STUDY OF A SUPPLY CHAIN PERFORMANCE FOLLOWING A PUSH AND A PUSH-PULL STRATEGY

Sónia Marisa Valadas Nunes Correia Santos
Bosch Thermotechnik GmbH
TT/LOG
Junkers Str. 20-24
73249 Wernau
Germany

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Orientador: Prof. João Claro (FEUP-DEIG)

FEUP

Faculdade de Engenharia da Universidade do Porto
Mestrado Integrado em Engenharia Industrial e Gestão

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Sónia Correia Santos
Kirchheimer Str 73
73249 Wernau
Germany

Date of birth: 08.04.1975 – Luanda, Angola

Declaration:

I declare that I prepared this document on my own. Used literature and internet sources are completely listed in the appendix of this work. I assure to have marked everything what has been taken from the work of third parties.

Porto,
August 31st, 2008 ______________Sónia Santos______________________

Resumo

O presente projecto de dissertação dedica-se ao estudo comparativo da performance de uma cadeia logística segundo a estratégia “Push-Pull” e da tradicional estratégia Push quando sujeitas a “uncertainties”. Serão realçados e estudados elementos fundamentais de gestão como: “Inventory Management”, “Demand Forecasting” e a transparência obtida através da “Information Sharing”.

As conclusões deste projecto, suportadas por dois modelos de simulação, concentram-se no estudo do “trade-off” entre o nível de satisfação ao cliente e os custos diários totais logísticos, assim como, na análise do impacto da variação de determinados parâmetros (como a flutuação da procura do cliente e do “lead time”) na performance da cadeia logística.

A conclusão principal do trabalho reflecte a importância de uma aplicação adequada do modelo de “forecast” e de gestão de stocks, tanto para a estratégia “Push” como para o caso “Push-Pull”. A segunda mensagem foi direccionada para o conhecido “Bullwhip effect”: não podendo ser este completamente eliminado, poderá ser significativamente reduzido, especialmente no caso da estratégia “Push-Pull”, como foi demonstrado pelas experiências de simulação.

Abstract

This paper examines the beneficial impact of a Push-Pull strategy on a supply chain (SC) performance compared to the traditional Push system under uncertainty. It evaluates the different SC Strategies and underlines the importance of the elements: Inventory Management, Demand Forecasting and the transparency obtained by the Information Sharing.

Supported by two simulation models, this paper studies the trade-off between the service level towards the customer and the total logistics daily costs. It also analysis the impact of changing certain parameters, such us the short term demand fluctuation and the non-reliability of the lead time, on the overall SC's performance.

The main conclusion of this paper is the importance of an adequate Demand Forecasting Methodology and a systematic Inventory Management for both: Push and Push-Pull system, in order to achieve an higher SC's performance. The second main conclusion is that the Bullwhip Effect can not be completely eliminated but it can be significantly reduced as shown by the simulation experiments especially for the Push-Pull system.

Content

LIST OF ABBREVIATIONS

BPS	Bosch Production System
DC	Distribution Center
EDI	Electronic Data Interchange
JIT	Just in Time
LDC	Local Distribution Center
LT	Lead Time
MRP	Material requirements planning
MTO	Make to Order
MTS	Make to Stock
PI	SC Performance Indicator
RDC	Regional Distribution Center
RT	Review period under Periodic Review inventory policy
SC	Supply Chain
SCM	Supply Chain Management
TT	Thermo technology
WH	Warehouse

LIST OF FORMULAS

$$\textbf{Service Level}_t = \begin{cases} \mathbf{1}, \text{ if } \dfrac{Delivered\_Qt\_in\_period_t}{Demand_t} = 100\% \\ \mathbf{0}, \text{ otherwise} \end{cases}$$

$$\textbf{Total daily costs} = \frac{\sum_{t=1}^{720} \begin{bmatrix} \text{(transport costs from Production site to RDC)} + \\ \text{(holding costs Production site raw material and product j)} + \text{(holding costs RDC product j)} + \\ \text{(warehousing costs RDC product j)} + \text{(production costs product j)} \end{bmatrix}}{720}$$

$$\textbf{Stock Indicator} = \frac{\text{Average stock RDC product j} * \text{price from production}}{\text{Average stock RDC product j} * \text{price from production}} * 30$$

$$\textbf{Forecast Accuracy}_t = 1 - \frac{\text{Forecast}_t}{\text{Real sales}_t}$$

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1 INTRODUCTION

1.1 Background

A global economy and increasing customer expectations in terms of cost and services have put a premium on effective supply reengineering [/SwStNo-98/]. More and more companies are changing their Inventory Management Systems from decentralized information to centralized information sharing. There are several motivations behind this attitude. One of the first is to achieve the best service level towards the customer at minimum costs throughout transparency and reliability. A clear Supply Network Strategy with reliable logistics processes is the key factor for a satisfied customer at lower prices. This is especially the case for large multinational companies in the retail goods business, with several plants producing and delivering customized finished products to several markets. Tendency shows us that the Supply Network Strategy is moving towards a Pull system where production orders are released as a reaction to the arrival of customers and the withdrawal of goods from an inventory.

1.2 Motivation and Aim

We were particularly interested in studying a Supply Chain[1] (SC) under uncertainty and to underline the differences and advantages of a Push-Pull system with shared information in relation to a traditional Push (classical MRP[2]) system.

The fundamental discussion of this thesis is the Inventory Management. There are several reasons for building up inventories, for instance: distance, seasonality, lot sizing and uncertainty (as the non-reliability of production flow time and the customer demand variability). The essential question is how much and when to place an order [/SezKit-07/] from suppliers. However, the uncertainty, which is

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[1] Supply Chain or Supply Network

[2] MRP: material requirements planning

present in all Supply Chains, is making the Inventory problem even more complicated.

In this paper, one SC, which is currently managed by an MRP system with no information sharing and non satisfactory performance, is analysed (details are described on chapter 3.2.) and a suggestion to optimise the current Supply Network supported by simulation experiments is given. Finally, it is presented a SC model (re-engineering) following a Push-Pull strategy with information sharing according to the new TT[3] SC structure and the requirements of BPS[4]-factories

The performance evaluation of the current situation and the proposed restructured SC is supported by Monte Carlo simulation experiments. The decision model, which allows the minimisation of the supply network costs while the service level is maximised[5], answers the following addressed questions:

- Different transport networks (by sea freight, by truck, mixed) from the producer;
- Reliability of the supplying network and the impact of the Lead Time (LT);
- Reliability of the forecast planning and the fluctuation of short term customer demands;
- The impact of different Inventory management strategies on SC's performance;
- The impact of the different locations of the boundary Push-Pull;
- The impact on "Bullwhip Effect".

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[3] TT: Bosch ThermoTechnology
[4] BPS: Bosch Production System
[5] Trade-off of the conflicting objectives: Total Logistics Costs and Customer Service Level

1.3 Structure of the Thesis

After a first insight into the Background and the Motivation and Aim of this thesis, the rest of the paper is organized as follows:

- chapter 2 gives an overview about the published studies in the area of production-distribution problem, inventory management, demand forecasting and optimisation of the SC's performance under uncertainty.

- chapter 3 introduces the SC, describes its logistics processes evaluates current performance and gives the suggestion, in the direction of Push-Pull strategy [/SiLe-02/], for the optimisation of the SC's performance.

- chapter 4 presents a simulation model for the evaluation of the Today's situation performance and how it can be improved using an Inventory Management policy.

- chapter 5 describes a re-structured SC based on Push-Pull strategy and presents a second simulation model for its performance evaluation.

- the final results and comparisons are discussed on chapter 6

- chapter 7 closes the thesis with the summary and outlook.

2 STATE OF THE ART

2.1 Background

According to several authors [/EhBe-00/;/Gar-98/; /BeBe-98/], a SC is a set of facilities, suppliers, customers, warehouses, products and processes of controlling inventory, purchasing and distribution. In this network, suppliers are linked to customers through several echelons (each echelon can consist of many facilities) exchanging materials (beginning with the production of raw material by suppliers and ending with the consumption of finished products by the customer), information and money. These sub-systems are interrelated in such a way that the control and the decision making of one sub-system has an effect on the performance of others.

In the past decades, problems related to supply-production, production-distribution and inventory-distribution systems have been analysed and documented by several authors. The first work in systems dynamics in relation to SC Management (SCM) goes back to Forrester (1958). Towill [/ChTw-96/], calls Forrest the father of systems dynamics and the originator of many techniques of modern SCM. Later in 1961, Forrester studied the so called “Bullwhip Effect”, proving that small variations of customer demand causes demand variations amplification along the SC creating system instability [/For-61/].

SCM can be divided into Strategic and Operational levels. The Strategic level has the primary objective of optimising the most cost-effective location of facilities (production sites, distribution centre – DC), flow of goods throughout the SC and assignment of customers to DCs. The operational level is in charge of the optimisation of the stock levels for each product at each location, the size and frequency of the production batches that are replenished or assembled, the replenishment transport and production lead times and also the customer service levels [/EhBe-00/].

In her studies, Benita Beamon [/EhBe-00/], presents a model to optimise simultaneously both: the strategic and operational levels in SC design under uncertainty. Her model looks at the SC from a “system point of view” and the results are shown in terms of the SC’s performance (not only costs are considered).

2.2 Review on production-distribution problems

This thesis deals with the operational level and so focuses on the inventory management under uncertainty of a production distribution system. In this area, most of the models available in the literature assume deterministic demands but, since this paper studies stochastic demand, it is not reviewed the literature on deterministic demand.

In 1988, Cohen and Lee [/CoLe-88/] developed a comprehensive modelling framework for linking the material management activities with material production-distribution SC. It consists of 4 stochastic sub-models, which are optimized individually under certain assumptions. It could be difficult to find the optimal solution, from a “system point of view”. In 1990, Cohen and Pyke [/MCoPy-90/] developed a model of a simple integrated production-system and examined its performance characteristics. They also analysed the results of an algorithm using a basic network of 3 locations and one single product. Tetsuo Iida [/Tet-99/], studied a non-stationary periodic review production inventory model with uncertain production capacity and uncertain demand. He obtains upper and lower bounds for the order-up-to-levels and for the minimisation of the total costs (production, inventory holding and backorder costs). In his work, he considers the lead time equal to zero.

In the field of Fuzzy Sets, there are very interesting papers from J. Wang and Y. Shu [/WaSh-07/] [/WaSh-05/] and from Petrovic and Roy [/PeRo-99/]. In case the demand historical data is not available, (for instance the introduction of a new product in a new market), it is possible to deal with the uncertainty describing the customer demand by the terms: “demand is about d_m but definitely not greater than d_{m1} and not less than $d_{m2.}$ In their work, [/PeRo-99/], considered a production SC with all facilities in serial connection in an uncertain environment. Uncertainty is caused by customer demand, supply deliveries along the SC and external or internal supply. The objective is to determine the order quantities for each inventory in the SC for a given service level to the customer and with reasonable costs. Also Wang and Shu in their works, [/WaSh-07/] and [/WaSh-05/], developed a model to evaluate the performance of the entire SC and a genetic algorithm approach which returns near-optimal solutions. Depending on decision makers’ attitude towards risk, the model allows trade-off analysis amongst customer service levels and costs of production and inventory.

Heuristics based on Lagrangian relaxation and sub-gradient methods can be applied to non-linear-mixed-integer-programming. Studies using this methodology were performed by Pablo Miranda and Garrido [/PaGa-02/]. The objective of their paper is to incorporate the tactical and operational decisions into inventory management decisions.

Another technique to solve mid-term SC planning under demand uncertainty is the so-called two-stage modelling. This methodology is a stochastic programming based approach to model the planning process as it reacts to demand realizations along the time horizon [/GuMa-03/]. The production decisions are made before the realization of the demand (“here and now decisions”) while the SC decisions are postponed (“wait and see”). Their proposed model is a development of the deterministic model which was first analysed by McDonald and Karami [/McKa-97/]. The objective is to analyse the trade-off between service level to customer and profit.

Following Forrester’s theory [/For-61/], Arnold and Faiβt [/ArFa/] studied a three-stage supply chain with local control policies. By using simulation results they analytically verified the existence of the “Bullwhip Effect” in this SC. They also presented the potential improvements (41% reduction) within the SC by implementing an information sharing system. Also related to the “Bullwhip Effect”, Kelle and Milne [/KeMi-99/] documented the effect of an (s,S) ordering policy on the SC. They show analytically how changes in demand, lead time and (s,S) policy alters the inconsistency of orders. They conclude their study showing that high frequent and small orders/deliveries reduce significantly the inconsistency and uncertainty in a SC. Such small and frequent orders are economical for partners if the ordering costs are not significant compared to holding costs. Nonetheless, ordering costs can be always reduced by implementing EDI[6] and by appropriate cooperation towards JIT[7] deliveries. Later, in 2002, the team Z. Yu, H. Yan and TCE Cheng [/ZYCh-02/], studied that the increase in information sharing amongst the members of a two-level decentralised SC leads to a Pareto improvement in the performance of the entire chain. In particular, the manufacturer obtains benefits in terms of inventory reduction and cost savings.

At the end of this chapter and as the topic is addressed in this thesis (see chapter 3.5.), the last comment goes to the Push and Pull systems. On the one hand, as it can be read in the literature, Push systems are characterised by production plans based on forecasts. On the other hand, in a Pull system the production reacts to the realization of the random variable: customer demand. The activities are triggered by the arrival of a demand at the most downstream node of the SC [/HTp-06/]. By other words, all Push processes are performed in anticipation of the customer demand and all Pull processes are performed in response of the customer demand [/ChMeHaRi-01/]. A pure Pull-system does not hold any inventories (it is a MTO process) According to Simchi-Levi [/SiLe-02/], one SC should develop to a Push-Pull based Strategy. He particularly studied the trade-off between demand uncertainty and logistics costs and for some industries, proposing where to locate the boundary Push-Pull. His conclusions will be applied in this thesis as a suggestion for the SC's optimisation (chapter 5).

