -60% -20% to -40%	0 20 107 57 5	-63%
Unchanged	97	

Table 6: The categorization of the 286 stock items based on their stock level change.

For 97 stock items, the stock levels remained unchanged (0% reduction). For the remainder, an average reduction of 63% is obtained.

When considering Table 6, for the $286 - 97 = 189$ stock items, we found the current stock levels were reduced. For these 189 stock items, the *average change of stock level* is -63%, because:

$$\tfrac{1}{189}\sum \tfrac{s-S}{S} \times 100\% = -63\%$$

Though a reduction of 63% closely corresponds to our expected reduction of 66%, this reduction only counts for 189 stock items. For some reason, 97 stock items had their stock levels unchanged. This might indicate the role of the OR-assistant in determining new stock levels.

<u>Comparison 2:</u>

A stock level reduction of 63% concerning 189 stock items seems reasonable, but in the new inventory system, two-bins are reserved per stock item. The total stock reduction therefore is much smaller. When we compare S to $2 \times s$, we find a stock reduction of 27%, because:

$$\tfrac{1}{189}\sum \tfrac{2s-S}{S} \times 100\% = -27\%$$

This closely corresponds to our expected average reduction of 33%.

We conclude that the stock reduction of the 189 stock items equals our expectation. Nevertheless, the number of stock items that had their current stock levels reduced is relatively small (189 out of the 286).

<u>Comparison 3:</u>

In Table 4, we presented the sum of all stock levels in OR H in the current inventory system. For a selection of stock items, we now calculate $\sum s$, $\sum 2s$, and $\sum S$. Of all stock items stored in OR H, we exclude small stock items packed in supplier boxes per 100 (or more) units. If we include these stock items and next compare $\sum 2s$ to $\sum S$, we would incorrectly suggest a large increase in the total inventory. Take for example a type of needles stored per 100 units in one (small) supplier box. If the current stock level equals 100 units, the RdGG will not reduce this stock level in the two-bin system, since this would mean storing these small items outside their supplier boxes. For these small stock items, that is very unpractical. For this stock item, comparing $2 \times s$ to S would suggest a drastic increase in the number of units stored (100 units), though only one additional small supplier box is stored in the two-bin system.

In Table 7 we present the sum of $\sum s$, $\sum 2s$, and $\sum S$ for 341 stock items.

New two-bin inventory system:	
Sum of all stock levels: $\sum s$	5,747 units
Sum of all stock levels when considering two-bin per stock item: $\sum 2s$	11,494 units
Current (R, S) inventory system:	
Sum of all stock levels in: $\sum S$	9,799 units

Table 7: A comparison between the sum of the stock levels of 341 stock items stored OR H in the new and current inventory system.

The number of units stored did not decrease when reserving two-bins per stock items in the new system compared to reserving a single bin per stock item in the current system.

We conclude that the new inventory system decreases stock levels for 189 stock items, but this does not drastically decrease inventory. There is almost no reduction in the total number of units stored in OR H. We do note that we might still have included some small stock items in comparison 3. Therefore, the data from Table 7 must not be taken too literally: it roughly indicates that the stock levels in the two-bin system do not drastically reduce inventory. In reality, the RdGG might have physically reduced inventory in OR H, because a stock level reduction obtained for large stock items will definitely create more free space. However, we state that, considering a two-bin system with daily replenishment, inventory in OR H is far from minimized. The current methodology for minimizing stock levels is unaltered. The stock levels are still calculated by using the average weekly demand and adjusted based on the experience of the OR-assistant. We argue that a consistent inventory system should comprise a short review time and a reliable methodology for minimizing stock levels under stochastic material demand. In the new inventory system, the review time has been reduced, but the methodology for determining stock levels is still far from optimal. We therefore suggest an alternative methodology for minimizing stock levels in the new two-bin replenishment policy.

5 A new methodology for minimizing stock levels

In this chapter, we present the calculation of stock levels in a two-bin policy under continuous review based on Silver et al. (1998). In section 5.2, we project this continuous review policy on the periodic review policy of OR H. To support the calculations, we compare the cycle of delivery and withdrawal of pieces of a stock item in both the continuous and periodic review policies. This comparison indicates how the number of units per bin influences the replenishment cycle. Subsequently, we state how the stock level per bin can be defined by the expected demand. We choose the average daily demand as an estimator for this expected demand. The average daily demand is calculated with the available replenishment data.

5.1 The two-bin policy under continuous review

Silver et al. (1998) and Winston (1993) do not describe the two-bin policy under periodic review. They do describe the two-policy under continuous review. We therefore use their description of the two-bin policy under continuous review as the basis for the periodic review policy of the RdGG. We first determine some notations used for the two-bin replenishment policy as described by Silver et al.:

- *L* is defined as the lead-time 8:00$^{\text{A.M.}}$ - 12:00$^{\text{A.M}}$ (4 hours)
- k is the safety factor
- $p(x \geq k)$ is the probability that demand x for a standard normal distributed stock item takes on a value of k or larger. We can express $p(x \geq k)$ as $1-\Phi(k)$, where $\Phi(k)$ is the cumulative distribution of the standard normal distributed stock item.
- P is the probability of no stock-out per replenishment cycle: $P = 1 - p(x \geq k)$

