The design of a differentiated inventory control model

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The Design of a Differentiated Inventory Control Model

This report is part of the Master's Thesis Project for graduation at the Eindhoven University of Technology, faculty for Industrial Engineering and Management Science in the Netherlands.

Company:

Philips Eindhoven,
Consumer Electronics,
Business Group Television & CE-Europe

Company supervisors:

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Inventory as seen by:

The president	**a topic that comes up at every meeting.**
The Chairman of the Board	**something the President should get on top of.**
The Stockholder	**where his dividends went.**
The Treasurer	**the BIG number in the upper left of the Balance Sheet.**
The Accountant	**a set of accounts which never balances at month's end.**
The Company Auditor	**a set of accounts which never balances at the end of the year either.**
The Salesman	**good customer service in spite of the idiots in Production.**
The Plant Manager	**efficient operation in spite of the idiots in Sales.**
The Foreman	**steady work for his crew.**
The Purchasing Manager	**the HOT/RUSH item, air-freighted in and still sitting unused.**
The Inventory Clerk	**a pain in the neck, but also a job.**
The Expediter	**his lifeblood: what just ran out.**
The Consultant	**his lifeblood: the problem that is never quite solved.**
The Scholar	**excellent dissertation topic: the square root of demand.**

Anecdote:

When students give a party they tend to buy a lot of beer, just in case they become too thirsty or more visitors come by than expected. Most of the time it appears that at the end of the party a lot of beer remains or it appears that they run out of beer at ten o'clock already. Do students have a problem? Yes, they seem not to control the situation.

Contents

Abstract

The new logistics concepts of Philips' product division Consumer Electronics, that will be introduced in the near future, require a new inventory control model. To benefit from the proposed logistics concepts a differentiated inventory control model is designed.

Summary

A main issue for many industrial companies is the reduction of inventory. In most cases inventory is needed to overcome a temporary discrepancy between the need of goods and the delivery of goods. If finished goods are considered in a make-to-stock situation, inventory will be needed to overcome sales variations and supply constraints. In other words inventory is used to guarantee the company's marketplace.

In this report provides an examination of the inventory of Philips' televisions. The business group Television of Philips Electronics is engaged in the manufacturing of televisions in Europe and as a result of one of the taskforces of Centurion[1] the stock levels became a hot item again. Furthermore a project was started, called PHOENIX, that aims at significant stock reductions and improved customer service levels.

Inventory must be seen as part of the working capital and is used as a tool to generate revenue and profit. Hence inventory is a means and not an aim. A way to monitor the effectiveness of inventory at this point, is the observation of the Return On Net Assets (RONA). This long-term performance indicator can be used to observe how much income from operations is created in relation to the available working capital. To improve the RONA, one should aim at three logistics objectives: a high customer service and a low relative investment in stock, both at low logistics costs.

It appears that the RONA can be improved. An analysis of the basic problems, that cause an excess of stock, shows that the design of a differentiated inventory control will help to reduce the total inventory. A differentiated inventory control provides a tool to set inventory norms on type level that matches the top-down inventory budget. So it is possible to specify a set of input parameters and a corresponding stock level for each individual product type. However to keep the actual stock close to the budgeted stock level, the deviations from stock norms have to be monitored. Both the determination of required stock levels and a procedure for monitoring deviations from stock norms are worked out for the future logistics situation.

A study of the present and future logistics situation and an examination of existing stock control models, show that one can best use a replenishment method with variable loads at fixed time points. In other words the designed inventory control assumes that at fixed points in time a variable load of televisions can be ordered. A calculation of the safety stock norms with actual data conform the future logistics

[1] A company-wide project that consists of several crucial activities, introduced by Philips' president J.D. Timmer

situation shows that the control model is realistic and easy to use. The three remaining stock elements: batch, seasonal and sailing stock are discussed separately.

The safety stock calculation is based on two changeable parameters: the customer service level and the stock policy. Both parameters are used to deliberately differentiate product types and seem to work satisfactory.

The customer service level is defined as the long-run fraction of demand satisfied directly from stock on hand during the replenishment cycle. The optimum customer service level (CSL) can be determined through a financial analysis. First of all the total (top-down) inventory budget has to be determined. Secondly the bottom-up approach has to decide what optimum CSL's and corresponding stock norms should be used for each individual product type.

The top-down budget is calculated per main article group (MAG). This long term decision is based on a trade-off between (total variable) stockcosts and the income from operations: a higher CSL results in more stockcosts and less lost back orders (= more income from operations). This top-down budget is used to determine the inventory norms on type level. One could try to calculate the optimum CSL of one product type, but it is easier to make a trade-off between the specific product types. The demonstrated method starts with one CSL for all product types within one MAG, whereafter the CSL is adjusted until the sum of all individual inventory norms matches the top-down norm. After that one trade-off of two product types is made based on the differences in contribution margin, as an example of the way to find the optimum CSL per product type.

Some product types require a different calculation of stock norms, given a specific CSL, as a result of the differentiation in stock policies. Three different stock policies are defined for order, special and preferred product types. The order types will not be stored whereas the special types will be stored at national sales organizations. The preferred types will use two stock-points: one at the national sales organization (NSO) and one at an European distribution centre (EDC). The optimum allocation of stock can be determined for each preferred product type, however a general conclusion is that a stock level of one week future sales at an EDC is sufficient.

To calculate the batch and safety stock norm the following data are required: the time between two replenishment orders (= review time), the order lead time, the supply deviation time, the planned (average) weekly sales and the corresponding mean absolute deviation (MAD). All required data are available and can be obtained from the GIPSY (Goodsmovement Information and Planning System) database with help of its reporting tool FOCUS. However an additional database is required to record data of e.g. forecast errors. The program code that is used to calculate the stock norms, is available in C[2].

As a result of the differentiated inventory control it is possible to achieve a stock reduction of $1.0 \cdot 10^5$ pieces (from a mean physical stock of $4.0 \cdot 10^5$ to $3.0 \cdot 10^5$ pieces). This corresponds with a non-recurring cash flow of about f $48.3 \cdot 10^6$ (NLG), whereas the RONA is improved strongly. This will only be achieved if the future logistics improvements are truly realized. The most essential improvements are the switch from plan driven supply to order driven supply and the decrease of the review period.

To implement the presented differentiated inventory control a few more essential steps have to finished. First of all the procedure for monitoring deviations from stock norms must be worked out further. Secondly the program code has to be translated into the "FOCUS- language" and finally an additional database has to be created that records data from GIPSY.

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[2] C is a programming language released by the company Borland.

List of abbreviations

12NC	12 characters that represent an unambiguous code for a product type
100HZ	"100 Hertz" television
BG	Business Group
BG TV	Business Group Television
CE	Consumer Electronics
CM	Contribution Margin
CODP	Customer Order Decoupling Point
CPC	Commercial Product Class
CPL	Consumer goods Planning and Logistics
CRT	Cathode Ray Tube
CSL	Customer Service Level
CTV	Commercial Type Version
EDC	European Distribution Centre
FOCUS	A reporting tool for GIPSY
FTY	Factory
GIPSY	Goodsmovement Information and Planning System; database that records goodsmovements
IFO	Income From Operations (ION + TPD)
IIP	Intercompany Invoice Price
IMS	Interactive Media Systems
ION	Income From Operations NSO
IPC	International Production Centre
K	× 1000 pieces
KMG	Key Module Group
MAD	Mean Absolute Deviation of the forecast error
MAG	Main Article Group
NLG	Netherlands Guilders
NP	Net Price
NSO	National Sales Organization
OEM	Original Equipment Manufacturer
PCB	Printed Circuit Board
PD	Product Division
Phoenix	Project for improvement of the logistics activities of CE
PIP	Profit Improvement Project
PRECOM	database that records pre-calculated and actual financial data
PTV	Projection Television
ROE	Return On Equity
ROIC	Return On Inventory Capital
RONA	Return On Net Assets
ROTA	Return On Total Assets
SMD	Surface Mounted Device
STECO	Standard Economy
TO speed	Turnover Speed
TPD	Target Price Difference
TV	Television

Preface

This report examines the inventory control and its performance of a company that has to act in a turbulent market. The company sells a large assortment of goods that requires a good customer service in order to outlast the competition. Inventory can be seen as tool to overcome deficiencies of the supply process. Inventory indicates that a part of the supply chain is out of control or that a part of it does not response to the market fast enough. For example if a machine can only manufacture products at the end of a month, then this shortcoming will be "solved" by the storage of finished products. That way the process can proceed throughout the month without removing the real bottleneck. **So inventory is a means and not an aim.** For that reason inventory should be controlled and kept within limits. However when no inventory is used in a situation where customers require an immediate delivery (from stock on hand) and supply constraints restrict the delivery of goods, the company will lose his marketplace. Nonetheless one must recognize that this lead time performance is not the only competitive issue, e.g. product quality and prices are as important.

This report discusses the inventory control of the Business Group Television. This Business Group is part of the Product Division Consumer Electronics and provides a substantial part of Philips' revenue.
More than twenty years inventory control has been an issue. Several large projects have been started, especially since computer supported data processing was available to control the enormous diversity of products. In 1968 the "stock inspector" was introduced and was replaced by a "stock control team" 5 years later. In 1979 Philips designed its own Consumer goods Planning and Logistics (CPL) system, supported by McKinsey. However until now no real breakthrough has been achieved.
A new project has been started recently that improves the logistics activities of the supply chain for finished goods. This project is called PHOENIX and aims at a breakthrough in customer service levels and significant inventory reductions. This improvement should be realized mainly by introducing a distribution resources planning (DRP II) system, so the present plan driven supply turns into an order driven supply.

However not the inventory reduction but the inventory control is the leading issue of this report. Nevertheless a good inventory control should take account of the logistics objectives, so the inventory reduction can be realized. Hence the second part of this report examines the inventory performance of the present logistics control.

The result of this report is the design of an inventory control model that can be used in a supply chain of finished goods, where the customers require a delivery from stock. This model provides a means to realize and control the proposed inventory reduction.

This report is part of the Master's Thesis Project for graduation at the Eindhoven University of Technology, faculty for Industrial Engineering and Management Science in the Netherlands.

CHAPTER 1: Introduction

1.1: Project initiation

The proposal for this Master's thesis project was formulated in July 1992 by the Television's logistics department of the Philips company. The initial proposal of this business group contained a description of the established problem area and the corresponding solution approach. The two most important items, mentioned in that proposal, were:

- the design of a differentiated inventory control model,
- the correspondence with the new Ways of Working of the PHOENIX[1] project [reference 10].

The mentioned proposal provided a good starting point, but **was more a solution than a problem description.** Shortly afterwards it appeared that the project required a broader view. Thus the financial aspects of inventory were to be included. It became clear that the PHOENIX project itself didn't start from explicit financial objectives. The PHOENIX project aims more at significant stock reductions and improved customer service levels. Nevertheless the PHOENIX project will strongly influence the future logistics control. Afterwards a second project of importance was identified: the Profit Improvement Plan Logistics (PIP logistics). The PIP logistics of the Television's logistics department aims at the improvement of the logistics (order driven) capabilities. These new order driven capabilities influence the final results of this Master's thesis project, but will not be examined separately. Most analyzed problems are worked out by PHOENIX and PIP logistics, what emphasizes the link between this project and PHOENIX or PIP.
Nonetheless the most important conclusion was that the financial objectives for inventory control should be used to analyze the problems and to design a differentiated inventory control model.

1.2: Differentiated inventory control

The differentiated inventory control provides a tool to set inventory norms on type level. The possibility to change inventory control parameters of a specific product type is called differentiation. Nevertheless the sum of all these inventory norms on type

[1] this project improves the logistics activities concerning the finished goods supply chain of the Product Division Consumer Electronics.

level has to correspond with the total budget for inventory. If not, the parameter settings of each product type can be changed till the cumulative inventory norms do not exceed the total budget. Two types of inventory control parameters can be defined:

1• changeable (endogenous) parameters that can be used to control the stock norm,
2• fixed (exogenous) parameters that are a result of the environment.

An example of the first type is the customer service level (CSL) which is used to specify the targeted safety stock level. An example of the second type is the forecast error which is a result of the sales forecast and the actual demand. Thus the customer service level is a parameter that can be used to differentiate between the different product types, whereas the forecast error is a result of other business processes and is fixed (but **not** the same) for all product types during a certain period. So calculating inventory norms on type level and changing the parameter settings for several product types, with help of the changeable parameters, is one way to decrease the total stock. This is done by introducing a differentiated stock control. The other way to reduce the total stock is change the environment (or in other words change the business processes). By changing the business processes it is possible to influence the fixed parameters. More reliable forecasting, more flexibility and more commonality are examples of how to change the fixed parameters and to reduce the total stock level.

1.3: Final assignment and problem definition

The design of an inventory control demands a solid analysis of the requirements of the system. The primary requirements do not only consist of the calculation of the inventory norms but also consist of the way to control deviations from this norm. Hence the final assignment is divided in two parts: a normative part and an operational part. First of all the normative part will be discussed with emphasis on the financial objectives, but still concentrated on the need of a differentiated stock control model. The other (operative) assignment provides an approach for monitoring and evaluating the deviations from norm stock. The results of these assignments should be that an inventory reduction can be realized. This call for stock reduction is based on the following problem definition:

The actual stock of finished goods of CE TV, which is a result of the logistics planning (resource, supply, commercial/sales), the manufacturing situation and the stock control, is high and unbalanced and does not match the financial objectives.

To achieve a situation in which the stocks of finished goods are normal and balanced, two major tasks have to be completed.

• the first assignment (normative part):

Design a differentiated stock control model that provides a procedure for setting

stock targets and takes into account the future logistics control (proposed by PHOENIX) and the companies financial objectives.

• the second assignment (operational part):
  Search for a procedure to monitor, evaluate and reduce or allocate the deviations from norm stock. This in order to keep the actual stock close to the stock norm and to achieve the companies objectives.

Throughout the final assignment it should be taken into account that:

- it is important to check the consistency of the created stock model with the PHOENIX project,
- practical usability for the marketing and logistics department and possibility to implement it in the organization.

1.4: Reporting structure

Figure 1.1 illustrates the reporting structure that has been used to design a differentiated inventory control. Chapter 2 describes the present logistics situation of the business group Television which can be used to examine the problem area. This part is less important for readers that are familiar with the present and future logistics situation. Chapter 3 provides an analysis about the actual inventory and the inventory control of the business group Television. It discloses more details about the necessity to reduce inventory and to control inventory on type level.

The problem area can be seen as a gap between the present and desired logistics situation. Chapter 4 examines this problem area, what results in a few basic problems. The examination of those basic problems was executed according the "Quick Scan"-method [reference 4]. One of those basic problems: the lack of a consistent stock model, is worked out in chapter 5. Hence chapter 5 gives the final results of the mentioned assignments. Finally chapter 6 provides some conclusions and feedback of the total research.

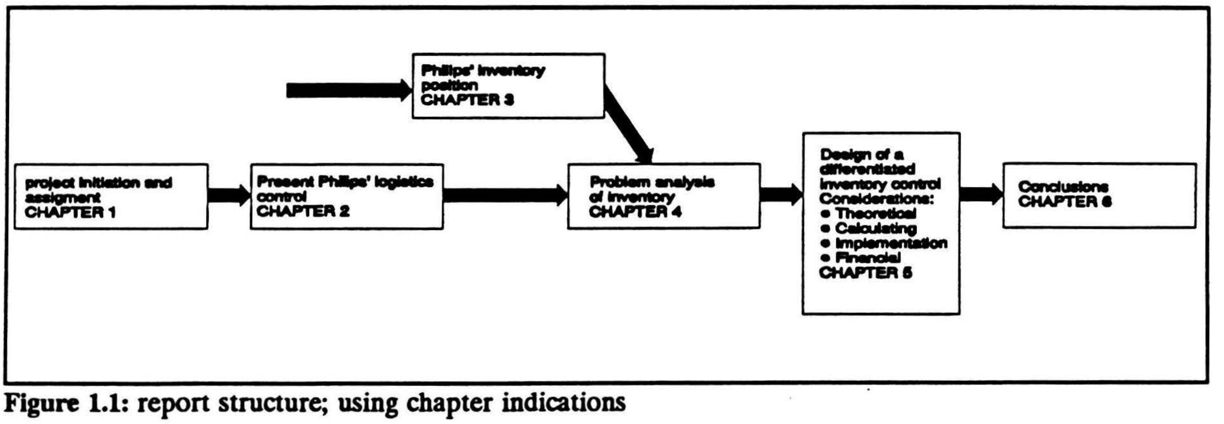

Figure 1.1: report structure; using chapter indications

CHAPTER 2: Present Philips' logistics control

This chapter provides detailed information about the logistics control of Philips' business group Television. It also provides some general characteristics of the business group Television and CE-Europe.
This chapter is used as a starting-point for the analysis of the basic problems and the design of a differentiated inventory control.

2.1: Philips, the Business Group Television and CE Europe

The Business Group (BG) Televisions (TV) is responsible for the production of Colour Televisions, whereas the department CE Europe controls the national sales and marketing of all BG's. Both are part of the Product Division (PD) Consumer Electronics (CE) (see appendix 2.1). Consumer Electronics provides about 47% of Philips' total turnover.
The BG TV consists of several departments e.g. Finance & Accounting and Industrial Management. This project concerns the logistics activities of TV that come within the Industrial Management Department of TV. The main activities of TV logistics aim at the coordination between the International Production Centres (IPC's) on the one hand and the National Sales Organizations (NSO's) on the other hand. Therefore TV logistics itself consists of several departments that strongly communicate with both IPC's and CE Europe.
CE Europe consists of a department for marketing activities, several support departments and a department for coordination of the NSO's. CE Europe coordinates Philips' national sales of all BG's, so the capacity of the IPC's can be tuned to the total European sales. Hence CE Europe communicates with both the NSO's and the BG TV.

The National Sales Organization (NSO) take care of the sales of Philips products. Each specific region in Europe is represented by one NSO. A NSO does also sell second and third brands such as Aristona and Erres in the Netherlands. Appendix 2.2 contains more information about the existing NSO's in Europe.

The BG TV has 3 large International Production Centres (IPC's), each manufacturing products for one different product segment[1]. The IPC Brugge manufactures products of the High End segment whereas Dreux produces Standard products and Monza Standard Economy products. 2 Subordinate factories are: Barcelona and Singapore as

[1] This classification will be discussed in § 2.2

subordinate plants for Monza. The IPC's in Europe are only used to supply televisions for the European market. This situation is illustrated in appendix 2.3

Until now only the sales and the manufacturing of televisions have been discussed. However another important activity is the product creation process. A part of the product creation process that is important for the inventory control of finished goods, is the phasing-in of new product types and the phasing-out of old product types. Specially the start and end dates of supplies and the expected sales of a successor are relevant information for the inventory control.
The product creation process also determines what product types will be introduced. Hence the diversity of televisions can be controlled by the product creation process.(A high diversity appears to be a cause of mud or slow moving inventory.)

2.2: The television

The BG TV is responsible for the manufacturing of colour televisions (, until recently also monitors were part of the activities of the BG TV[2]). This research however only examines the processes between the IPC's and the NSO's, which are coordinated by TV logistics and CE Europe logistics. Hence only finished goods will be considered.
One can classify televisions (= finished goods) on several aggregation levels according specific criteria:

1) product segment
2) Main Article Group (MAG)[3]
3) Commercial Product Class (CPC)
4) Commercial Type Version (CTV)

A product segment represents a certain price level. The three product segments are:

- STECO
- Standard
- High End

The Standard Economy (STECO) products like the 14 inch television are provided with a few features and small picture tubes (CRT's). These STECO products represent the lowest price level. The High End products such as the 100 HZ or 16:9 (wide image) televisions have many sophisticated features and supply a special part of the total market. Each product segment is divided in a few MAG's. The division of the MAG's is based on the screen size and some major features. Within a MAG several chassis constraints can be observed. These chassis restrict the flexibility of production.

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[2] Monitors are now part of the BG: Business Electronics.

[3] This aggregation level used to be called: Commitment Article Group.

Nowadays the BG TV defines 13 MAG's:

STECO :	Standard:	High End:
• Mono 14"	• Stereo Medium	• HI-TOP Medium
• Tiny Rest	• Mono Large	• HI-TOP 50HZ
• Mono Medium	• Stereo Large	• HI-TOP 100HZ
• Pocket	• Wide Screen Standard	• Wide Screen High End
		• Projection TV

A MAG consists of many CPC's. The sales organizations use these CPC's to indicate a certain product-market combination. Successors and predecessors of a specific product type come within one CPC. A product type or CTV has an unique identification code, e.g. 14GR1221/02B. The first 8 characters represent a commercial type. The last 4 characters are called the standard stroke number. The standard stroke number is used to indicate distinct versions of a commercial type. Generally the stroke numbers correspond with a region or a group of region's because each region demands a different version. This demand depends on: the image and sound transmission standards of a specific country (like PAL, SECAM or SECAM BK and NICAM Stereo or Stereo), the alternating current (AC: 220/240V), the "teletext" standards, the manual and the service videotape. It is important to know that all these different standards result in a large diversity of product types. The BG TV has about 2000 different commercial type versions a year. An example: the 14GR1221/02B represents a black (B) Mono Tiny 14" television (14GR1221) for Germany (/02), whereas the 14GR1221/10B represents the same black Mono Tiny 14" television in a different version for Portugal and Austria.

Each of the above classifications serves its own purpose. Nevertheless all four aggregation levels are used for planning. The different planning horizons require separate aggregation levels. For example a medium long term decision (like resource planning) can not be derived from detailed information on product type level because it is too unreliable and irrelevant. On the other hand a customer will order a specific product type and not a MAG, so the NSO's will use information on CTV level.

2.3: Manufacturing process Television

The differentiated inventory control, discussed in this report, only considers the inventory of finished goods. Hence the actual manufacturing will be considered as a black box. Nevertheless it is important to reckon with the supply constraints. Due to the cyclic production (batch production), capacity constraints (especially restricted flexibilty of human resources) and lack of critical components (especially Integrated

Circuits) it is not possible to deliver all the time. Especially the critical components that have to be purchased in the Far East cause long order lead times.
The inventory of critical components differs per product type, what results in variety of type-specific order lead times. The inventory of critical components also affects the flexibility of production. Furthermore this flexibility is also constrained by chassis properties. A switch within one family causes only a small loss of time. On the contrary a switch between two families requires considerably more time.

The actual production of televisions can be divided into three shops:

- automatic insertion of components on a printed circuit board (PCB),
- manual insertion and soldering of large components (SMD's),
- sub-assembly and encasing of final components: chassis, cabinet, speakers, wire tree, degaussing coil and picture tubes (CRT's).

The final assembly ends with the picture adjustment, registration and packaging of a television. The process quality is monitored at several measuring-points, particular at the end of a shop.
Only a part of the order lead time consists of throughput time. The automatic insertion of components takes only a few hours, but the insertion of an average batch takes about 2 days (including programming). Therefore a decoupling point is needed between the first and the second shop. The manual insertion and soldering takes about half an hour and the final assembly requires about one hour and a quarter.
The average operations lead time is only a few hours, the remaining time after the order release consists mainly of waiting time. The total throughput time of a product after the order release is about 8 days. After that it will be stocked at the NSO. For some product types in the IPC Brugge an order desk system is used. In this case goods will not be transported immediately, but only when the expected order has really arrived.
The actual order lead time consists of the throughput time, the waiting time before the order release, the waiting time for materials to arrive and the transport time. The throughput time is the sum of the time for operations and the waiting time between the operations. The order lead time is approximate 4 weeks. The exact order lead times are not known because the present logistic control is plan driven.
All these constraints differ per specific product that has to be produced. For example in Brugge a Projection Television (PTV) is not produced as oft as the 28 inch Matchline Television, what is reflected in the cyclic production plan. The 28 inch Matchline Television is produced on a flow line with a production cycle of one week, whereas a PTV is manufactured on a flow line with a cycle of two weeks.

2.4: Sales Television

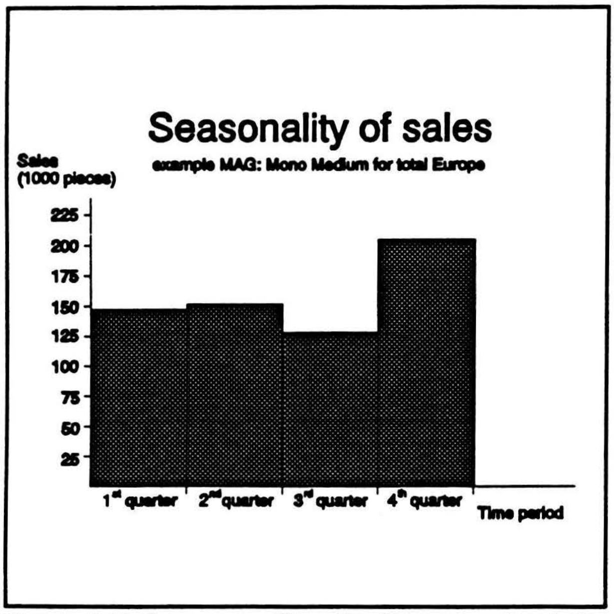

Figure 2.1: the seasonality of sales, example of the MAG Mono Medium

The BG TV sells about televisions a year on the European market. The actual sales were about in 1992. Products were sold in the STECO product segment, in the Standard and in the High End segment.