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[6] EDI: Electronic Data Interchange

[7] JIT: Just in Time

2.3 Review on Inventory Management problems

Concerning Inventory Management, the well known policies are the re-order point (r,Q) and the order-up-to-level (S,T). Of course, several alternatives were studied based on these two policies (as presented by [/MohYv-06/]). Mohamed and Yves prove, in a previous study in 2005 [/MohYv-05/], for a single-stage and single-item inventory system under non-stationary demand, there are advantages in using forecast based inventory management systems instead of the classical standard inventory management systems (this topic is discussed on chapter 5.2.3.). Where single and multi-stage inventory management is concerned, numerous studies were carried out in the last few decades. Horst Tempelmeier [/HTp-06/] in his book “Inventory Management in Supply Networks: Problems, Models and Solutions” presents a comprehensive explanation along the theories of production planning and inventory policies. He performs several exhaustive analyses of multi-inventory and single-inventory policies making. For instance, the comparison of (r,S), (s,q) and (s,S) policies under stochastic conditions, with continuous and periodic review. He presents his results in terms of customer service level, stock-out management and costs effectiveness.

Simulation experiments can be always used, as an alternative to the analytical models formulation, to study SC’s performance and analyse different Inventory Management policies. [/DelErh-05/] and [/SezKit-07/] studied the performance of a SC and the Risk Management by using Monte Carlo Simulation. In this thesis, the Monte Carlo simulation is used to answer some proposed questions.

3 SUPPLY CHAIN CHARACTERISATION

3.1 Introduction

The present chapter deals with the characterisation of the SC in terms of the analysis of the current logistics processes and how they are interacting and performing. It introduces the question of Push vs Pull strategy and it suggests a development direction towards a Push-Pull system to improve the customer service level and reduce the total logistics costs.

3.2 Description of the Logistics processes

To recap, a SC is a set of interlinked agents represented by customers, producers, warehouses, distributors and suppliers. It is considered as a chain where the flow of material, money and information meets the business requirements.

In this paper, an existing SC consisting of one supplier, one production site, one distribution centre and a set of customers (ordering a single-item product *j*) is analysed[8].

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[8] Due to confidentiality further details about the SC are not published in this paper.

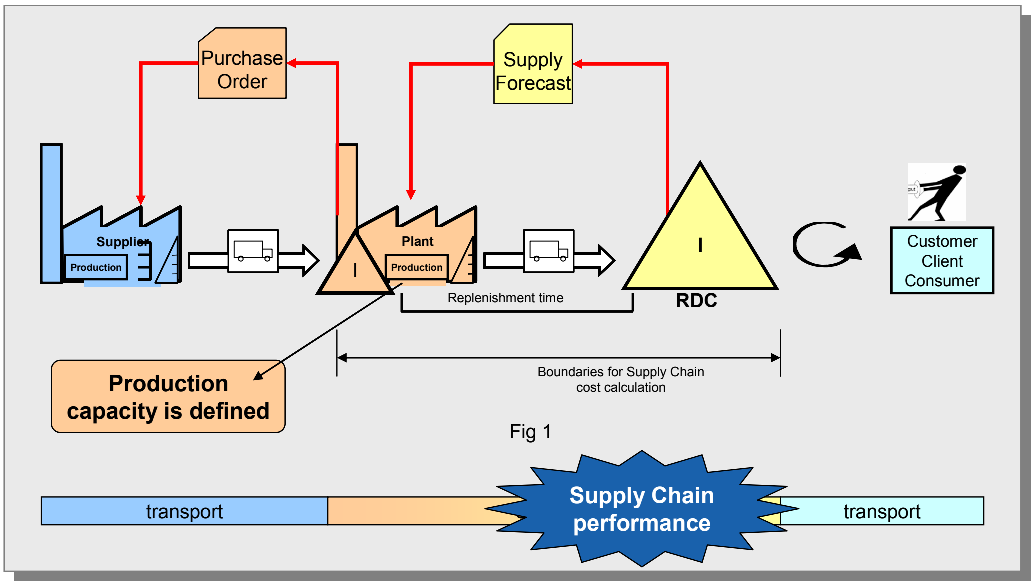

Figure 3.1. – Current SC Structure

The customer picks the finished goods up at RCD[9] (product *j*). The customer demand is characterised by big order sizes (full trucks) and small orders (carried out by “smaller” customers – e.g. installers). Customer orders not fulfilled are backlogged.

Currently, the RDC is replenished directly from the production site (plant). At the beginning of a forecast period, the new sales forecast (sales plan) is made by the RDC (based on customer orders received). This sales plan, the inventory position at the end of the previous forecast period and the defined safety stock are the inputs for the coverage calculation. The output is the supply forecast. The quantity produced by the production site is based on this supply forecast made by the RDC. The production site orders raw material *r* from the supplier in order to replenish a buffer warehouse (WH) located at the production site. The purchased quantity is defined by the inventory position of raw material of this buffer WH. The total necessary capacity of the production site is based on the supply forecast.

Inventory nodes are needed when no sufficient planning data is available, which could be used for a deterministic scheduling of the production (based on predicted development of the future demand). This is the case of retail goods (as presented

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[9] RDC – Regional Distribution Center

in this paper) where the demand process is out of the control of inventory management.

The inventory node RDC is supplied from a “source” (the production site) after a certain replenishment time, which is subject to random deviations such as non reliability of the production site or of the transport network. For a certain length of the replenishment lead time (LT_j), the demand during the LT period is the sum of the LT_j period demands. Of course, the probability distribution of this sum depends on the probability distribution of the period demand.

3.3 Detailed description of the Logistics processes

Supply Chain Management (SCM) is concerned with the integration and controlling of key business activities from the procurement of the raw material to the distribution of finished goods to customers in a volatile environment.

The customer orders are fulfilled from RDC stock, and those that are not fulfilled are backlogged. The RDC is replenished from the production site (plant). At the beginning of a forecast period, the new sales forecast is made by the RDC. This new sales plan, the inventory position at end of the previous forecast period and the defined safety stock (1,5 months safety) are the inputs for the coverage calculation and the supply forecast (net requirements: NET_j). The quantity produced by the production site is based on the supply forecast made by the RDC and the inventory position of product *j* at the production site. The total necessary capacity of the production site is also based on supply forecast. The production site orders raw material from the supplier in order to replenish a buffer WH located at the production site. The purchased quantity is defined by the inventory position of raw material of this buffer WH and the planned production quantity of product j - b_{jt} (resulting in the net requirements: NET_r). Additional production quantities are allowed (Express Orders) but incur extra costs.

The total necessary capacity of the production site is defined as follows:

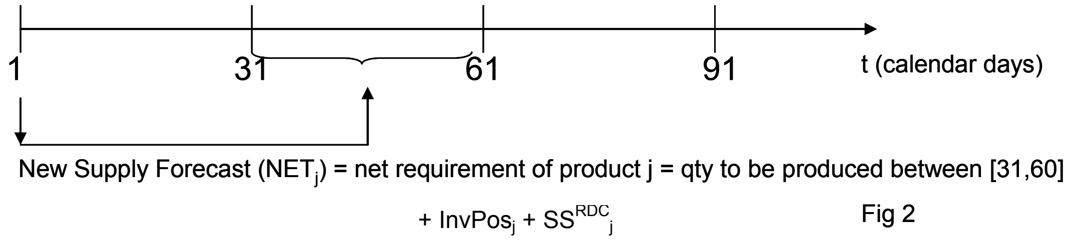

Figure 3.2. – Production capacity: today'model

The activities take place in the following sequence:

Monthly activities (t=1, 31, 61, 91, …):

- RDC places a new supply forecast to production site;
  - Production capacity (for production site) is defined according to Fig 3.2.;
  - New safety stock levels are calculated (the RDC works with 1,5 months safety);
  - Raw material is ordered according to inventory level at buffer WH and supply forecast (1,5 months safety).

Daily activities:

- Demand occurs;
  - Additional quantities from production site to RDC are possible. Additional costs are incurred;
  - Raw material *r* is booked (received) in at buffer WH located at production site;
  - Production site produces product *j*;
  - Production site delivers product *j*;
  - Product *j* is booked in at RDC (received);
  - Inventory levels, backlogs, service Level, forecast accuracy and costs are calculated.

3.4 Performance of the Supply Chain

The current problems experienced by the partners interacting in this SC can be described as follows:

- No communication
- No transparency
- Planning based on sales forecast
- Each process step is doing independently his “best guess”
- No common takt of activities
- The overall SC is performing badly

Concerning the performance evaluation, the table 3.1.[10] summarises the service level to the customer, the total logistics daily costs (without raw material storage costs), stock indicator and the accuracy of the forecast.

		Current Situation
Serv_Leve	%	**80,0**
Total Costs (daily)	€	**12.810,45 €**
Stock Indicator $^{RDC}_{jt}$	days	**10**
Forecast Accuracy	%	**-136%**

Table 3.1. – Performance evaluation current SC

The graphic 3.1. shows the effect of the Push system and the non-satisfactory forecast accuracy. During the period under analysis, the delivered quantity from the production site was the double of the quantity ordered by the customer (in the same period).

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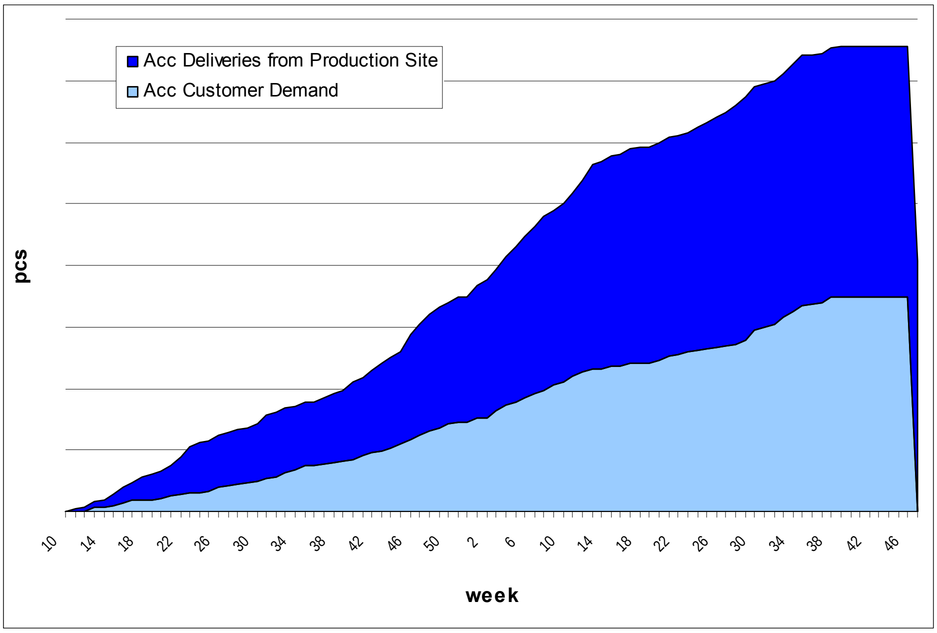
[10] The data is divided by an arbitrary factor.



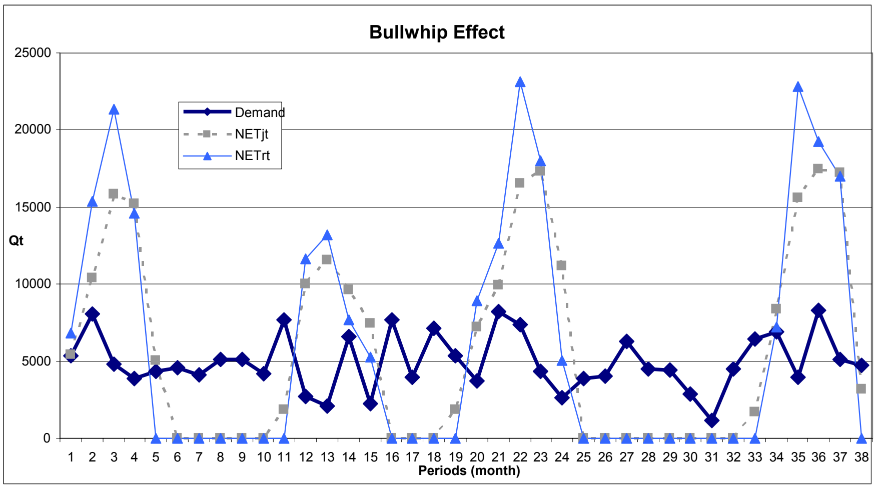
Graphic 3.1. – Deliveries from production site vs customer demand

The Graphic 3.1. clearly shows that in a Push based supply chain the reaction to the changing marketplace takes too long. According to [/SiLe-02/] the four principles of long-term forecast should be well understood and know by the partners in one supply chain:

- The Forecast is always wrong
- The longer the forecast horizon, the worse is the forecast
- Data updates lead to forecast updates and
- Aggregated forecasts are more accurate

The result of the forecast accuracy (table 3.1.: -136%) indicates the first two principles.

The third implies the well known “Bullwhip effect”, which is shown on Graphic 3.2. The variability of the orders received by the supplier of the raw material is higher than the variability of the orders received by the plant and much higher than the customer demand. Important to underline is also that the increase in variability is related to the lead time of the supply chain: the longer the lead time the stronger the “Bullwhip effect” [/SiLe-02/].



Graphic 3.2. – Variability of the orders along the supply chain

3.5 Evolution of the Supply Chain Strategy

As described above, the Push-based strategy does not lead to an acceptable SC's performance. The question is then, in which direction should the SC develop. Simchi-Levi studied the evolution of the SC strategies [/SiLe-02/]. He particularly studied the trade-off between demand uncertainty and logistics costs. He grouped the analysed products into four categories (as shown in figure 3.3.).