For a particular stock item in the storage room:

- *Q* is the predetermined standard number of units delivered per replenishment (units)
- *s* is the order point (units)
- *SS* is the safety stock (units)
- μ_L is the expected demand and equals the number of units used (or withdrawn) during lead-time (units)
- σ_L is the standard deviations of the expected demand during lead-time (-)

Under continuous review, on-hand stock is constantly monitored. At any moment in time, the number of units in bin 1 (and 2) is known. Computer systems are often used to monitor transactions and keep track of the inventory position. When bin 1 runs out of stock, a replenishment order for Q units is placed directly. The number of units in bin 2 is then used to satisfy demand during lead-time. In the inventory management literature, the value for Q is based on a calculation of cost factors (e.g. the *Economic Order Quantity*). The value of Q can be calculated by evaluating, for example, holding costs versus ordering costs. The safety stock is used as a buffer for fluctuations in demand. See Figure 12 for an illustration of the two-bin policy under continuous review.

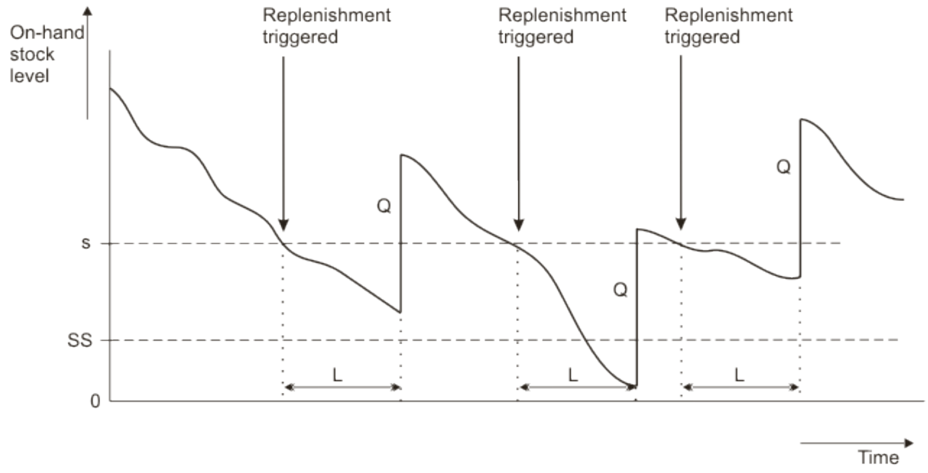

Figure 12: The two-bin inventory policy under continuous review.

Three replenishment cycles for the two-bin policy under continuous review are shown: when on-hand stock drops below s, Q units are directly ordered. The safety stock (SS) is used as a buffer when fluctuations in demand are expected.

Silver et al. argue that for most stock items demand can be represented by a normal distribution. However, when demand is relatively small, or the standard deviation is relatively high, a normal distribution is less favourable. Therefore, Silver et al. present two exceptions: when…

1. The coefficient of variation (CV), σ_L / μ_L , is greater than 0.5, and when
2. Expected demand X_L is less than 10 units.

When demand is less than 10 units, or the coefficient of variation is greater than 0.5, they advocate the use of a Gamma distribution to model demand. Let α and β be the parameters of the Gamma distribution. Then:

- $\alpha\beta$ is the average daily demand and
- $\alpha\beta^2$ is the variance of the average daily demand

The follow from the Gamma distribution relation.

Given a value of Q, the number of units in bin 2 and the safety stock are respectively defined by the following equations when demand is represented by a Normal distribution:

Equation 2: $s = X_L + SS$

Equation 3: $SS = k\sigma_L$

When demand is represented by a Gamma distribution, the number of units in bin 2 and the safety stock are respectively defined by:

Equation 4: $s = Inv.Gamma(P, \alpha, \beta)$

The value for *P* is selected by the inventory manager and indicates what relative number of stock-out occurrences is accepted. The value of P is often selected within the range of 95 to 99 percent. This means that 95 to 99 percent of the time, demand is satisfied from on-hand stock and no stock-out occurs. The value of k is directly related to P: when P is raised, k rises as well. A higher level of P thus results in a higher safety stock. By defining s as the expected demand plus safety stock (Equation 2), the probability of stock out should be minimized. The safety stock now serves as a buffer when high material demand occurs (as displayed in Figure 12).

We continue with the situation in OR H: a two-bin policy under periodic review. The equations used for determining stock levels in the continuous review policy are projected on the two-bin policy under periodic review. This way, new equations are derived from the equations of section 5.1. These equations form the methodology used for determining stock levels in a two-bin policy.

5.2 The two-bin policy under periodic review

Under periodic review, the stock levels are checked every *R* units of time. We add the following notations, used for describing the periodic review policy:

- *R* is the replenishment (or review) time (working days)
- μ_R is the expected demand during replenishment time, with $\mu_R \geq \mu_L$ (units)
- σ_R is the standard deviations of the expected demand during replenishment time (-)

Because the RdGG decided to store the same number of units in bin 1 and 2, we redefine s as the number of units in both bin 1 and bin 2. When replenishment is triggered, s units are ordered for the empty bin. The standard order quantity Q equals s. Our goal is to minimize s and simultaneously minimize stock-out occurrences.