The MAG's Mono 14", Mono Medium and Stereo large televisions account for (respectively about 65% of the total sales (in pieces). Only 1% of the total sales (pieces) consists of pocket and projection televisions. The sales show a strong seasonality that differs per region. In general one can say that the sales are large in the 4th quarter of a year and low in the 3rd quarter. This seasonality is depicted in figure 2.1.

2.5: TV logistics control

The present logistics control is based on a dialogue between four parties. The IPC, the NSO, CE Europe and the BG TV itself. CE Europe logistics and TV logistics can be considered as one and are addressed as the TV logistics organization (see appendix 2.1). At this moment 5 different levels of logistics control are distinguished:

	Horizon
• Business Unit Strategy	± 5 Years
• Operational Plan	± 2 Years
• Master Plan	± 1 Year
• Schedule	± 2 Months
• Execution control	± 1 Week

Specially the Master Plan and the Schedule level are of interest, because of their large impact on sales and supplies. The Master Plans consist of volume orientations and mix orientations, which are monthly reviewed. The short term plans or schedules consist of volume commitments and mix call off plans and are monthly reviewed. Figure 2.2 illustrates these present information flows between the three logistics participants. This figure also depicts some operational information flows, such as the order acceptance and the customer order. The short to medium term messages of the

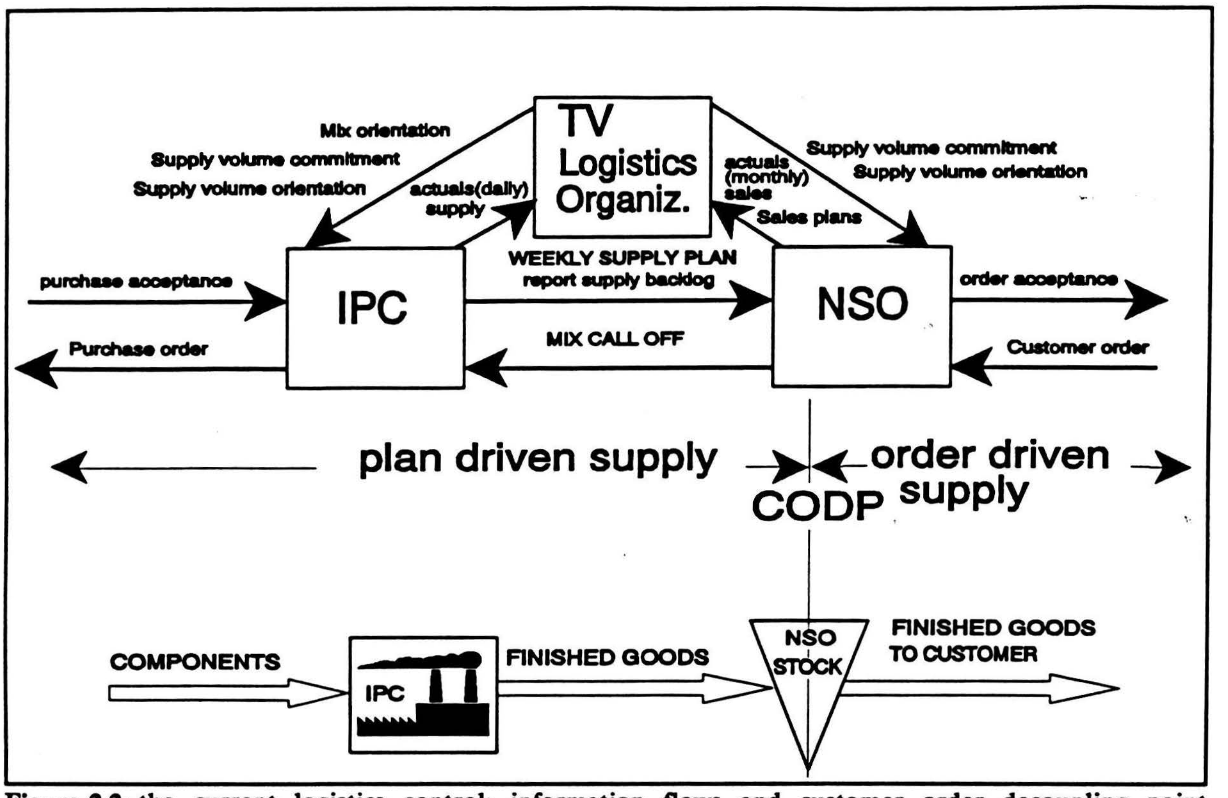

Figure 2.2: the current logistics control; information flows and customer order decoupling point (CODP)

TV logistics organization are not triggered by a customer order. Hence this part of the logistics planning is plan driven. The logistics chain after the customer order decoupling point (CODP, see picture 2.2) is order driven. A customer order triggers the supply of goods from the NSO stock, which is called order driven supply. Nevertheless the real logistics chain from IPC to NSO is more complicated.

Figure 2.3 shows the present goodsflows of televisions. An European Distribution Centre (EDC) is added to picture 2.3 although an EDC for televisions has not been introduced entirely. The supplies from IPC's to Original Equipment Manufacturers (OEM's) are in most cases direct deliveries. Direct deliveries also occur when product types are ordered that can not be supplied from stock on hand. In case of direct deliveries the CODP is situated at the IPC, because a customer order triggers the production at the factory. When the EDC is used to replenish the NSO inventory, the supply between EDC and NSO becomes order driven. Hence the EDC can be seen as a decoupling point for NSO orders; a NSO order triggers the supply from EDC to NSO. However in the near future the present plan driven supply between the IPC and the NSO will be replaced by an order driven supply (DRP II). This new logistics concept is worked out by PHOENIX and is an important improvement for the inventory control. The NSO stocks will be replenished instead of supplied according plan. To control this process, information about order lead times will be required. The significant lead times are also shown in the picture 2.3 because the lead time depends on which part of the logistics chain is regarded. Often confusion about lead times is caused by the impact of certain decisions in a plan driven supply. For example, when

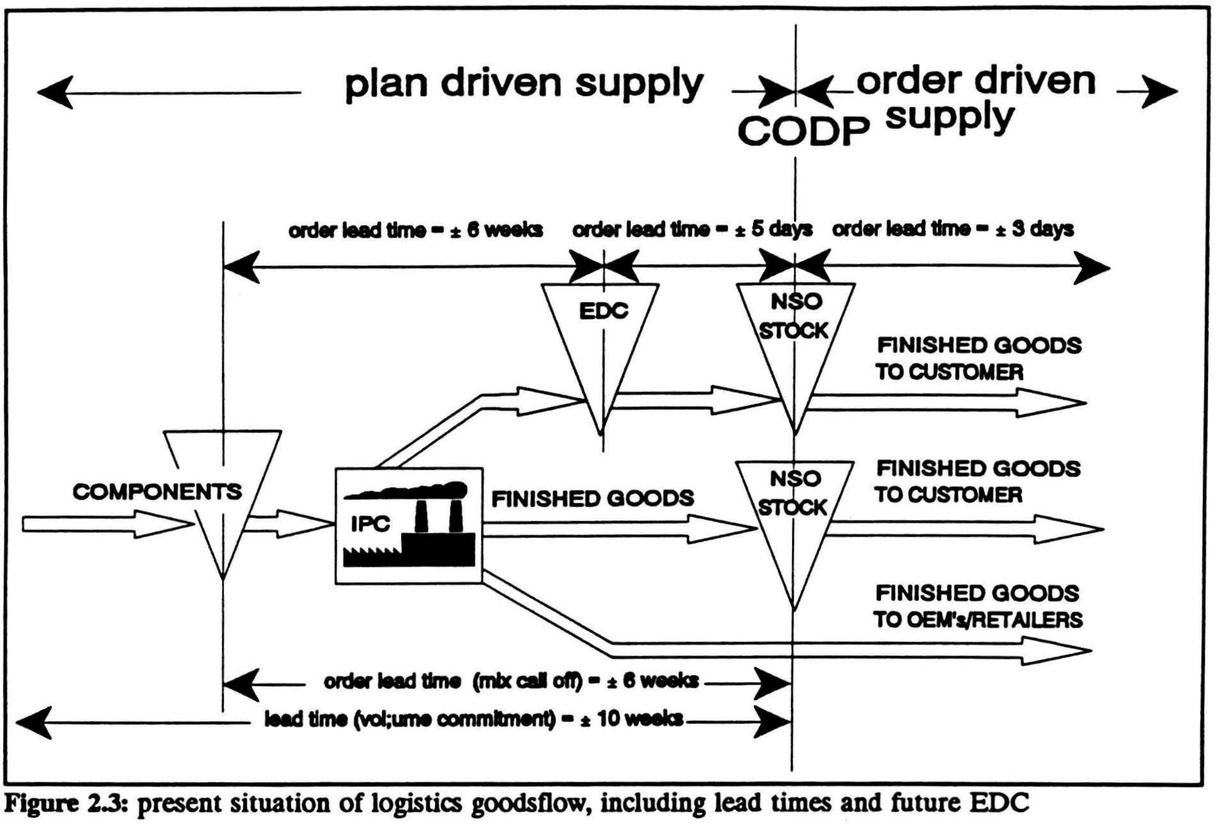

Figure 2.3: present situation of logistics goodsflow, including lead times and future EDC

a volume commitment is made, the purchasing of several components[4] is started. Hence the volume commitment can be seen as the start of an order process, even if the real mix call off is different. The purchasing of components limits the possibilities of supply and could therefore be seen as the start of the order lead time. The limits of supply, caused by for example purchasing, are ignored for the moment in order to simplify the inventory control situation. This means that the order lead time on type level will be based on the mix call off.

An NSO order is delivered in one or more batches. How many or at what time these batches arrive, depends on the agreements between the IPC and the NSO or EDC. Small orders are supplied in one batch whereas large orders are supplied in for example 4 batches. Thus an NSO order for the coming month has variable lead times. If the total NSO order arrives at the beginning of the month, the order lead time is 4 weeks. However if the NSO order arrives in 4 batches (one each week) the order lead time varies between 4 and 8 weeks (on average 6 weeks). The supply deviation time can be derived from these numbers. Suppose the lead times are continuous uniform distributed on interval [4,8], so the standard deviation (σ) of the order lead times can be calculated with:

$$\sigma = \sqrt{\frac{(b-a)^2}{12}} = \sqrt{\frac{(8-4)^2}{12}} = 1.15 \quad (\approx 1)$$

[4] However some critical components with long purchasing lead times are supplied from stock.

2.6: Summary

The differentiated inventory control examines the inventory on type level. The corresponding control model will be based on the future order driven supply. The present order lead time is about 6 weeks from IPC to NSO or EDC and a supply deviation time of about 1 week. The monthly ordered televisions arrive in one or more batches at the NSO/EDC, depending on the agreements between the IPC and the NSO/EDC. Most customer orders are supplied from stock with a transport time of about 3 days. Depending on the situation both the IPC and the NSO can be seen as the CODP. Nowadays most televisions are stored at the NSO's.

CHAPTER 3: Philips' inventory position

The need and the way to reduce inventory will be explained in this chapter. The first paragraph provides some definitions of inventory and the second paragraph will discuss the objectives and effects of inventory reduction. Hence it provides a start for the problem analysis (chapter 4).

3.1: The definition of inventory

Inventory is caused by a discrepancy in time between sales and supply of goods. Figure 3.1 illustrates that inventory will occur when the time dependent sales do not correspond with the time dependent supply at a certain point in time [reference 6]. Even when the average supply equals the average sales, inventory can be inevitable.
A close examination of the cause just mentioned, results in four stock elements: safety, batch, seasonal and sailing stock.

1• Safety stock is needed to cover the variations between expected and actual demand during the order lead time and also provides for the variations in the order lead time.

2• Batch stock is needed to meet sales before the next supply receipt, because the deliveries are committed to standard shipment or production batches. This will be based on the frequency of supply and minimum or optimum batch sizes.

3• Seasonal stock is the preplanned (and regularly reviewed) inventory held to cover for extreme seasonality of sales when the volume flexibility is not sufficient.

4• The sailing stock level covers the flow of finished goods from supply to sales organization. It consists of loading, transit and receiving stock that is not available for delivery to customers.

This project mainly examines the safety and batch stock.

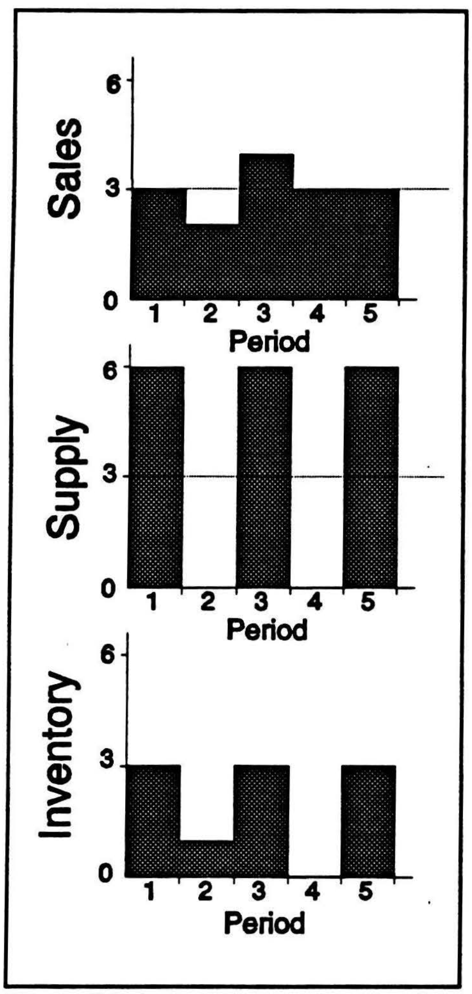

Figure 3.1: inventory on discrete time points

The inventory level at a certain warehouse depends on how inventory is defined. If inventory is defined as the sum of the physical stock and all ordered goods for which the stock point is responsible, it is called effective stock. The physical stock consists of

all tangible goods at the stock point, whereas the available (or free) stock represents only a part of the physical stock that is available for sale. The commercial stock consists of all goods for which the stock point is responsible. In other words commercial stock is the sum of all ordered goods and available stock. The key issue of these different definitions is a matter of responsibility.
In most cases the phrase inventory is used whenever the commercial stock is meant.

3.2: The need to decrease inventory

Inventory is seen as a part of the working capital of an enterprise. One of the well-know taskforces of Centurion[1] that were introduced around 1991, aims at a reduction of the inventory as part of the working capital requirements. During one of the meetings of that taskforce it was stated that "we cannot afford to tie up the working capital in our stocks at the actual level. Efforts so far have not yet led to an optimal overall stocklevel". Hence the assignment is to improve the present stockmanagement and to establish an overall stocklevel target. The "end of year" stocklevel[2] showed that about 20% of the total assets of Philips Electronics LG) in 1991) were stocks. This situation showed only a slight decrease over time (from NLG) in 1990 to G) in 1991). It appeared that the inventory-reduction potential was the largest in the commercial area's. At that time the recommended target was an overall reduction of stocklevels by 20% in two years, based on information of external benchmarking and internal product division tasksetting. The benchmarking showed that most other companies need less inventory to generate a specific sales volume. Philips operates with about 20% inventory[3] as percentage of the total sales, against 14% on average for other companies in 1991. A considerable amount of the stock-levels consists of obsolete inventory. In 1991 the provision for obsolescence was), in other words 15% of the total inventory. This ratio used to be much lower.

Before the discussion on inventory reduction can be started, some details about the objectives of the BG TV have to be clear. The necessity to decrease inventory with help of a differentiated inventory control must be based on Philips' objectives. Every possible decision should take into account these companies objectives. One tends to forget these objectives whenever the subject becomes rather complex. For this reason a few simple objectives will be defined which are derived from the general company's

[1] Introduced by J.D. Timmer, president of Philips Electronics.

[2] The real "working capital" is represented better by the "average inventory" level.

[3] "end of year" gross inventory

objectives and are significant for this project. The derived logistics objectives that will be used to analyze the possibilities to decrease inventory are:

1) A High Customer Service Level (CSL) together with,
2) low relative investment in inventory,
3) both at low logistic costs

All three logistics objectives can be explained with help of the general stated objectives of Philips. To come up to the expectations of shareholders the Return On Equity (ROE, see appendix 3.1^A) should be maximized. In other words their investment in net operation capital should create a large net income [reference 1]. A part of this operation capital is inventory. So the BG TV has to accomplish a low level of inventory and create a large income at the same time. The words "**relative** investment in inventory" (see second logistics objective) are used to indicate that a discussion solely on inventory is not sufficient, the corresponding income is as important.
This brings us to the discussion of the Return On Net Assets (RONA[4]). Appendix 3.1^A shows the procedure to calculate the RONA. The above logistics objectives all influence the RONA, hence this performance indicator seems to present a good means to evaluate the entire project. The RONA-model instead of the ROE-model will be used, because the RONA-model is used within Philips as a performance indicator for BG's.
To be able to evaluate the consequences of a differentiated inventory control model, the link between the logistics objectives and the RONA will now be discussed. The RONA consists of two components: the denominator presents the net operation capital and the numerator presents the corresponding income from operations.

3.2.1: Long term effect

The RONA is considered to be a long term performance indicator, hence all long term variables have to be examined. Long term variables that influence the income from operations are the sales and the costs of organization and material. The CSL is an important element that has to assure a certain level of sales. A high CSL indicates a good performance towards customers what contributes to the continuity of business (long term) and guarantees a certain level of revenue. However the market position of Philips compared with the competitors is far more important (market share and market price), although a high CSL is supposed to take care of a good market position. The proposed differentiated inventory control will improve the current application of the CSL which results in an improvement (or at least preservation) of the present level of sales. If the sales remain at the same level and the situation in a factory does not change, the costs of material will not change either. What does

[4] Usually Return On Total Assets (ROTA) is used; the phrase "net" indicates that the total assets are corrected for e.g. depreciation and risk of obsolescence.

change on the long term are the costs of organization. The third logistics objective (low logistics costs) indicated that these costs should be kept as low as possible. A differentiated inventory control has both a positive as a negative result on the organization costs. An inventory reduction results in less stock holding costs, however the differentiated inventory control will lead to a rise of the handling costs. This rise is a result of the additional EDC that is going to be used. The costs of organization are affected as yet in an uncertain direction, nevertheless the presented financial evaluations always consider the most negative prospectives.

The denominator presents the net operation capital. This capital will be cut down corresponding the decrease of inventory. Furthermore on the long term an additional decrease of net operation capital is obtained, because less fixed assets are needed to store televisions. The second logistics objective embodies this decrease of inventory and reckons with a certain level of sales at the same time.
All long term variables of the RONA have now been discussed, thus it is possible to evaluate the long term decision (paragraph 5.4.2). **Not the absolute values of the RONA and its components are important, but the change of these values.**

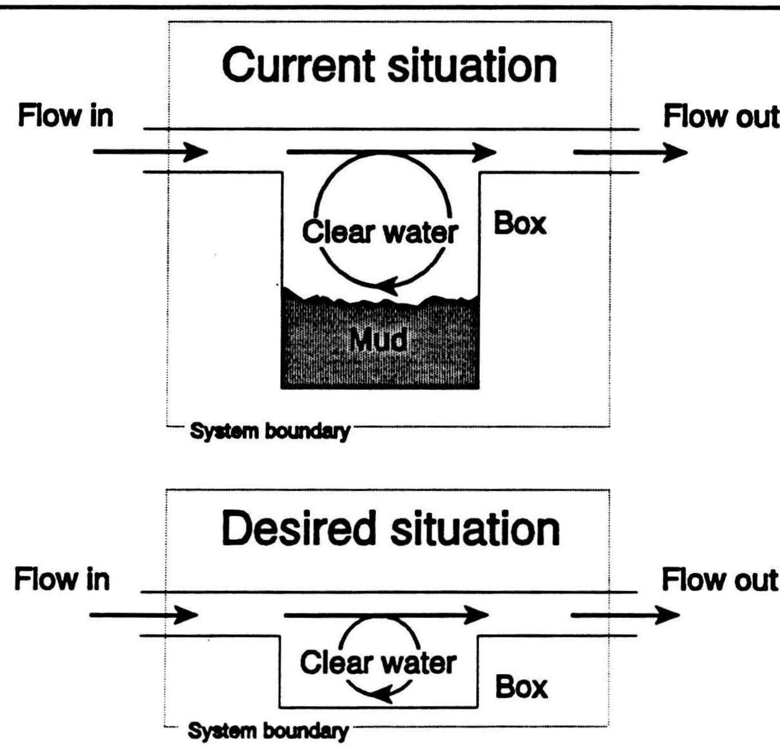

Figure 3.2: example to clarify the logistic objectives of the inventory reduction

The above can be illustrated with the following example; figure 3.2.
Assume that the inventory of finished goods is a **box** of water. The **flow** of water embodies the goodsflow. The water enters the box and leaves it after a certain period. The amount of water that leaves the system does not depend on the size of the box, but depends on what enters the system. Nevertheless the box has to be filled continu-

ously. This box can be compared with the inventory finished goods and the size of the box presents the required inventory. A problem is that this box expands when mud flows into this box. Mud embodies those products that can not be sold, so only clear water will leave the box. The objective is to preserve the present flow that leaves the system and to increase the relative part of clear water. Another problem is that the required part of clear water itself is too large. When mud has been eliminated, the remaining box of clear water should also be minimized. In other words the turnover speed (or RONA) of the box has to be maximized.

3.2.2: Short term effect

The RONA has been examined as a long term performance indicator. However an inventory reduction (= long term decision) has also a short term effect. A decrease of inventory generates a non-recurring cash flow. This non-recurring cash flow occurs when a part of the inventory is sold but not replenished. This generated cash flow does not consist of irrevocable expenses which will be indicated as fixed costs. Only costs of material i.e. variable costs will be used to calculate the generated cash flow.

3.2.3: The actual RONA

The commercial inventory level of Europe for 1992 was on average [redacted] pieces ([redacted] which corresponds with an inventory capital of about [redacted] LG). However at the end of that year the closing commercial stock was [redacted] which is maintained until now. The calculation of the average inventory capital was based on the intercompany invoice price (IIP) according the procedures within Philips, although it is better to calculate the inventory capital with the net price (NP). The motivation to use the NP instead of the IIP is that the contribution margin of the national sales organizations should also be considered; not only the contribution margin of the factories and its suppliers. The average inventory capital, based on the NP, is abo[redacted] LG). The total fixed assets of the BG TV are abo[redacted] LG) and the rest of the total working capital amounts to [redacted] G).

The income from operations (IFO) of both factories and national sales organizations (NSO's) is defined as the sum of the income from operations NSO (ION) and the target price difference (TPD). Appendix 3.1B shows the build-up of the mentioned prices. The ION + TPD for 1992 of Europe is abo[redacted] G). Thus the RONA for the BG TV in 1992 according these figures is:

RONA = [redacted] (3.1)

A differentiated inventory control examines inventory levels on product type level, hence a glance at the RONA's of single product types provides a better understanding of the possible impact of a differentiated inventory control. If the individual RONA's are compared and significant differences occur, this would demonstrate that mud possibly exists. This mud would then be caused by specific product types.

To examine these individual RONA's a more transparent indicator will be used. The total sales will be used instead of the income from operations, because the separation of sales, costs of material and costs of organization is not clear. On high aggregation level it is quite obvious what revenue is achieved and what corresponding costs are generated, but on product type level it is less clear which type generated which costs. The database that was used to calculate the income from operations and the sales on type level did not provide a solution for this issue, hence to avoid this problem another indicator is used. Now the expression turnover speed is used instead of the RONA, because the costs of material and the costs of organizations are ignored for the moment.

A disadvantage of using sales to compare the turnover speed of several product types is that the costs of material and the costs of organization are not entirely allocated (or better caused) corresponding the sales volume. In other words large sales of a product type do not automatically result in a large income from operation for that product type, so a high turnover speed does not automatically result in a high RONA. However to give an impression of the difference between product types the sales figures will do.