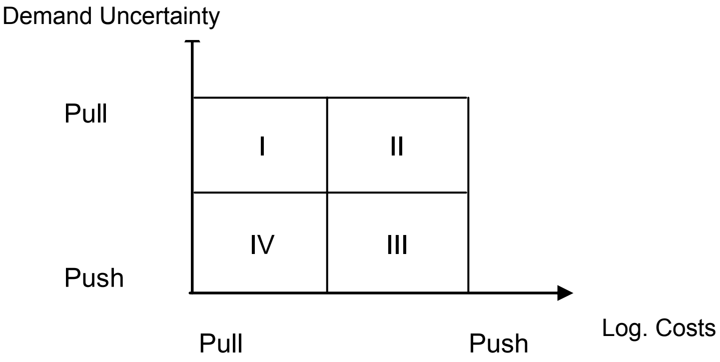


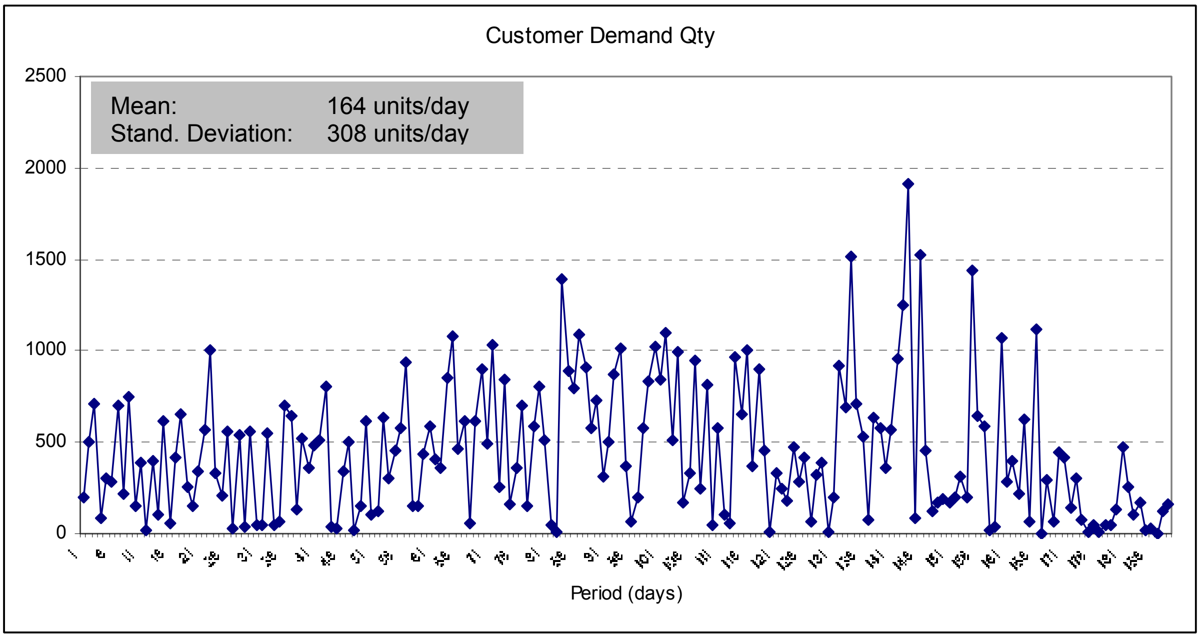
Figure 3.3. – Evolution of the supply chain strategy

Inside Group I, we have the industries (as PC Industry) with high Demand uncertainty and low Logistics costs, which should follow the Pull-based strategy.

Inside the Group III fall the products with high logistics costs (per unit) and low demand uncertainty. That is the case of Grocery Industry to which the Push system brings more advantages.

In the Groups II and IV, the uncertainty leads to a Pull-based strategy while the logistics costs motivate the Push structure. Some e.g. are the Book (group IV) and Furniture Industries (group II).

The SC studied in this paper falls into Group II. The demand uncertainty is considered high and the unit Logistics costs too. For that reason, the Plant delivers only full containers/trucks to the RDC.



Graphic 3.3. – Customer Demand

According to Simchi-Levi [/SiLe-02/], the SC should develop to a Push-Pull based strategy. The challenge is now to define the Push-Pull boundary (or degree of Pull strategy).

From one side it must be considered the LT of the SC and the service level required from the customers. In case the service time required is lower than the LT of the SC, the inventory is needed. As already said, there are several reasons for building up inventories, for instance: distance, seasonality, non-reliability of production flow time, lot sizing and random disturbances. This suggests that the boundary should be located closer to the customer demand.

From other side, the logistics costs motivate the location of the stock at upper stream nodes of the SC (the raw material stock is less expensive than finished goods stock).

Not only should the location of the boundary be considered but also the structure of the SC. Should we keep the inventory node closer to the production site to take advantage from the aggregated forecasts or should we place the warehouse closer to the customer and implement mechanisms which allow supply chain visibility and collaboration (Transparency)?

The transparency and collaboration allow the reduction of the “Bullwhip Effect”. If all stages of the supply chain know the customer demand, the forecast will be more accurate and the variability of the orders along the supply chain does not increase as in a pure Push-based strategy and no transparency. From other side, the strategy for replenishment and inventory management should also be known and agreed by the partners [/SiLe-02/].

In the next chapter, a simulation tool is presented. This tool provides some important conclusions about the potential performance of the Today’s situation.

4 SIMULATION MODEL FOR PERFORMANCE EVALUATION

4.1 Introduction

The aim of this chapter is to model the current SC and run several simulation scenarios to answer/explain the addressed questions presented on chapter 1.2.

4.2 Demand Modelling

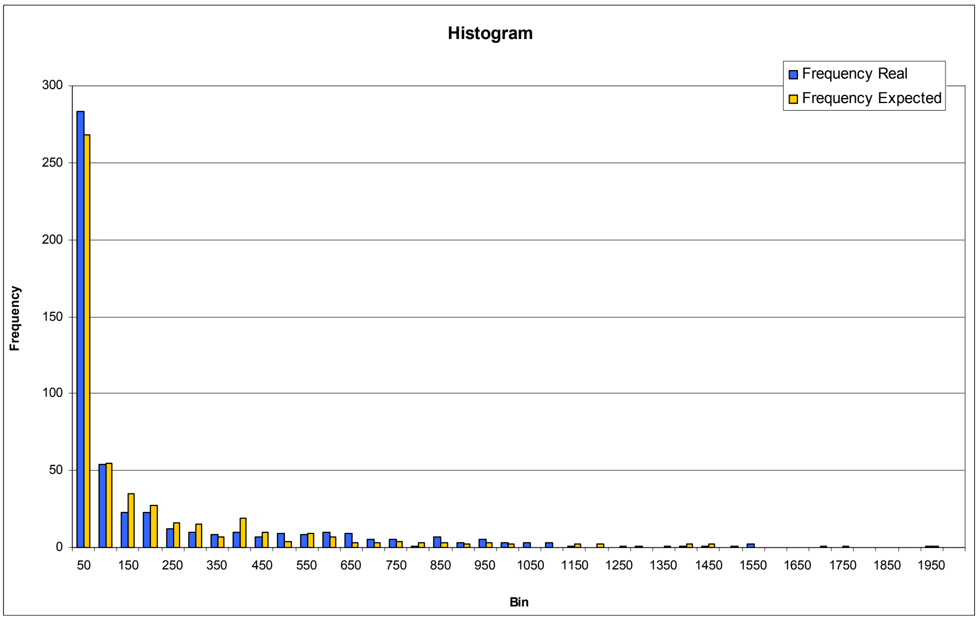
Sources of uncertainty in production-distribution planning are divided into short and long term sources. Included in the short term category are, amongst others, the day-to-day processing variations, cancelled or rush orders, transport failures, machine breakdowns, scheduling according to priority rules. The long term category handles the raw material/final product price fluctuations, forecast errors, customer demand, [/GuMa-00/] and [/HTp-06/]. Deterministic planning results in unrealistic data by failing to capture the effect of the demand variability with clear negative impact on customer service level and inventory holding costs. Describing the demand uncertainty requires the representation of stochastic parameters [/GuMa-00/]. There are two ways of representing the uncertainty. The first is the scenario based approach by forecasting all the possible future outcomes. The drawback of this methodology is the exponential increase of scenarios with the increase of uncertain parameters. The second approach, which overcomes the drawback of the first technique, is to use continuous probability distributions for the random parameters [/GuMa-00/]. In this thesis the second approach is followed.

First one must study the probability distribution of the demand during the risk period knowing that the risk period is composed of the review period plus the replenishment lead time.

According to Horst Tempelmeier [/HTp-06/], the Gamma distribution is very flexible in describing the randomness of the period demands. The Gamma distribution can be used to model a wide variety of demand distributions with very different shapes, particularly in the presence of an erratic demand.

For this Supply Network it is assumed that the period demands follow a stationary Gamma distribution of random uncorrelated variables. The Graphic 4.1. represents the histogram of the demand and makes a comparison of the real demand data and the demand generated by the Gamma distribution.

=> D – period demand with density function $f_D(d)$ and probability distribution $F_D(d) = P\{D \leq d\}$



Graphic 4.1 – Histogram of the Demand

In industrial practice and in this paper, the lead time (LT) follows a discrete probability distribution. LT is then a random variable mainly due to the fact that production activities have random duration (not only in case of MTO but in the MTS[11] strategy as well).

As it is considered a Gamma distribution for the demand with mean k/α and variance k/α^2. The random variables Y and Z are Gamma distributed too, (where Y is the demand during the replenishment lead time and Z is the demand during the

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[11] MTO – make to order
MTS – make to stock

replenishment lead time LT plus the order cycle RT). The scale and shape parameters are:

$\alpha_Y = \alpha_Z = \alpha_D$ E.1.

$k_Z = k_D * (RT + LT)$ E.2.

$k_Y = k_D * LT$ E.3.

4.3 Simulation Model

4.3.1 The Importance of the Simulation

Simulation provides a pragmatic approach for the detailed analysis and evaluation of a SC design and management alternatives. The use of simulation as a vehicle for understanding issues of organizational decision making has gained considerable attention in recent years [/SwSt-98/]. Sezen and Kitapci [/SezKit-07/] demonstrate how spreadsheets can be used to simulate SC inventory problems. Their study was important for the development of the simulation tool proposed in this thesis.

For the modelling of an Inventory system the time axis assumes high importance due to several respects. The length of the review period and also the assumptions about the structure of the arrival of the demand determine how to model the time axis accurately.

In this stud,y a discrete-event simulation model is used. It is assumed the demand is a discrete time process on a daily basis. The observed demands form a time series. As expressed by Tempelmeier [/HTp-06/] if only the inter-arrival times A and order sizes D_a are observed and recorded, the demand period D_t can be computed as the sum of a random number of random variables[12].

4.3.2 Simulation Tool: description of the model

The simulation is performed in excel (VBA) in the following way (figure 4.1.):

- The planning horizon is divided into a number of periods defined by the user (duration of a period: one day). For the one time simulation for a specific period [/KorKonSaTs-04/], the first iteration corresponds to the first day activity and the next iteration corresponds to the next day activity.
  - The user defines the % of sea freight to be used by the simulation tool.
  - Based on historical data a forecast is generated by applying the moving average methodology. The forecast period equals to thirty periods (or thirty days).
  - The planning model is then solved. After defining the safety stocks, net requirements are calculated taking the inventory position at the end of the last forecast period (for product *j* and raw material *r*).
  - Replenishment orders are released from RDC to production site (product *j*) and from production site to supplier (of raw material *r*).
  - The net production quantity of one forecast period is divided by thirty to get the daily production plan at the production site.
  - During each forecast period, the production site produces the product *j* (daily quantities) and delivers to RDC.
  - During each forecast period, the supplier delivers the replenishment quantity of *r* ordered in the previous forecast period (divided by thirty – daily deliveries).
  - During the forecast period, product *j* is received by RDC (according the LT_j) and raw material *r* is received by the production site (according to LT_s).
  - At the end of each period, stock levels are recorded, demand is updated into the historical data, customer service level reported and total costs of the SC summarised.

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[12] Which in this SC is a Gamma distributed.

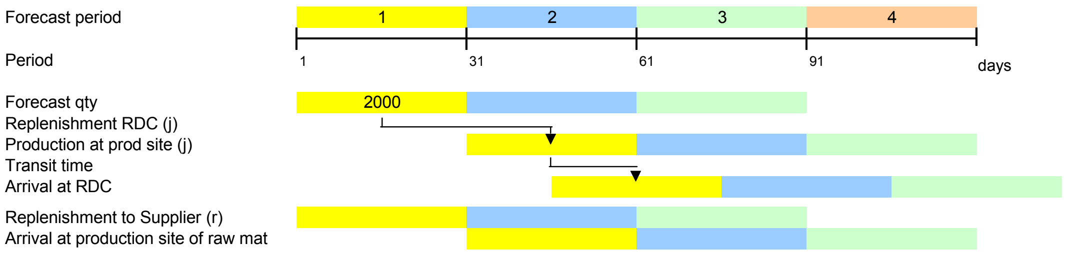


Figure 4.1. – Planning Stepps

Assumptions:

- Only one product group is considered;

  - There is a 1:1 ratio between raw material *r* and finished goods *j*;

  - The SC model is assumed to be based on a rolling horizon where the forecasts may be updated when the horizon is shifted;

  - For the demand, it is considered a stationary stochastic process. The demands of each period are i.i.d. on [o,∞[. It is assumed a Gamma Distributed Demand with (α,k);

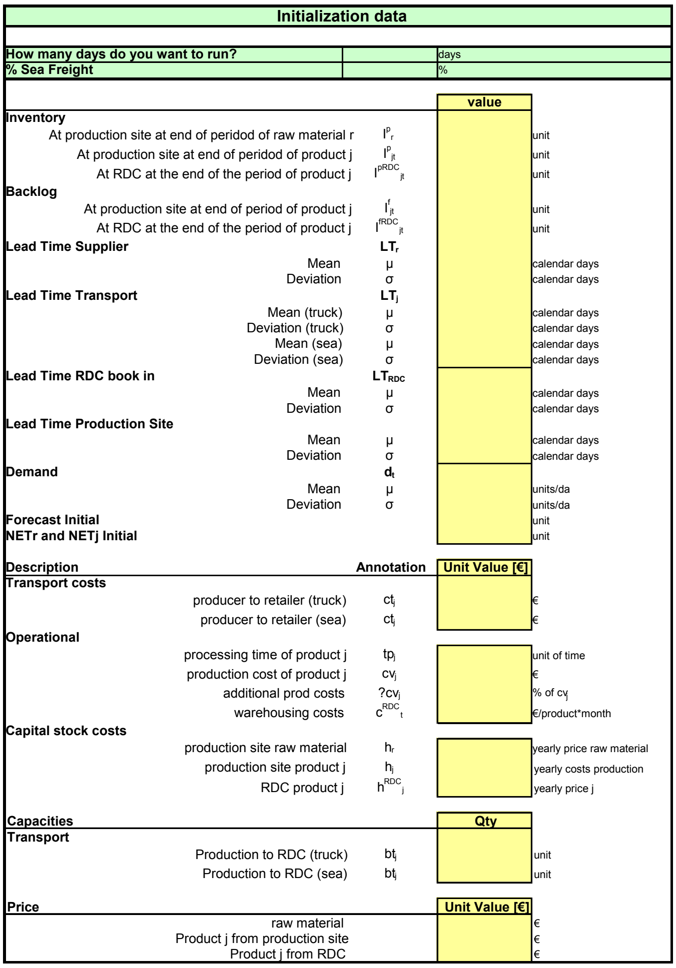
  - The deterministic LT from supplier is assumed to be equal to the transport time between supplier and producer. The suppliers' capacity is assumed to be infinite;

  - The stochastic LT from producer is assumed to be = planning time + process time + transportation time + waiting buffers time + storage => Replenishment time = time required from the withdrawal of material at the point of availability until the material is replenished at this point of availability;

  - The production capacity is defined according to the Fig 4.1.. Additional quantities are allowed when necessary with an extra cost (resulting in infinite capacity).