Under periodic review, there is no constant monitoring of on-hand stock. On-hand stock is checked once per working day (see Figure 13).

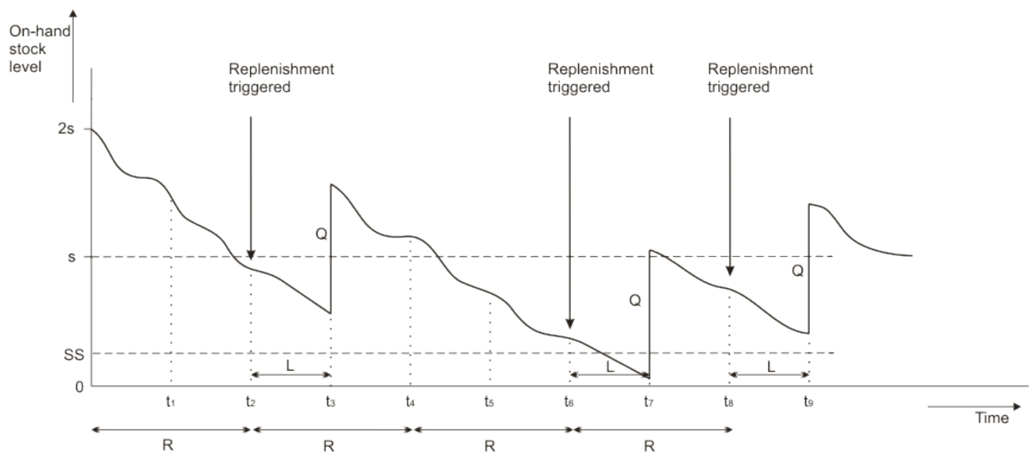

Figure 13: The two-bin inventory policy under periodic review.

Four replenishment cycles for the two-bin policy under periodic review are shown. On-hand stock is checked every R units of time: t_2, t_4, t_6, and t_8. At t_4, on-hand stock had not dropped below s. Therefore, no replenishment was triggered.

The replenishment time is one working day. For a stock item, expected daily demand therefore equals μ_R. Most of the time, demand occurs either before or after 12:00$^{A.M.}$. Sometimes demand is distributed evenly over the day. There are 3 possible situations per day:

1. Demand occurs before 12:00$^{A.M}$ (or during lead-time)
2. Demand occurs after 12:00$^{A.M}$
3. Demand is distributed over the day

During lead-time, all demand must be satisfied from one bin. Therefore, one bin should contain enough units to satisfy demand during this period. On average, the maximum number of units that we expect to be withdrawn during this period equals μ_R. This corresponds to situation 1. We can thus use μ_R to calculate the stock level per bin.

When demand can be represented by a Normal distribution, we define the number of units per bin and the safety stock by the following equations:

Equation 5: $s = \mu_R + SS$

Equation 6: $SS = k\sigma_R$

The equations are analogous to Equation 2 and Equation 3.

When demand can be represented by a Gamma distribution, we define the number of units per bin and the safety stock by:

Equation 7: $s = Inv.Gamma(P, \alpha, \beta)$

Before we can use Equation 5 and Equation 6, we first need to calculate the expected demand per day (μ_R). This expected number can be estimated by the average daily demand in units. That leaves us to state how to calculate this average daily demand per stock item.

5.3 Determining the expected demand

For determining the value of μ_R and σ_R we use the available replenishment database. This database gives us the number of units ordered over a selected period. We can then calculate the average daily demand per stock item.

We add the following notations per stock item:

- D is the total number of orders placed, with d being the d^{th} order placed, and $0 \leq d \leq D$ (order ID)
- The interarrival time Δt_d is the time between order d and order $d+1$ (working days)
- q_d is the number of units ordered at order d (units)
- The daily demand between order d and d+1 is defined as $X_d = q_d / \Delta t_d$, units/working day)
- $\overline{X}$ is the average demand and S *is* the standard deviation of the average daily demand

We use the average daily demand ($\overline{X}$) and the standard deviation (S) as estimators for, respectively, the expected demand (μ), and the standard deviation (σ). For all stock items, we can now determine the average daily demand ($\overline{X}$), its variance (S^2), and standard deviation (S):

Equation 8: $\overline{X} = \frac{1}{D-1}\sum_{d=1}^{D-1} X_d$ or $\overline{X} = \frac{1}{D-1}\sum_{d=1}^{D-1} {q_d}/{\Delta t_d}$

Equation 9: $S^2 = \frac{1}{n-1}\sum_{j=1}^{n}(X_j - \overline{X})^2$

Equation 10: $S = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(X_j - \overline{X})^2}$

Based on these the values of $\overline{X}$ and S, we categorize all stock items in one of 2 categories:

Category 1: Comprises all stock items with $CV > 0.5$ or $\overline{X} < 10$:

Demand is represented by a Gamma distribution.

Category 2: Comprises all stock items with $CV \leq 0.5$ and $\overline{X} \geq 10$:

Demand is represented by a normal distribution relation.

Every stock item in OR H can thus be represented by either a Gamma or a normal distribution. By classifying the stock items in one of the two categories, the individual stock levels per bin can be determined. This leaves us with formulating the methodology to be used.