Figure 3.3 shows an inventory analysis of the sales organization in Italy for 1992. This

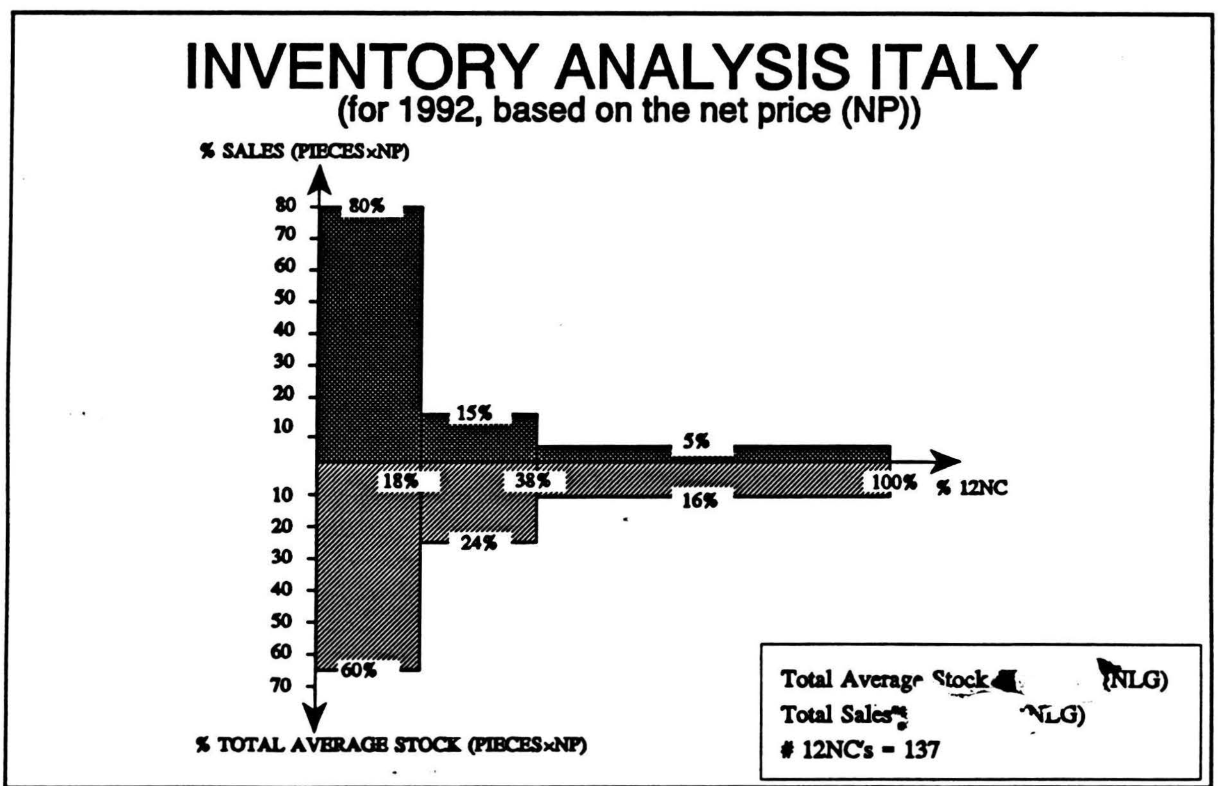

Figure 3.3: analysis of differences in turnover speed on product type level

figure depicts the sales of one year and the corresponding average inventory level of that year. It appears that 18% of all product types sold in Italy represent 80% of the total sales and 60% of the total average inventory. Both sales and inventory are based on the NP. Figure 3.3 also shows that about 44% of all product types represent only 5% of the total sales and 16% of the total average inventory. It is interesting to see the difference in turnover speed regardless the exact total sales volume and inventory level:

$$\frac{\text{TO speed}_{18\%\text{types}}}{\text{TO speed}_{44\%\text{types}}} = \frac{\dfrac{80\%\text{sales}}{60\%\text{inventory}}}{\dfrac{5\%\text{sales}}{16\%\text{inventory}}} = \frac{16\% \times 80\%}{60\% \times 5\%} = 4 \qquad (3.2)$$

This difference can not be explained solely with the existence of mud. Some product types demand a higher level of inventory (a larger "box of clear water" is preferred) because of high commercial expectations. For example a product type with a high calculated ION + TPD maybe justifies a relative low turnover speed. That mud does exist and that the diversity in turnover speed can not be explained only by differences in income from operations as shown in appendix 3.2.
Instead of mud the words slow moving or obsolete inventory are often used. The possibilities to avoid mud will be explained in chapter 4.

Not only slow moving inventory (mud) was indicated as an issue that should be examined, also the large volume of clear water (= a high level of inventory) was mentioned. In other words the RONA of all product types should also be improved and not only the RONA's of specific product types. One of the budgeted objectives of the BG TV is to reduce the inventory from 400K to 300K pieces. The question is how this can be achieved without damaging the planned sales. A differentiated inventory control provides a part of the solution.

3.3: Summary

It was shown that the RONA plays a key role in the evaluation of the differentiated inventory control. Three logistics objectives have been defined and for each of them a link with the RONA was made. To illustrate the inventory dilemma an example was used that specially indicated the problem of a low RONA (~ a low turnover speed). These problems were quantified to get more feeling of the subject.
Paragraph 5.4.2 will discuss the improvements that can be attained. A result will be a sound decrease of the inventory level whereas a part of the income from operations is slightly cut back by the costs of extra logistics features.

CHAPTER 4: Problem analysis

To decrease the inventory level a close examination of the causes of inventory is needed. The need to decrease inventory is analysed in chapter 3, but more information is required to understand why inventory excesses occur. This chapter discusses the basic problems of inventory excesses and provides at the same time the possibilities to reduce inventory.
The analysis is accomplished according the "Quick Scan"-method [reference 4], based on information of e.g. Bertrand (1991) [reference 2] and Brown (1977) [reference 3].

4.1: The derived problems

The difficulty of detecting problems is the clear separation of basic problems and derived problems which are caused by other problems. The desired situation represented by the logistics objectives and the present situation can be easily stated but the real bottleneck that causes the difference between the two situations all the worse.
Figure 4.1 depicts the problem analysis. The boxes in the upper part of the picture present the logistics objectives (desired situation). The second and third row of boxes show the derived problems and indicate the gap between the present and desired situation. The problem description stated that the present situation results in a high and unbalanced stock. However this present situation is only a result of the basic problems which are depicted also.

To understand the 6 derived problems some comments are necessary.

1• **slow moving stock:**
This box indicates that too much inventory is kept to cover the sales. The slow moving stock usually becomes **obsolete** that has to be sold with a small margin. However obsolete stock also occurs when the phasing out is poorly planned. This problem is closely related with "High Stock Norm" however,

2• **high stock norm:**
This box presents the problems that arise when the norm is accurate and doesn't cause obsolescence but is based on low expectations of the RONA. This problem is mainly caused by the seasonal sales and supply and the diversity of products (commonality).

3• **too little stock:**
This box indicates that not enough stock is build up to achieve a specified CSL. When both the situation of "slow moving stock" as the the situation of "too little

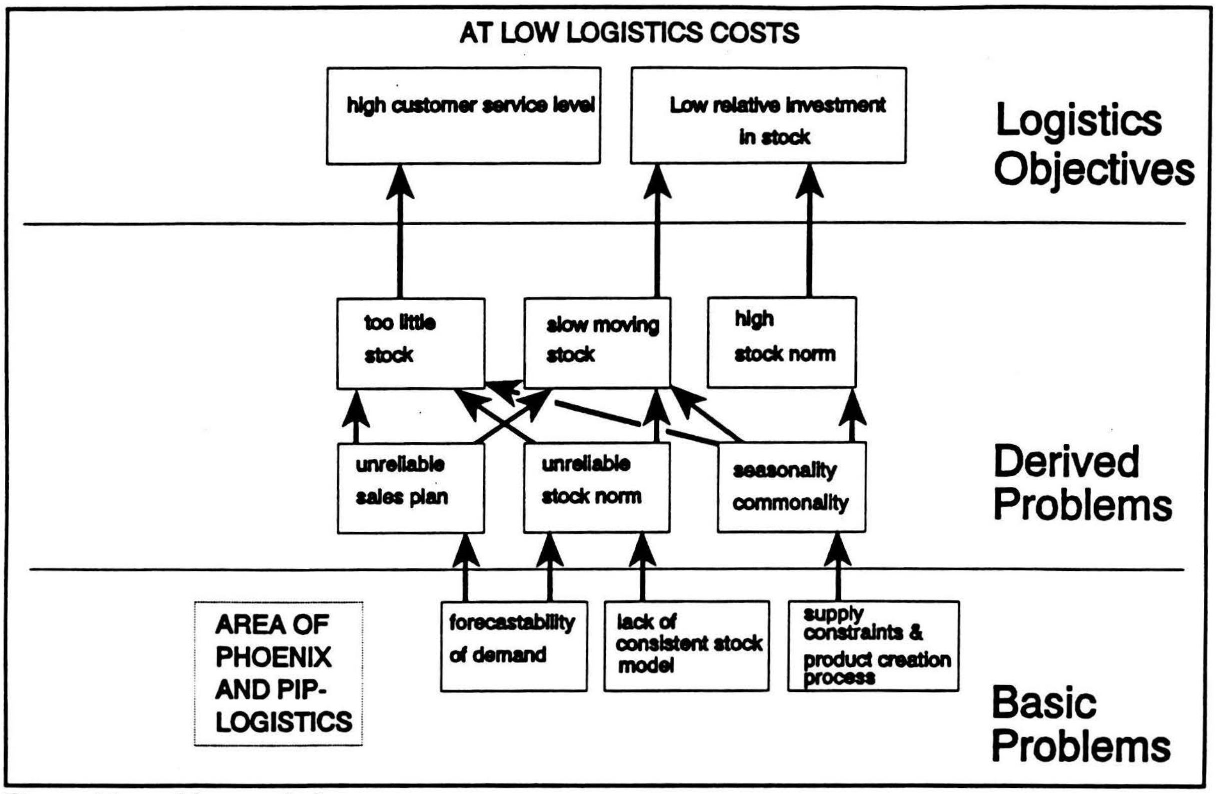

Figure 4.1: problem analysis

stock" occur, it will be addressed as **unbalanced stock**. Unbalanced stock indicates that on total enough stock is build up, but not at the right place or for the right products. For example unbalanced stock occurs when a product type, that can be sold in more than one country, is stored in country A when it is needed in country B.

4• **unreliable stock norm:**

A stock norm that doesn't present the real situation will create too much or too little stock.

5• **unreliable sales plan:**

All stock is a result of sales and supply. So an unreliable sales plan will automatically cause unbalanced and obsolete stocks.

6• **seasonality and commonality:**

(as problem 5: All stock is a result of sales and supply). A relative low mix and volume flexibility of the supplier and the large diversity as a result of the product creation process, cause unbalanced and obsolete stocks. Furthermore the seasonal production and the large diversity result in a high stock norm.

The basic problems that cause these 6 derived problems are numerous. The PHOENIX project and the PIP logistics take care of most of these problems. This is indicated in figure 4.1 with "area of PHOENIX and PIP logistics". In reality PHOENIX and PIP logistics cover the complete picture except one part: "lack of consistent stock model". Hence the first assignment concentrates on the design of an inventory control model. A discussion of the PHOENIX project and the PIP logistics is considered to be outside the scope of this research.

4.2: The way to deal with the basic problems

By tackling the basic problems the total stock can be reduced that is needed to realize the specified customer service level at low logistics costs. The three basic problems are used to indicate that there are three separate areas of improvement.

1• **The first basic problem: "lack of consistent stock model"** deals with the calculation of the four stock elements and the differentiation of the changeable parameters. A sound differentiation between product types and a sound control of the stock elements enables us to decrease the total stock level and to increase the customer service level.

2• **The second problem: "forecastability of demand"** deals with the variance of the forecast error. An improved forecast of demand will decrease the MAD and justifies a reduction of the safety stock level. This basic problem is closely related to the supply and product creation process (basic problem 3), because e.g. more commonality or shorter order lead times will simplify the forecast of sales.

3• **The third problem: "supply constraints & product creation process"** deals with the exogenous parameters that are a result of supply and product creation processes. It was stated that these exogenous parameters can be influenced by changing the business processes. The following logistics improvements will most of all affect the need of seasonal stock and inventory caused by a large diversity of products.

- More commonality in a product range will increase the total sales per product type. If separate product types are replaced by one universal product type this will increase the demand per product type and decrease the MAD (sales should be independent and of the same volume; law of large numbers). Hence less safety stock is needed. Less country specific product types (= less diversity) also increases the possibility to use an EDC. The existence of unbalanced stock in an EDC is less likely, because inventory can not be stored at the wrong place.
- More volume flexibility results in a better adjustment of the available capacity to the actual demand. Hence rescheduling is less necessary and less seasonal stock will be build up.
- Shorter order lead times lower the need to forecast a long period ahead which results in less need of safety stock.
- Due to limited mix flexibility, the IPC's use a cyclic production schedule. This forces the IPC to supply the NSO's or EDC's with batches. More mix flexibility

and smaller minimum[1] batch sizes offer the possibility to cut down the batch sizes. Hence less batch stock will occur.

- An improved phasing-in and phasing-out plan results in less obsolete stock and a solid CSL.

The forcastability of demand should be improved by the sales organizations whereas the supply constraints and the product creation process should be altered by the BG TV. The design of a consistent stock control model is an assignment of the TV logistics department.

4.3: Summary

To achieve a breaktrough on the three basic problems, the actions presented in table 4.1 should be considered. This way a more balanced stock will be attained. Furthermore less slow moving inventory (mud) and more fast moving inventory (clear water) will be part of the total stock.
This list of possible activities is not complete, it only gives an indication of areas for improvement that are closely related with the differentiated inventory control model.

Table 4.1: possible activities to reduce the total inventory according the logistics objectives

New logistic concept (PHOENIX)	•NSO stock replenishment according inventory norms on type level •weekly review period •use of an EDC
Differentiated Inventory Control	•differentiated CSL to calculate inventory norms on type level •differentiated supply chain (EDC, NSO or no inventory) to calculate inventory norms on type level
Sales organizations	•improved foracastability of demand
Supply process	•increasing mix and volume flexibility •shorter order lead times
Product creation process	•less diversity of product types •improved phasing-in and phasing-out plan

1 Usually the optimum batch size will determine the production volume.

CHAPTER 5: The differentiated inventory control

The calculation of inventory norms depends on which cause of inventory has to be budgeted. Four causes of inventory can be distinguished, as explained in paragraph 3.1, of which the safety stock will receive most attention.
A continuous growth of the volume and mix flexibility improves the possibility to follow seasonal sales patterns. Hence it is less necessary to build up seasonal stock and the relative part of the safety stock increases. So more emphasis on the safety stock is needed to effectively control the total inventory. A result of the safety stock calculation is the batch stock (paragraph 5.1.2). The sailing stock is considered to be a result of the supply process, hence no changeable parameters are available to differentiate between product types. In other words mainly the safety stock can be used to express the differences between product types.

5.1: Theoretical considerations

The theoretical considerations are divided into two subparagraphs. First of all the calculation of the safety stock will be discussed. Secondly the three remaining stock elements will be discussed.

5.1.1: Basic concepts of the safety stock calculation

Safety stock is needed to cover the variations between expected and actual demand during the order lead time and also provides for variations in the system lead time [reference 8]. This coverage for variations or safety stock has to satisfy a certain customer service level (CSL).

CSL= the long-run fraction of demand satisfied directly from stock on hand during the replenishment cycle $[iR+L_i, (i+1)R+L_{i+1}]$, where R is the review period and L_i is the lead time of the delivery ordered at time iR.

In a stationary situation L_i is considered fixed, so the length of a replenishment cycle equals the review period:

$$\text{length replenishment cycle} = ((i+1)R+L_i)-(iR+L_i) = R \qquad (5.1)$$

Nowadays the review period (R) equals 1 month for the replenishment of televisions, however in the near future a replenishment cycle of 1 week will be used.
At fixed (iR) points in time loads of televisions are ordered. An amount is ordered

such that the inventory position, i.e. the commercial stock minus back orders, immediately after the review moment equals S, the order-up-to-level. The calculation of inventory norms will not consider lower limits for replenishment orders caused by production batch sizes[1]. The replenishment concept is presented in figure 5.1.

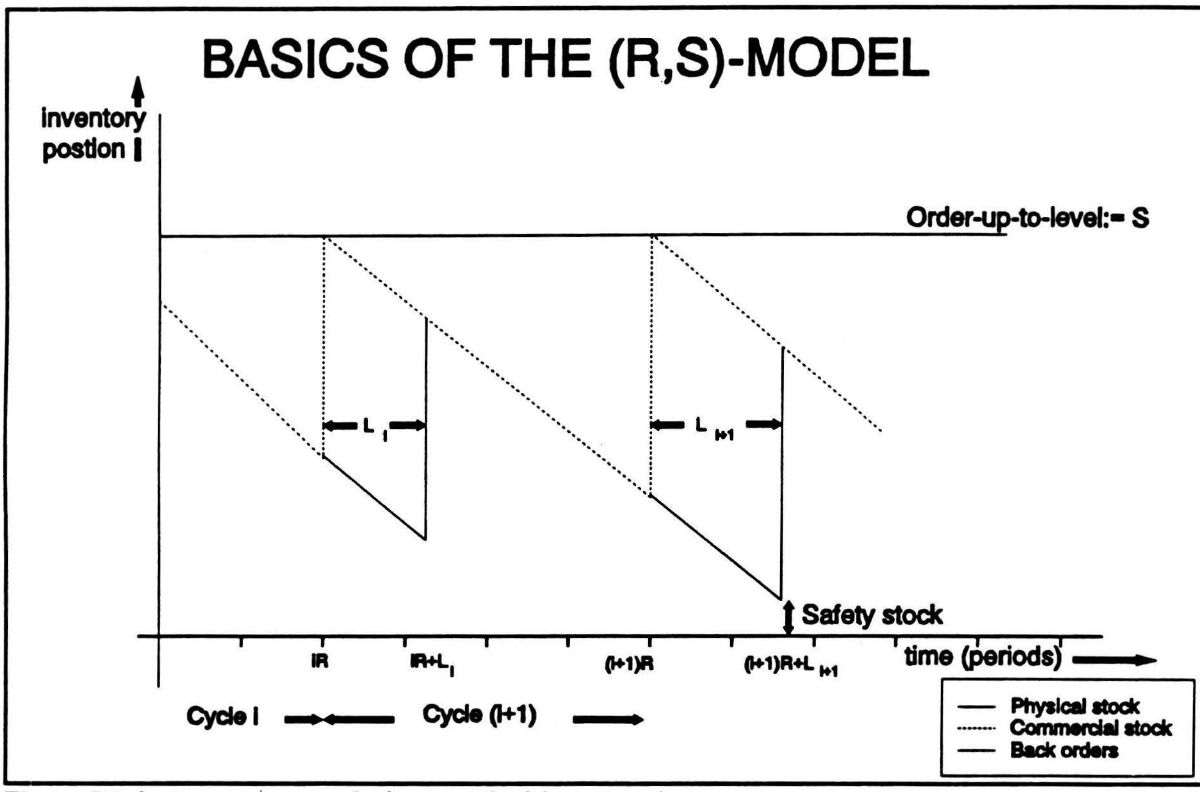

Figure 5.1: inventory pattern during a replenishment cycle

This figure shows that at time iR an amount of goods is ordered that covers the demand from now until receipt of the order, which will be placed at the IPC one review period from now. In other words a load of televisions is ordered that covers the demand of interval $[iR,(i+1)R+L_{i+1}]$. The order-up-to-level can easily be translated in safety stock, because the inventory that remains after interval $[iR,(i+1)R+L_{i+1}]$ is defined as safety stock. Suppose that iR=0, so the CSL is defined as

$$CSL = 1 - \frac{E[(D(0,R+L_1)-S)^+] - E[(D(0,L_0)-S)^+]}{E[D(L_0,R+L_1)]} \tag{5.2}$$

and the safety stock level as

[1] Later this report three criteria will be defined of which one of them discusses the production batch size.

$$\text{safety stock} = S - E[D(0,R+L_1)] \quad (5.3)$$

where

- R= review period • D(t,s)= demand during [t,s], $0 \leq t \leq s$ • $(k)^+$= max (0,k)
- L= lead time • S= order-up-to-level
- i= period index • E[k]= expected value of variable k

Suppose a stationary situation, then both expressions (5.2) and (5.3) can be simplified.

$$CSL = 1 - \frac{E[(D(0,R+L)-S)^+] - E[(D(0,L)-S)^+]}{E[D(0,R)]} \quad (5.4)$$

$$\text{safety stock} = S - (E[R+L] \times E[D]) \quad (5.5)$$

Appendix 5.1 provides more information about the calculation of the CSL.
In practice the CSL is known and can be used to determine the safety stock norm. Hence the calculation has to be executed the other way around [reference 9]. The idea seems simple, but a computer program has to be used to calculate the reverse situation.
For this reverse calculation the following data are needed:

- CSL= customer service level
- R= review period
- L= order lead time
- sL= supply deviation time
- $D^F(0,1)$= forecasted demand for 1 time period
- $\epsilon(0,1)$= forecast error of $D^F(0,1)$, when forecasting L periods ahead

Here $D^F(0,1)$ is the sales forecasts and therefore a known constant. The deviation from the forecast is given by $\epsilon(0,1)$, which is a random variable. These expressions of the forecast error and the forecasted demand are used to calculate the random variables $D(0,R+L_1)$ and $D(0,L_1)$, so the expected sales volume can be determined. The future sales are not known but can be seen as a stochastic process. The random variables $D(0,R+L_1)$ and $D(0,L_0)$ of expression 5.2 are rewritten as follows:

$$D(0,R+L_1) = D^F(0,R+L_1) + \epsilon(0,R+L_1)$$
$$D(0,L_0) = D^F(0,L_0) + \epsilon(0,L_0),$$

If the sales are considered to be a stationary stochastic process then expression (5.2) can be written as

$$CSL = 1 - \frac{E[(D^F(0,L+R)+\epsilon(0,L+R)-S)^+] - E[(D^F(0,L)+\epsilon(0,L)-S)^+]}{E[D^F(L,R+L)]} \quad (5.6)$$

To be able to calculate the demand of a specific interval, the inventory model assumes that the random variables $D(0,R+L_1)$ and $D(0,L_0)$ are independent. The program determines the average demand and the corresponding standard deviation of the forecast error of both intervals [0,R+L] and [0,L]. These averages and standard deviations can be used to fit the gamma probability distribution because the sales process is assumed to be gamma distributed (see appendix 5.2), so

$$D(0,R+L_1) \rightarrow \Gamma(\mu_{[0,R+L]},\sigma^2_{[0,R+L]})$$
$$D(0,L_0) \rightarrow \Gamma(\mu_{[0,L]},\sigma^2_{[0,L]})$$

With help of the gamma probability distribution that represents the stochastic sales the reverse calculation can be performed. This calculation involves 5 steps,

Step 1:

Determine $D^F(0,1)$ using a combination of expert estimates and mathematical techniques, so the inventory model can determine $D^F(0,R+L_1)$ and $D^F(0,L_0)$.

Example: The monthly demand of CTV 25ML8505/00B forecasted on January 1993 is the average of the X monthly sales plans (table 5.1). If one takes X=2 then $D^F(0,1)$ of CTV 25ML8505/00B will be (1200+1300)/2 = 1250. Hence in a stationary situation the weekly forecasted demand is 1250 × 12/52 = 288 (52 weeks per year).

Table 5.1: example of sales plans and sales actuals per month 1992/1993

Sales plans and actuals 1992/1993, according the GIPSY database

CTV's:
- 25ML8505/***
- 28ML8805/***
- 33ML8905/***

	NOV pl	NOV act	DEC pl	DEC act	JAN pl	JAN act	FEB pl	FEB act	MAR pl	MAR act
Netherlands										
25ML8505/00B	1107	1257	1000	1146	891	1306	1200	744	1300	776
28ML8805/00B	911	964	900	1280	828	1379	1100	892	1100	895
33ML8905/00B	49	60	42	61	81	109	-	88	100	64
Greece										
25ML8505/00B	213	336	69	140	250	104	300	170	194	206
28ML8805/00B	212	130	146	20	250	186	200	134	117	166
33ML8905/00B			-	48	50	17	90	20	41	17
Italy										
25ML8505/08B			274	209	242	339	150	299	170	160
28ML8805/08B			447	458	529	465	669	660	510	549
33ML8905/08B			248	195	235	338	349	351	465	303
Germany										
25ML8505/02B	662	433	418	695	700	685	500	455	400	402
28ML8805/02B	2377	2087	2190	2630	1500	1520	2300	2155	1000	1176
33ML8905/02B	577	830	627	632	500	426	400	488	300	417
Austria										
25ML8505/02B	240	246	164	197	170	78	125	92	110	106
28ML8805/02B	700	654	446	472	596	583	500	338	350	351
33ML8905/02B	43	63	64	95	38	59	23	39	21	51
Switzerland										
25ML8505/06B	569	569	568	505	472	401	350	219	200	194
28ML8805/06B	1077	1369	1184	1183	1143	917	957	973	500	451
33ML8905/06B	148	136	580	564	267	211	237	228	230	205

Step 2:

Use the Mean Absolute Deviation (MAD, see appendix 5.3) to determine $\sigma(\epsilon(0,1))$, so $\sigma(\epsilon(0,R+L_1))$ and $\sigma(\epsilon(0,L_0))$ can be determined.

Example: In January 1993 it appears that the CTV 25ML8505/00B has a MAD of: $(|1107-1257|+|1000-1146|+|891-1306|)/3 = 237$. This MAD is based on the forecast of the monthly demand L periods (= 1 month) ahead. If the forecast errors are independent and normally distributed then: $\sigma(\epsilon(0,1)) = k \times MAD$, where $k \approx 1.25$ (see appendix 5.3).
So the monthly standard deviation of the forecast error is:
$1.25 \times 237 = 296$
and the weekly standard deviation of the forecast error is:
$\surd(12/52) \times 296 = 142$.

Step 3:

Compute S with help of the computer program, assuming gamma distributions.

Example: Table 5.2 shows examples of the order-up-to-levels for several CTV's. The computer program, programmed in (Borland) C, that is used to calculate these inventory levels is depicted in appendix 5.4.
If the CTV 25ML8505/00B is stored at the NSO for country 670, the order-up-to-level should be 2076 pieces. This level S holds whenever the review period is one week, the planned sales are 288 pieces a week, the standard deviation of the forecast error is 142, the order lead time is 4 weeks, the supply deviation time is 1 week and the CSL is 95%.