4.3.3 Simulation tool: Input data

In the table 4.1. below, the initialization sheet, which contains the input data for one simulation run, is presented. Ordering and backlog costs are not considered in the simulation tool.



Initialization data			
How many days do you want to run?			days
% Sea Freight			%
		value	
Inventory			
At production site at end of peridod of raw material r	I^{p}_{r}		unit
At production site at end of peridod of product j	I^{p}_{jt}		unit
At RDC at the end of the period of product j	I^{pRDC}_{jt}		unit
Backlog			
At production site at end of period of product j	I^{f}_{jt}		unit
At RDC at the end of the period of product j	I^{fRDC}_{jt}		unit
Lead Time Supplier	LT_r		
Mean	μ		calendar days
Deviation	σ		calendar days
Lead Time Transport	LT_j		
Mean (truck)	μ		calendar days
Deviation (truck)	σ		calendar days
Mean (sea)	μ		calendar days
Deviation (sea)	σ		calendar days
Lead Time RDC book in	LT_{RDC}		
Mean	μ		calendar days
Deviation	σ		calendar days
Lead Time Production Site			
Mean	μ		calendar days
Deviation	σ		calendar days
Demand	d_t		
Mean	μ		units/da
Deviation	σ		units/da
Forecast Initial			unit
NETr and NETj Initial			unit
Description	**Annotation**	**Unit Value [€]**	
Transport costs			
producer to retailer (truck)	ct_j		€
producer to retailer (sea)	ct_j		€
Operational			
processing time of product j	tp_j		unit of time
production cost of product j	cv_j		€
additional prod costs	$?cv_j$		% of cv_j
warehousing costs	c^{RDC}_{t}		€/product*month
Capital stock costs			
production site raw material	h_r		yearly price raw material
production site product j	h_j		yearly costs production
RDC product j	h^{RDC}_{j}		yearly price j
Capacities		**Qty**	
Transport			
Production to RDC (truck)	bt_j		unit
Production to RDC (sea)	bt_j		unit
Price		**Unit Value [€]**	
raw material			€
Product j from production site			€
Product j from RDC			€

Table 4.1. – Input data: Today’s model

4.3.4 Simulation tool: validation

In a simulation model not all details are captured by the model. Therefore, the model must be validated before the simulation scenarios run and any conclusions are made about its results. In this chapter, the validation of the model is done.

For that, the first simulation experiment, using the current input data, will verify whether the results achieved are comparable with the performance of the current SC (table 4.2.).

		Current Situation	Validation
Serv_Level	%	**80,00**	**80,00**
Total Costs (daily)	€	**12.810,45 €**	**12.687,21 €**
Stock Indicator $^{RDC}_{j}$	days	**105**	**104**
Forecast Accuracy	%	**-136%**	**-114%**

Simulation Periods		**0**
		Validation
BullwhipEffectD-Prod		**361,16**
BullwhipEffectProd-RawMat		**1,54**
Serv_Level	%	**80,00%**
Total Costs (daily)	€	**12.687,21 €**
Average I^{pRDC}_{j}	units	**27663**
Average I^{p}_{j}	units	**361**
Average $I^{p}r_{t}$	units	**8600**
Average sales	units	**4456**
Coverage I^{pRDC}_{j}	months	**5,64**
Stock Indicator$^{RDC}_{j}$	days	**104**
Forecast Accuracy	%	**-114%**
Demand	Mean	163,6
	Var	304,6
Sea Freight %	N. Containers	8396
	N.Trucks	4525
	Total	12921

Table 4.2. – Model validation

4.3.5 Simulation scenarios

The simulation[13] ran for 720 periods (approx. 2 years), which is in average the maturity time (life cycle) of the product under analysis.

Several scenarios[14] were created taking into consideration the aim and the expected results already presented on chapter 1.2.

- Different transport networks (by sea freight, by truck, mixed) from the producer:

  All the parameters remain the same, only the % sea freight varies.

  . Scenario 1: Sea freight = 0%

  . Scenario 2: Sea freight = 100%

  . Scenario 3: Sea freight = 50%

---

[13] Due to confidentiality, the data does not reflect real numbers as they are divided by an arbitrary factor.

[14] One scenario (e.g.) is presented on appendix 1.

. Scenario 4: Sea freight = 25%

. Scenario 5: Sea freight = 75%

- Reliability of the supplying network and the impact of the LT:

  First, it is studied the impact of increasing the transport time per sea and its reliability.

  . Scenario 6: Sea freight = 25% and LT (sea) μ = 18 days σ = 10 days

  . Scenario 7: Sea freight = 100% and LT (sea) μ = 18 days σ = 10 days

  . Scenario 8: Sea freight = 75% and LT (sea) μ = 18 days σ = 10 days

  Secondly, the impact of the reliability of the production site in the SC performance for the different sea freight percentages.

  . Scenario 9: Sea freight = 0% and Prod. LT μ = 2 days σ = 4 day

  . Scenario 10: Sea freight = 100% and Prod. LT μ = 2 days σ = 4 day

  . Scenario 11: Sea freight = 50% and Prod. LT μ = 2 days σ = 4 day

  . Scenario 12: Sea freight = 25% and Prod. LT μ = 2 days σ = 4 day

  . Scenario 13: Sea freight = 75% and Prod. LT μ = 2 days σ = 4 day

- Short term fluctuation of customer demand:

  . Scenario 14: Sea freight = 0% and Demand μ = 328 σ = 656

  . Scenario 15: Sea freight = 100% and Demand μ = 328 σ = 656

  . Scenario 16: Sea freight = 50% and Demand μ = 328 σ = 656

  . Scenario 17: Sea freight = 25% and Demand μ = 328 σ = 656

  . Scenario 18: Sea freight = 75% and Demand μ = 328 σ = 656

- The impact of different Inventory Management strategies on SC's performance:

The aim of this paper is also to further investigate and present some small improvements to the current logistics process, which leads to an optimisation of the results. The first change to be carried out is related to the net requirement calculation for product j which is performed by the RDC. Following that and based on Horst Tempelmeier [/HTp-06/], it will be calculated a more appropriate order level S considering the review period = 30 days. Also, it will be calculated the optimal review period (but it should be kept in mind that in industrial practice, one must have a compromise between the optimal review period and a realistic procedure to be implemented).

Tempelmeier [/HTp-06/] describes that the smallest S for a defined RT (review period) is subject to the following constraint:

$$(1-\beta) * RT * E\{D\} \geq E\{I_{end}^{f}(S)\} - E\{I_{beg}^{f}(S)\} \qquad \text{E.4}$$

Where β is the target service level:

$$\beta = 1 - \frac{E\{Backorders\_period\}}{E\{Period\_Demand\}} \qquad \text{E.5}$$

The period demand follows a Gamma distribution with parameters[15] α_D=0,001723 and k_D=0,2835, so the random variables Y and Z (where Y equals the demand during the replenishment lead time and Z equals the demand during the replenishment lead time plus the review period) have the parameters:

$$\begin{array}{ll} Scale: & \\ \alpha_D = \alpha_Y = \alpha_Z & \text{E.6.} \\ Shape: & \\ k_Z = k_D * (RT + LT) & \text{E.7.} \\ k_Y = k_D * LT & \text{E.8.} \end{array}$$

	LT (calendar days)							
RT	**Prod**	**Transp**	**WH**	**Total**	**α_D=α_Y=α_Z**	**k_D**	**k_Y**	**k_Z**
30	2	18	1	21	0,00173	0,28352	5,95396	14,45961

RT	β	left side eq.	k_Y/α	k_Z/α	Gamma k_Z+1	Gamma k_Y+1	Gamma k_Z	Gamma k_Y
30	98%	98,4	3444	8364	0,88730	0,99980	0,92476	0,99994

---

[15] For detailed calculation: appendix 2.

RT	E{Backlog End(S)}	E{Backlog Beg(S)}	S (units)
30	98,35169	0,04192	**11702**

Table 4.3. – Calculation S level (TM's model)

Now, the optimal review period is calculated:

$$RT_{opt} = \sqrt{\frac{2 * cv_j}{h_j^{RDC} * E\{D\}}} = 1{,}19 \Rightarrow RT=1 \text{ (daily review)} \qquad \text{E.9.}$$

With RT=1, the order level S is 13925 units. One can be surprised as to why reducing the review period does not lead to a decrease in the S level. The reason is related to the fact that the left side of the equation E.4. decreases from 98,4 to 3,28 due to the decrease of RT = 30 to RT =1. The lead time remains constant but in the case RT = 30, the first 30 days of the lead time are included in the RT. To conclude, the daily ordering does not bring benefits if the production zone remains.

In order to compare the effectiveness of the new order level S=11700 and the one used with 1,5 months safety, the net requirement calculation (done by RDC for product j) has to be changed:

<u>Old method</u>:

$$NET_{jt} = \max\left[GROSS_{jt} - (INVPOS_{jt}^{RDC} - SS_{jt}^{RDC};0\right] \qquad \text{E.10.}$$

<u>New method:</u>

$$NET_{jt+1} = \max\left[11700 - (I_{jt}^{pRDC} + I_{jt}^{f} + NET_{jt-30+1} - GROSS_{jt});0\right] \qquad \text{E.11.}$$

The simulation runs for the same 720 periods and for the following scenarios:

Demand $\mu = 164$ $\sigma = 308$

. Scenario 19: Sea freight = 0% with S = 9900 units

. Scenario 20: Sea freight = 100% with S = 11700 units

. Scenario 21: Sea freight = 50% with S = 11700 units

. Scenario 22: Sea freight = 25% with S = 11700 units

. Scenario 23: Sea freight = 75% with S = 11700 units

and Demand $\mu = 328$ $\sigma = 656$

. Scenario 24: Sea freight = 0% with S = 20295 units

. Scenario 20: Sea freight = 100% with S = 24075 units

. Scenario 21: Sea freight = 50% with S = 24075 units

. Scenario 22: Sea freight = 25% with S = 24075 units

. Scenario 23: Sea freight = 75% with S = 24075 units

4.3.6 Analysis of the Results

The following tables summarise the results of the simulated scenarios presented on previous chapter.

	Sea %	0	100	50	25	75	25	100	75
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
BullwhipEffect D-Prod		133,88	161,66	72,56	194,68	106,97	72,98	147,22	45,65
BullwhipEffect Prod-RawMat		4,81	0,99	1,71	0,17	0,89	1,79	3,06	1,08
Serv_Level	%	76,4%	76,5%	85,3%	84,9%	77,1%	76,7%	74,4%	80,0%
Daily Total Costs	€	14.029,62 €	14.331,25 €	14.159,92 €	13.139,47 €	12.036,27 €	13.525,97 €	14.191,06 €	16.374,49 €
Average IpRDCjt	units	7102	7657	6842	6600	6371	6034	5971	5532
Average Ipjt	units	366	333	422	416	346	437	348	441
Average Iprt	units	20552	22121	22263	24287	20152	19823	23768	19005
Average sales	units	4904	4945	4814	4839	4640	4779	4705	5344
Coverage IpRDCjt	months	1,45	1,55	1,42	1,36	1,37	1,26	1,27	1,04
GEZ RDCjt	days	37	39	36	35	35	32	32	26
Forecast Accuracy	%	7,6%	2,5%	-0,3%	2,4%	5,0%	1,3%	1,6%	12,1%

	Sea %	0	100	50	25	75
		Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13
BullwhipEffect D-Prod		94,69	111,63	141,41	196,76	81,89
BullwhipEffect Prod-RawMat		4,07	0,70	1,94	1,60	1,60
Serv_Level	%	88,3%	72,6%	69,9%	85,1%	70,3%
Daily Total Costs	€	12.623,75 €	14.363,17 €	15.203,04 €	13.652,87 €	16.103,42 €
Average IpRDCjt	units	6123	7246	7945	6934	7135
Average Ipjt	units	407	369	394	445	335
Average Iprt	units	20775	25644	29574	24365	22373
Average sales	units	4858	5018	5205	4917	5155
Coverage IpRDCjt	months	1,26	1,44	1,53	1,41	1,38
GEZ RDCjt	days	32	37	39	36	35
Forecast Accuracy	%	0,2%	4,9%	8,5%	8,7%	8,5%

	Sea %	0	100	50	25	75
		Scenario 14	Scenario 15	Scenario 16	Scenario 17	Scenario 18
BullwhipEffect D-Prod		132,57	156,63	152,07	180,81	156,58
BullwhipEffect Prod-RawMat		5,41	1,81	1,55	1,48	1,36
Serv_Level	%	67,6%	61,0%	54,0%	64,4%	59,0%
Daily Total Costs	€	27.089,81 €	29.987,24 €	27.343,68 €	27.868,48 €	26.100,04 €
Average IpRDCjt	units	10181	11754	11836	10618	12409
Average Ipjt	units	418	425	434	345	382
Average Iprt	units	45683	51101	56083	40194	59916
Average sales	units	9163	10596	9922	9766	10024
Coverage IpRDCjt	months	1,11	1,11	1,19	1,09	1,24
GEZ RDCjt	days	28	28	30	28	32
Forecast Accuracy	%	14,2%	25,8%	19,8%	24,9%	31,6%

	Sea %	0	100	50	25	75
		Scenario 19	Scenario 20	Scenario 21	Scenario 22	Scenario 23
BullwhipEffect D-Prod		143,04	128,31	78,81	144,60	209,21
BullwhipEffect Prod-RawMat		3,22	3,20	4,43	6,82	3,42
Serv_Level	%	92,1%	95,8%	96,3%	94,0%	92,9%
Daily Total Costs	€	12.460,45 €	11.875,03 €	12.369,00 €	13.548,99 €	13.027,48 €
Average IpRDCjt	units	4422	6105	5402	5218	5888
Average Ipjt	units	404	383	412	414	427
Average Iprt	units	12299	13337	12282	12677	17852
Average sales	units	4703	4377	4871	4760	4710
Coverage IpRDCjt	months	0,94	1,39	1,11	1,10	1,25
GEZ RDCjt	days	24	36	28	28	32
Forecast Accuracy	%	5,5%	-5,2%	4,9%	2,9%	2,9%