5.4 The new methodology defined

Based on section 5.2 and 5.3, we define a methodology to be used for minimizing stock levels in a two-bin replenishment policy under periodic review. This methodology comprises the following steps:

A. Calculate the average daily demand $\overline{X}$ per stock item based on the available replenishment data, with $\overline{X} = \frac{1}{D-1}\sum_{d=1}^{D-1} {q_d}/{\Delta t_d}$
B. Calculate the CV, ${S}/{\overline{X}}$
C. Choose an acceptable probability P of *no stock out occurring per replenishment cycle*
D. Classify the stock items in one two categories:
   1. **Category 1: Gamma distributed stock items, when**
      $CV > 0.5$ or $\overline{Y} < 10$
   2. **Category 2: normal distributed stock items, when**
      $CV \leq 0.5$ and $\overline{Y} \geq 10$
E. Calculate the stock level per bin

In the chapter 6 we calculate the new stock levels. We test the methodology by simulating the replenishment cycle in MS Excel. The calculated average daily demand for a number of stock items is verified as well. Based on the simulation experiment and the verification of average daily demand, we indicate whether the methodology is suitable for the two-bin inventory system of OR H.

6 Experiment

In this chapter, we will verify the new methodology. We first compare the calculated daily average demand with the actual daily demand in OR H. The results of the monitoring of actual demand during a working day are presented in section 6.1. In section 6.2, we test the stock levels by simulating a large number of replenishment cycles. For this simulation, we use the spreadsheet program MS Excel.

6.1 The verification of daily demand

For determining the average daily demand per stock item in OR H, we use the replenishment data over the period January to September 2006. For every stock item, we calculate $\bar{X}$ and S in MS Excel. We next select a number of stock items with either a high or low average daily demand. We monitor these stock items for two weeks. The number of items withdrawn per day is registered. Therefore, we check on-hand stock twice per day: during lead-time and after lead-time. See Table 8 for the results.

	Monitored demand		Calculated demand	
	Average	Standard deviation	$\bar{X}$	S
Jacket	37,67	56,13	34,5	3,45
Catheter	5,18	3,30	6,33	3,99
Curettage set	0,82	1,27	1,29	0,69
Diathermy plate	2,55	2,97	2,87	2,33
Sanitary towel	0,73	0,75	0,84	0,36
Camera cover	6,64	5,58	7,48	8,97
Surgical table sheet	3,27	4,79	3,2	0,63
Laparoscopic sheet	0,45	0,50	1,8	0,82

Table 8: The average daily demand for a collection of stock items in OR H.

Demand was calculated based on of the replenishment data from January to September 2006. The demand is verified by monitoring actual demand over a 2-week period.

Not all replenishment data corresponds to the actual demand: the laparoscopic sheet was replenished according the replenishment data, but the sheets were not replenished in the cabins. Apparently, the sheets were delivered to another location in the OR-complex. We were not able to find out what caused this irregularity.

The average monitored and calculated demand correspond reasonably well. For some stock items, the standard deviations do not correspond. To more closely verify our calculations, the stock items should be monitored during a longer period. Because of the time horizon of this research, we were not able to monitor the stock items for a longer period. We therefore, for this research, accept this verification.

It thus seems acceptable to approximate the average daily demand based on the available replenishment data. Now that the average daily demand is known, we calculate the stock level per stock item. We verify these stock levels by simulating a large number of replenishment cycles. The average number of stock-outs per replenishment cycle should be minimized, and should be less than or equal to 1-P.

6.2 The replenishment simulated

We use MS Excel to simulate the replenishment. In section 5.2, we described that daily demand either occurs before or after 12.00$^{A.M.}$, or demand is distributed over the day. We therefore test the stock levels for both situations:

1. In the first situation, all demand occurs either before or after 12.00$^{A.M.}$. Whether demand occurs before or after midday, is randomly generated with both a 50% chance of occurrence.
2. In the second situation, demand is distributed over the day. Given a daily demand x, we let Excel generate a value *j* per day between 0 and 1. Then, $j \times x$ equals the demand before 12.00$^{A.M.}$, and $(1-j)\times x$ the demand after 12.00$^{A.M.}$. On the average, one half of daily demand occurs before midday, and the other half of demand occurs after midday.

One simulation run simulates replenishment over 260 weeks (or 5 years), from Monday to Friday. This corresponds to 1300 replenishment cycles per simulation run. We programme Excel to generate the daily demand. This demand thus corresponds to the number of units withdrawn during the day. Depending on the average demand and the coefficient of variation, Excel either generates a normal or gamma-distributed daily demand.

A simulation run starts on Monday (week 1) with an on-hand stock of $2 \times s$ units. Per day, the generated demand is subtracted from the number of units of on-hand stock. When on-hand stock drops below s, Q units are delivered at the next day.

We set the probability of no stock-out per replenishment cycle (P) to 95%. As described in chapter 5, P is directly related to the stock levels. We verify whether the value of P actually results in reliable stock levels. When $P = 0.95$, we expect the average number of stock-out occurrences to be 5% or less:

Let Y be the average number of stock out occurrences per simulation run with expectation $\nu = E(Y)$. If we run the simulation *b* times, then $\bar{Y} = \frac{1}{k}\sum_{1}^{k} Y$ is the average value of Y. We want to estimate ν on a $100(1-\alpha)$ percent confidence interval, so that $\left|\bar{Y}-\nu\right| / |\nu| \leq \gamma$. Here, γ is the relative error when estimating ν. The statistical analysis for *terminating simulations* as described by Law and Kelton (1991) helps us to determine the number of runs (*b*) needed to obtain a certain precision. This statistical analysis describes an iterative process that results in the number of simulation runs needed to obtain an average that has a relative error $\gamma/1-\gamma$ with a probability of $1-\alpha$.