Table 5.2: example of the reverse calculation, what results in inventory norms

MAG	C	CPC	CTV	R	$D^F(0,1)$	$\sigma(\epsilon(0,1))$	L	sL	CSL	S
'C13	'670	'1000	'25ML8505/00B	1	288	142	4	1	0.95	2076.13
'C13	'410	'1000	'25ML8505/00B	1	57	68	4	1	0.95	599.02
'C13	'520	'1000	'25ML8505/08B	1	74	49	4	1	0.95	580.74
'C13	'320	'1000	'25ML8505/02B	1	104	104	4	1	0.95	981.45
'C13	'720	'1000	'25ML8505/02B	1	27	26	4	1	0.95	249.60
'C13	'980	'1000	'25ML8505/06B	1	63	27	4	1	0.95	440.89

Step 4:

Compute the safety stock norm according figure 5.1.

$$\text{Safety stock} = S-(L+R)\times D^F(0,1) \quad (5.7)$$

Example: The CTV 25ML8505/00B for country 670 should apply an order-up-to-level of 2076. So the corresponding safety stock level is:
$2076-(4+1)\times 288 = 636$

Step 5:

Compute the mean physical stock during $(L_0, R+L_1)$,
the mean physical stock in a stationary situation is

$$\text{Ph stock}(0,R) = CSL \times \left(\frac{MAX(0,S-E[L]D^F(0,1)) + MAX(0,S-(E[L]+R)D^F(0,1))}{2} \right) \quad (5.8)$$

The advantage of using the mean physical stock as an indicator of the average stock capital is that it provides some information to evaluate the profitability of the total inventory. However from a logistic point of view the mean physical stock does not say much about the actual stock position, in this case the safety-stock level is more interesting.

Example: An order-up-to-level of 2076, a review period of 1 week, an order lead time of 4 weeks and a weekly demand of 288 results in a mean physical stock of

$$\text{Ph stock}(0,R) = 0.95 \times \left(\frac{MAX(0,(2076-4\times288)) + MAX(0,(2076-(4+1)\times288))}{2} \right) = 780$$

To be able to calculate the safety stock norm some basic concepts have been provided. These basic concepts represent several definitions and limitations, of which a few are explicitly mentioned. Some concepts are more restrictive than others, hence this norm calculation is concluded with some weaknesses and strengths of the total exercise; table 5.3.

Table 5.3: strengths and weaknesses of the proposed safety-stock norm calculation

Strengths:
• simple but realistic representation of the "near future"-situation • realistic and usable expression of the CSL • most important parameters are considered • use of the standard deviation of the forecast error instead of the standard deviation of demand • automatic calculation based on information that is easy obtained from Philips' database GIPSY • simple calculation of the standard deviation of the forecast error with help of the Mean Absolute Deviation (MAD) and exponential smoothing

Weaknesses:

- No production batch size considerations
- The MAD should correspond with a specific interval (according expression (5.6)), but for practical reasons the MAD is used that corresponds with the forecasts L periods ahead for 1 time period. The demand is assumed to be independent.
- Complex (but inevitable) calculation
- No considerations for a single order that is delivered in several batches
- No minimum replenishment level is used, that triggers a replenishment order when it is crossed. An order-up-to-level is used that triggers a variable load of televisions at **each** fixed time point.
- The defined CSL and the average sales that are used to determine the safety stock, do not take into account the orders that are delivered with a certain delivery time[2].

Remark: the presented definition of the CSL assumes that all demand is delivered from stock-on-hand. However not all orders require an immediate delivery. So a part of the sales requires an alternative CSL, e.g.:

CSL′ = the long-run fraction of demand satisfied within 1 week...... (see expression 5.2),

Hence the budgeted inventory level, derived from the original CSL and calculated with help of expression 5.2, will result in an actual CSL′ which is higher than the original CSL. In other words the original CSL corresponds with a higher CSL′.
The BG TV does not monitor a formal CSL at this moment. But whenever a formal definition of the CSL is specified, one has to avoid confusions about the calculations of the presented CSL and the new specified CSL′.

5.1.2: Batch, sailing and seasonal stock norms

The total stock level does not only consist of safety stock but also of seasonal, sailing and batch stock. Therefore a short discussion is needed about the inventory norms of the three inventory elements not yet discussed.
Seasonal stock is the preplanned (and regularly reviewed) inventory held to cover for extreme seasonality of sales if the volume flexibility is not sufficient. It can be seen as a reservation of capacity that can be used when capacity becomes short. It is often stated that the safety stock should be zero whenever seasonal stock is held for a specific product type. However a clear separation between seasonal stock and safety

[2] The use of market channels can provide a solution; see ways of working [reference 10]

stock should prevent the situation in which all available stock has to be used to cover for the seasonality, so eventually no safety stock is available to assure a certain CSL. In other words the seasonal stock can be used as safety stock (to cover for the random fluctuations of time and demand), but eventually the safety stock may not be used to cover for seasonality. Hence it is advisable to maintain a safety stock level as part of the total stock level, the remaining part is called seasonal, batch or sailing stock. The seasonal stock level is budgeted according to the planned sales and the planned capacity for one year. Hence this long term decision needs more information about yearly sales and supply constraints. The seasonal inventory norm does not depend on the replenishment method.
The budget for seasonal stock is limited to 25% of the total commercial stock. Furthermore it is preferable to stock up those product types that have least risk to become slow moving or obsolete. This report will not discuss this seasonal stock any further because the long term decision is difficult to specify on type level.

The sailing stock level covers the flow of finished goods from IPC to sales organization. It consists of loading, transit and receiving stock that is not available for delivery to customers. The sailing stock for the BG TV in Europe is small compared with e.g. the BG Audio. This difference is caused by the fact that (almost) all televisions are supplied from European IPC's whereas audio equipment is supplied from the Far East. The sailing stock can be calculated as

$$\text{sailing stock} = \text{load} \times \frac{L_{sailing}}{\frac{load}{\mu}} = \mu \times L_{sailing} \tag{5.9}$$

where
load= the transported load of televisions
μ= average sales per time period
$L_{sailing}$= sailing time in time periods

The average sailing time for the BG TV is about 3 days. So a sailing norm for all product types is about 3 days planned (= future) sales. The sailing stock will not be examined further because the sailing stock norm is fixed for all product types and is relatively small.

The batch stock is needed to meet sales before the next supply receipt, because the deliveries are committed to standard shipment or production batches. This will be based on the frequency of supply and minimum or optimum batch size. The targeted level can be derived from figure 5.1. The batch stock norm is derived from:

$$\text{Mean physical stock} = \text{batch stock} + \text{safety stock} \tag{5.10}$$

The total stock level is the sum of the 4 stock elements, so the total stock level is:

Total stock level = mean physical stock + seasonalstock + sailingstock . (5.11)

It was already mentioned that the advantage of an indicator like the total stock level is that it provides some information to evaluate the profitability of the total inventory. However from a logistic point of view the total stock level does not say much about the actual stock position, because the total stock level is an average for a specified time interval.

5.2: Calculation of differentiated inventory norms

The theoretical considerations of the previous paragraph can be used to determine all required inventory norms. The replenishment method was discussed and it was mentioned that the CSL provides a means to differentiate product types. However the CSL is not the only changeable parameter. Figure 2.3 (logistics goodsflow) showed another way to distinguish product types. A product type can be distributed along three different channels with each a corresponding stock policy:

1•from an IPC to an EDC and afterwards to a NSO (preferred types)
2•from an IPC to a NSO (special types)
3•from an IPC straight to a customer (order types)

For each channel three criteria are defined, so the total distribution of televisions will be optimized. Table 5.4 gives the criteria for each channel.

Table 5.4: criteria for three specific stock policies

product type	criteria	stock policy/ channel	calculation replenishment level
Preferred types	•more than 1 destination •planned ~~monthly~~ year sales/~~12~~ ≥ 1 production batch •commercial expectations	•inventory in EDC •weekly replenishment calculation in EDC •daily replenishment calculation in NSO •lead time EDC → NSO max 1 week (5 days) •limited NSO inventory	•EDC replenishment level = order-up-to-level (S) •NSO replenishment level = order-up-to-level (S)
Special types	•1 destination only •planned monthly sales/12 ≥ 1 production batch •commercial expectations	•NO EDC inventory •weekly replenishment calculation •lead time FTY → NSO equals production lead time + transport time •inventory in NSO only	•NSO replenishment level = order-up-to-level (S)
Order types	•planned monthly sales/12 ≤ 1 production batch •unique material (e.g. OEM's) •commercial expectations	•NO EDC and NSO inventory •NO replenishment calculation •customer orders straight to IPC •lead time FTY → NSO equals production lead time + transport time	•fixed inventory level: preferable 0

The main difference between the mentioned stock policies is the number of stock points. The preferred types use two stock points[3], the special types one and the order types none.

[3] In literature often referred to as two-echelon stock.

The motivation to use the criterion: "more than 1 destination" is that the use of an EDC will only be beneficial if a product type is distributed to more than one NSO. The second criterion is added because the "from stock delivery" should only be applied in situations of regular demand. A simple selection is made when the monthly planned sales volume must be larger than one production batch. Besides to keep stock for a product type with erratic and unpredictable demand is not desirable. The selection of a distribution channel also depends on the strategy of the marketing department. The possibility to overrule the previous criteria is offered by the input of commercial expectations.

5.2.1: Order types

The inventory norms for order types need no further examination because the inventory norm is budgeted zero, so the actual stock level is kept close to zero. Some stock can never be avoided because of e.g. transport time and return of televisions.

5.2.2: Special types

The special types are stored at a NSO. For these types the calculation of paragraph 5.1 can be applied directly. First of all information on batch sizes and destinations determines to which category a type belongs. Secondly the inventory norm and corresponding replenishment level can be calculated. The input parameters that are needed to calculate the safety stock norm in a stationary situation are presented in table 5.5.

Table 5.5: primary information to calculate inventory norms at the NSO

fixed parameters	type specific parameters
•R= The review period= .... 1 week •L= order lead time= .... 4 weeks •sL= supply deviation time= .... 1 week	•$D^F(0,1)$= forecasted demand for 1 week •MAD= Mean Absolute Deviation of $D^F(0,1)$ when forecasting 4 weeks ahead •CSL= Customer Service Level

Table 5.5 distinguishes two input parameters: parameters that are fixed for all product types and parameters that have to be specified for each individual product type. Appendices 5.5 and 5.6 provide the results of the calculation based on the above information. Two MAG's are selected, each of a different product segment, in order to test the validity of the calculation. No use has yet been made to variate the CSL within a MAG. Furthermore all running product types are considered to be special types, because the current inventory norms are based on the situation without an EDC. The results match the stock proposals per 31-12-'93 (exclusive of seasonal and sailing stock). Hence the top down approach, based on the total budget for inventory, agrees with the bottom up approach. A small modification of the CSL was needed for MAG D41 to match the stock proposal. The CSL had to be reduced from 95% to

90%, which is reasonable for products from the STECO segment. By varying the CSL within a MAG, the inventory of more profitable types can be increased whereas the stock level for other types can be reduced in order to match the total budget for inventory. As a result the RONA can be improved even further. This trade-off will be discussed in §5.4.1.

These outcomes show that the differentiated inventory norm calculation is usable for the special types. However two items still have to be discussed: the non-stationary or the phasing-in/out situation and the replenishment level that triggers a NSO order.

To determine the inventory norm in a non-stationary situation more information is needed than just mentioned. The extra needed information is shown in table 5.6.

Table 5.6: additionally information to calculate inventory norms at the NSO

fixed parameters	type specific parameters
•time to build up inventory= .... 2 months	•start date= start date of supplies for a CTV
•$R_{calc.}$= the time between	•end date= end date of supplies for a CTV
the review of inventory norms = ... 1 month	•MAD_p= MAD of a predecessor

Let's consider a phasing-in situation. The "time to build up inventory" indicates how long before the start date goods will be stored, in order to be able to deliver on the start date. The inventory will be build up 2 months before the start date. For example suppose the start date of the CTV 25ML8505/00B is november 1992; see example table 5.1. So in September a start will be made to generate stock. In September the expected sales are derived from 3 months (= time to build up inventory + $R_{calc.}$) future sales, thus the inventory norm is based on two months of "zero-future-sales" (September and October) and one month of planned sales (November). The calculation is depicted in table 5.7. The situation changes one month later; in October the inventory norm is based on only one month "zero-future-sales" (October). The calculation of the inventory norm for November is based on 3 months planned sales, so the stock level is satisfactory at the start date.

Table 5.7: example of a phasing-in plan for the CTV 25ML8505/00B

September	October	November
$D^F(0,1) = \frac{0+0+1107}{3} \times \frac{12}{52} = 85$	$D^F(0,1) = \frac{0+1107+1000}{3} \times \frac{12}{52} = 162$	$D^F(0,1) = \frac{1107+1000+891}{3} \times \frac{12}{52} = 230$
$MAD^p = \sqrt{(1/3)} \times 142 = 82$	$MAD^p = \sqrt{(2/3)} \times 142 = 116$	MAD^p= 142 (fictive)
R= 1 week	R= 1 week	R= 1 week
L= 4 weeks	L= 4 weeks	L= 4 weeks
sL= 1 week	sL= 1 week	sL= 1 week
CSL= 0.95	CSL= 0.95	CSL= 0.95
Order-up-to-level= 786	Order-up-to-level= 1308	Order-up-to-level= 1763
Mean physical stock= 404	Mean physical stock= 579	Mean physical stock= 728

The advantages of this method are:

- simple procedure and easy to combine with the available norm calculation,

• a gradual transition to the required inventory level.
The same procedure can be applied for a phasing-out situation.

Now both in a stationary and a non-stationary situation inventory norms can be determined. Nevertheless some remarks are necessary regarding the replenishment level. The replenishment level equals the order-up-to-level in case the average weekly demand is larger than the minimum production batch. If not, a problem will be caused by the fact that the presented calculation assumes that (at fixed time points) the commercial stock level could always be raised to the order-up-to-level. In that case two alternatives can be applied.

1• Alter the review period for this type and recalculate the inventory norm. For example a review of two weeks would result in an order-up-to-level that can be used as replenishment level. Because a result is that the minimum (production) batch becomes smaller than the demand during the replenishment cycle, so the required replenishment volume can always be ordered.

2• The required replenishment volume is round off upwards, so one production batch is ordered. If the replenishment level (= order-up-to-level) is not crossed at the next order point, no televisions will be ordered. However a result is that the actual mean physical stock is larger than the calculated one.

5.2.3: Preferred types

The preferred types need another approach than the special types, although the same computer program can be used. The computation of the total mean physical stock alone is not enough, one has also to determine what part of the total stock will be stored at the NSO and what part at the EDC. The most profitable allocation of the total stock can be found with help of the demonstrated computer program, nevertheless some modifications of the input parameters are necessary. This discussion of the EDC profitability does not pretend to optimize the RONA, but merely tries to explain the effects of variable stock in an EDC. This part attempts to minimize the amount of stock that is necessary in both the EDC and the NSO.

When varying the EDC stock, both the CSL of an EDC changes as the probability that a NSO will be supplied within a certain supply time. If the NSO stock and the EDC stock are considered separately, a key has to be used that transforms the CSL of an EDC into a supply lead time and supply lead time deviation from EDC to NSO. Suppose the CSL (or better: supply reliability) of the EDC is 100%, this implies that every product can be immediately supplied from EDC stock. In this case only transport time deviations will occur, thus:

• the supply lead time= $L_{EDC\text{-}NSO}(100\%)$
• the supply lead time deviation= $sL_{transport}$.

If the CSL of an EDC is less than 100%, the probability decreases that a product will arrive at a NSO within $L_{EDC-NSO}(100\%)$ periods. Because not only transport time deviations will occur but also "out of stock" situations. What really happens in such a situation can be best explained with help of figure 5.2.

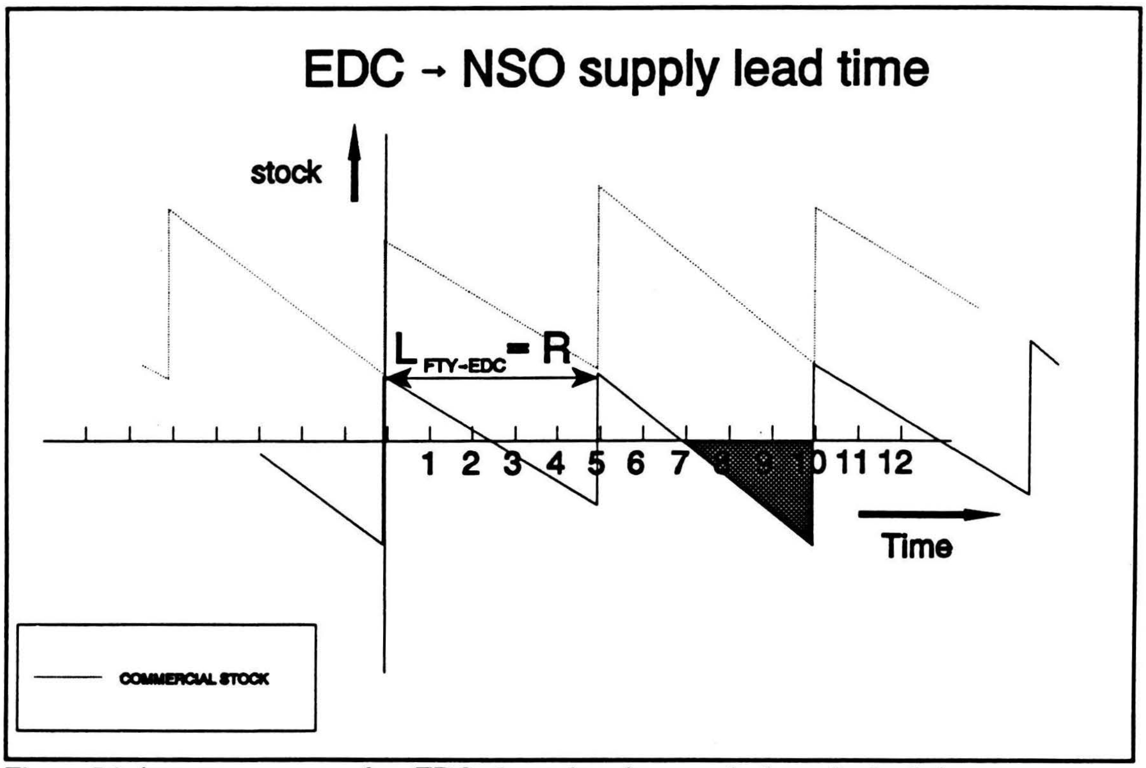

Figure 5.2: inventory pattern of an EDC; the review time equals the order lead time

Figure 5.2 shows the stock positions of an EDC with a CSL of less than 100%. If the sales are equally spread over one review period, it can be stated that the CSL is 40% (2/5), because the EDC can supply the NSO in 2 out of 5 periods. The grey area illustrates the back orders. This causes a longer order lead time ($L_{EDC-NSO}(40\%)$) for those products that can not be supplied immediately. For example a load of televisions, ordered at 8 (time periods) will be delayed 2 time periods, because the order has to wait until the next batch from the FTY arrives at the EDC. So if an order arrives after 7 time periods, the expected delay is:

$$\frac{10-7}{2}=1.5 \text{ periods} . \qquad (5.11)$$

So the expected supply lead time between the EDC and the NSO is:

$$L_{EDC-NSO}(40\%)=0.40L_{EDC-NSO}+0.60(L_{EDC-NSO}+\text{Delay})=0.40\times5+0.60\times6.5=5.9 \ , \qquad (5.12)$$

where

$L_{EDC-NSO}(40\%)$= expected order lead time (non-conditional) from EDC to NSO; the CSL of the EDC is 40%,

$L_{EDC-NSO}$= the order lead time from EDC to NSO (conditional: load of televisions is ordered between time points 5 and 7).

In general, an approximation of the expected delay in a stationary situation is:

$$E[Delay\,|\,Delay>0]=\frac{R_{FTY\text{-}EDC}(1-\beta)}{2}\ \text{periods}\ , \tag{5.13}$$

where
$R_{FTY\text{-}EDC}$= review time of an EDC,
ß= Customer Service Level (CSL) of an EDC

Besides the average lead time between EDC and NSO is:

$$L_{EDC\text{-}NSO}(\beta)=\beta L_{EDC\text{-}NSO}+(1-\beta)(L_{EDC\text{-}NSO}+E[Delay\,|\,Delay>0])\ . \tag{5.14}$$

Now expression 5.13 of the expected delay can be merged with expression 5.14,

$$L_{EDC\text{-}NSO}(\beta)=\beta L_{EDC\text{-}NSO}+(1-\beta)(L_{EDC\text{-}NSO}+\frac{R_{FTY\text{-}EDC}(1-\beta)}{2}) \tag{5.15}$$

what equals,

$$L_{EDC\text{-}NSO}(\beta)=L_{EDC\text{-}NSO}+\tfrac{1}{2}(1-\beta)^2R_{FTY\text{-}EDC} \tag{5.16}$$

The expected supply deviation time can be found with expression,

$$sL^2_{EDC\text{-}NSO}(\beta)=sL^2_{transport}+sDelay^2\ , \tag{5.17}$$

where
$sL_{transport}$= transport time deviation,
sDelay= Delay time deviation,
$sL_{EDC\text{-}NSO}$(ß)= expected supply deviation time (non-conditional) from EDC to NSO, given a CSL of ß.

The supply deviation time depends on the transport deviation time and the standard deviation of the delay time. The transport deviation time is fixed for all values of ß, so at first only the supply (time) **before** transport will be examined.
Suppose the delay is uniform distributed on interval [0,(1-ß)R] so,

$$E[Delay^2\,|\,Delay>0]\ =\ \frac{(1-\beta)^2R^2}{12}+\frac{(1-\beta)^2R^2}{4}\ =\ \frac{(1-\beta)^2R^2}{3}\ , \tag{5.18}$$

where
ß= CSL
R= Review time of an EDC ($R_{FTY\text{-}EDC}$)

$$E[Delay^2] = (1-\beta) \times E[Delay^2 | Delay>0] = (1-\beta) \times \frac{(1-\beta)^2R^2}{3} = \frac{(1-\beta)^3R^2}{3}, \qquad (5.19)$$

and

$$E[Delay] = \tfrac{1}{2}(1-\beta)^2R \qquad (5.20)$$

Expressions 5.19 and 5.20 are combined to get an expression for sDelay,

$$sDelay^2 = E[Delay^2]-E[Delay]^2 = \frac{(1-\beta)^3R^2}{3}-\frac{(1-\beta)^4R^2}{4} = \frac{(1-\beta)^3R^2}{12} \times (1+3\beta)\ . \qquad (5.21)$$

Hence the supply deviation time from an EDC to a NSO is

$$sL^2_{EDC\text{-}NSO}(\beta)=sL^2_{transport}+\frac{(1-\beta)^3R^2}{12} \times (1+3\beta) \qquad (5.22)$$

For ß=1 (=100%, all products are supplied from stock) it appears that $sL_{EDC\text{-}NSO}$ equals $sL_{transport}$, which agrees with previous remarks.

Given a specified CSL of an EDC, expressions 5.16 and 5.22 can be used to determine the required stock at a NSO. The parameters L and sL of table 5.5 are modified according to both expressions. The other input parameters are not modified. Nevertheless more information is needed than indicated in table 5.5 because now two stock point have to be considered. The information needed to calculate the two-echelon stock is presented in table 5.8.

Table 5.8: primary information to calculate inventory norms at both the NSO and the EDC

fixed parameters	type specific parameters
• R_{EDC}= the review period in an EDC= .... 1 week	• $D^F_{EDC}(0,1)$= forecasted demand at an EDC for 1 week
• L_{EDC}= order lead time of an EDC= .... 4 weeks	• MAD_{EDC}= Mean Absolute Deviation of $D^F_{EDC}(0,1)$ when forecasting 4 weeks ahead
• sL_{EDC}= supply deviation time of an EDC= .... 1 week	• CSL_{EDC} or $ß_{EDC}$= Customer Service Level of an EDC
• R_{NSO}= the review period in a NSO= .... 1 day	• $D^F_{NSO}(0,1)$= forecasted demand at an NSO for 1 day
• $L_{NSO}(ß_{EDC})$= order lead time of a NSO	• MAD_{NSO}= Mean Absolute Deviation of $D^F_{NSO}(0,1)$ when forecasting 4 weeks ahead
• $sL_{NSO}(ß_{EDC})$= supply deviation time of an EDC	• CSL_{NSO} or $ß_{NSO}$= Customer Service Level of an NSO

Some remarks are necessary concerning the calculation of the MAD's. The available data during this research were not adequate to calculate the MAD's of the NSO's, because the GIPSY database only provides forecast errors for monthly (= 4 weeks) sales. The required information to determine the MAD_{NSO} has to correspond with an

order lead time of 5 days instead of 4 weeks. Nevertheless the monthly data are used to estimate the MAD. For this reason the MAD_{NSO} is defined as "Mean Absolute Deviation of $D^F_{NSO}(0,1)$ when forecasting 4 weeks ahead" (see table 5.8).
The MAD_{EDC} is derived from the consolidated plans and sales actuals of the NSO's that will be supplied from an EDC. If the individual errors of the NSO's are independent the MAD_{EDC} will be smaller than the sum of all corresponding MAD_{NSO}'s. Nevertheless the sum of all $D^F_{NSO}(0,1)$'s (of one specified product type) equals the $D^F_{EDC}(0,1)$.

By varying the CSL_{EDC} figure 5.3 can be created.