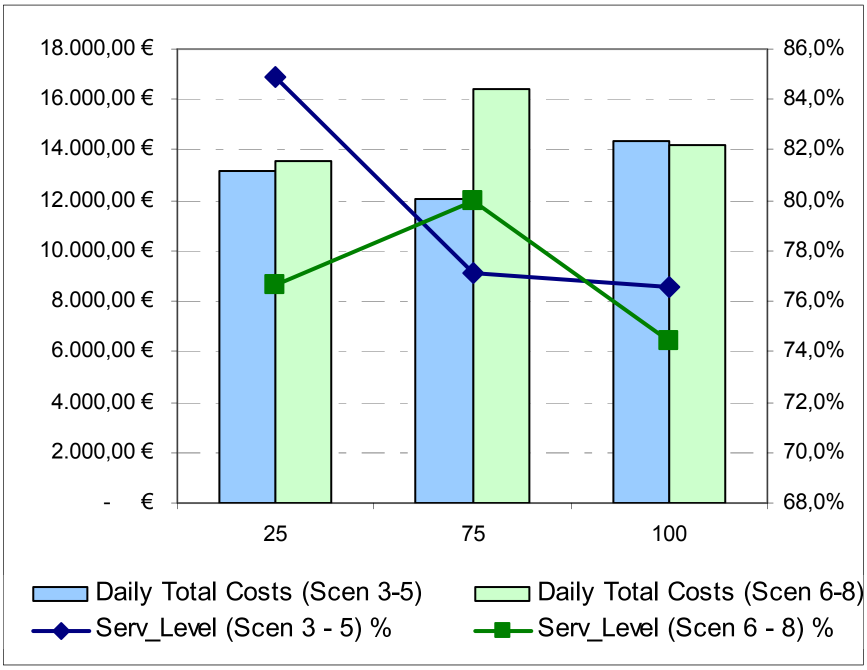
	Sea %	0	100	50	25	75
		Scenario 24	Scenario 25	Scenario 26	Scenario 27	Scenario 28
BullwhipEffect D-Prod		138,31	170,48	167,47	151,11	157,70
BullwhipEffect Prod-RawMat		5,30	6,48	6,28	6,30	7,85
Serv_Level	%	83,1%	80,0%	84,9%	95,1%	71,4%
Daily Total Costs	€	23.825,00 €	25.471,19 €	26.757,93 €	24.894,36 €	28.919,47 €
Average IpRDCjt	units	8885	10750	9807	10648	8338
Average Ipjt	units	379	376	422	464	410
Average Iprt	units	36117	44438	40423	44162	37961
Average sales	units	9134	9464	9690	8656	10407
Coverage IpRDCjt	months	0,97	1,14	1,01	1,23	0,80
GEZ RDCjt	days	25	29	26	31	20
Forecast Accuracy	%	26,2%	22,3%	23,0%	21,1%	14,3%

Table 4.5. – Results of Today's model (simulation)

For the current situation, the tendency suggests that the 0% and 25% sea freight returns better SC' performance (higher service level at low total logistics costs). This is particularly evident when the customer demand fluctuates at short term and the forecast accuracy is not satisfactory (scenarios 14-18).

On the other hand, with a more sophisticated inventory management (scenarios 19-23), one can take the advantage of lower sea freight transport costs (compared to truck). As it can be seen, the scenario 20 with 100% sea freight gives a very interesting compromise between total logistics costs and customer service level. Finally, the scenarios 24 to 28 study the short term fluctuation of the customer demand under an (r,S) inventory policy. One can compare the scenarios 14-18 and the scenarios 24-28: in average the service level increases by 35% when the strategy for the inventory management is more sophisticated as simple apply 1,5 months coverage as in real practice is very often application (for the same Demand $\mu = 328$ $\sigma = 656$).

The reliability of the supplying network is studied with scenarios 6-8. The graphic 4.2. indicates that the service level drops when the supplying unit varies the delivery time, underling that a non-reliable supplier brings instability and lower performance to the SC.



Graphic: 4.2. – Scenarios 3-5 vs Scenarios 6-8

4.3.7 Further optimisation

So far, this chapter has analysed the potential improvement of the Inventory Management in the RDC for the product *j*. The second step should be the analysis of the Inventory Management of the raw material *r* stored in the production site. This study is performed for the re-structured SC presented in chapter 5.

Further optimisation can be gained if RT and S order level are not fixed but the definition of the replenishment periods based on target stock levels are allowed. Although, the logistics mission is also to keep the rhythms in the information flow leading to higher reliability due to standardisation of the logistics processes. This point will be discussed later when analysing the re-structured SC model.

5 RE-ENGINEERING OF THE SUPPLY CHAIN

5.1 Introduction

Based on Simchi-Levi's studies [/SiLe-02/] and as concluded in chapter 3.5., this SC should develop to a Push-Pull system. A re-structure SC is now proposed (Fig. 5.1):

- The "new" SC follows a Push-Pull principle, where the boundary is located at RDC (this customers is picking at the RDC location up);
- There is an agreed strategy for Inventory Management and Demand Forecast;
- There is information sharing along the SC.

The restructured SC is planned and controlled centrally by a decision authority that has access to all relevant information and to release decisions for the entire SC (this authority shares the sales forecast and defines the new inventory levels), the production capacity and the percentage of sea freight.

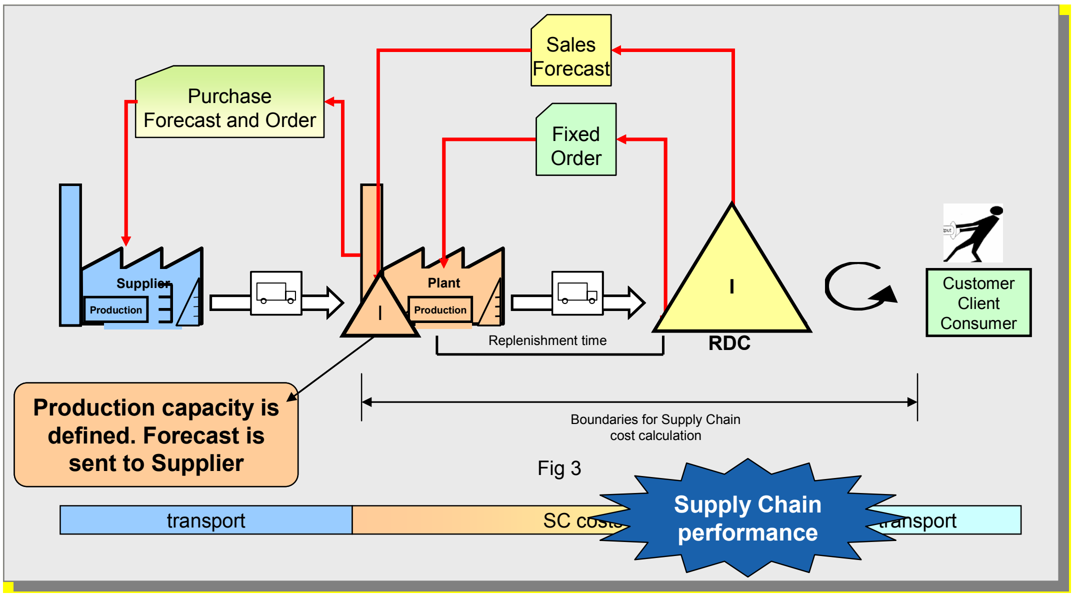


Figure 5.1. – Re-structured SC model

By making these changes, one expect a considerable increase the SC's performance due the fact that the LT is reduced.

In the next chapters, some theory on Inventory Management and Forecast models are introduced.

5.2 Inventory Management Policies

5.2.1 (r,S) inventory policy

The inventory policy considered is the so called (r,S) which proceeds according to the following decision rule [/HTp-06/]:

> "=> In constant intervals of RT periods launch a replenishment order that rises the inventory position to the target inventory level S."

The order size at the time of the review (RT) is a function of the observed demand and the inventory development in the preceding periods.

The optimal value for RT can be calculated by the average period demand as described in chapter 4.3.5. For the re-structured SC model will be considered RT=1 (1 day). In practice, inventory is reviewed once per period, normally at the beginning or at the end of the day. Also, the consumption data is normally stored in the IT-system on daily basis.

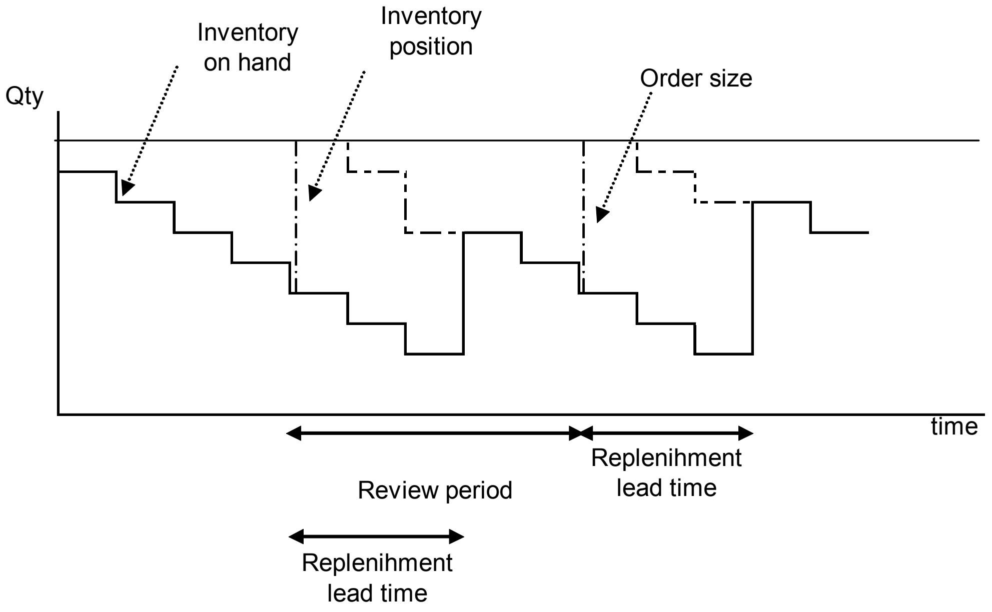


Figure 5.2. – Periodic review policy

The main advantage of the (r,S) inventory policy is the fact that is possible to synchronize the timing of the orders, meaning a standard and easy realization of the logistics processes. From a "system point of view", this is an advantage of this inventory policy [/HTp-06/].

5.2.1.1. (R,S) INVENTORY POLICY WHERE S IS SUBJECT TO THE SERVICE LEVEL

As the basic requirement is the assurance of a target service level, the optimal order level S considers the expected backlog at the beginning and at the end of a typical order cycle. Especially in the case of large demand variances, the backlog at the beginning of an order cycle may have a non-negligible value. If the backlog is ignored the optimal order level S is increased and the service level is overachieved (with higher associated costs of inventory) [/HTp-06/].

To recap, the formula E.4.

$$(1-\beta) * RT * E\{D\} \geq E\{I_{End}^{f}(S)\} - E\{I_{Beg}^{f}(S)\} \qquad \text{E.4.}$$

	LT							
RT	**Prod**	**Transp**	**WH**	**Total**	$\alpha_D=\alpha_Y=\alpha_Z$	k_D	k_Y	k_Z
1	32	18	1	51	0,00173	0,28352	14,45961	14,74313
1	32	9	1	42	0,00173	0,28352	11,90791	12,19143

RT	**β**	**left side eq.**	k_Y/α	k_Z/α	**Gamma** k_Z**+1**	**Gamma** k_Y**+1**	**Gamma** k_Z	**Gamma** k_Y
30	98%	**3,3**	8364	8528	0,97091	0,97509	0,98354	0,98616
30	98%	**3,3**	6888	7052	0,96995	0,97461	0,98384	0,98664

E{Backlog End(S)} z	**E{Backlog Beg(S)} y**	**Dif**	**S**
18,93253	15,63287	**3,29966**	**13925**
17,41505	14,11773	**3,29733**	**12040**

Table 5.1. – Calculation S level (SC's model)

So far, we have calculated the S order level for the product *j*. The next step is to find the smallest S for the raw material *r* as well.

The random portion of a raw materials period demand is usually assumed to follow a certain probability distribution [/HTp-06/]. Although, this could lead to wrong results due to the fact the demand for a raw material is only partly random because it also results from decisions concerning production quantities of finished goods.

In this thesis, it was considered the mean and the variance of the customer demand to calculate the S level of raw material *r*. As shown in the simulation results, the variability of the production quantity is approximately the same as the variability of the customer demand. Correctly, it should be considered the variability of the production quantity and the effect of raw material stock out (impact on the production quantity per period).

With RT = 1 and LT = 30, I get an $S_{\text{raw material}}$ order level of 9455 units.

5.2.2 (s,q) inventory policy

Compared to (r,S) inventory policy, the (s,q) brings more stability to the production node upstream the SC by breaking down the period demand randomness. This can be an important advantage in the case of large demand variations (e.g. in the case of the retail goods business). Although, concerning the customer order waiting time, the (s,q) policy can bring disadvantages due to the undershoot[16].

The inventory policy (s,q) proceeds according to the following decision rule [/HTp-06/]:

> "=> If at a review instant, the inventory position has reached the re-order point s, then a replenishment order of size q is released."