We set γ and α to 0.05. Given these values of γ and α, we verified that $b = 700$ is satisfactory when estimating μ.

We are especially interested in how μ and σ (and their CV) influence the average number of stock-out occurrences. We expect this average number to be equal or less than $1-P$. To thoroughly test our methodology, we therefore simulate the replenishment for some real and fictive values of μ and σ. Table 9 shows the result of some values of μ and σ tested. For the ease of reading, we linked all combinations of μ and σ to a stock item ID.

Stock item	Daily demand			Average number of stock-out occurrences	
ID	μ	σ	CV	Situation 1	Situation 2
1	0.02	0.003	0.15	0.51%	0.35%
2	0.05	0.05	1	3.06%	2.54%
3	68	92	1.35	4.00%	3.47%
4	10	5	0.5	0.98%	0.68%
5	10	6	0.6	1.91%	1.55%
6	9	5	0.56	1.73%	1.37%
7	3.6	17.48	4.86	23.48%	23.24%

Table 9: The average number of stock-out occurrences over 700 simulation runs for various stock items.

The results are obtained for $P = 0.95$, $\gamma = 0.05$, ***and*** $\alpha = 0.05$.

Considering Table 9, for stock item 1 to 6, we see that the average number of stock-out occurrences is smaller than 1-P. When $P = 0.95$, we therefore conclude that the stock levels are reliable for all stock items that correspond to this range of the CV. Apparently, when a stock item has a relatively large CV (see stock item 7: the average stock-out occurrence is larger than 5%), the average stock-out occurrence out raises the value of P-1 for $P = 0.95$. Consequently, larger values of P are needed to obtain reliable stock levels for stock items that have a large CV. Based on our testing, we conclude:

When the average number of stock-out occurrences should be 5% or less:

1. P should be set to 95% when $\overline{Y} < 10$ or $0.5 < CV \leq 2$
2. P should be set to 97.5% when $2 < CV \leq 4$
3. P should be set to 99% when $4 < CV \leq 10$

We thus state that P should be slightly increased when the CV increases. Note that increasing P simply results in higher stock levels. We remark that — as a result of the relation between the value P and the probability distribution used — further increasing P to 100% results in enormous stock levels. We therefore advise the inventory manager to consider what stock level is appropriate whenever the CV is greater than 10.

6.3 The new stock levels compared

We defined a methodology that should minimize stock build-up and simultaneously minimize the number of stock-outs per replenishment cycle. Because we successfully verified the stock-out occurrences, we now compare the new stock levels with the current stock levels.

We concentrate on the replenishment data of the last 12 months: from January 2006 to December 2006. We calculate the stock levels for the stock items ordered during this period. However, not all stock items in OR H are included in our calculation. The stock items that are excluded from calculation are:

1. The stock items that are not replenished in the past 12 months:

   Not all stock items stored in OR H are replenished in the past year. Because we use the replenishment data to calculate the stock levels, for some stock items no new stock levels can be calculated. Most of the time, this includes stock items that are not used anymore though a number of units of the stock item is still stored. It currently is the OR-assistant's task to withdraw these stock items from the inventory.

2. The stock items that are ordered 1 or 2 times during the past 12 months:

   We need the time interval between two consecutive orders to calculate the demand. At least two intervals are needed to calculate the average daily demand and its standard deviation. To obtain two intervals, at least 3 replenishment orders should have been placed. Therefore, stock items with 1 or 2 replenishment orders are excluded.

From January to December, 313 different stock items were ordered. All 83 stock items that were ordered 1 or 2 times are excluded from the selection. Next, another 5 stock items are excluded. For these stock items, the current stock levels could not be located in the database. This suggests these stock items are not stored in OR H, although they have been ordered. This indicates the data extracted from the databases of the RdGG do not always mutually correspond.

The remaining 224 stock items in OR H will use the same 3 subsequent comparisons as described in section 4.3. We calculate the new stock levels *s* for this collection of stock items. For reasons of simplicity, we calculate all stock level based on $P = 0,99$.

<u>Comparison 1:</u>

We categorize all 224 stock items based on their stock level reduction defined by $\frac{s-S}{S} \times 100\%$. See Table 10 for the results of this categorization.

Stock level change	***Number of stock items***	***Average change of stock level***
-100% to -80%	0	
-80% to -60%	79	
-60% to -40%	64	
-40% to -20%	30	
-20% to 0%	5	-56%
0% to 20%	40	
20% to 40%	0	
40% to 60%	2	
60% to 80%	1	
80% to 100%	0	
Larger than 100%	2	

Table 10: The categorization of the stock level change for 224 stock items when comparing the stock levels of the (R, S) policy to the stock levels of our new methodology.

Most stock items have their stock level decreased by 40 to 100 percent. On average, the stock levels decreased by 56%.