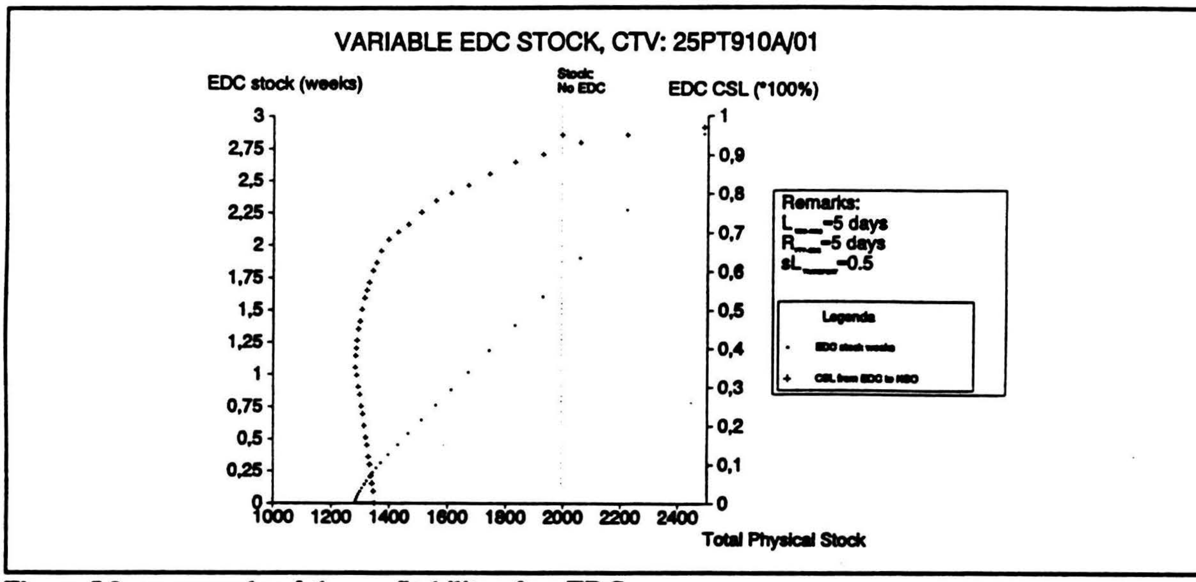

Figure 5.3: an example of the profitability of an EDC

This figure shows the impact on the total mean physical stock, when varying the CSL_{EDC}. It was explained that both the L_{NSO} and sL_{NSO} depend on the CSL_{EDC} whereas the other parameters are assumed to be fixed. Appendix 5.7 contains the exact data that were used to create figure 5.3. A vertical line shows the inventory level that is needed when no EDC is used. Each point at the left side of the vertical line indicates an allocation of stock that is more profitable than an inventory level without an EDC. A sample of other product types showed that the same pattern could be drawn for most of the types, hence one could (carefully) conclude that:

- it is safe and profitable to store 1 week at an EDC,
- an EDC can be used to achieve a higher CSL compared with the situation without an EDC, given a specified inventory level.
- the profitability of an EDC largely depends on the number of NSO's that can be supplied from an EDC; the more NSO's that are supplied, the smaller the MAD of an EDC.

5.2.4: Summary

The CSL and the stock policies can be used to differentiate between product types. Of the four defined stock elements only the batch and the safety stock norms are examined because those (only) could be used to differentiate between product types. The theoretical concept and the program code proved to calculate a realistic inventory norm. Besides the approach seemed to be simple enough, that data on type level (input parameters) can be obtained immediately. However a weakness of the approach is the negligence of the minimum batch size that should be ordered.

5.3: Implementation of the differentiated inventory control

The previous two paragraphs provided the results of the normative assignment. This paragraph will discuss the operational part of the differentiated inventory control.

5.3.1: Gathering input parameters

All data that were used to calculate the inventory norms, can be obtained from GIPSY (Goodsmovement Information and Planning System). The previous paragraphs elucidated how the GIPSY data can be transformed in parameters of the computer program. FOCUS, the reporting tool of GIPSY, can be used to calculate the inventory norms, however the program code has first to be translated. If FOCUS can execute the same calculations as the examined program code, it will be easy to obtain the required data. The translation has not yet been made, nevertheless appendix 5.4 provides the gives the required program code.

5.3.2: Review of inventory norms

Paragraph 5.2.2 (table 5.6) already mentioned the review of inventory norms. The review time between the calculations determines the response time to changes of business processes. Too long review times cause rigid goodsflows whereas too short review times cause nervous goodsflows. Close to the market one would like to have a quick response to changed market situations. On the other hand the manufacturing side would like to have a stable situation, hence a longer review period is preferred. A review time of about 1 month seems to be a reasonable choice. If required, the review period for NSO's can be shortened in case an EDC is used.
Another consequence of the length of the review time is the impact of a modified inventory norm. Suppose an inventory norm is fixed for more than 1 month, this would mean that more stockcosts are variable because more costs are affected within this period. In other words the effects of the decision to change an inventory norm become more significant.
If a review of 1 month appears to require too much work it is possible to use a

different expression for the stock norms. Instead of absolute quantities one can use the norm in future weekly sales (in appendices 5.5 and 5.6 denoted with "Ph w"). So not the entire calculation has to be executed, but only a simple multiplication of the norm and the future weekly sales.

5.3.3: Monitoring inventory norms

Although the calculation of inventory norms is triggered each review period, it is still necessary to monitor the inventory norms. Large deviations of the actual stock from the stocknorms indicate that business processes have changed or were not foreseen. The control process that is used to monitor the deviations of the logistic objectives (CSL and relative investment in stock) is based on 3 basic activities:
- observe
- compare
- interfere

These activities are depicted as grey areas in figure 5.4. In order to control the goodsmovement, one has to observe for instance the stock position and compare this observation with the norm. The turnover speed of a product type should be high enough to justify its part of the total mean physical stock. An easy way to observe "mud" is to compare the actual stock on CTV level with the expected sales (future demand) for that product type. If for example the inventory exceeds 2 months of expected sales, which can not be justified by a extremely high CSL, one should interfere in the business processes or review the stock norms. It should be noticed that nothing has been said yet about the causes of this inventory excess. It is possible that the sales forecasts are unreliable and that the supply lead times do not come up to the expectations or that the norm is simply wrong.

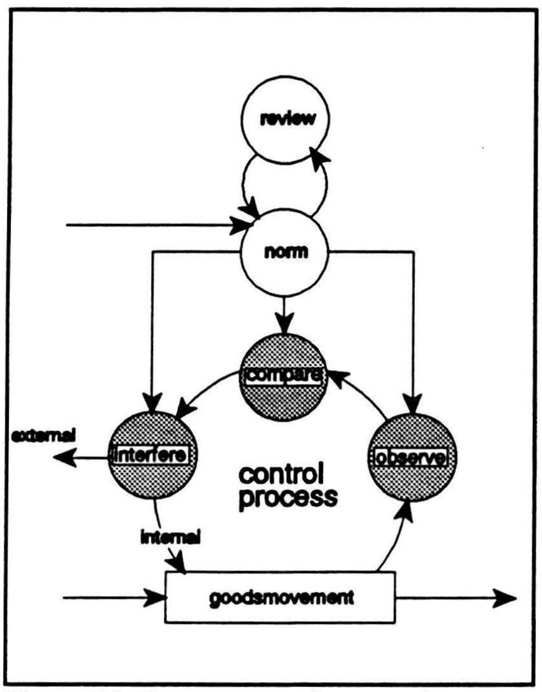

Figure 5.4: the concepts of a control process

Thus for each product type a upper limit and a lower limit should be determined. A simple limit is:

$$\frac{1}{2} \times \text{month future sales} < \text{actual stock} < 2 \times \text{months future sales} \tag{5.23}$$

The same considerations should be made for the actual value of the CSL, so both logistics objectives are monitored. In case a deviation occurs, one has to search for the causes of this deviation. However it is better to monitor the main causes in order to prevent the deviation. These main causes are represented by the input parameters. (Of course, otherwise the input parameters should be ineffective!) The parameter that requires special attention is the MAD (to determine $\sigma(\epsilon(0,1))$). The next part provides an example of the observation of the MAD. The other parameters are not discussed, because no complications are expected when monitoring these parameters.

5.3.4: Monitoring deviations of forecast reliability

One of the main causes of a deviation from the targeted stock is a defective or unreliable forecast. Therefore it seems advisable to monitor the quality of forecast as well. To understand the way one could do so, it is necessary to understand the basics of forecasting [reference 5].

Expression 5.6 already indicated that the real demand is assumed to be generated by a function of the following kind:

$$D(0,R+L)= q(0,R+L) + \epsilon(0,R+L),$$

where,

- $\epsilon(0,R+L)$= random fluctuation (component),
- $D(0,R+L)$= actual demand.
- $q(0,R+L)$= presents the level of demand; for example this could be a constant $q=d$, a time dependent $q= a + bt + ct^2$ or an expert estimate,

If the actual demand consist of a constant level of demand ($q(0,R+L) = d(0,R+L)$) that is only affected by random fluctuations ($\epsilon(0,R+L)$), then the model will be: $D(0,R+L) = d(0,R+L) + \epsilon(0,R+L)$. When forecasting the expected demand, the best one can do is to identify correctly the value of $d(0,R+L)$. The forecast will then equal $D^F(0,R+L)$ and hence: $D(0,R+L) - D^F(0,R+L) = \epsilon(0,R+L)$. Thus the observed error will reflect the true variability of the underlying process, something that cannot be forecast and which one has to make plans to accommodate. Thus, the statistical distribution of these errors can be used to establish safety stocks for inventories[4].

How can one discover a significant deviation of the forecast reliability? The best way to monitor these deviations is to keep an eye on the observed forecast errors.
The average (absolute) forecast error is calculated like:

$$MAD_t= b|e_t| + (1-b)MAD_{t-1}, \qquad (5.24)$$

where,

[4] The demonstrated norm calculations of §5.1.1 use these distribution of errors to fit the parameters of the gamma probability distribution.

MAD_t= Mean Absolute Deviation at time t,
e_t= observed $\epsilon(0,R+L)$ or forecast error at time t,
b= smoothing average parameter.

This error can indicate two derived problems:

1• The absolute value of the forecast error is too large,
2• The forecast error is continuously positive or negative.

Both problems will be explained next.

1• The absolute value of the forecast error is too large

The first deviation of the forecast error to be examined, is the absolute deviation which indicates the forecast accuracy. For this the coefficient of variation can be used or the standard deviation of the errors, but the MAD_t provides a better indication. The MAD_t is calculated by applying the exponential smoothing concept to the absolute deviations and hence emphasizes the more recent errors, what can be regarded as an advantage.
If the observed $\epsilon(0,L+R)$ is growing out of proportion one can try to discover which of the bottlenecks is relevant. There are two potential bottlenecks:

- the model of q(0,R+L) is "wrong" and therefore $\epsilon(0,L+R)$ is unnecessary large,
- the model of q(0,R+L) is "right" but the random fluctuations are naturally large as a result of a "bad" process control (for example: malfunctioning quality control on a production process).

2• The forecast error is continuously positive or negative

The second indicator that will be discussed here, warns you when the forecasts are **consistently** too large or too small. It may be possible that the MAD_t remains low but that the actual demand is consistently overestimated (or underestimated). Table 5.9 shows a fictitious example of a CTV from the U.K. of which only January 1993 (bold type) presents actual figures. It shows the expected sales of month t as forecasted just before the beginning of the month t. The table also presents the actual sales, the observed forecast error (e_t), the cumulative error, the MAD_t and the ratio between the cumulative error and the MAD_t. Suppose that if the ratio between the MAD_t and the cumulative error exceeds 4, a fundamental change has taken place in the average (actual) demand. Nevertheless it is still possible that nothing has actually changed and eventually no correction is needed.
The ratios of the first 3 months should not be taken into account because the forecast

errors of the previous months were assumed to be zero (what results in a relative low MAD_t). It can be noticed that the last three months are forecasted rather bad. A few bad forecasts at a row indicate that something could be wrong (, for this reason one has to examine the cumulative error and not at the absolute e_t). At the end of the year the expected sales appear to be structural to high what indicates that the forecasting becomes less reliable. The expected large sales at the end of the year are overestimated.

Table 5.9: Forecast reliability check

14GR1227-/05B 1993 Month	1 Actual	2 Fore-cast	1-2 e_t	3 $\sum e_t$	4 MAD_t (b:=0.2)	3:4 reliability check
Jan.	1221	1210	11	11	2.20	5.00
Feb.	900	1040	-140	-129	29.76	-4.33
Mar.	1125	1250	-125	-254	48.81	-5.20
Apr.	1400	980	420	166	123.05	1.35
May	1024	1392	-368	-202	172.04	-1.17
Jun.	970	1123	-153	-355	168.23	-2.11
Jul.	1240	976	264	-91	187.38	-0.48
Aug.	700	850	-150	-241	179.90	-1.34
Sep.	1435	1320	115	-126	166.92	-0.75
Oct.	1370	1745	-375	-501	208.54	-2.40
Nov.	1356	1965	-609	-1110	288.63	-3.84
Dec.	1228	1629	-401	-1511	311.10	-4.86

In case one of the mentioned problems arise, four actions are possible:

1• examining D(0,R+L) for unforseen changes like a marketing campaign or "bad" process control,
2• examining q(0,R+L) in order to check the validity of the forecast model,
3• increasing b which results in more emphasis on the more recent data,
4• checking for calculation and other data errors.

It is possible that more than one bottleneck causes a forecast problem, in that case more actions will have to take place. But one should be aware of the fact that the observed errors could be a statistical exception and that it is possible that nothing is actually "wrong" or in need of correction.

5.4: Financial considerations of the differentiated inventory control

This paragraph provides the financial considerations of the differentiated inventory control model. The determination of the CSL, one of the changeable parameters, is part of these financial considerations (paragraph 5.4.1). Paragraph 5.4.2 concludes with an evaluation of the stock reduction and the RONA as a result of the differentiated inventory control.

5.4.1: Financial decisions

Chapter 3 already mentioned that long and short term effects can be distinguished. The main difference between long and short term effects is the part of irrevocable expenses [reference 7]. For the long term (e.g. one year) decision more costs are variable and less costs are fixed, compared with the short term decision. An example is the lease of a warehouse. If the stock reduction from is a long term decision (more than two years), the costs of leasing a warehouse will be variable because the lease is fixed for less than two years[5]. Hence this part examines 2 levels of decision-making:

1• long term decision: reduction of the total mean physical stock from
2• medium term decision: allocation of the amount of inventory o product types.

Remark: only the effects of the long term decision will be actually quantified: a short term effect (cash flow) and a long term effect (RONA) as indicated in chapter 3. The consequences of the medium term decision will only be discussed theoretically, because not enough data were available to examine the medium term decision.

1• The long term decision

The long term decision is required to specify the total amount of stock that has to be used. The BG TV has already budgeted about 300K pieces for the future logistics situation. Nevertheless this paragraph shows that a budget of 300K is plausible and can be used to make a medium term decision. The effects of this new inventory level will be discussed in paragraph 5.4.2.

The demonstrated long term decision is based on the trade-off between the (total variable) stockcosts and the income from operations. The income from operation is derived from the RONA definition (appendix 3.1^A), hence

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[5] If necessary, the fixed period of a lease can be reduced through negotiation.

IFO = sales - costs of material - costs of organization . (5.26)

The presented trade-off will increase the IFO till the optimum value is achieved. By varying the inventory levels one can try to increase the IFO, e.g. a higher stock level results in less lost [redacted] (= more income from operations) but also in more st[redacted]

The only costs of organization that vary [redacted]ff are stockcosts. Hence the stockcosts will be used in expression 5.26 instead of the costs of organizations. However the abbreviation IFO will still be used.

The stockcosts are supposed to be variable and can be expressed like,

stockcosts = k × mean inventory capital (5.27)

where k is a percentage that presents the stockcosts as part of the total inventory capital. In general one can state that the stockcosts are approximate 20% (k=0.20) of the total inventory capital. These costs consist of housing, risk of obsolescence and interest.

The costs of material can be derived from the Factory Production Price (FPP). In general one can state that the costs of material are on average 85% of the FPP (see appendix 5.8). Suppose that FPP = 0.70 × NP, so the costs of material can be derived from the NP as,

costs of material = 0.85 × 0.70 × NP = 0.60 × NP (5.28)

So expression 5.26 becomes,

IFO = (sales volume × NP) - (sales volume × 0.60NP) - (0.20 × stocklevel × NP)

The sales volume depends on the CSL, because a part of the calculated back orders will not be sold. Assume that 15% of the calculated back orders will not be sold and that the BG TV's market potential offers a sales volume of V, then

IFO = ((1-0.60) × (1 - 0.15(1-CSL)) × (V × NP) - (0.20 × stocklevel × NP) (5.29)

or

IFO = (0.34 + 0.06CSL)(V × NP) - (0.20 × stocklevel × NP) . (5.30)

The stocklevel can be estimated in accordance with the presented calculation. The only changeable parameter is the CSL, so expression 5.30 results in

IFO = (0.34 + 0.06CSL)(V × NP) - (0.20 × f(CSL) × NP) (5.31)

An example of the trade-off is given in figure 5.5. Figure 5.5 shows the impact of the

CSL on the total IFO. Not the absolute values of the IFO's are meaningful but the increase of the calculated IFO. The figure displays an example of the MAG D41 (the sales figures and forecast errors are derived from appendix 5.5), where

- average NP=
- sL= 1 week
- R= 1 week
- L= 4 weeks

The ideal CSL seems to be about 90%, what corresponds with the stockproposal per 31-12-'93. Hence the conclusion can be justified that an inventory level of 80K for the MAG D41 is sufficient. Appendix 5.9 contains the input parameters and the results of expression 5.31, which are used to create figure 5.5.

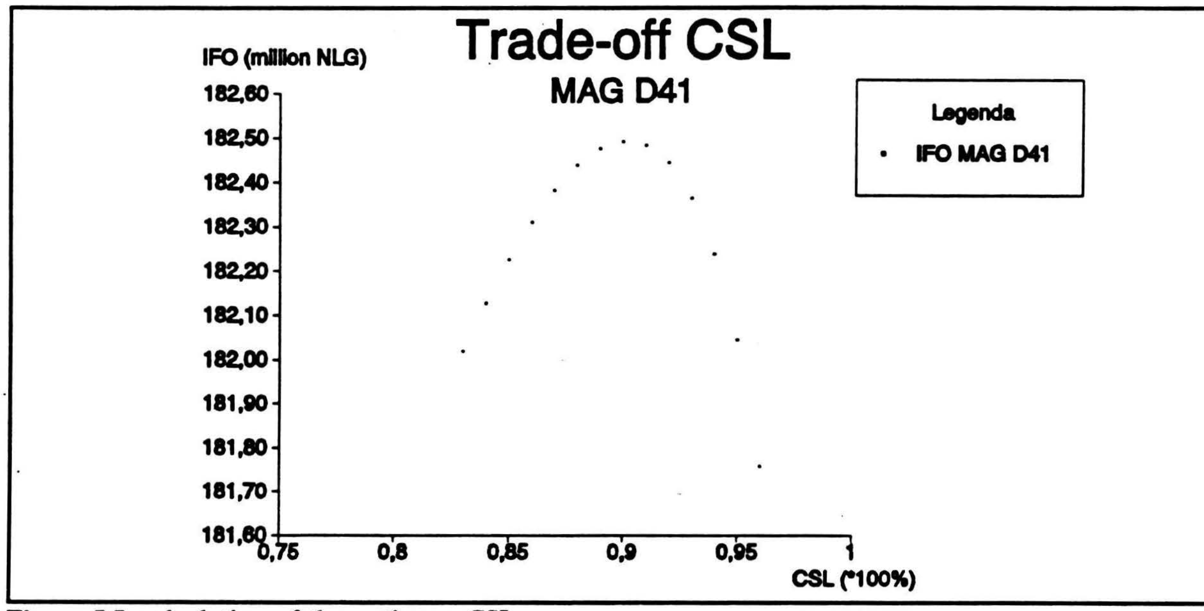

Figure 5.5: calculation of the optimum CSL

This trade-off is not performed for other MAG's because of a lack of time. Nonetheless the same trade-off can be made for all MAG's, and it probably would appear that the stockproposals per 31-12-'93 are satisfactory. Hence the reduction of about 100K is assumed to be realistic and can be used to formulate the medium term decisions.

A brief comment about the presented trade-off is required, to justify the fact that only the numerator of the RONA definition is optimized. The real nature of the RONA is to compare the individual BG's. Each BG has a budgeted working capital and will try to achieve the maximum IFO what results in an optimum RONA. Philips' logistics management has determined that a stock level of 300K should be realized with the new logistic concept and the differentiated stock control. Hence the objective of the performed trade-off is to indicate that the stock proposals per 31-12-'93 are reasonable and provide a maximum IFO according the approximate parameters. Thus the denominator was not considered in the calculation, because the new inventory norm corresponding the new logistics concepts was already limited. Nevertheless the budgeted inventory capital should always take into consideration the mentioned trade-off.

2• The medium term decision

The medium term decision deals with the changeable parameters of the differentiated stock control model. The inventory norms will be monthly evaluated and each time one has to decide what CSL and which stock policy will be applied. The medium term decision has to fit the long term decision, thus the stocklevel of about 300K is a restriction for all medium term decisions. In other words the bottom up approach has to fit the top down approach. The decision to use a specified stock policy is based on the criteria presented in table 5.4. The determination of type-specific CSL will be discussed now.

The calculation of an ideal CSL per product type according the trade-off of figure 5.5 is not valid, because all stockcosts are considered to be variable (expression 5.27). For the medium term[6] however only a few stockcosts are variable, in other words the total stockcosts are: k' × mean inventoy capital + fixed costs. Unfortunately it is very difficult, if not impossible, to determine the fixed costs on type level. Fixed costs of one product type can not be isolated from the fixed costs of another product type. Hence a bottom up approach based on a financial analysis is not possible, but it is feasible to determine the required inventory norms top down and allocate this top down budget to product types.

The first step consists of the calculation of inventory norms on type level with one CSL for all product types. Examples of such calculations are provided by appendices 5.5 and 5.6. As a result of these calculations one valid CSL is obtained that fits the top down budget. After that one can try to find better individual CSL's with help of the "trial and error"-method. A sound CSL for each product type can increase the RONA within the budgeted top down approach.

Table 5.10 demonstrates one step of the trade-off that has to be made in order to find the ideal CSL. In practice several steps of a "trial and error"-method are needed to find an optimum CSL.

[6] The inventory norms on type level are monthly reviewed

Table 5.10: an example of the trade-off to find an ideal CSL

OPTION A

Product type X	Product type Y
NP= 180 $D^F(0,1)$= 100 MAD= 75 R= 1 week L= 4 weeks sL= 1 week CSL= 90%	NP= 180 $D^F(0,1)$= 100 MAD= 75 R= 1 week L= 4 weeks sL= 1 week CSL= 90%
Lost back orders=0.40×(1-0.90)×100= 4	Lost back orders=0.40×(1-0.90)×100= 4
revenue= 180×(100-4) = ... 17.280 costs of material= 50×(100-4) = . 4.800 fixed costs= .... 9.480 **Income from operations= ..... 3.000** **mean physical stock= 277**	revenue= 180×(100-4)= ...... 17.280 costs of material= 140×(100-4)= 13.440 fixed costs= .... 840 **Income from operations= ..... 3.000** **mean physical stock= 277**

OPTION B

Product type X	Product type Y
NP= 180 $D^F(0,1)$= 100 MAD= 75 R= 1 week L= 4 weeks sL= 1 week CSL= 95%	NP= 180 $D^F(0,1)$= 100 MAD= 75 R= 1 week L= 4 weeks sL= 1 week CSL= 81%
Lost back orders=0.40×(1-0.95)×100= 2	Lost back orders=0.40×(1-0.81)×100= 7.6
revenue= 180×(100-2) = ... 17.640 costs of material= 50×(100-2) = . 4.900 fixed costs= .... 9.480 **Income from operations= ..... 3.260** **mean physical stock= 372**	revenue= 180×(100-7.6) = ... 16.632 costs of material=140×(100-7.6)= 12.936 fixed costs= .... 840 **Income from operations= ..... 2.856** **mean physical stock= 182**

Table 5.10 shows two optional situations (A and B) for two product types. The change of the CSL's caused an increase of the IFO although the total mean physical stock did not change. The outcome is that the IFO increases from 6.000 to 6.116 (an improve-

ment of 2%), using the same amount of stock. Thus the RONA is improved without exceeding the budgeted stocklevel. If more of these trade-offs are performed one finally should be able to determine the optimum CSL for the two product types. However no time was available during this project to thoroughly examine this trade-off.

The improvement of the IFO on type level within the specified top-down budget does not depend on the fixed costs, which are a consequence of the long term decisions. The increase of the IFO specially depends on the difference between the particular contribution margins per television. The contribution margin is defined as the revenue minus the variable costs. If this difference is large enough to cover for a progressive[7] lost of back orders, the change of the IFO will be positive.
For example according table 5.10 the number of lost back orders for type X was dropped by 2 televisions, on the other hand the number of lost back orders for type Y was raised from 4 to 7.6 televisions. Hence the IFO will only be improved if the contribution margin per television of type X is 1.8 times larger than of type Y, because:

$$\Delta(IFO) = 2 \times (NP_X\text{-variable costs}_X) - 3.6 \times (NP_Y\text{-variable costs}_Y) = (2CM_X) - (3.6CM_Y)$$

so,

$$\Delta(IFO) > 0 \rightarrow 2CM_X > 3.6CM_Y \rightarrow CM_X > 1.8CM_Y \ .$$

The required difference between contribution margins will change if the logistics parameters, like the MAD, are changed. But one may conclude that significant improvements of the IFO for product types with about the same market characteristics, require large differences in contribution margins. If the market characteristics are not the same, real information about the variable costs and the net prices will provide an answer.