The optimal order quantity is computed (Demand $\mu = 164$):

$$q_{opt} = \sqrt{\frac{2 * cv_j * E\{D\}}{h_j^{RDC}}} = 195{,}4 \Rightarrow 195 \text{ units} \qquad \text{E.9.}$$

The re-order point (smallest s) is solved by the service level constraint E.4.a.:

$$(1-\beta) * q_{opt} \geq E\{I_{End}^{f}(S)\} - E\{I_{Beg}^{f}(S)\} \qquad \text{E.4.a.}$$

Where β is the target service level:

$$\beta = 1 - \frac{E\{Backorders\_period\}}{E\{Period\_Demand\}} \qquad \text{E.5.}$$

The period demand follows a Gamma distribution with parameters α_D=0,001723 and k_D=0,2835, so the random variables Y* =Y + U (for Y equals the demand during the replenishment lead time and U equals the undershoot) have the parameters:

---

[16] The undershoot (U) is the difference between the re-order point and the inventory position at the beginning of the lead time [/HTp-06/].

$$E\{Y*\} = E\{Y\} + E\{U\} \qquad \text{E.10.}$$

$$VAR\{Y*\} = VAR\{Y\} + VAR\{U\} \qquad \text{E.11.}$$

$$E\{U\} = \frac{E\{D\}^2 + VAR\{D\}}{2 * E\{D\}} = 371{,}2 \qquad \text{E.12.}$$

$$VAR\{U\} = \frac{k_D{}^2 + 6 * k_D + 5}{12 * \alpha_D{}^2} = 189086{,}5 \qquad \text{E.13.}$$

$$E\{Y\} = E\{D\} * LT = 164 * (32 + 18 + 1 + 4) \qquad \text{E.14.}$$

$$VAR\{Y\} = \frac{k_D * LT}{\alpha_D^2} = 5217520 \qquad \text{E.15.}$$

$$E\{Y*\} = 9391{,}2 \qquad \text{E.16.}$$

$$VAR\{Y*\} = 54006607 \qquad \text{E.17.}$$

Please note that the lead time is LT=32+18+1+4 where 4 is the number of periods necessary to complete a container (850/195=4,35). For this reason, in the following it is considered q=212 units (850/4=212,5).

kY*	16,312451
alfaY*	0,001737
k/alfa	9391,2
I[k+1,s*alfa]	0,96758
I[k,s*alfa]	0,98100
I[k+1,(s+q)*alfa]	0,97220
I[k,(s+q)*alfa]	0,98390
E{Backlog End(S)}	22,7633
E{Backlog Beg(S)}	19,0508
s (units)	**14825**

Table 5.2. – Results

5.2.3 (r,S) inventory policy where S results from the standard calculation

Mohamed Zied Babai and Yves Dallery [/MohYv-05/] studied the inventory management under the forecast based approach and standard approach. Even if the forecast model is robust, the forecast obtained is an average value and does not match 100% with the real demand. So, they say in their study we must determine a measure of the forecast uncertainty. They concluded when the demand is non-stationary it is worth using forecast based inventory management but, when the demand is stationary, the two approaches result in almost identical values.

In the following SC model, I will study a stationary demand and a standard (r,S) inventory management methodology where the inventory levels are given by:

$$IL_{jt}^{RDC} = \frac{Fq_{jt}}{30} * (LT + 1) + z_{serv} * \sqrt{(LT + 1) * \sigma^2 + \mu^2 * \sigma_{LT}^2} \qquad t = 1,2,..., T \tag{E.18.}$$

$$IL_{rt} = \frac{Fq_{jt+30}}{30} * (LT_s + 1) + z_{serv} * \sqrt{(LT_s + 1) * \sigma^2} \qquad t = 1,2,..., T \tag{E.19.}$$

The inventory levels are calculated when the forecast period is shifted.

5.3 Demand Forecasting Models

The demand forecasting represents the basis for all strategic and planning decisions in a SC [/ChMeHaRi-01/]. The planning activities of one SC should be linked to the forecast. These include capacity planning, resource planning, promotion planning, purchase planning and others.

It is essential to identify the components of the demand forecast. Demand consists in a systematic and in a random component. The systematic component measures the level, the trend and the seasonality. The random part measures the fluctuation in demand from the expected value. The SC, which is discussed in this thesis, denotes a level and a trend but not seasonality of the customer demand. For this reason, and based on [/ChMeHaRi-01/], it is studied the Holt’s model. In the literature [/HTp-06/], one can found that the forecast method which returns the lower “Bullwhip Effect” is the moving average method. Based on these 2 factors, in the next chapters, it is considered the moving average model and the Holt’s model as a rolling process to forecast the customer demand.

5.4 Re-structured SC: description of the logistics processes

Customer orders are fulfilled from RDC stock. Customer orders not fulfilled are backlogged. The RDC is replenished from the production site (plant) based on a base-stock policy (up to max level – E.18.) with periodic review (r,S). The production site orders raw material from the supplier in order to replenish a buffer WH located at the production site. This inventory node also follows a base-stock policy (up to max level – E.19.) with periodic review.

The total necessary capacity of the production site is defined as follows based on sales forecast:

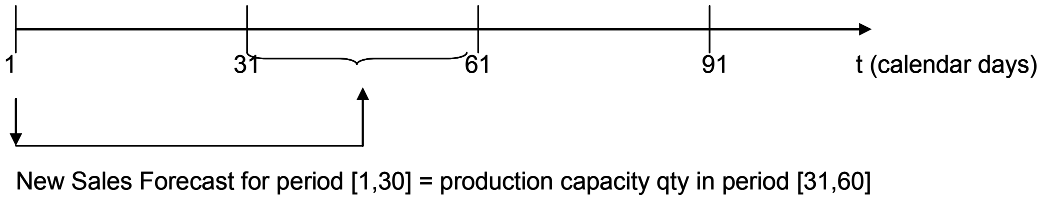


Figure 5.3. – Capacity planning: SC model

The activities take place in the following sequence:

Monthly activities (t=1, 31, 61, 91, etc):

- RDC sends a new sales forecast to the production site;
  - Production Capacity (for the production site) is defined according to Fig 5.3.;
  - New Inventory levels are calculated for RDC (product *j*) and for the production site (raw material *r*).

Daily activities:

- Customer demand occurs;
  - Following the customer demand, a replenishment order (of product *j*) to the production site and a replenishment order to the supplier (of raw material *r*) are released;

- Raw material *r* is booked in the buffer WH located at the production site;
- Production site produces product *j*;
- Production site delivers product *j* (only complete deliveries);
- Product *j* is booked in at RDC;
- Inventory levels, backlogs, service level, forecast accuracy and costs are calculated.

5.4 Simulation Model

5.4.1 Simulation tool: description of the model

The simulation is performed in excel (VBA) in the following way:

- The planning horizon is divided into a number of periods defined by the user (duration of a period: one day). For the one time simulation for a specific period [/KorKonSaTs-04/], the first iteration corresponds to the first day activity and the next iteration corresponds to the next day activity.
  - The percentage of sea freight is defined by an agreed rule (to allow standardization and a reliable process): if the inventory on hand at RDC is lower than xx% of the target inventory level, the next delivery is by truck.
  - Based on historical data, the forecast is generated by applying the moving average methodology. The forecast period equals thirty periods (or thirty days).
  - Inventory levels are defined according to standard inventory approach (chapter 5.2.3).
  - The production capacity is defined according to the Fig 5.3. Additional quantities (the replenishment is triggered by consumption) are automatically allowed when necessary with an extra cost.
  - Following the customer demand, a replenishment order (of product *j*) to production site and a replenishment order to supplier (of raw material *r*) are released.

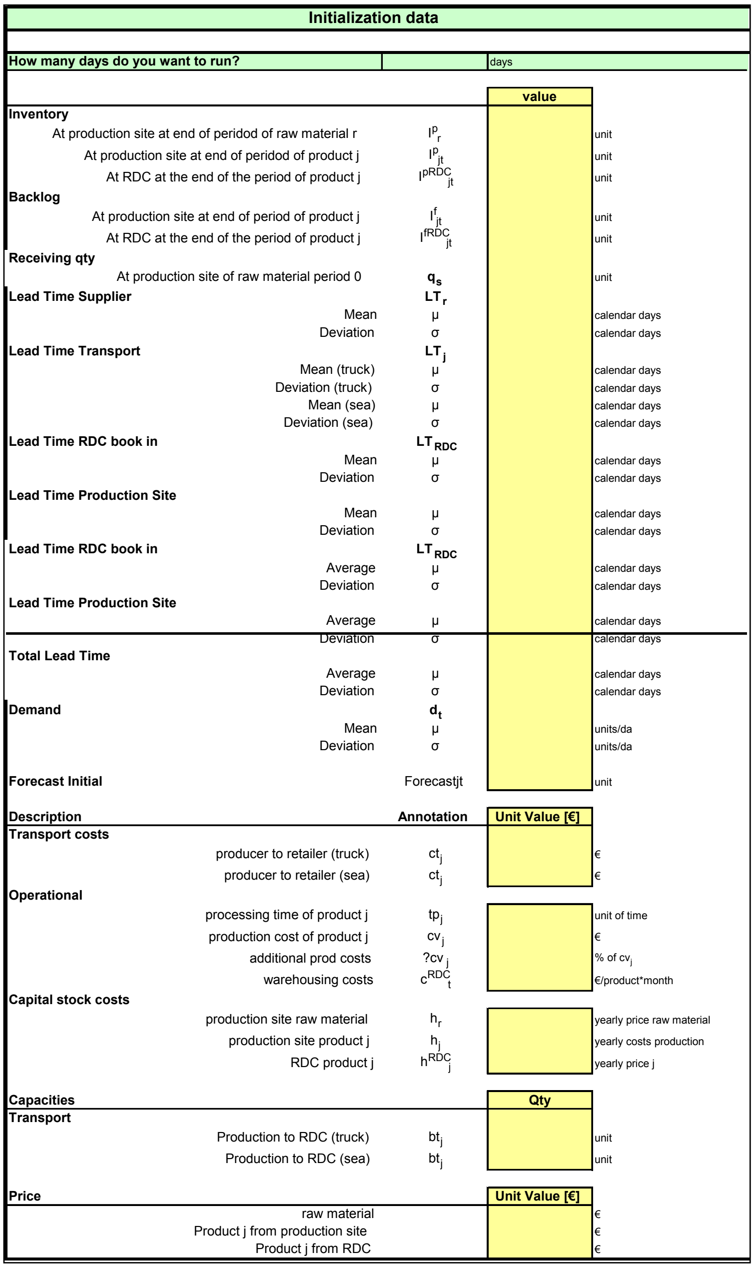
- Each period, the production site produces the product *j* and delivers to RDC.
- Each period, the supplier delivers the replenishment quantity of raw material *r*.
- Each period, product *j* is received by RDC (according the LT_j) and raw material *r* is received by production site (according to LT_s).
- At the end of each period, stock levels are recorded, demand is updated into the historical data, customer service level reported and total costs of the SC summarised.

Assumptions:

- Only one product group is considered;
  - There is a 1:1 ratio between raw material r and finished goods j;
  - The SC model is assumed to be based on a rolling horizon where the forecasts may be updated when the horizon is shifted;
  - For the demand, it is considered a stationary stochastic process. The demands of each period are i.i.d. on $[o,\infty[$. It is assumed a Gamma distributed demand with (α,k);
  - The deterministic lead time from the supplier is assumed to be equal to the transport time between supplier and producer. The suppliers' capacity is assumed to be infinite;
  - The stochastic lead time from the producer is assumed to be = planning time + process time + transportation time + waiting buffers time + storage => Replenishment time = time required from the withdraw of material at the point of availability until the material is replenished at this point of availability;
  - The production capacity is defined according to the Fig 5.3. Additional quantities (the replenishment is triggered by consumption) are automatically allowed when necessary with an extra cost (resulting in infinite capacity);
  - Deliveries are always complete trucks or sea containers. If the inventory on hand at RDC is lower than xx% of the target inventory level, the next delivery is by truck.

5.4.2 Simulation tool: Input data

The table 5.3. below presents the initialization sheet, which contains the input data for one simulation run. Ordering and backlog costs are not considered in the simulation tool.



Initialization data			
How many days do you want to run?		days	
		value	
Inventory			
At production site at end of peridod of raw material r	I^{p}_{r}		unit
At production site at end of peridod of product j	I^{p}_{jt}		unit
At RDC at the end of the period of product j	I^{pRDC}_{jt}		unit
Backlog			
At production site at end of period of product j	I^{f}_{jt}		unit
At RDC at the end of the period of product j	I^{fRDC}_{jt}		unit
Receiving qty			
At production site of raw material period 0	$\mathbf{q_s}$		unit
Lead Time Supplier	$\mathbf{LT_r}$		
Mean	μ		calendar days
Deviation	σ		calendar days
Lead Time Transport	$\mathbf{LT_j}$		
Mean (truck)	μ		calendar days
Deviation (truck)	σ		calendar days
Mean (sea)	μ		calendar days
Deviation (sea)	σ		calendar days
Lead Time RDC book in	$\mathbf{LT_{RDC}}$		
Mean	μ		calendar days
Deviation	σ		calendar days
Lead Time Production Site			
Mean	μ		calendar days
Deviation	σ		calendar days
Lead Time RDC book in	$\mathbf{LT_{RDC}}$		
Average	μ		calendar days
Deviation	σ		calendar days
Lead Time Production Site			
Average	μ		calendar days
Deviation	σ		calendar days
Total Lead Time			
Average	μ		calendar days
Deviation	σ		calendar days
Demand	$\mathbf{d_t}$		
Mean	μ		units/da
Deviation	σ		units/da
Forecast Initial	Forecastjt		unit
Description	**Annotation**	**Unit Value [€]**	
Transport costs			
producer to retailer (truck)	ct_j		€
producer to retailer (sea)	ct_j		€
Operational			
processing time of product j	tp_j		unit of time
production cost of product j	cv_j		€
additional prod costs	$?cv_j$		% of cv_j
warehousing costs	c^{RDC}_{t}		€/product*month
Capital stock costs			
production site raw material	h_r		yearly price raw material
production site product j	h_j		yearly costs production
RDC product j	h^{RDC}_{j}		yearly price j
Capacities		**Qty**	
Transport			
Production to RDC (truck)	bt_j		unit
Production to RDC (sea)	bt_j		unit
Price		**Unit Value [€]**	
raw material			€
Product j from production site			€
Product j from RDC			€

Table 5.3. – Input data: SC model

5.4.3 Simulation scenarios

The simulation[17] ran for 720 periods (approx. 2 years).

Several scenarios were created taking in consideration the aim of this thesis and its proposed questions (chapter 1.2.). The simulated scenarios are listed in the appendix 3.

- Different transport networks (by sea freight, by truck, mixed) from the producer:

  - Scenario 1: if the inventory on hand at RDC is lower than half of the target inventory level, the next delivery is by truck;

  - Scenario 2: if the inventory on hand at RDC is lower than one third of the target inventory level, the next delivery is by truck;

  - Scenario 3: if the inventory on hand at RDC is lower than one fourth of the target inventory level, the next delivery is by truck;

  - Scenario 4: only by truck;

  - Scenario 5: only by sea freight.

- Reliability of the supplying network:

  - Scenario 6: only by sea freight and LT (sea) μ= 18 days and σ = 10 days

- Impact of different Inventory Management policies:

  - Scenarios 1 to 6: Standard Inventory Management introduced by chapter 5.2.3.

  - Scenarios 7 to 11: (r,S) Inventory policy with fixed S and equal to the smallest S subject to E.4. (chapter 5.2.1.)