Concerning the 224 stock items of Table 10, the average stock level decreased by 56%. This average reduction, although we included more stock items (224 versus 189), is slightly smaller than the average reduction obtained by the RdGG.

Comparison 2:

Since two bins are reserved per stock item, the actual stock reduction will be smaller. When we compare the current stock levels (S) with the stock levels per two bins ($2 \times s$), an average stock reduction of 11% is obtained. Compared to section 4.3 (where we found an average stock reduction of 27% after the implementation of the two-bin inventory), the new methodology does not directly seem beneficial. However, we remark that our methodology increased s compared to S for some stock items. This indicates that the RdGG set the current stock level S too low. When calculating the average stock reduction by $\frac{1}{224}\sum \frac{2s-S}{S} \times 100\%$, we consequently find a small (11%) reduction. In comparison 3, we show that our methodology does reduce inventory in OR H considerably.

Comparison 3:

In comparison 1 and 2 we used the average stock change for 224 stock items. We now sum the stock levels for 212 stock items. We thus exclude 12 stock items. These are the small stock items that are stored in small supplier boxes. See Table 11 for the results.

Two-bin inventory system (as calculated with our methodology):	
Sum of all stock levels: $\sum s$	1,582 units
Sum of all stock levels when considering two-bin per stock item: $\sum 2s$	3,164 units
Two-bin inventory system (as calculated by the RdGG):	
Sum of all stock levels: $\sum s$	3,645 units
Sum of all stock levels when considering two-bin per stock item: $\sum 2s$	7,290 units
Sum of all stock levels in: $\sum S$	6,200 units

Table 11: A comparison of the sum of the stock levels for 212 stock items.

Concerning the 224 stock items extracted from the replenishment database, the total number of units stored in OR H can be drastically reduced.

When considering Table 11, we see large differences between the summations of stock levels. Note that we drastically reduced the total number of units stored. We remark that we might still included some small stock items stored in large numbers (like needles) as explained in section 4.3. Secondly, we did not take into account all stock items stored in OR H. This means that the data from Table 11 must be interpreted as a rough indication of the potential reduction of inventory in OR H. In Table 4 we presented the total number of units stored in the storage rooms of OR H in the current inventory system. We conclude that this inventory (or the total number of units stored) in OR H can be reduced by 50% to 70%. Remember that this is primarily the result of our methodology that calculates the stock levels on the basis of one working day instead of 3 to 4.

Based on our simulation, we conclude that the new stock levels can cope with the stochastic demand in the OR-complex. Though some stock levels might still be adjusted to match the content of supplier boxes, the new methodology can help the RdGG to minimize inventory in its two-bin inventory system under periodic review.

We finally implemented the methodology in an Excel worksheet located one of a central network computer of the RdGG. This sheet is automatically updated once per week based on the most recent replenishment data. In this worksheet, the stock level per stock item is automatically calculated. The sheet was presented to the RdGG to support the minimization of stock levels in the OR-complexes of the RdGG. For the future, the methodology might be exploited to other inventory locations in the RdGG.

7 Conclusion

A wide range of disposable materials is used during the surgical procedures performed in the RdGG. All these plus minus 365 stock items are stored in the storage rooms of the OR-complex. Most of these stock items are withdrawn from the storage rooms and placed in the ORs; the rest of the stock items is withdrawn the moment they are needed, and thus not placed in the ORs. As a result, at random points in time, various numbers of stock items are withdrawn from the storage rooms. The number of units of stock item withdrawn per working day varies as well. We therefore characterized the demand for stock items in the storage rooms as stochastic.

The RdGG advocates that the current inventory policy is not able to deal with demand. Therefore, they decided to implement an alternative inventory system: a two-bin inventory policy with an increased review time. Our research objective was to study this two-bin inventory system and indicate whether the new inventory solves the main problems of the current system.

We started this research with an analysis of the current inventory system: we subsequently analyzed the replenishment policy and the methodology used to determine the stock levels. The OR-assistant anticipates on the shortcomings of the current system to guarantee all stock items are available: he places additional replenishment orders to raise on-hand stock and he adjusts the stock levels. We analyzed the frequency by which additional orders are placed and argued that these orders are the symptoms of an inconsistent inventory system. We concluded that the current inventory system is inconsistent, because:

1. The current (R, S) replenishment policy cannot cope with the stochastic material demand in the ORs, and
2. The methodology used to minimizing stock levels is unreliable.

We evaluated these two main problems when analyzing the new inventory system. The new inventory system clearly simplifies the replenishment for the stock clerk. We do expect extra orders are still being placed by the OR-assistant: he can anticipate on fluctuating demand by placing the barcode inside the cabin door when he expects extra on-hand stock is needed. When this barcode is placed, replenishment is automatically triggered.

The two-bin replenishment better copes with stochastic demand because of the decreased review time. However, the calculation of stock levels still seems unreliable, and inventory is far from being minimized. We argued that the new policy should be supported by an alternative methodology for minimizing stock levels.

We defined a new methodology that can be used under stochastic demand. We therefore calculated the expected daily demand. The methodology was tested and the new stock levels were compared to the current stock levels. The new stock levels should be able to cope with stochastic demand. A considerable decrease of the current inventory can be obtained: for most stock items stored in OR H, the average stock levels can be decreased by 56%, and the total number of units stored in the storage rooms can be decreased by 50%. We estimate total inventory can be reduced by 50% to 70%.