5.4.2: Evaluation of the long term decision

Paragraph 3.2 indicated that the long term decision results in a medium term and a long term effect. The long term effects will be discussed first, in accordance with the RONA definition (appendix 3.1^A). After that an indication of the generated cash flow will be provided.

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7 A specific increase of the CSL requires a change (increase) of inventory that is larger than an equivalent decrease of the CSL.

1• The long term effect

The long term effect is determined by the reduction of the mean physical stock and the additional costs of organization. These additional costs are caused by the use of an EDC. An EDC will be used to assure a satisfactory CSL for preferred types, although the stocklevel of 300K could be achieved without an EDC (see calculations of paragraph 5.2.2).
An approximation of the additional costs of an EDC can be derived from the amount of televisions that have to be stored and handled. The additional transport costs are ignored, because the increase of these costs depends on the location of an EDC. Possibly no significant extra transport costs have to be made. Paragraph 5.2.3 concluded that it is safe to store about 1 week future sales in an EDC. An unanswered question remains: how many product types will be stored in an EDC. Suppose that [redacted] of the sales will be stored in an EDC. The BG TV sells about [redacted] a year. so around [redacted] are handled by an EDC whereas about [redacted] are permanently stored in an EDC. The seasonal stock requires that about [redacted] extra goods can be stored. So, it should be possible to store [redacted] televisions.
Table 5.11 shows the calculation of the approximate additional cost of an EDC. The financial data of table 5.11 are estimations of internal specialists.

Table 5.11: calculation of the additional EDC costs

•Physical handling costs= f 10,- (NLG) per unit	$0.195 \cdot 10^6 \times 10 =$ .. $f 1950.0 \cdot 10^3$,-(NLG)
•Clerical handling costs= f 7,- (NLG) per order line Suppose a NSO orders around 25 televisions per product type each replenishment cycle, so the clerical handling costs= f 7/25 = f 0.28,- (NLG) per unit	$0.195 \cdot 10^6 \times 0.28 =$ ... $f 54.6 \cdot 10^3$,-(NLG)
•Housing costs= f 100,- (NLG) per m^2/year if the maximum volume efficiency is 35% and one can stack up 5m high, then housing costs= f 100/(5×0.35) = f 57,- (NLG) per m^3/year. Suppose the average volume per unit is 0.3 m^3 per unit, so housing costs= f 57×0.3 = f17,- (NLG) per unit	$4.7 \cdot 10^3 \times 17 =$ ..... $f 79.9 \cdot 10^3$,-(NLG)
Total additional EDC costs	total= .... f $2084 \cdot 10^3$,- (NLG)

Table 5.11 shows that an estimate of the additional costs is f $2.1 \cdot 10^6$,- (NLG).
Besides table 5.11 indicates that the additional costs are mainly caused by the required physical handling. Thus specially an improved calculation of the physical handling costs should provide a better examination of the EDC costs.

On the other hand the proposed inventory reduction results in less stockcosts. The change of these costs can be derived from expression 5.27. However the interest costs (9%) should not be considered in the RONA calculation (see appendix 3.1^), so

$$k = 0.20 - 0.09 = 0.11. \qquad (5.32)$$

Hence an approximate reduction of stockcosts is:

$$\Delta \text{ stockcosts} = 0.11 \times 100K \times \quad) = -f10.6 \cdot 10^6 (NLG). \qquad (5.33)$$

The change of costs of organization is a result of the decrease of stockcosts (expression 5.33) and the additional EDC costs (table 5.11). So the change of cost of organization is:

$$\Delta \text{ costs of organizations} = f2.1 \cdot 10^6 - f10.6 \cdot 10^6 = -f8.5 \cdot 10^6 (NLG). \qquad (5.34)$$

Furthermore the stock reduction causes both a decrease of inventory capital and a decrease of required fixed assets (e.g. warehouses). However the decrease of fixed assets depends on the possibility to e.g. sell these assets. The fixed assets are supposed not to change.

Supposed that the sales and the costs of material do not change as well as the remaining part of the working capital, expression 3.1 of the RONA becomes,

RONA= [illegible] (NLG) [illegible] . (5.35)

So a strong improvement of the RONA could be achieved, compared with the RONA of the beginning of 1992. Nevertheless not the absolute value of the calculated RONA is significant but the increase of this RONA.

2• The medium tem effect

The medium term effect of the long term decision is easy to calculate. A stock reduction of 100K generates a cash flow that consists of the medium term variable costs: costs of material.

Table 5.12: costs of material per unit (television)/the allocation of the stock reduction

Product Segment	Factory Production Price (per unit)	Costs of material (per unit)	Actual stock end 1992	stock proposal end 1993
STECO	[redacted] (NLG)	[redacted] (NLG)	[redacted]	[redacted]
Standard	[redacted] (NLG)	[redacted] (NLG)	[redacted]	[redacted]
High End	[redacted] (NLG)	[redacted] (NLG)	[redacted]	[redacted]

Table 5.12 shows that around (1-15%)= 85% of the FPP consists of costs of material. Appendix 5.8 provides the financial data that were used. If the stock reduction is spread over the product segments, then generated cash flow will be:

cash flow = [redacted]

(5.36)

It should be noticed that this improvement for the BG TV results in less revenue for its suppliers. Unfortunately most of these suppliers are part of the Philips company, so the generated cash flow for Philips Electronics is less [redacted]llion NLG.

5.4.3: Summary

The determination of the changeable parameters is a result of the long and medium term decision. A stocklevel of [redacted]ppeared to be plausible and results in an improved RONA. The ideal CSL for each product type was theoretically discussed but could not be worked out, because of a lack of time and required information. The results of the stock reduction seem promising, but the actual value of it depends on the feasibility of the new logistics concept.

CHAPTER 6: Conclusions

This chapter provides both conclusions and recommendations for future implementation of the differentiated inventory control. First of all the conclusions will be discussed: a comparison between the initial assignments and the final results.

6.1: Conclusions

This report worked out both the normative and the operational assignment, reckoning with the financial objectives of these assignments. The normative assignment stated that a model should be designed to budget the inventory on type level. The second (operational) assignment was added because it was clear that an observation for stock deviations is required to actually control the stock levels. At the end of this report one can conclude that the normative assignment is thoroughly examined, but the operational part will have to be worked out further. Especially a feasible procedure to monitor deviations from stock norms needs further examination.

The designed differentiated inventory control provides a tool to control the total stock level and to achieve the planned stock reduction, so the financial objectives can be realized. Though the financial results need to be contemplated carefully, because the financial results depend on the achievement of the identified logistics improvements. These essential logistics improvements will now be mentioned.
One of the improvements that is used to perform the norm-calculations, is the decrease of the review time from 1 month to 1 week. Furthermore the order lead time is supposed to be 4 weeks with a supply deviation time of 1 week, whereas the present order lead time varies between 4 and 8 weeks. If these improvements will not be realized the proposed inventory norms will be too low. This results in an actual CSL that is lower than the planned CSL. In that case the norms have to be recalculated with longer lead times and larger supply time deviations. Consequently the expected financial results will be achieved only partly. This uncertainty can also be met with the introduction of an EDC. An EDC can be used to achieve a higher CSL compared with the situation without an EDC, given a specified inventory level. However an EDC has not yet been implemented.
Another logistics feature that is being implemented, is the stock replenishment on type level. The logistics control between the NSO and the IPC will switch from plan to order driven supply. **It needs no further explanation that the feasibility of the proposed inventory control model strongly depends on the accomplishment of this logistics improvement.**

A last remark is needed to identify two major deficiencies of the presented differentiated inventory control:

1• the lack of batch size considerations,
2• the restrictive definition of the CSL.

The first weakness of the presented model results in lower stock norms than is actually required. It is assumed that a variable load of televisions can be ordered, however each time an order has to be adjusted to a minimum order size it will cause more stock than planned. If an order is cancelled for this reason, it will endanger the required CSL.
The CSL itself can also cause a problem. The described CSL assumes that all orders are delivered from stock, however some orders allow or **demand** a specified delivery time. In that case the average sales-from- stock, derived from the GIPSY database, will be overestimated. A result is that for some product types too much stock is build up, while it could be useful for other product types. In other words an entirely balanced stock will not be achieved.

Still the results of the proposed logistics improvements and the differentiated inventory control are promising. The inventory reductions are feasible and the logistics improvements correspond with the new ways of working of the PHOENIX project. Nevertheless the practical usability of the presented inventory model for other BG's has yet to be examined. Altough the presented model is simple enough to apply in many make-to-stock situations.

6.2: Recommendations

This report will be concluded with some recommendations that will make the inventory control to a success. The sequence of recommendations corresponds with the priority of the individual suggestions. The following actions should be started:

1• the design of the procedure for monitoring actual and expected deviations from stock norms,

2• the translation of the program code into the "FOCUS-language",

3• a study to obtain type specific data from GIPSY;

-the present database can be used:
- to provide a sound approximation of the average demand; question: how many sales plans are needed to provide a sound approximation?

- to provide start and end dates of sales,
- to provide data about batch sizes,
- to provide data about destinations,

-a supplementary database will have to be created in order to:

- hold the required data for the MAD calculation, the next questions will have to be answered:
  - how long will data of the past have to be kept (,using exponential smoothing),
  - what procedure can be used to assign a MAD of a predecessor to a new product type,
- hold data of commercial expectations

4• a study to determine the fixed parameters e.g. what actual order lead times have to be used; question: is a default sufficient,

5• a study of the optimum CSL with actual data,

6• a study of the real type-specific and fixed parameters for the norm-calculation of preferred types, particularly when the MAD's of the NSO's are considered. A result should be a better understanding of the best allocation of stock to NSO's and EDC.

7• a study of the possibilities to record data corresponding the true CSL definition (expression 5.2), in other words a study of the possibilities to record weekly data.

The most difficult actions will be those dealing with the gathering of input parameters. Hence it is advisable to appoint an experienced employee that will be responsible for the correct input of data.

Furthermore once the gathering of data is a fact and the actual norm-calculation is put into practice, one could start to the improve the presented basic concepts. For example the lack of batch size considerations can be worked out later. The same input data can be used and almost no efforts are needed to modify the program code.

It appears that the implementation of the differentiated stock model takes a few more months, thus it is recommendable to assign this last step to an external specialist.

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Appendices

Master's Thesis Project:

The Design of a Differentiated Inventory Control Model

by Harry Smulders

PHILIPS

Eindhoven 9 June 1993

Contents

Appendix 2.1: Philips' organization

The organization of Philips is depicted in figure 1. The Product Division Consumer Electronics (CE) does not only consists of BG's but also of a staff department and several regional organizations. This project was launched by the Business Group Television (BG TV) and CE-Europe (indicated as region Europe). The organization of the BG TV is illustrated in figure 2. Figure 3 shows the organization of CE-Europe. The TV logistics department is depicted in figure 4. The grey areas indicate the logistics departments that are of interest for this project

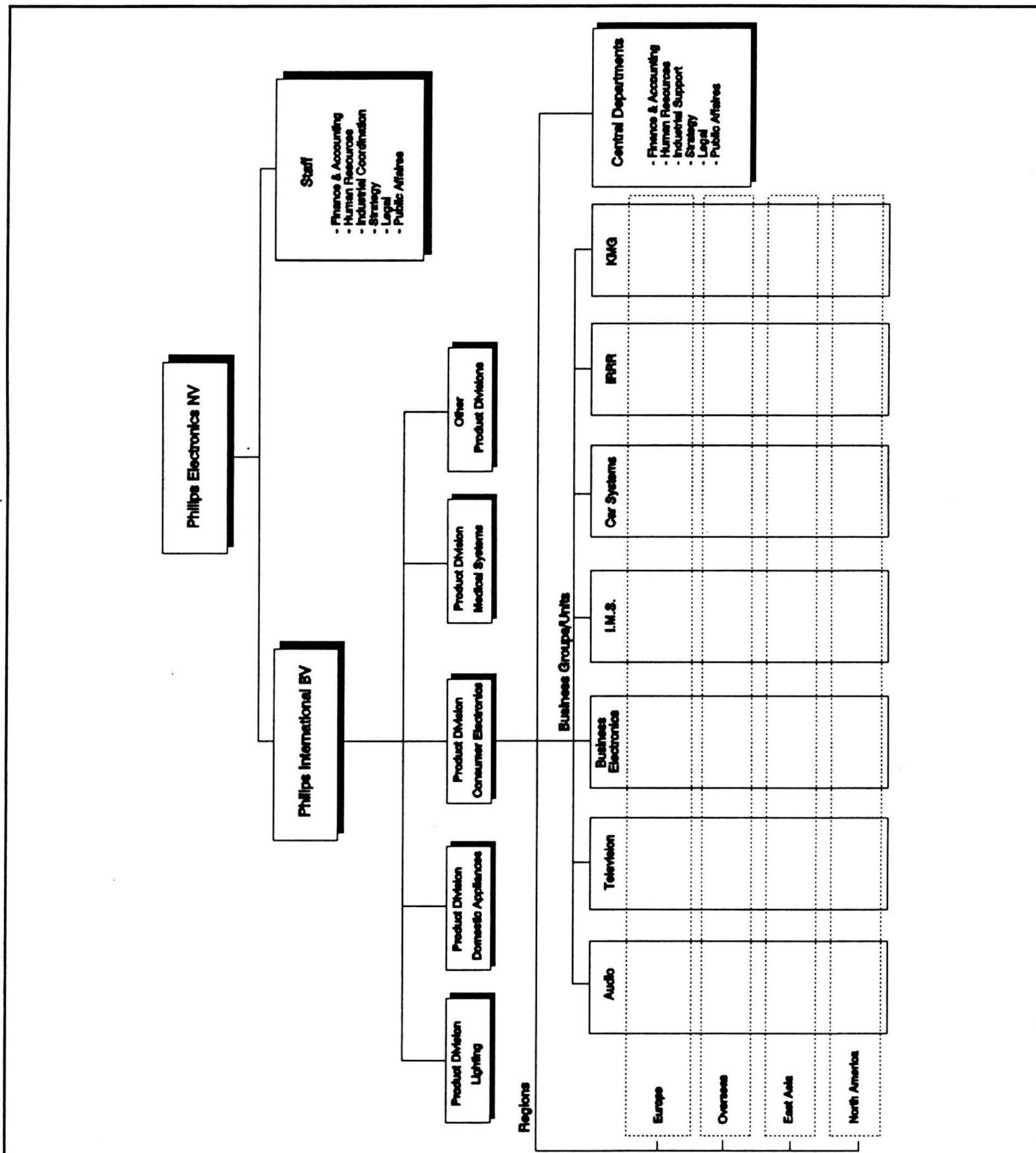


Figure 1.: Philips Electronics organization diagram

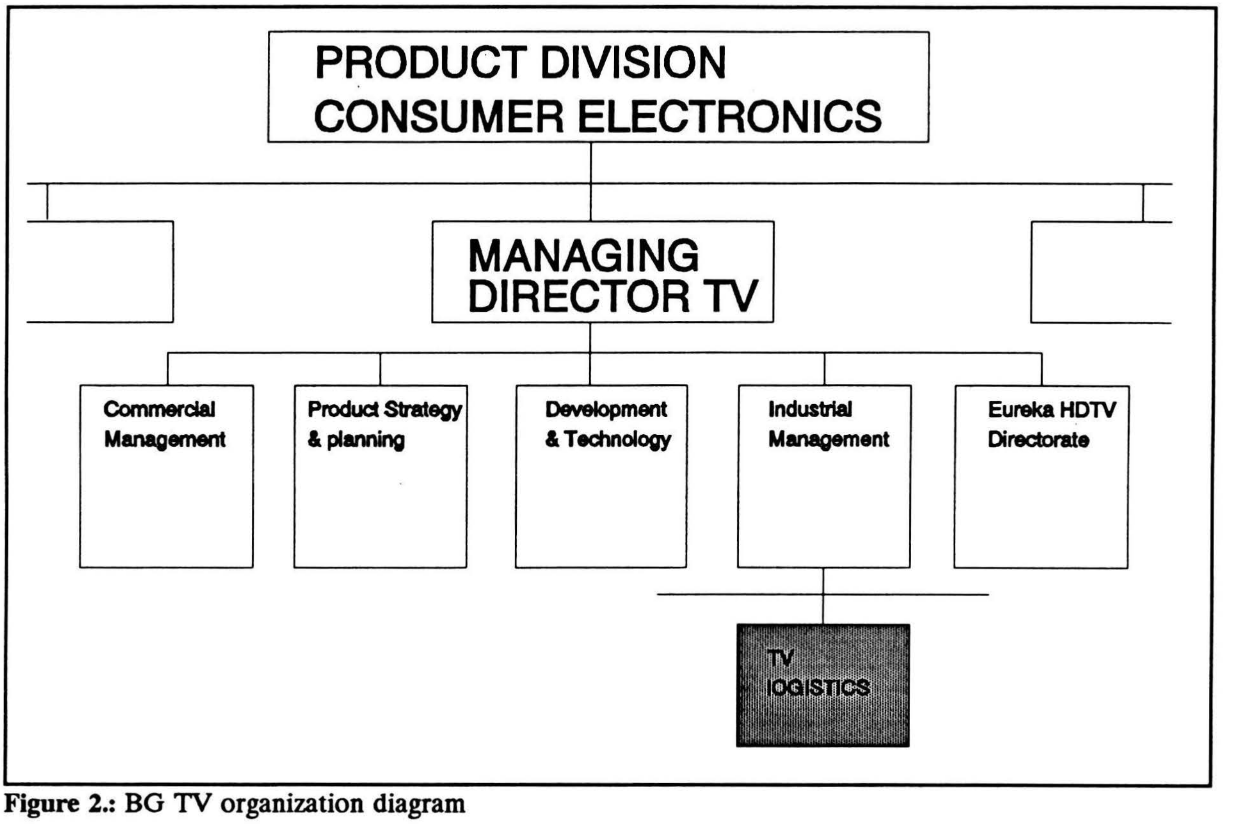


Figure 2.: BG TV organization diagram

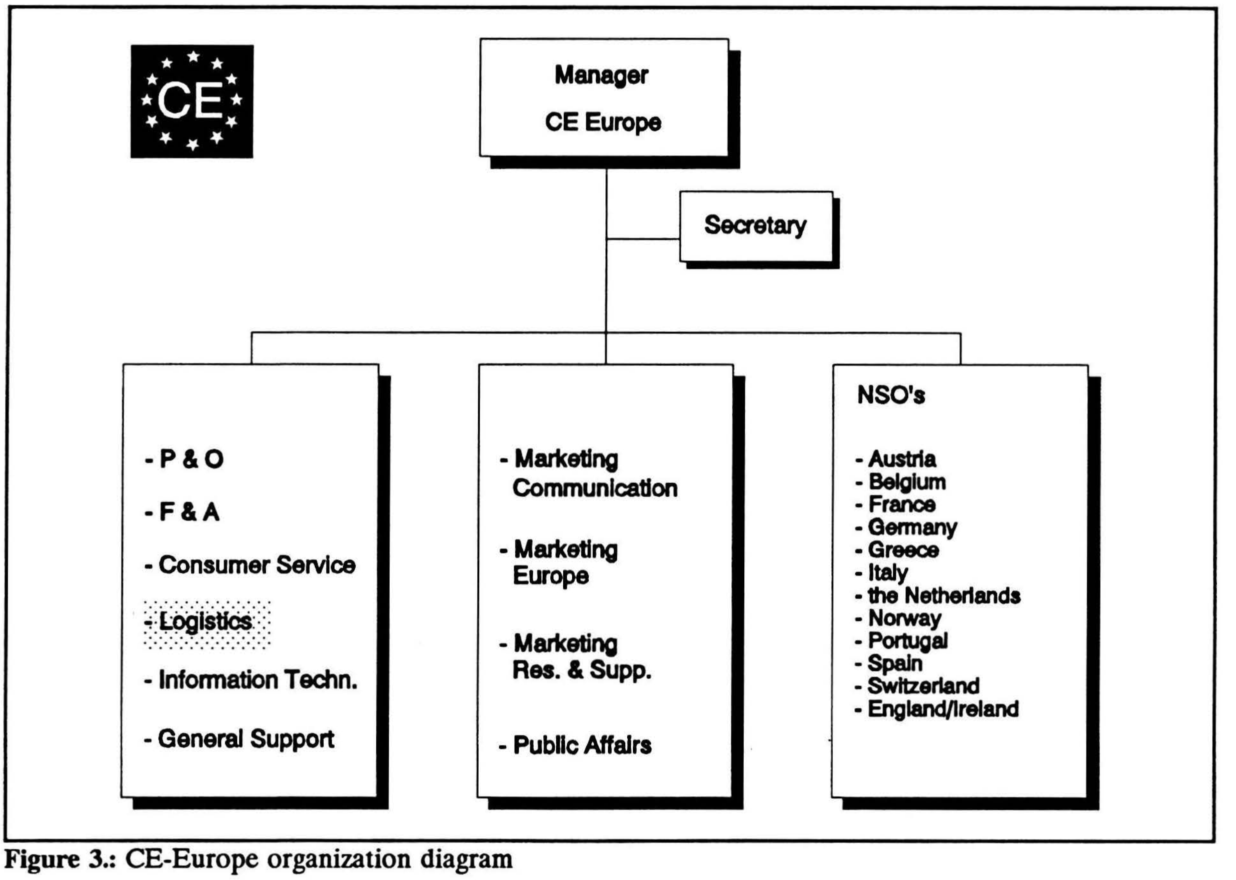


Figure 3.: CE-Europe organization diagram

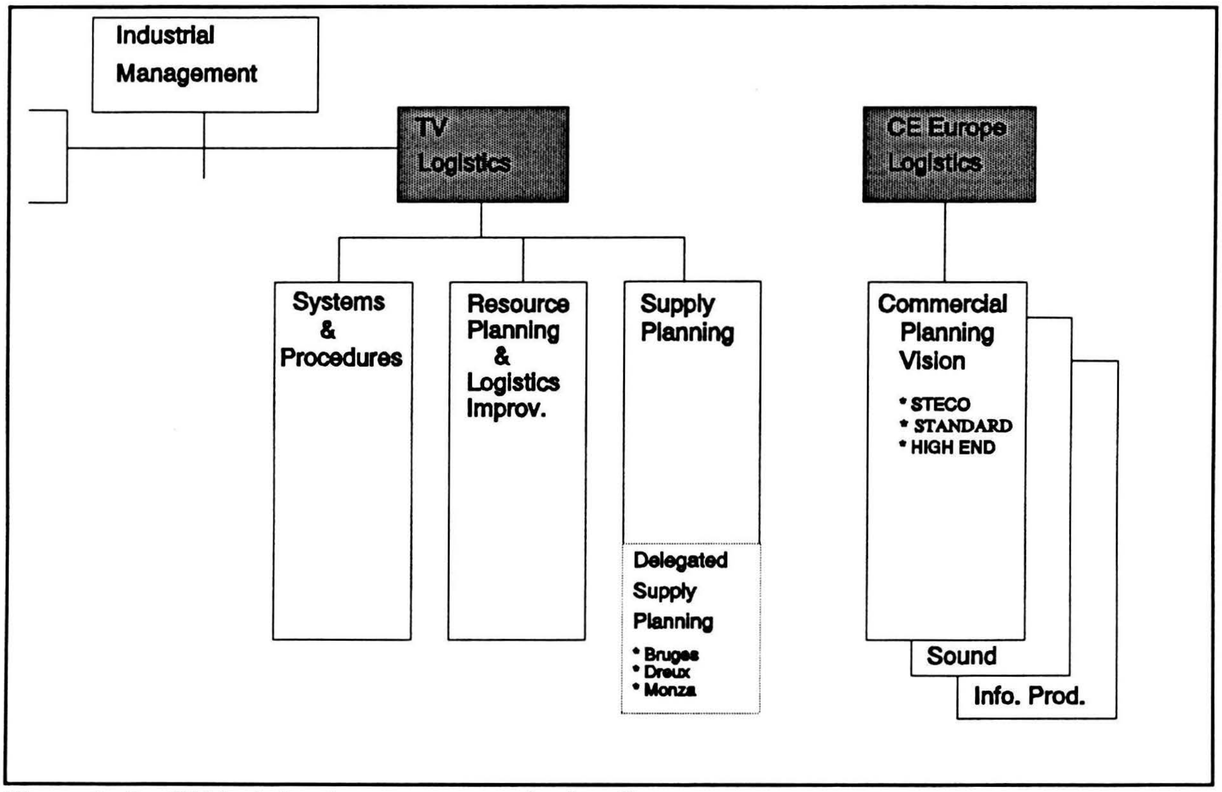


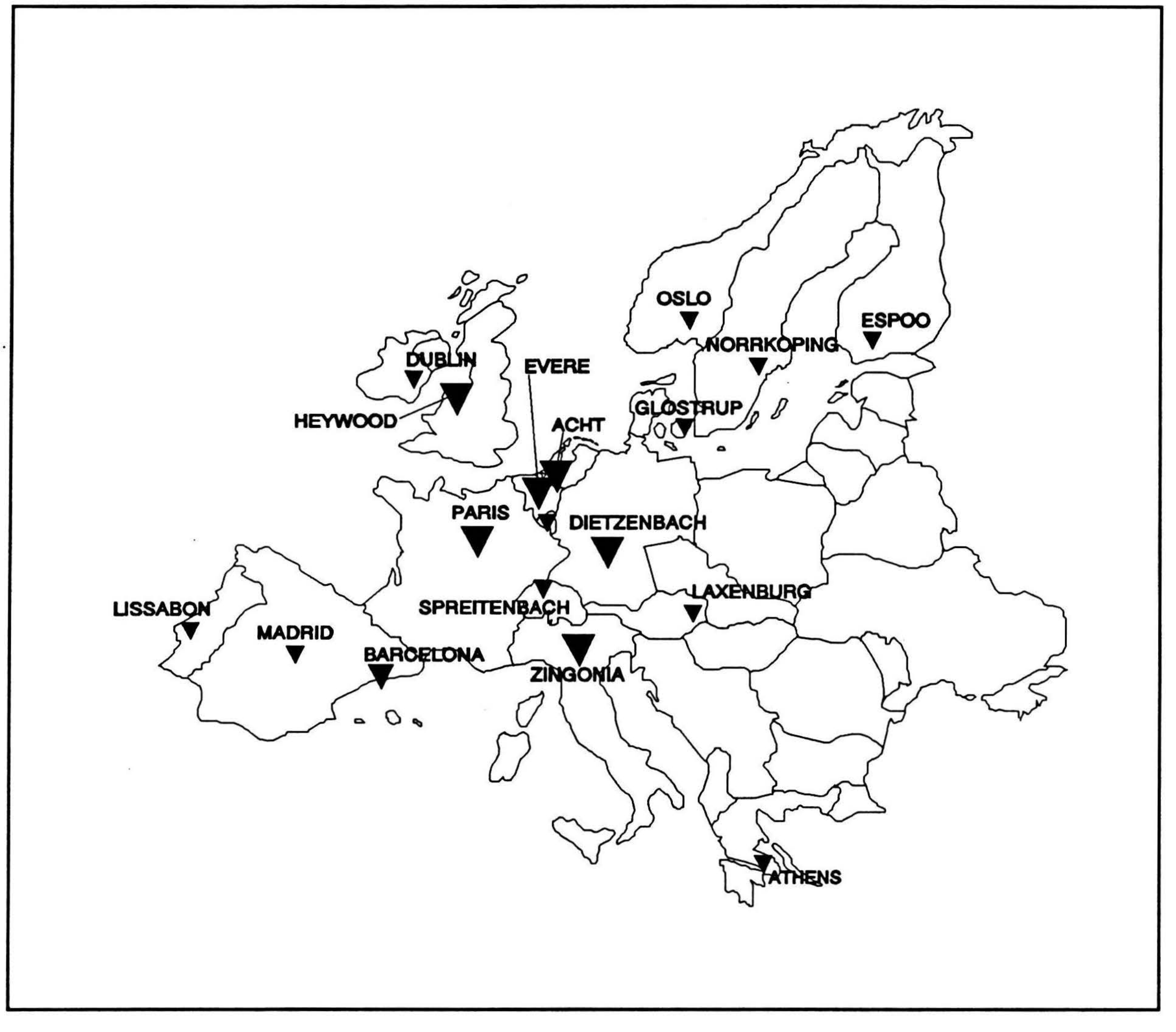
Figure 4.: the TV logistics department organization diagram