  - Scenarios 12 and 13: (s,q) Inventory policy discussed on chapter 5.2.2.

- Impact of short term customer demand fluctuation

    - Scenarios 1a to 7a

- Impact of different Customer Demand Forecasting

    - Scenarios 14 to 25

=> Summarising: Scenarios Overview

		Demand (Mean: 164; Deviation: 308)					**Demand (Mean: 328; Deviation: 656)**				
	Sea %	1/2	1/3	1/4	Only truck	Only Sea	1/2	1/3	1/4	Only truck	Only Sea
Forecast	**Inventory policy**										
Moving average	Standard	Scen 1	Scen 2	Scen 3	Scen 4	Scen 5 Scen 6	Scen 1a	Scen 2a	Scen 3a	Scen 4a	Scen 5a
	(r,S) where S is fixed	Scen 7 $S_j = 13945$ $S_r = 9455$	Scen 8 Sj = 13945 Sr = 9455	Scen 9 Sj = 13945 Sr = 9455	Scen 10 Sj = 12040 Sr = 9455	Scen 11 Sj = 13945 Sr = 9455	Scen 7a $S_j=30545$ $S_r=19610$	Scen 8a $S_j=30545$ $S_r=19610$	Scen 9a $S_j=30545$ $S_r=19610$	Scen 10a $S_j=26600$ $S_r=19610$	Scen 11a $S_j=30545$ $S_r=19610$
	(s,q)	-	-	-	Scen 13 s=14655 q=192	Scen 12 s=14825 q=212	-	-	-		
Holt's Model	Standard	Scen 14	Scen 15	Scen 16	Scen 17	Scen 18					
	(r,S) where S is fixed	Scen 19 $S_j = 13945$ $S_r = 9455$	Scen 20 Sj = 13945 Sr = 9455	Scen 21 Sj = 13945 Sr = 9455	Scen 22 Sj = 12040 Sr = 9455	Scen 23 Sj = 13945 Sr = 9455					
	(s,q)	-	-	-	Scen 25 s=14655 q=192	Scen 24 s=14825 q=212					

Table 5.4. – Overview Scenarios

5.4.4 Simulation experiments: results

The following tables summarise the simulated scenarios presented in the previous chapter. The first conclusions are discussed below. The comparison between the Today`s model and the SC's model will be subject of the next chapter 6.

		1/2 Scenario 1	1/3 Scenario 2	1/4 Scenario 3	0 Scenario 4	100 Scenario 5	100 Scenario 6
BullwhipEffect D-Prod		1,65	1,55	1,54	1,61	1,40	1,75
BullwhipEffect Prod-RawMat		1,35	1,27	1,24	1,19	1,24	1,27
Serv_Level	%	94,86	93,47	95,14	98,06	93,61	93,33
Total Costs	€	9.679.873,93 €	9.107.531,26 €	9.201.020,13 €	9.111.886,87 €	8.229.141,18 €	9.368.382,03 €
Daily Total Costs	€	13.444,27 €	12.649,35 €	12.779,19 €	12.655,40 €	11.429,36 €	13.011,64 €
Average IpRDCjt	units	4659	4543	4515	5566	4496	3434
Average Ipjt	units	404	415	432	382	423	421
Average Iprt	units	3606	3950	3823	3536	4261	3594
Average sales	units	5015	4770	4822	4690	4354	4990
Coverage IpRDCjt	months	0,93	0,95	0,94	1,19	1,03	0,69
GEZ RDCjt	days	24	24	24	30	26	18
Forecast Accuracy	%	1,6%	1,5%	-5,1%	-4,7%	1,1%	4,2%

---

[17] Due to confidentiality, the data does not reflect real numbers as they are divided by an arbitrary factor.

		1/2	1/3	1/4	0	100
		Scenario 1a	Scenario 2a	Scenario 3a	Scenario 4a	Scenario 5a
BullwhipEffect D-Prod		1,60	1,42	1,57	1,80	1,64
BullwhipEffect Prod-RawMat		1,40	1,37	1,37	1,38	1,11
Serv_Level	%	83,19	83,89	80,42	86,67	82,08
Total Costs	€	18.648.252,02 €	19.207.387,41 €	18.405.311,54 €	20.252.877,71 €	16.111.276,70 €
Daily Total Costs	€	25.900,35 €	26.676,93 €	25.562,93 €	28.129,00 €	22.376,77 €
Average IpRDCjt	units	7339	6805	5914	7231	6434
Average Ipjt	units	397	413	410	383	417
Average Iprt	units	7211	7566	5043	7032	5998
Average sales	units	9504	9853	9448	10287	8348
Coverage IpRDCjt	months	0,77	0,69	0,63	0,70	0,77
GEZ RDCjt	days	20	18	16	18	20
Forecast Accuracy	%	8,6%	24,9%	25,4%	23,8%	20,0%

		1/2	1/3	1/4	0	100	100	0
		Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13
BullwhipEffect D-Prod		1,63	2,57	2,27	1,42	2,08	0,07	0,04
BullwhipEffect Prod-RawMat		1,42	1,22	1,28	1,47	1,35	11,30	16,90
Serv_Level	%	92,50	92,92	92,78	97,22	92,08	100,00	99,03
Total Costs	€	10.153.318,72 €	10.925.563,26 €	10.382.267,68 €	7.712.004,14 €	8.918.371,69 €	9.071.310,77 €	9.001.231,26 €
Daily Total Costs	€	14.101,83 €	15.174,39 €	14.419,82 €	10.711,12 €	12.386,63 €	12.599,04 €	12.501,71 €
Average IpRDCjt	units	4580	4329	4414	5662	5252	9674	6087
Average Ipjt	units	407	406	397	373	426	379	360
Average Iprt	units	4570	3624	4005	5396	4748	6342	6423
Average sales	units	5299	5782	5511	3982	4719	4938	4781
Coverage IpRDCjt	months	0,86	0,75	0,80	1,42	1,11	1,96	1,27
GEZ RDCjt	days	22	19	20	36	28	50	32
Forecast Accuracy	%	9,4%	17,3%	15,6%	-11,5%	5,3%	1,7%	2,3%

		1/2	1/3	1/4	0	100
		Scenario 7a	Scenario 8a	Scenario 9a	Scenario 10a	Scenario 11a
BullwhipEffect D-Prod		3,63	2,90	3,09	2,67	2,85
BullwhipEffect Prod-RawMat		1,27	0,99	1,25	1,22	0,93
Serv_Level	%	85,56	90,42	91,11	91,25	88,06
Total Costs	€	22.380.001,22 €	18.842.343,72 €	18.821.784,62 €	19.256.112,12 €	17.892.816,55 €
Daily Total Costs	€	31.083,34 €	26.169,92 €	26.141,37 €	26.744,60 €	24.851,13 €
Average IpRDCjt	units	11441	12972	12878	10971	12269
Average Ipjt	units	388	429	404	395	443
Average Iprt	units	10191	10966	10552	11314	12130
Average sales	units	11441	9551	9531	9787	9104
Coverage IpRDCjt	months	1,00	1,36	1,35	1,12	1,35
GEZ RDCjt	days	25	35	34	29	34
Forecast Accuracy	%	18,1%	27,9%	20,3%	25,8%	21,8%

		1/2	1/3	1/4	0	100
		Scenario 14	Scenario 15	Scenario 16	Scenario 17	Scenario 18
BullwhipEffect D-Prod		1,50	1,38	1,43	1,19	1,81
BullwhipEffect Prod-RawMat		1,33	1,47	1,27	1,26	1,32
Serv_Level	%	96,67	91,94	93,61	100,00	93,89
Total Costs	€	9.414.259,02 €	9.296.294,23 €	9.573.255,25 €	7.983.187,39 €	9.981.544,63 €
Daily Total Costs	€	13.075,36 €	12.911,52 €	13.296,19 €	11.087,76 €	13.863,26 €
Average IpRDCjt	units	6187	6367	5496	6709	4960
Average Ipjt	units	389	438	419	377	432
Average Iprt	units	4967	5335	4740	3816	3749
Average sales	units	4825	4805	4945	4018	5205
Coverage IpRDCjt	months	1,28	1,32	1,11	1,67	0,95
GEZ RDCjt	days	33	34	28	43	24
Forecast Accuracy	%	-15,4%	-19,2%	-6,1%	-7,9%	0,4%

		1/2	1/3	1/4	0	100	100	0
		Scenario 19	Scenario 20	Scenario 21	Scenario 22	Scenario 23	Scenario 24	Scenario 25
BullwhipEffect D-Prod		2,30	2,14	1,92	2,07	1,92	0,07	0,06
BullwhipEffect Prod-RawMat		1,20	1,48	1,27	1,26	1,30	12,14	13,99
Serv_Level	%	97,22	89,17	95,69	98,33	95,69	98,89	100,00
Total Costs	€	10.228.358,10 €	9.193.079,98 €	9.543.958,26 €	9.451.941,86 €	9.246.068,00 €	9.140.557,54 €	8.471.946,64 €
Daily Total Costs	€	14.206,05 €	12.768,17 €	13.255,50 €	13.127,70 €	12.841,76 €	12.695,22 €	11.766,59 €
Average IpRDCjt	units	5275	5582	5019	6111	4683	5172	7242
Average Ipjt	units	373	416	408	392	394	391	345
Average Iprt	units	4817	4796	4813	4448	6172	4718	5417
Average sales	units	5345	4820	5030	4881	4906	5056	4476
Coverage IpRDCjt	months	0,99	1,16	1,00	1,25	0,95	1,02	1,62
GEZ RDCjt	days	25	30	25	32	24	26	41
Forecast Accuracy	%	-5,6%	-26,1%	-9,9%	-11,9%	-4,9%	-10,0%	-5,8%

Table 5.5. - Results of SC’s model (simulation)

=> Results overview (main messages):

- The tendency shows that the deliveries only by truck result in better SC' performance;
- The minimum total daily logistics costs was achieved with scenario 10: only by truck, with moving average forecast model and (r, S) inventory policy with S fixed and equal to the smallest S subject to E.4. ;
- Concerning the service level, the (s,q) policy returns the highest percentages for both forecast models: moving average and Holt's model.

=> Further conclusions based on the addressed questions (chapter 1.2.):

- Inventory Management policy

  . The Standard Inventory Management results in slightly higher service level and lower costs than the (r,S) inventory policy.

- Forecast model:

  . The Holt's model achieves lower forecast accuracy than the moving average model. The tendency shows: when the customer is taking less than the forecasted quantity the coverage and the total logistics costs are higher and the service level lower.

- Bullwhip Effect:

  . The Standard Inventory Management policy tends to better results than the (r,S) inventory policy. Interesting remarks go to the (s,q) inventory policy, which suggests lower variability between the RDC and the Plant (when compared to the standard or to the (r,S) inventory policies), but it results in much higher variability between the Plant and the Supplier of raw material (when compared with the same two mentioned inventory policies).

6 RESULTS

Over the previous chapters, several conclusions have already been discussed. However, it is still necessary to make an overall comparison between the Today's performance (without any improvements to the logistics processes), the best performance which can be achieved with the currently Push system, and finally, the best results reached by the re-structured SC (under the simulation conditions). Following that, the table 6.1. shows the achieved absolute results of the Today's SC and the re-structured SC.

		Today's model		SC's model	
	Sea freight %		100	0	0
		Current performance	Scenario 20	Scenario 10	Scenario 17
BullwhipEffect D-Prod		?	128,31	1,42	1,19
BullwhipEffect Prod-RawMat		?	3,20	1,47	1,26
Serv_Level	%	80,0%	95,8%	97,2%	100,0%
Daily Total Costs	€	12.810,45 €	11.875,03 €	10.711,12 €	11.087,76 €
Average IpRDCjt	units	18145	6105	5662	6709
Average Ipjt	units	832	383	373	377
Average Iprt	units	8590	13337	5396	3816
Coverage IpRDCjt	months	4,13	1,39	1,42	1,67
GEZ RDCjt	days	105	36	36	43
Forecast Accuracy	%	-136,0%	-5,2%	-11,5%	-7,9%

Table 6.1. – Overall comparison

By using an Inventory Management policy the Today's SC can decrease by 8% the total logistics costs and increase by 20% the service level. Of course, in a more and more competitive world, the simulation results clearly show that the SC must develop to a Push-Pull system (20% less total logistics costs and 25% improvement of the service level).

Finally, the first main conclusion is the importance of an adequate demand forecast method and a systematic inventory management in both: the Push and Push-Pull system, for achieving a higher SC performance. Of course, the second main conclusion is that an SC following a Push-Pull system results in lower total costs and almost eliminates the negative effect of the increasing variability of the orders along the SC.

7 SUMMARY AND OUTLOOK

In this thesis, the non-satisfactory performance of a SC, which follows a Push system strategy, was analysed. Some improvements regarding the inventory management policy were proposed and have been examined in simulation experiments. The performance was evaluated by the trade off between the service level towards the customer and the total logistics costs. The impact of changing certain parameters, such as the short term demand fluctuation and the non-reliability of the lead time, was also simulated.

In the second part of this thesis, the SC was redesigned to a Push-Pull system strategy, performing much better when compared to Today's situation. Several analyses concerning the best inventory policy to apply to the proposed SC were made.

The problem of managing inventories and optimisation of the total SC (production, warehousing and distribution) is difficult to solve analytically. For this reason, the simulation achieves an important role helping the decision makers to evaluate concrete SC problems (in the strategic and operational level).

The thesis is concentrated on the operational level and taking an existing SC, which currently performs badly, several improvement possibilities of the SC's performance were simulated. The elements: Inventory Management, Demand Forecasting, Push vs Pull system, value of the "Information Sharing" assumed an important role. The analyses were based on several studies in the area of Inventory Management and optimisation of a SC under uncertainty, mainly the book "Inventory Management in Supply Networks: Problems, Models and Solutions 2006" - [/HTp-06/].

After this thesis, the fundamental conclusions are the following:

- The first key factor for improving the SC's performance is an adequate demand forecasting methodology and Inventory Management policy (as they are the pillars for stock reduction and service level increasing);
- The second is the fact that the uncertainties of a SC must be known and taken into the inventory levels calculation;
- The "Information Sharing" assumes an important role when optimising the production capacity, inventory levels and transport network planning;
- From the range of inventory policies available in the literature, one should decide:
    - If the demand is non-stationary, maybe a forecast based inventory approach fits better;
    - If it is important to synchronise ordering activities, maybe an (r,S) inventory policy results in lean logistics processes;
    - If the levelling of the production quantities assumes a high importance, the (s,q) inventory policy could give us the solution;
- A lean process is clearly achieved when a Pull system is established between the RDC, the production site and the supplier. Contrary to certain opinions in real life, even in presence of high customer demand fluctuations, the production site will have its production quantity stabilised by following the customer takt. The overall benefit is shown by the increasing of SC's performance and higher profit;
- The "Bullwhip Effect" can not be completely eliminated. It is examined in this thesis, certain tools to reduce the amplification of the orders along the SC, such as, the Information Sharing, the Demand Forecasting method, the positive impact of the Push-Pull system strategy and the Inventory Management.