The problems of the current inventory system might thus be solved when supporting the two-bin policy by a consistent methodology for minimizing stock levels. The methodology proposed in this research should first be implemented before we can finally state whether the main problems are definitely solved. The computer tool stemmed from this research should help the RdGG with the implementation.

We remark that a two-bin policy simplifies replenishment, but does not minimize inventory by itself. The methodology proposed in this research helps minimizing inventory under the condition of a two-bin policy under periodic review, as implemented in the storage rooms of OR H. There is an important alternative for minimizing inventory an OR-complex: preventing secondary stock build-up:

Currently, most stock items are stored in both the storage rooms and the ORs. For some stock items, we showed the overall number of units stored in the OR-complex is a multiple of the number of units stored in the storage rooms. The constant relocating of stock items from the storage rooms to the ORs partially results in the fluctuating demand. In the current setup, we can interpret the storage rooms as buffers in the supply chain from the warehouse to the ORs: the main warehouse temporarily stores the stock items in the storage rooms of the OR-complex, to be able to satisfy the demand in the ORs.

For the near future, we advise the RdGG to supply all stock items directly to the ORs. This reduces the fluctuations in demand and reduces the overall inventory position in the OR-complex. The inventory management literature presents different alternative inventory systems that minimize inventory for slow-moving and fast-moving stock items. An alternative policy might than be favourable for the RdGG.

In this research, we described the methodology used by the RdGG to determine stock levels in the OR-complex. We described how these stock levels are calculated and adjusted by the OR-assistant. We note that we took into account that this system of determining stock levels is the result of a business (or hospital) culture, where people got accustomed to manually controlling inventory like we described. These manual controlling activities were necessary to guarantee timely delivery of stock items, since the current inventory system could not cope with stochastic demand. It will take some time for the new inventory policy and methodology to be fully beneficial. People have to get used to the new working instructions and guidelines. At this moment, most nurses are not yet used to these instructions when withdrawing stock. Every nurse is now responsible for monitoring on-hand stock, and should thus place the barcode inside the cabinet door when a stock item runs out of stock. Secondly, the RdGG should prevent people from placing the barcode inside the cabin door when they feel the need to anticipate on future demand: the inventory system by itself should eventually fully control the replenishment of stock items in the OR-complex.

8 Discussion

We started this research with a comparison of the current inventory system and new inventory system. Based on this comparison, we described what main problems we expect not to be solved in the new system. We argued that the RdGG needs an alternative methodology for determining stock levels. This methodology will minimize stock levels and stock-out occurrences. The two-bin policy was implemented in OR H in December 2006. On the short term, the RdGG implements the two-bin policy in OR B.

Because the two-policy was implemented in the final weeks of this research, we were not able to accurately monitor daily demand and replenishment activities. We also could not get a clear indication of a reduction of on-hand stock. Combined with the computer database that holds all stock levels, we concluded on-hand stock did not significantly decrease. We advise the RdGG to closely monitor replenishment activities when the two-bin policy is fully implemented. Only then, the new methodology can be evaluated more effectively.

The computer databases we used did not always mutually correspond. Some stock items that were replenished according the replenishment database cannot be located in the inventory database that registers all stock items stored in the storage rooms. We could therefore not match all stock items. We also noticed that the databases did not always correspond to the real-time replenishment. For example, the laparoscopic sheet that we monitored for two weeks was replenished according the computer database. In reality, no new deliveries of sheets could be located in the OR-complex. It is still unclear whether these sheets were ordered or not.

Despite the shortcomings experienced in the process of our research, we expect our methodology will simplify the minimization of stock levels in the OR-complex. Especially the computer tool we designed will help the inventory manager in minimizing stock levels. At the moment, this tool can calculate stock levels for all stock items replenished in OR B and OR H. For the near future, the functionality can be easily expanded so that stock levels in other departments of the RdGG can be calculated as well.

However, the methodology does not calculate stock levels for stock items that were not replenished. This way, not all stock items are automatically evaluated when determining new stock levels. It is the inventory manager’s task to compare the stock items replenished with the stock items stored in the storage rooms. Any stock items that are not matched require special attention. We suggest, if any stock items are ordered less than 3 times over a long period of time, management should consider not placing these items in a two-bin policy. Maybe, these items can be ordered in advance at the main warehouse when they are needed for next week’s surgical procedures.

The RdGG plans to register all materials used in the ORs. Because of these plans, a computer system is placed in the ORs. The nurses then register all stock items used, but these plans are not yet fully implemented. For the near future, the data available from these computer systems can be very useful in verifying daily demand. Then, stock levels can be matched more accurately to daily demand. Theoretically, on-hand stock can then be monitored real-time. This raises the possibility of a continuous review policy. Further research should then point out whether this is a realistic option.

In this research, we did not study the cost effects of the current and new inventory system. As a result, the order-quantity was not evaluated based on an evaluation of cost factors, like holding and ordering costs. In the inventory management literature, the optimum order-quantity is calculated by evaluating these cost factors. Since these cost aspects were not analyzed, we suggest this is a subject for further research.