Appendix 2.2: NSO's in Europe

Europe is divided in several regions. About 13 NSO's represent each region nowadays. These NSO's are:

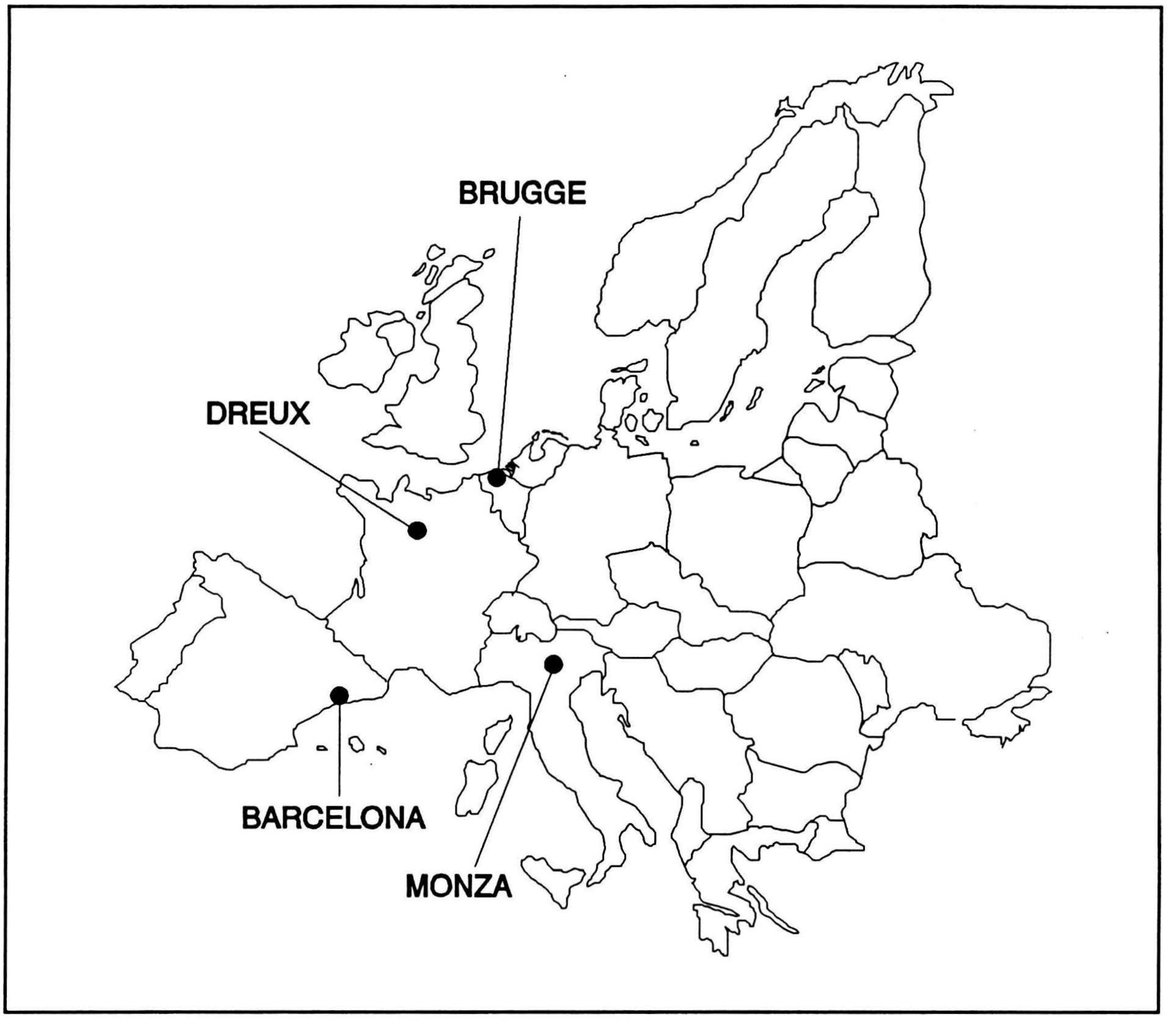
- Netherlands
- Belgium
- Germany
- Italy
- Nordic
- Portugal
- Spain
- France
- U.K.
- Austria
- Switzerland.
- Ireland
- Greece

The warehouses that are used to distribute goods to the customers are depicted in the picture given below.
Remark: the inventory levels are reported per region.

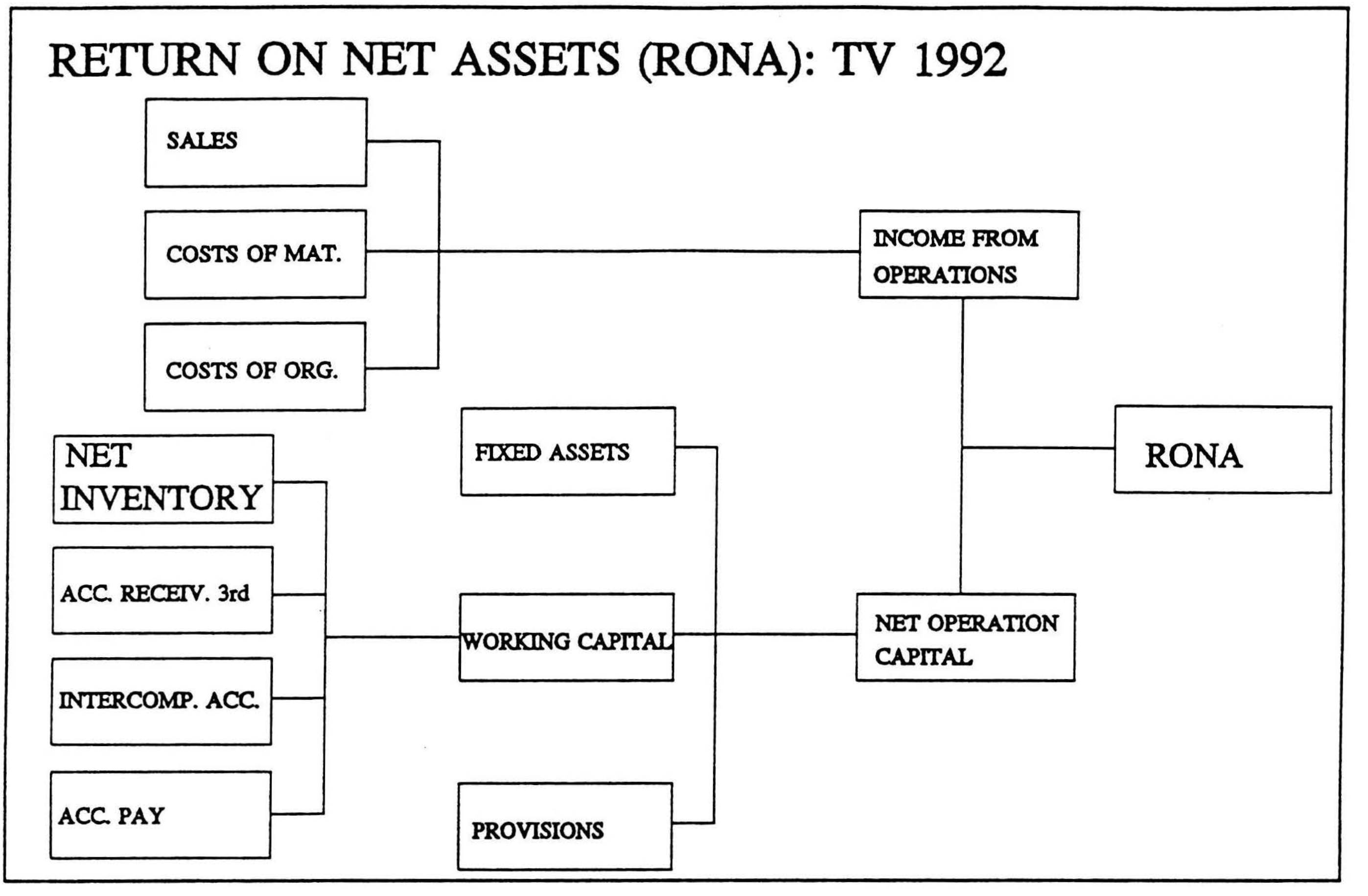


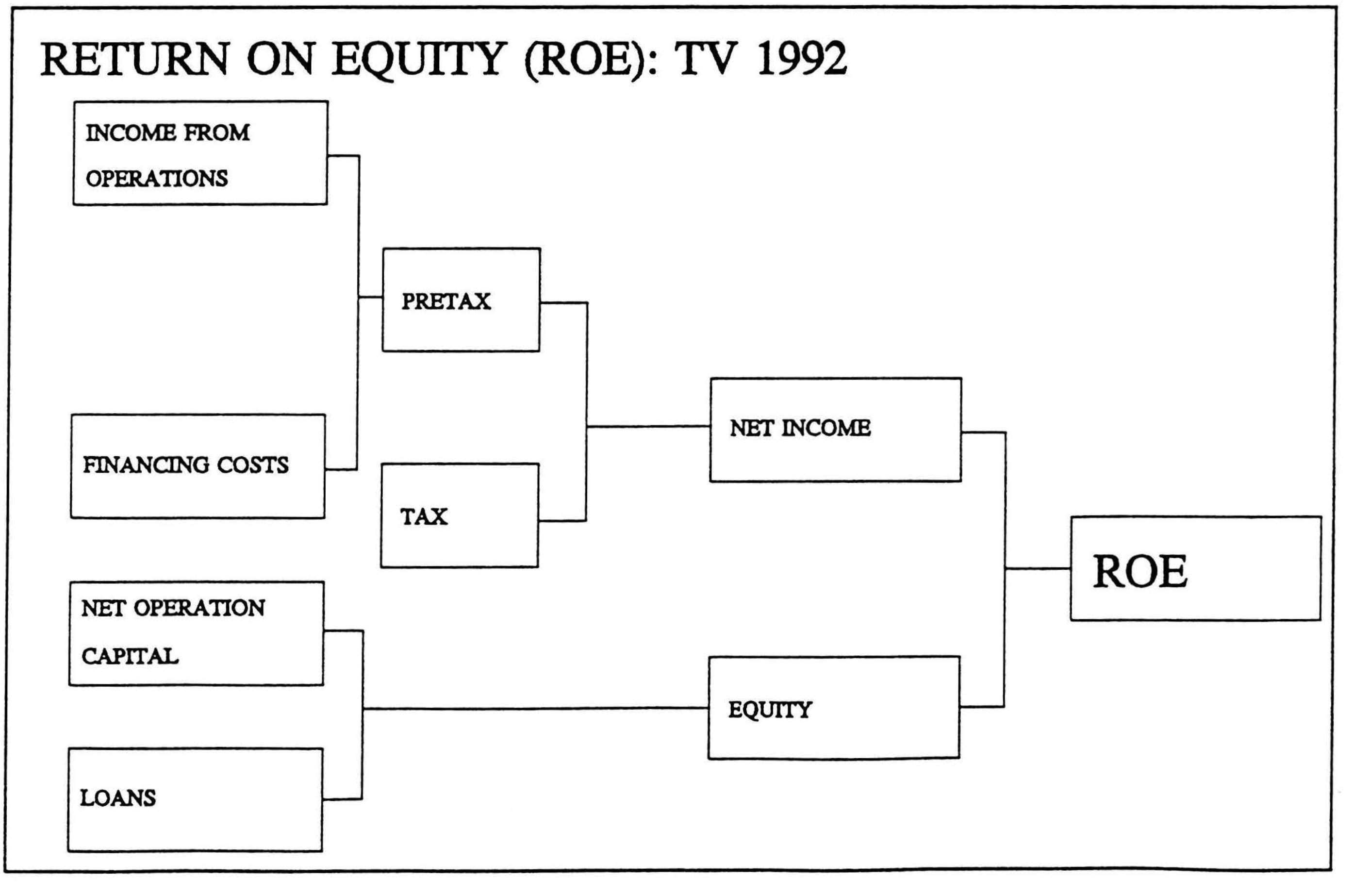
Appendix 2.3: IPC's in Europe

A total of five factories supply the required televisions for Europe. The number of factories that assembled for the European market used to be much higher, but in time this number is reduced to 5 plants. The IPC Singapore is not indicated for obvious reasons.



Appendix 3.1^A: ROE and RONA diagram





Appendix 3.1B: Build-up of Prices and data on IFO

BUILD-UP OF PRICES

a. Build-up of costprice

```
Material                              (1)
Direct labour                         (2)
---------------------
Variable costs                        (1 + 2)

Depreciation moulds & dies            (3)
Depreciation machines                 (4)
----------------------
MLD                                   (1 + 2 + 3 + 4)

Overhead factory                      (5)
----------------------
MLO                                   (MLD + 5)

Initial costs industry                (6)
Initial costs concern                 (7)
----------------------
FPP (factory production price)        (MLO + 6 + 7
```

b. Build-up of invoice-price

```
TP (Transfer Price)                    (9)
Freight & Insurance                   (10)    }
Guarantee costs                       (11)    }} supply
Calculated interest acc.rec.          (12)    }} invoice factor
Concern costs                         (13)    }
------------------------
IIP (Intercompany Invoice Price) (9 + 10 + 11 + 12 +13)
```

BUILD-UP OF RESULTS

```
     TP  (Transfer Price)
-/-  FPP (Factory Production Price)
     ----------------------------
     TPD  (Transferprice result)        (14)

     Result on freight & insurance      (15)
     Result on guarantee costs          (16)
     Calc. interest acc. rec.           (17)
     Other results IPC                  (18)
     ----------------------------
     Income from operations IPC         (14 + 15 + 16 + 17 + 18)
```

```
    TPD        SF        DUT     CC/SE/ ION      DM     VAT
 |--------|--------|--------|--------------|------|-------|

FPP       TP       IIP     LP          NP       GPeV    GP
```

FPP fabriekskostprijs
TP transferprijs (fabrieksverkoopprijs)
IIP intercompany invoice prijs
LP landed prijs
NP netto prijs
GPeV going prijs ex vat
GP going prijs

"toeslagen" structuur:

TPD target price difference
SF supply factor
DUT duties
CC concern costs
SE selling expenses
ION income from operations NSO
DM dealer margin
VAT value added tax

Appendix 3.2: Slow moving or obsolete stock (Mud)

The existence of mud was verified in a survey on July 1992. This survey on the inventory position showed that about 25% percent was slow moving or obsolete. A survey 3 months later showed that it is possible to eliminate mud. However the source of mud has to be eliminated, what can be done partly by implementing differentiated inventory control.

qty*1000-/NSO excl.	7 October '92			1 July '92		total
	current	obsolete	total	current	obsolete	
Fr	76 90%	9 10%	85	91 73%	34 27%	125
Ge	58 90%	7 10%	65	59 74%	21 26%	80
Ne	41 93%	3 7%	44	39 75%	13 25%	52
No	30 97%	1 3%	31	43 72%	17 28%	60
Sp	41 90%	5 10%	46	58 77%	17 23%	75
UK	53 90%	6 10%	59	46 77%	14 23%	60
IT	52 90%	6 10%	58	65 72%	25 28%	90
Total NSO's	351	37	388	401	141	542
Europe	411	44	455	487	162	649
Per-centage μ σ CV	91% 2,5 0,03	9% 2,5 0,30		75% 2.0 0.02	25% 2.0 0.08	

source: Monthly report COLOUR TELEVISION NSO stock analysis CTV

table: 2

Appendix 5.1: The definition of the CSL

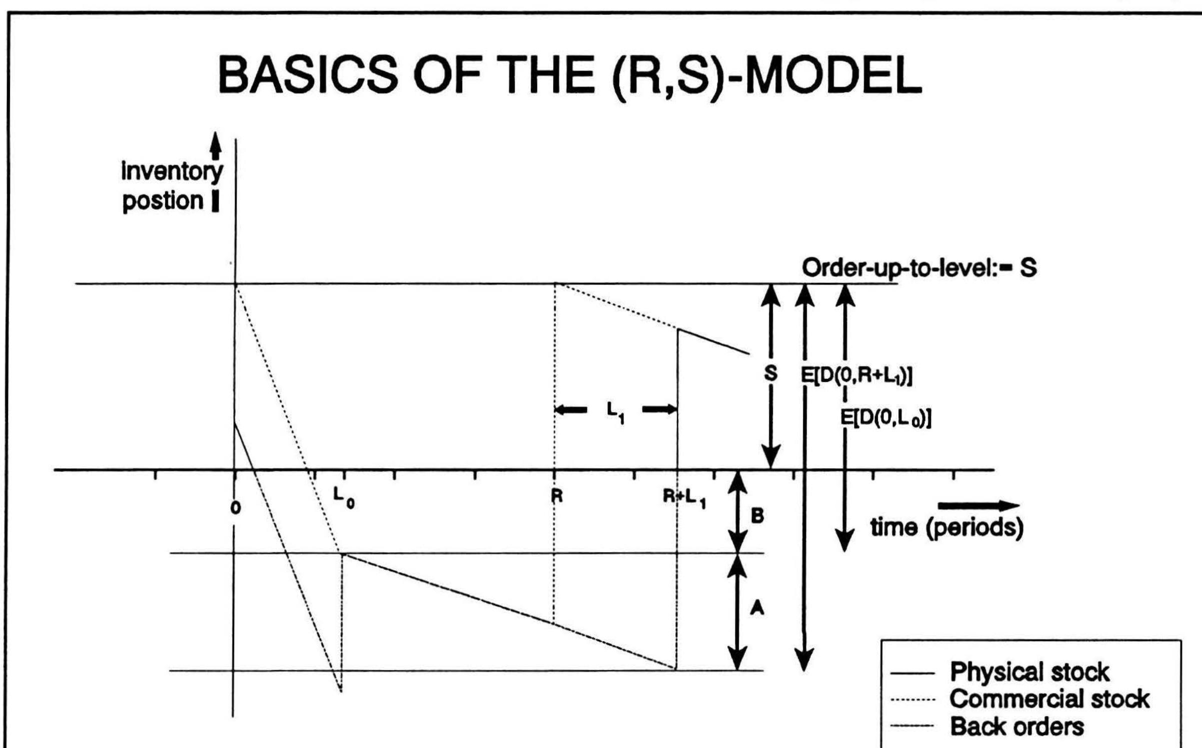
This appendix provides more infomation about expression (5.2).
In this report the CSL is defined as,

CSL= the long-run fraction of demand satisfied directly from stock on hand during the replenishment cycle $[iR+L_i, (i+1)R+L_{i+1}]$, where R is the review period and L_i is the lead time of the delivery ordered at time iR.

To understand the corresponding expression, the figure below can be used. This picture presents both the physical stock as the commercial stock. According equation (5.2) the CSL is zero, because during the replenishment cycle nothing can be supplied.
Suppose:

$|B| =$ $E[D(0,L_0)] - S$, when $S > E[D(0,L_0)]$ then $|B| = 0$
$|B + A| =$ $E[D(0,R+L_1)] - S$, when $S > E[D(0,R+L_1)]$ then $|B + A| = 0$,
$|A| =$ $\{E[D(0,R+L_1)]- S\} - |B|$ so
$|A| =$ $\{E[D(0,R+L_1)] - S\} - \{E[D(0,L_0)] - S\}$,

$|A|$ equals the numerator of equation (5.2) what appears to be the real fraction of demand that can not be delivered during interval $[L_0,R+L_1]$ (= replenishment cycle).



example of an inventory pattern, to explain the CSL expression

One only wants to know the fraction of demand satisfied directly from stock on hand **during one replenishment cycle.** So if one takes part $|B + A|$ the total amount of back orders will be overestimated. The CSL would in this case appear to be:

$$CSL = 1 - \frac{|B + A|}{|A|} < 0 \ ,$$

what is impossible. Hence $|A|$ has to be taken as the amount of back orders to calculate the CSL.

Appendix 5.2: The stochastic sales process

The sales are assumed to be gamma distributed in order to avoid the probability of a negative demand. The probablity density function is,

$$f(x)=\frac{\lambda(\lambda x)^{r-1}e^{-\lambda x}}{\Gamma(r)} \quad , x\geq 0 \quad \mu=\frac{r}{\lambda} \quad \sigma^2=\frac{r}{\lambda^2} \tag{1}$$

and if the sales forecast and the variance of the forecast are known,

$$r=\frac{\mu^2}{\sigma^2} \text{ and } \lambda=\frac{\mu}{\sigma^2} \tag{2}$$

If the sales forecast of one time period is known, for example the monthly sales plan, then the weekly sales can be estimated like,

$$\mu_{(0,1)} = D^F(0,1) = \frac{1}{c} \times D^F(0,c) \tag{3}$$

and the standard deviation of the forecast error of the weekly sales can be estimated like,

$$\sigma_{(0,1)} = \sigma(\epsilon(0,1)) = \frac{1}{\sqrt{c}}\sigma(\epsilon(0,c)) \tag{4}$$

where c= 52/12 weeks = 1 month,
and the forecast errors are considered to be independent.

The parameters to fit the gamma probability distribution are derived from $\mu_{(0,1)}$, $\sigma_{(0,1)}$, L, sL and R. At first $\mu_{[0,R+L]}$ or $D^F[0,L+R]$ and $\mu_{[0,L]}$ or $D^F[0,L]$ are determined together with the corresponding $\sigma_{[0,R+L]}$ or $\sigma(\epsilon(0,R+L))$and $\sigma_{[0,L]}$ or $\sigma(\epsilon(0,L))$. Secondly the averages and the corresponding standard deviations of the forecast errors of the specific intervals are used to fit the parameters r and λ.

Appendix 5.3: The calculation of $\sigma(\epsilon(0,L))$ and $\sigma(\epsilon(0,R+L))$ in practice

According the definition of the CSL an estimation of the customer service level is:

$$CSL=1-\frac{E[(D^F(0,L+R)+\epsilon(0,L+R)-S)^+]-E[(D^F(0,L)+\epsilon(0,L)-S)^+]}{E[D^F(L,R+L)]} \tag{5.6}$$

For this estimation one would like to know the forecast error for a certain period, e.g. $\epsilon(0,L+R)$. However it is easier to use a probability function and estimate the characteristic parameters. The paramters of a gamma probability distribution r and λ can be determined from historical data or (sales) plans. Afterwards the expected demand for the intervals [0,R+L] and [0,L] can be determined, supposed that the forecast errors are independent. Nevertheless a direct calculation of $\epsilon(0,L+R)$ from historical data will be more realistic and therefore much better. However to calculate the $\epsilon(0,L+R)$ straightforward, a very specific database is needed that keeps data for specific intervals.

The most practical way to calculate the parameters of the gamma probability distribution is with help of the Mean Standard Deviation (MAD). First $\epsilon(0,s)$ is determined for s periods according $D(0,s)-D^F(0,s) = \epsilon(0,s)$; in other words the sales forecast for period [0,s] (forecasted at time point 0) is compared with the sales actuals for the same period. A problem is how to choose s, because period [0,s] should equal E[0,L+R] or E[0,L]. However this way one should keep data for a long period at frequent times. For example if the lead time plus review time is 6 weeks one should not only keep monthly figures but also 2 weeks-(or shorter periods) figures.
To avoid this problem, $\epsilon(0,s)$ is derived from an interval that comes closest to both intervals [0,L] and [0,L+R] and is easiest to obtain. In this case R=1 week and L=4 weeks, so L is considerably larger than R. Hence if one has to choose an "easy" interval, [0,L] will be preferrable. In other words $\epsilon(0,s)$ is derived from the forecast error of the forecasted demand of 1 time period[1] (= 1 month) L periods (= 4 weeks) ahead. So every month the sales figures are compared with the plans of the beginning of the month. Thus s = 1 month what accidentally equals the order lead time (L). Hence in this case $\epsilon(0,s)$ equals $\epsilon(0,L)$, nevertheless the input parameter of the computer program, the expected $\sigma(\epsilon(0,1))$, is still unknown. Supposed that the forecast errors are independent it is stated that:

$$\sigma(\epsilon(0,s))=\sigma(\epsilon(0,1))\sqrt{s} \tag{1}$$

The $\epsilon(0,s)$ is known, but the $\sigma(\epsilon(0,s))$ has still to be derived. This can be done with help of the figure 1. That figure indicates the parameters that have to be measured. It

[1] The GIPSY database only keeps monthly figures.

indicates that the expected forecast error = 0.
It appears that the MAD can be expressed as a ratio of the $\sigma(\epsilon(0,s))$ and vice versa. The MAD is the average of the absolute values of $\epsilon(0,s)$. If the forecast errors are (assumed to be) distributed according the normal distribution function then:

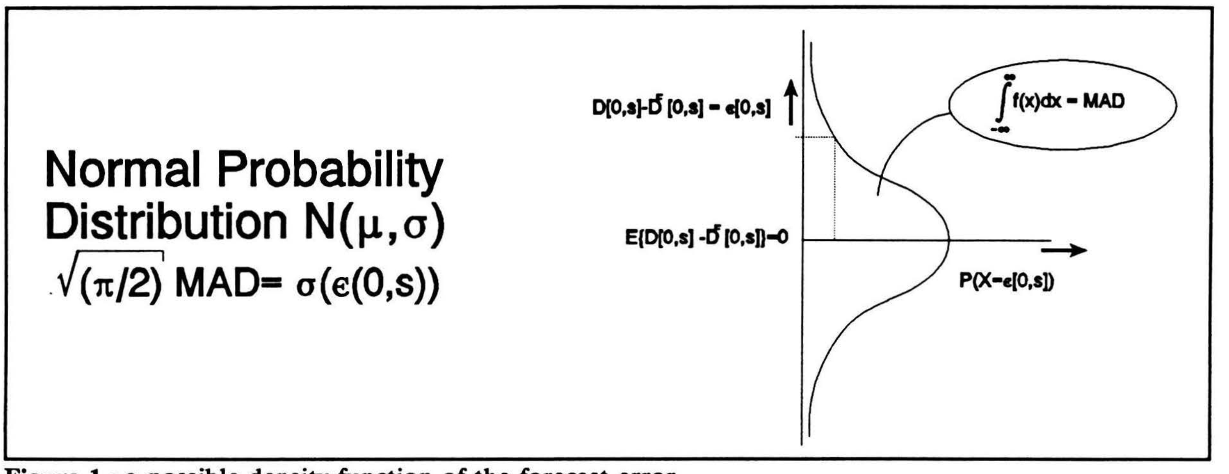


Figure 1.: a possible density function of the forecast error

$$MAD=E[|D-D^F|]=\int_{-\infty}^{\infty}|D-D^F|\frac{1}{\sigma(\epsilon)\sqrt{2\pi}}e^{-\frac{1}{2}\frac{(D-D^F)^2}{\sigma(\epsilon)^2}}dD \ . \tag{2}$$

What results in:

$$MAD=\int_{D^F}^{\infty}(D-D^F)\frac{1}{\sigma(\epsilon)\sqrt{2\pi}}e^{-\frac{1}{2}\frac{(D-D^F)^2}{\sigma(\epsilon)^2}}dD+\int_{-\infty}^{D^F}(D^F-D)\frac{1}{\sigma(\epsilon)\sqrt{2\pi}}e^{-\frac{1}{2}\frac{(D^F-D)^2}{\sigma(\epsilon)^2}}dD \ , \tag{3}$$

$$MAD=\frac{\sigma(\epsilon)}{\sqrt{2\pi}}+\frac{\sigma(\epsilon)}{\sqrt{2\pi}}=\frac{\sigma(\epsilon)}{\sqrt{\frac{\pi}{2}}} \ . \tag{4}$$

In other words $\sigma(\epsilon(0,s)) \approx 1.25 \times MAD$.
However when another probability distribution has to be applied (instead of the normal distribution) it is possible that the ratio between the MAD and the $\sigma(\epsilon)$ is

$$MAD=k \times \sigma(\epsilon(0,s)) \ , \tag{5}$$

where k=1. So the MAD could be applied straightforward instead of the $\sigma(\epsilon)$.

The MAD is calculated with help of exponential smoothing. The advantage of this method is that more or less weight can be put on current errors. Besides less data will have to be maintained. The MAD is calculated like,

$$MAD_t := b\,|\,\epsilon(0,s)_t\,| + (1-b)MAD_{t-1} \tag{6}$$

where

$e(0,s)_t=$ observed forecast error at time t

$b=$ smoothing average parameter.

In case exponential smoothing is not used but the algebraic average, then

$$MAD_t=\frac{\sum_{t-n}^{t} |D_i^F(0,s)-D_i(0,s)|}{n}=\frac{\sum_{t-n}^{t} |\epsilon_i(0,s)|}{n}$$

The $\sigma(\epsilon(0,1))$ can now be derived from expressions 1 & 5 and will be used to fit the gamma parameters. Using the above procedure, a sound approximation of the gamma parameters is obtained that approximates the actual situation.

Appendix 5.4: Program code to calculate order-up-to-level

The software is programmed in (Borland) C and is written by Prof. Dr. A.G. de Kok [reference 9].

```
#include <stdio.h>
#include <conio.h>
#include <stdlib.h>
#include <math.h>
#include <ctype.h>
#include <string.h>

#define sqr(x) ((x) * (x))

double muu1, nuu1, muu2, nuu2, p, q, c12, c22, EX, cX2, EX2, mu1, sigma1, mu2, sigma2;
int    k, l, m, n;

double gamma(double x)
{
	const  sqrttwopi = 2.5066283;
	double gam, z, t, hulp;
	int         k, n;

	if(x < 1.0e-50)
		return(1.0e+50);
	else
		if(x < 8) {
			if(x < 1)
				t = x + 1.0;
			else
				t = x;
			n = (int) floor(9 - t);
			z = t + n;
			gam = gamma(z);
			for(k=1; k<=n; k++)
				gam = gam / (z - k);
			if(x < 1)
				gam = gam / x;
			return(gam);
		}
		else {
			z = 1 / (x * x);
		hulp = (((- z / 1680 + 1 / 1260) * z - 1 / 360) * z + 1 / 12);
		gam = exp(hulp / x);
		return(sqrttwopi * exp((x - 0.5) * log(x) - x) * gam);
	}
}

double qtaylor(double a, double x, double eps, double lnx)
{
	int    k;
	double p, q, r, s, t, u, v;
	double c[18];

	if(a > 0.5)
```

```
			s = 1 - 1.0 / gamma(a + 1);
		else {
			c[0] = 0.57721566e-0;
			c[1] = -0.65587807e-0;
			c[2] = -0.42002635e-1;
			c[3] = 0.16653861e-0;
			c[4] = -0.42197734e-1;
			c[5] = -0.96219715e-2;
			c[6] = 0.72189432e-2;
			c[7] = -0.11651676e-2;
			c[8] = -0.21524167e-3;
			c[9] = 0.12805028e-3;
			c[10] = -0.2013485e-4;
			c[11] = -0.1250493e-5;
			c[12] = 0.1133027e-5;
			c[13] = -0.2056338e-6;
			c[14] = 0.6116095e-8;
			c[15] = 0.5002008e-8;
			c[16] = -0.1181274e-8;
			c[17] = 0.1043427e-9;
			q = 0;
			r = a;
			k = 0;
			do {
				t = r * c[k];
				q += t;
				r *= a;
				k++;
			}while(abs(t / q) >= eps);
			s = - q;
		}
		r = a * lnx;
		if(- 0.69 < r && r < 0.41) {
			q = 1;
			t = 1;
			k = 2;
			do {
				t *= r / k;
				q += t;
				k++;
			} while(abs(t / q) >= eps);
			q *= r;
		}
		else
			q = exp(r) - 1;
		q *= (1 - s);
		u = s - q;		/* now: computation of v */
		p = a * x;
		q = a + 1;
		r = a + 3;
		t = 1;
		v = 1;
		do {
			p += x;
			q += r;
			r += 2;
			t = - p * t / q;
			v += t;
		}while(abs(t / v) >= eps);
		v = a * (1 - s) * exp((a + 1) * lnx) * v / (a + 1);
		return(u + v);
}

double ptaylor(double a, double x, double eps, double lnx)
{
		double c, p, r;
```

```
        p = 1;
        c = 1;
        r = a;
        do {
                r++;
                c = x * c / r;
                p += c;
        }while(c / p >= eps);
        return(p * exp(a * lnx - x) / gamma(a + 1));
}

double qfraction(double a, double x, double eps, double lnx)
{
        double g, p, q, r, s, t, tau, ro;

        p = 0;
        q = (x - 1 - a) * (x + 1 - a);
        r = 4 * (x + 1 - a);
        s = 1 - a;
        ro = 0;
        t = 1;
        g = 1;
        do {
                p += s;
                q += r;
                r += 8;
                s += 2;
                tau = p * (1 + ro);
                ro = tau / (q - tau);
                t *= ro;
                g += t;
        }while(abs(t / g) >= eps);
        return(g * exp(- x + a * lnx) / gamma(a) / (x + 1 - a));
}

void Incomgam(double  a,
           double  x,
           double  *p,
           double  *q,
           double  eps)
/*      computes p of formula 6.5.1 of Abramowitz & stegun, p. 260,
 *      and Q=1-p; accuracy: about 8d
 */
{
        double alfa, lnx;

        if(x < 1.0e-50)
                lnx = - 1.151293e2;
        else
                lnx = log(x);
        if(x > 0.25)
                alfa = x + 0.25;
        else
                if(x >= 1.0e-50)
                        alfa = -0.6931 / lnx;
                else
                        alfa = 6.02019e-3;
        if(a > alfa) {
                if(x < 1.0e-50)
                        *p = 0.0;
                else
                        *p = ptaylor(a, x, eps, lnx);
                *q = 1.0 - *p;
        }
        else {
                if(a < 1.0e-50)
```

```
                        *q = 0.0;
                else
                        if(x < 2.0)
                                *q = qtaylor(a, x, eps, lnx);
                        else
                                *q = qfraction(a, x, eps, lnx);
                *p = 1.0 - *q;
        }
}

double Sum_Inv_Erl(double x, int k)
{
        double hsum, term;
        int    j;

        hsum=0;
        term=1;
        for(j=0; j <= k; j++) {
                hsum+=term;
                term*=(x/(j+1));
        }
        return(hsum);
}

double Int1_Inv_Erl(double x, double mu, int k)
{
        return(exp(-mu*x)*Sum_Inv_Erl(mu*x,k-1));
}

double Int2_Inv_Erl(double x, double mu, int k)
{
        return(exp(-mu*x)*(k/mu*Sum_Inv_Erl(mu*x,k - 1)-x*Sum_Inv_Erl(mu*x,k - 2))); }

void Constants_Inv_Erl(double EX, double cX2, double *mu1, double *mu2, double *p, int *k, int *l)
{
        if (cX2 > 1) {
                *mu1 = 2.0 / EX * (1+sqrt((cX2-0.5)/(cX2+1)));
                *mu2 = 4.0 / EX - *mu1;
                *p = *mu1 * (*mu2 * EX - 1) / (*mu2 - *mu1);
                *k = 1;
                *l = 1;
        }
        else {
                *k = (int) floor(1.0/cX2);
                *l = *k + 1;
                *p = (*l * cX2 - sqrt((1 + cX2 * (1 - *l)) * *l)) / (1 + cX2);
                *mu1 = (*l - *p) / EX;
                *mu2 = *mu1;
        }
}

double F_Inv_Erl(double x)
{
        double i1, i2;

        i1 = Int1_Inv_Erl(x,mu1,k);
        i2 = Int1_Inv_Erl(x,mu2,l);
        return(1 - (p * i1 + (1 - p) * i2));
}

double Inv_Erl(double EX, double cX2, double Alpha)
{
        double x, y, w, mu1, mu2, p;
        int    k, l;

        Constants_Inv_Erl(EX, cX2, &mu1, &mu2, &p, &k, &l);
```

```
	x = EX;
	if(F_Inv_Erl(x) < Alpha) {
		while(F_Inv_Erl(x) < Alpha)
			x = x * 2;
		y = x;
		x = x / 2;
	}
	else {
		while(F_Inv_Erl(x) > Alpha)
		x = x / 2;
		y = x * 2;
	}
	while(abs(y - x) > 1e-4 * abs(x)) {
		w = (x + y) / 2;
		if(F_Inv_Erl(w) > Alpha)
			y = w;
		else
			x = w;
	}
	return((x + y) / 2);
}

double Inv_Norm(double a)
{
	double t;

	if(a > 0.5) {
		a = 1.0 - a;
		t = sqrt(log(1.0/a/a));
		return(-(t - (2.515517 + 0.802853*t + 0.010328*t*t)
			/(1 + 1.432788*t + 0.189269*t*t + 0.001308*t*t*t)));
	}
	else {
		t = sqrt(log(1/a/a));
		return((t - (2.515517 + 0.802853*t + 0.010328*t*t)
			/(1 + 1.432788*t + 0.189269*t*t + 0.001308*t*t*t)));
	}
}

double Inv_Gam(double EX, double cX2, double Alpha)
{
	double k, k1, kinf;

	if(cX2 < 1.5) {
		k1 = -(1 + log(1 - Alpha));
		kinf = Inv_Norm(1 - Alpha);
		k = kinf + (k1 - kinf) * sqrt(cX2);
		return(EX + k * sqrt(cX2) * EX);
	}
	else
		return(Inv_Erl(EX,cX2,Alpha));
		/* return(Inversincgam(1 / cX2,1 - Alpha) * cX2 * EX) */
}

void Constants_RS(double EX,
			double cX2,
			double *mu1,
			double *mu2,
			double *p,
			int *k,
			int *l)
{
	if(cX2 > 1) {
		*mu1 = 2.0 / EX * (1+sqrt((cX2-0.5)/(cX2+1)));
		*mu2 = 4.0 / EX - *mu1;
		*p = *mu1 * (*mu2 * EX - 1) / (*mu2 - *mu1);
```

```
		*k = 1;
		*l = 1;
	}
	else {
		*k = (int) floor(1/cX2);
		*l = *k + 1;
		*p = (*l * cX2 - sqrt((1 + cX2 * (1 - *l)) * *l)) / (1 + cX2);
		*mu1 = (*l - *p) / EX;
		*mu2 = *mu1;
	}
}

double Exps_RS(double x)
{
	if(x < -600)
		return(0);
	else
		return(exp(x));
}

double Sum_RS(double x, int k)
{
	double hsum, term;
	int    j;

	hsum=0;
	term=1;
	for(j=0; j<=k; j++) {
		hsum+=term;
		term*=(x/(j+1));
	}
	return(hsum);
}

double Int1_RS(double x, double mu, int k)
{
	double hsum;

	hsum = Sum_RS(mu*x,k-1);
	return(exp(-mu*x)*hsum);
}

double Int2_RS(double x, double mu, int k)
{
	double hsum1, hsum2;

	hsum1 = Sum_RS(mu*x,k - 1);
	hsum2 = Sum_RS(mu*x,k - 2);
	return(exp(-mu*x)*(k/mu*hsum1-x*hsum2));
}

double fICSL_RS(double x, double T, double ED)
{
	double i1, i2, i3, i4;

	i1 = Int2_RS(x,muu1,k);
	i2 = Int2_RS(x,muu2,l);
	i3 = Int2_RS(x,nuu1,m);
	i4 = Int2_RS(x,nuu2,n);
	return(1 - (p * i1 + (1 - p) * i2 - (q * i3 + (1 - q) * i4)) / T / ED); }

double Voorraad_RS(int T, double S, double ED, double SD)
{
	double es, cs2, muu1, muu2, qq, sum, i1, i2;
	int    i, kk, ll;
```

```
        sum = 0;
        for(i=1; i<=T; i++) {
                es = mu2 + (T - i) * ED;
                cs2 = sqr(sigma2) + (T - i) * sqr(SD);
                cs2 = cs2 / es / es;
                Constants_RS(es, cs2, &muu1, &muu2, &qq, &kk, &ll);
                i1 = Int2_RS(S,muu1,kk);
                i2 = Int2_RS(S,muu2,ll);
                sum += S - es + qq * i1 + (1 - qq) * i2;
        }
        return(sum / T);
}

double Voorraad2_RS(int T, double S, double ED, double SD)
{
        double es, sum, cs2, mu, p, Alpha, i1, i2;
        int    i;

        sum = 0;
        for(i=1; i<=T; i++) {
                es = mu2 + (T - i) * ED;
                cs2 = sqr(sigma2) + (T - i) * sqr(SD);
                cs2 = cs2 / es / es;
                Alpha = 1 / cs2;
                mu = Alpha / es;
                Incomgam(Alpha,mu * S, &p, &i1,1e-6);
                Incomgam(Alpha + 1,mu * S, &p, &i2,1e-6);
                sum = sum + S - es + Alpha / mu * i2 - S * i1;
        }
        return(sum / T);
}

void RS(int T,
                double ED,
                double SD,
                double EL,
                double SL,
                int BetaKnown,
        double *Beta,
                double *S,
                double *Stock)
/*   function berekent order-up-to-level gegeven gewenste servicegraad
 *
 *   T     : reviewperiode in aantal perioden
 *   ED    : gemiddelde vraag per periode
 *   SD    : standaard deviatie vraag per periode
 *   EL    : gemiddelde levertijd
 *   SL    : standaard deviatie levertijd
 *   *Beta : fraktie van de vraag direkt geleverd
 *   *S    : order-up-to-level
 *   *Stock: gemiddelde voorraad
 */
{
        mu1 = EL * ED + T * ED;
        sigma1 = EL * sqr(SD) + sqr(SL * ED) + T * sqr(SD);
        sigma1 = sqrt(sigma1);
        mu2 = EL * ED;
        sigma2 = EL * sqr(SD) + sqr(SL * ED);
        sigma2 = sqrt(sigma2);
        if(BetaKnown) {
                c12  = sqr(sigma1 / mu1);
                c22  = sqr(sigma2 / mu2);
                EX   = ((1 + c12) * sqr(mu1) - (1 + c22) * sqr(mu2)) / 2 / T / ED;
                EX2  = (1 + c12) * (1 + 2 * c12) * sqr(mu1) * mu1;
                EX2  = EX2 - (1 + c22) * (1 + 2 * c22) * sqr(mu2) * mu2;
                EX2  = EX2 / 3 / T / ED;
```

```
		cX2	= EX2 / sqr(EX) - 1;
		*S = Inv_Gam(EX, cX2, *Beta);
	}
	else {
		Constants_RS(mu1, sqr(sigma1 / mu1), &muu1, &muu2, &p, &k, &l);
		Constants_RS(mu2, sqr(sigma2 / mu2), &nuu1, &nuu2, &q, &m, &n);
		*Beta = flCSL_RS(*S, T, ED);
	}
	*Stock = Voorraad2_RS(T, *S, ED, SD);
}

void main(int argc, char *argv[])
{
	FILE	*invoer, *uitvoer;
	char	outname[13];
	char	*prog = argv[0];		/* programmanaam in foutmelding */
	double	ED, SD, EL, SL, Beta, S, Stock;
	int		T, i, record, cur_x, cur_y;
	char	CAG[5], Country[5], SAG[6], CTV[14], c;

	clrscr();
	printf("\nHarry's custom made programmaatje\n");
	record = 0;
	if(argc==1)
		fprintf(stderr, "\n%s: er zijn geen invoer- en uitvoerfiles opgegeven.", prog);
	else {
		if((invoer = fopen(*++argv, "r")) == NULL) {
			fprintf(stderr, "\n%s: niet te openen %s", prog, *argv);
			exit(1);
		}
		if(argc==2) {
			sprintf(outname, "out.dat");
			fprintf(stderr, "\nEr is geen output file opgegeven. Output gaat naar
'out.dat'");
		}
		else
			sprintf(outname, *++argv);
		if((uitvoer = fopen(outname, "w")) == NULL) {
			fprintf(stderr, "\n%s: niet te openen %s", prog, outname);
			exit(2);
		}
		window(0, 8, 40, 10);
		gotoxy(0,0);
		cprintf("Recordnummer: ");
		cur_x = wherex();
		cur_y = wherey();
		while(fscanf(invoer, "%s %s %s", CAG, Country, SAG)!=EOF) {
			getc(invoer);					/* \n vorige
regel lezen */
			for(i=0; ((c=getc(invoer))!='\n') && i<=13; i++)
				CTV[i] = (char) c;
			while(i<=13) {
				CTV[i] = '\0';
				i++;
			}
			fscanf(invoer, "%d %lf %lf %lf %lf %lf", &T, &ED, &SD, &EL, &SL,
&Beta);
			RS(T, ED, SD, EL, SL, 1, &Beta, &S, &Stock);
			gotoxy(cur_x, cur_y);
			clreol();
			cprintf("%-3d", record++);
			fprintf(uitvoer, "%-5s %-5s %-6s %-14s %3d %9.2lf %9.2lf %9.2lf %9.2lf
%9.2lf %9.2lf %9.2lf\n",
				CAG, Country, SAG, CTV, T, ED, SD, EL, SL, Beta, S, Stock);
		}
		fclose(invoer);
```

```
            fclose(uitvoer);
    }
    exit(0);
}
```

Appendix 5.9: The optimum CSL for the MAG D41

This appendix provides the results that are used to determine the optimum CSL. The calculated IFO includes the costs of organization, because these costs were not changed by the CSL and therefore irrelevant. Hence the actual IFO is different.

- R= review period
- $D^F(0,1)$= demand per week
- $\sigma(\epsilon(0,1))$= forecast error of $D^F(0,1)$
- L= lead time
- sL= supply deviation time
- CSL= Customer Service Level
- S= Order-up-to-level
- Ph= mean physical stock
- Ph w= Ph in weekly demand
- IFO= income from operations (excl. costs of organizations)

MAG	R	D^F	σ	L	sL	CSL	S	Ph	Ph w	IFO
'D41	1	26064.31	18221.17	4	1	0.96	215785.2	94556	3.627796	181758611.883
'D41	1	26064.31	18221.17	4	1	0.95	208578.2	86724.38	3.327323	182045619.986
'D41	1	26064.31	18221.17	4	1	0.94	202583.7	80176.64	3.076108	182238905.477
'D41	1	26064.31	18221.17	4	1	0.93	197432.6	74533.13	2.859586	182366181.207
'D41	1	26064.31	18221.17	4	1	0.92	192902.8	69564.36	2.668951	182444201.705
'D41	1	26064.31	18221.17	4	1	0.91	188850.4	65120.54	2.498456	182483900.445
'D41	1	26064.31	18221.17	4	1	0.9	185176.4	61098.29	2.344136	182492825.086
'D41	1	26064.31	18221.17	4	1	0.89	181809.7	57423.08	2.203131	182476415.134
'D41	1	26064.31	18221.17	4	1	0.88	178697.7	54039.34	2.073308	182438727.917
'D41	1	26064.31	18221.17	4	1	0.87	175800.3	50904.49	1.953034	182382872.423
'D41	1	26064.31	18221.17	4	1	0.86	173086	47985.08	1.841026	182311289.138
'D41	1	26064.31	18221.17	4	1	0.85	170529.9	45254.4	1.736259	182225928.526
'D41	1	26064.31	18221.17	4	1	0.84	168111.7	42690.72	1.637899	182128377.484
'D41	1	26064.31	18221.17	4	1	0.83	165814.8	40276.1	1.545259	182019944.499
										182492825.086