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Appendix A. The Hierarchical Planning model

	Medical planning	Resource capacity planning	Material planning	Financial planning
Strategic planning	Specialisms Education & training Alternative medical treatments Types of surgical procedures Target groups Scheduling technique medical procedures	Number of ORs Number of specialists, assistants, employees Number of (high tech) medical instruments Number of transportion means Capacity main warehouse, OR-complex, ORs Location storage rooms Layout OR-complex Materialflow in OR-complex Scheduling technique ORs IS for scheduling purposes	Select suppliers Select manufacturers Select managers inventories Hopital regulation hygiene (sterile handling) Implement IS for inventory management Implement bar codes for stock items Registration of stock items per unit or per piece Select order-picking method Define replenishment policy	Budgeting Define financial responsibilities Implement cost places Implement DBCs
Tactical planning	Planning of medical procedures Plan of medical treatment	Location cabins OR-comlex and ORs Number of cabins OR-comlex and ORs Locations computer systems Workforce planning OR scheduling	Determine stock levels Select frequency of replenishment Order new stock items for main warehouse Monitor material demand in OR B and H Select order picking routes in main warehouse Create new bar codes Define task description stock clerk	Monitor expenditure stock items Monitor costs medical procedures Monitor administrative costs
Operational control (Offline)	Entering of patient Begin anaesthetics Surgical procedure End anaesthetics Exit patient Clearing of used materials Register procedure	Prepare instrument tables for surgery Register surgery time Replenish stocks in cabins ORs	Place barcode on stock items Scanning of storage rooms in OR B and H Process scan orders Pick orders in main warehouse Transport stock items to OR B and H Raise stock levels in OR B and H Replenish cabinets in ORs Register material use in OR	Register material use and cost locations Pay suppliers for delivered items
Operationeel control (Online)	Emergency treatments Surgical procedure Complications		Check number of boxes outside cabins in the storage room during replenishment Replenish inventories in storage room from boxes Place extra or urgent orders Recieve deliveries in main warehouse from suppliers Put sterile products in boxes for transportation purposes Replenish cabins in ORs in case of stock-out Place items delivered in boxes outside cabins in storagerooms Withdraw pieces from supplier boxes in cabinets storage rooms Place urgent orders Deliver urgent orders to OR-complex	

Appendix B. The cabinets in OR H

The cabinets in storage room 1:

Most stock items are stored in storage room 1

The cabinets in storage room 2:

All jackets and sheets are stored in storage room 2

The cabinets in the ORs:

Most of the stock items are stored in the ORs as well. This way, the nurses can easily reach for these items during surgery. The picture on the left shows some sheets, the picture on the right different types of needles and sutures.

Appendix C. Frequently used terms

In this report, we use the following terms:

- Both OR-complexes have an assistant who is responsible for the inventories. We will call this person the *OR-assistant*.
- The operating nursing staff supports the surgeon during surgery. When we speak of the *nurses*, we refer to the operating nursing staff.
- The *transport* department is responsible for replenishing all inventories. The person on duty is referred to as the *stock clerk*.
- A stock item is defined as a specific item of stock to be controlled (also named *stock keeping unit* or *SKU* in the inventory management literature). A specific stock item is characterized by a unique function, size, weight, colour, location, and *number of pieces per unit*. Because stock items are delivered in packages containing one or more pieces, the *number of pieces per unit* specifies the number of pieces present in the package of a single unit. For example the stock item 'hand gloves': one unit of hand gloves is packed per box of 50 pieces.

  As a result, the inventory position can be analyzed from 3 perspectives (see Table 12):

  1. The total number of stock items stored: the number of different items of stock to be controlled
  2. The total number of units stored: the number of units of all stock items
  3. The total number of pieces stored: the number of single pieces of all stock items

	Perspective		
	Number of stock items stored	**Number of units stored**	**Number of pieces stored**
Inventory	ID 1	(units of ID 1)	(pieces of ID 1)
	ID 2	(units of ID 2)	…
	ID 3	…	…
	ID ..	…	…
	ID ..	…	…
	Total equals total number of stock items	**Total equals sum of all units stored**	**Total equals sum of all pieces stored**

Table 12: The 3 perspectives on the inventory position.

One or more units of a particular stock item are stored in the storage rooms. Every unit of a stock item contains one or more pieces.

- Inventory management literature distinguishes two major types of replenishment policies (see Silver et al., 1998): *continuous* review and *periodic* review policies. In continuous review policies, the stock levels are constantly monitored. For periodic review policies, stock levels are checked every *r* units of time ($r > 0$). This period is called the *replenishment* or *review time (R)*. In both continuous and periodic review policies, the time between a replenishment order placed and delivered is called the *lead-time (L)*.

The *on-hand* stock level is the number of units of a stock item that is physically in the cabinet at a certain moment in time. *Safety stock* is the number of units kept on hand that allows the uncertainty in demand. It can be interpreted as a buffer for unexpected demand.

Appendix D. The storage and delivery of supplier boxes in OR H

Some stock items are stored in supplier boxes in storage room 1. This creates extra stock build-up and, as a result, a lot of free space is wasted.

The central warehouse supplies all stock items. Some stock items are delivered in supplier boxes. Because these boxes cannot be placed in the cabinets, they are randomly put on the ground or on the tables.