In this thesis, the production site has infinite capacity (additional production quantities were allowed by incurring in extra costs). As explained by [/HTp-06/], the main reason for the unpredictability of an order's actual production flow time is the fact that the production capacity is not infinite but limited in resources. A further investigation of this thesis would be to consider the production capacity finite and to compare the results (knowing that the ranking position of each simulation experiment is not changed due to this).

Finally, one suggestion for further research is the enlargement of the SC to more customers and more LDC[18]'s, in order to study the impact of the aggregated forecasts in the SC's performance. As well, it could be also useful to evaluate the effect of positioning the Push-Pull boundary closer to the customer and closer to the supplying unit.

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[18] LDC: Local Distribution Center

8 APPENDIXES

A.1 Literature

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A.2 Appendix

1 – Scenario (e.g): Today's model

2 – Results of the S calculation

3 – Scenario (e.g): SC's model

4 – Simulation in VBA (e.g.): Today's model

5 – Simulation in VBA (e.g.): SC' model

Initialization data

How many days do you want to run?	**720**	days
% Sea Freight	**0**	%

Run Simulation

At production site at end of peridod of raw material r	I^{p}_{rt}	3500	units
At production site at end of peridod of product j	I^{p}_{jt}	500	units
At RDC at the end of the period of product j	I^{pRDC}_{jt}	5000	units
Backlog			
At production site at end of period of product j	I^{f}_{jt}	0	units
At RDC at the end of the period of product j	I^{fRDC}_{jt}	0	units
Lead Time Supplier	**LT_r**		
Average	μ	30	calendar days
Deviation	σ	0	calendar days
Lead Time Transport	**LT_j**		
Average (truck)	μ	9	calendar days
Deviation (truck)	σ	1	calendar days
Average (sea)	μ	18	calendar days
Deviation (sea)	σ	5	calendar days
Demand	**d_t**		
Average	μ	**164**	units/day
Deviation	σ	**308**	units/day
Forecast Initial		4000	units
NETr and NETj Initial		4000	units

Lead Time RDC book in	**LT_{RDC}**	
Average	μ	1
Deviation	σ	0,5
Lead Time Production Site		
Average	μ	2
Deviation	σ	0,5

Description	**Annotation**	**Unit Value [€]**	
Transport costs			
producer to retailer (truck)	ct_j	3200	€
producer to retailer (sea)	ct_j	1900	€
Operational			
processing time of product j	tp_j	1	unit of time
production cost of product j	cv_j	70	€
additional prod costs	Δcv_j	1,5	% of cv_j
warehousing costs	c^{RDC}_{t}	1,2	€/product*month
Capital stock costs			
production site raw material	h_r	8%	yearly price raw material
production site product j	h_j	8%	yearly costs production
RDC product j	h^{RDC}_{j}	8%	yearly price j

Capacities		**Qty**	
Transport			
Production to RDC (truck)	bt_j	770	units
Production to RDC (sea)	bt_j	850	units

Price	**Unit Value [€]**	
raw material	50	€
Product j from production site	85	€
Product j from RDC	100	€

Calculate S: (r, s) Inventory Policy

Todaymodel =>optimizar S level para (r,S) e Beta = 98%

Demand Data:

Mean	164
Deviation	308

$\alpha_D=\alpha_Y=\alpha_Z$	0,001728791		
Shape	KD	KZ=KD*(R+LT)	KY=KD*LT
	0,283521673		

	LT							
RT	**Prod**	**Transp**	**WH**	**Total**	**$\alpha_D=\alpha_Y=\alpha_Z$**	**k_D**	**k_Y**	**k_Z**
30	2	18	1	21	0,00173	0,28352	5,95396	14,45961
30	2	9	1	12	0,00173	0,28352	3,40226	11,90791
1	32	18	1	51	0,00173	0,28352	14,45961	14,74313
				0				

S
11702
9903
13925

RT	β	left side eq.	k_Y/α	k_Z/α	Gamma k_Z+1	Gamma k_Y+1	Gamma k_Z	Gamma k_Y	E{Backlog End(S)} z	E{Backlog Beg(S)} y	Dif	S
30	98%	**98,4**	3444	8364	0,8829785988	0,9997954720	0,92476	0,99994	98,35169	0,04192	**98,30977**	**11700**
30	98%	**98,4**	1968	6888	0,8760417590	0,9999302043	0,92323	0,99999	93,58040	0,00859	**93,57181**	**9900**
1	98%	**3,3**	8364	8528	0,9709068443	0,9750885816	0,98354	0,98616	18,93253	15,63287	**3,29966**	**13925**

Calculate S: (r, s) Inventory Policy

Todaymodel =>optimizar S level para (r,S) e Beta = 98%

Demand Data:

Mean	328
Deviation	656

$\alpha_D=\alpha_Y=\alpha_Z$	0,000762195		
Shape	KD	KZ=KD*(R+LT)	KY=KD*LT
	0,25		

	LT							
RT	**Prod**	**Transp**	**WH**	**Total**	**$\alpha_D=\alpha_Y=\alpha_Z$**	**k_D**	**k_Y**	**k_Z**
30	2	18	1	21	0,00076	0,25000	5,25000	12,75000
30	2	9	1	12	0,00076	0,25000	3,00000	10,50000
1	32	18	1	51	0,00076	0,25000	12,75000	13,00000
				0				

S
24076
20294
28697

RT	β	left side eq.	k_Y/α	k_Z/α	Gamma k_Z+1	Gamma k_Y+1	Gamma k_Z	Gamma k_Y	E{Backlog End(S)} z	E{Backlog Beg(S)} y	Dif	S
30	98%	**196,8**	6888	16728	0,8872603952	0,9996587417	0,92985	0,99991	196,94962	0,15084	**196,7988**	**24075**
30	98%	**196,8**	3936	13776	0,8756258228	0,9998557623	0,92527	0,99997	196,80605	0,03860	**196,7675**	**20295**
1	98%	**6,6**	16728	17056	0,9705599620	0,9745154542	0,98390	0,98632	40,19441	33,59619	**6,5982**	**28700**

Calculate S: (r, s) Inventory Policy

SCmodel =>optimizar S level para (r,S) e Beta = 98%

Demand Data:

Mean	164
Deviation	308

$\alpha_D=\alpha_Y=\alpha_Z$	0,001728791		
Shape	KD	KZ=KD*(R+LT)	KY=KD*LT
	0,283521673		

	LT							
RT	**Prod**	**Transp**	**WH**	**Total**	**$\alpha_D=\alpha_Y=\alpha_Z$**	**k_D**	**k_Y**	**k_Z**
1	32	18	1	51	0,00173	0,28352	14,45961	14,74313
1	32	9	1	42	0,00173	0,28352	11,90791	12,19143
1	30	0	0	30	0,00173	0,28352	8,50565	8,78917

S
13925
12038
9455

RT	β	left side eq.	k_Y/α	k_Z/α	Gamma k_Z+1	Gamma k_Y+1	Gamma k_Z	Gamma k_Y	E{Backlog End(S)} z	E{Backlog Beg(S)} y	Dif	S
1	98%	**3,3**	8364	8528	0,97091	0,97509	0,98354	0,98616	18,93253	15,63287	**3,29966**	**13925**
1	98%	**3,3**	6888	7052	0,96995	0,97461	0,98384	0,98664	17,41505	14,11773	**3,29733**	**12040**
1	98%	**3,3**	4920	5084	0,96824	0,97381	0,98451	0,98761	15,00253	11,73095	**3,27158**	**9455**

Calculate S: (r, s) Inventory Policy

SCmodel =>optimizar S level para (r,S) e Beta = 98%

Demand Data:

Mean	328
Deviation	656

$\alpha_D=\alpha_Y=\alpha_Z$	0,000762195		
Shape	KD	KZ=KD*(R+LT)	KY=KD*LT
	0,25		

	LT							
RT	**Prod**	**Transp**	**WH**	**Total**	**$\alpha_D=\alpha_Y=\alpha_Z$**	**k_D**	**k_Y**	**k_Z**
1	32	18	1	51	0,00076	0,25000	12,75000	13,00000
1	32	9	1	42	0,00076	0,25000	10,50000	10,75000
1	30	0	0	30	0,00076	0,25000	7,50000	7,75000
				0				

S
30545
26600
19610

RT	β	left side eq.	k_Y/α	k_Z/α	Gamma k_Z+1	Gamma k_Y+1	Gamma k_Z	Gamma k_Y	E{Backlog End(S)} z	E{Backlog Beg(S)} y	Dif	S
1	98%	**6,6**	16728	17056	0,98477	0,98699	0,99211	0,99339	18,86032	15,56947	**3,2909**	**30545**
1	98%	**6,6**	13776	14104	0,98419	0,98667	0,99227	0,99363	17,39523	14,10233	**3,2929**	**26600**
1	98%	**6,6**	9840	10168	0,96757	0,97288	0,98482	0,98769	32,05753	25,46864	**6,5889**	**19610**

Initialization data

How many days do you want to run?	**720**	days
How much % of sea deliveries?		%

Run Simulation

	Annotation	Time 0	
Inventory			
At production site at end of peridod of raw material r	I^{p}_{rt}	3500	units
At production site at end of peridod of product j	I^{p}_{jt}	500	units
At RDC at the end of the period of product j	I^{pRDC}_{jt}	5000	units
Backlog			
At production site at end of period of product j	I^{f}_{jt}	0	units
At RDC at the end of the period of product j	I^{fRDC}_{jt}	0	units
Receiving qty			
At production site of raw material period 0	$\mathbf{q_{st}}$	5000	
At RDC at period 0	Goods in (qt)	0	
Lead Time Supplier	$\mathbf{LT_r}$		
Average	μ	30	calendar days
Deviation	σ	0	calendar days
Lead Time Transport	$\mathbf{LT_j}$		
Average (truck)	μ	9	calendar days
Deviation (truck)	σ	1	calendar days
Average (sea)	μ	18	calendar days
Deviation (sea)	σ	5	calendar days
Demand	$\mathbf{d_t}$		
Average	μ	164	units/day
Deviation	σ	308	units/day
Forecast Initial	Forecast_{jt}	4000	units

Lead Time RDC book in	$\mathbf{LT_{RDC}}$		
Average	μ	1	calendar days
Deviation	σ	0,5	calendar days
Lead Time Production Site			
Average	μ	32	calendar days
Deviation	σ	0,5	calendar days
Total			
Average	μ	51	calendar days
Deviation	σ	6	calendar days

Description	Annotation	Unit Value [€]	
Transport costs			
producer to retailer (truck)	ct_j	3200	€
producer to retailer (sea)	ct_j	1900	€
Operational			
processing time of product j	tp_j	1	unit of time
production cost of product j	cv_j	70	€
additional prod costs	Δcv_j	1,5	% of cv_j
warehousing costs retailer	c^{RDC}_{t}	1,8	€/month
Capital stock costs			
production site raw material	h_r	8%	yearly price raw material
production site product j	h_j	8%	yearly costs production
RDC product j	h^{RDC}_{j}	8%	yearly price j

Capacities		Qty	
Transport			
Production to RDC (truck)	bt_j	770	units
Production to RDC (sea)	bt_j	850	units

Price		Unit Value [€]	
raw material		50	€
Product j from production site		85	€
Product j from RDC		100	€

```
Private Sub cmd_RunSim_Click()
Dim P As Long
'P counts period to be updated

   Sheets("Quantities").Select
   ActiveSheet.Range("A4:L4").Select
   ActiveSheet.Range(Selection, Selection.End(xlDown)).Select
   Selection.ClearContents
   Sheets("INVPOS").Select
   ActiveSheet.Range("A5:H5").Select
   ActiveSheet.Range(Selection, Selection.End(xlDown)).Select
   Selection.ClearContents
   Sheets("Forecast data").Select
   ActiveSheet.Range("A4:G4").Select
   ActiveSheet.Range(Selection, Selection.End(xlDown)).Select
   Selection.ClearContents
   Sheets("Historical_data").Select
   ActiveSheet.Range("H26:J26").Select
   ActiveSheet.Range(Selection, Selection.End(xlDown)).Select
   Selection.ClearContents
   Sheets("= Costs").Select
   ActiveSheet.Range("B4:I4").Select
   ActiveSheet.Range(Selection, Selection.End(xlDown)).Select
   Selection.ClearContents
   ActiveSheet.Range("A3").Select
   ActiveSheet.Range(Selection, Selection.End(xlDown)).Select


'' disconnects automatic recalculation
   With Application
         .Calculation = xlManual
         .MaxChange = 0.001
   End With
   ActiveWorkbook.PrecisionAsDisplayed = False

   'Reads number of periods to create
   Periodos = Sheet1.Range("B3").Value

   If Periodos > 65000 Then
      MsgBox "Simulation can only run to a maximum of 65000 periods", vbCritical, "Error"
      End
   End If

   'Fills in t periods defined in sheet Input data
   For J = 4 To Periodos + 3
      'Sheet5.Activate
      Sheet5.Range("A" & J & "").Value = J - 3
      If J < Periodos + 4 Then
         Sheet6.Range("A" & J - 1 & "").Value = J - 3
      End If
   Next J
```

```
    'calulates number of periods for Hist data and forecast data
    If Periodos Mod 30 = 0 Then
        m_periodos = Periodos / 30
    Else
        m_periodos = Round(Periodos / 30) + 1
    End If

    Conta = 1

    For P = 1 To m_periodos

        If Conta <> 1 Then
            'calculates Forecast Data one Period
            Sheet2.Activate
            Sheet2.Range("A" & 3 + P & "").Value = 30 * P + 1 - 30
            Sheet2.Range("B" & P + 3 & "").Select
            ActiveCell.FormulaR1C1 = _
                "=ROUNDUP((1/24)*SUM(Historical_data!R[-2]C[8]:R[21]C[8]),0)"
            Sheet2.Range("D" & P + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=(RC[-2]*1.5)"
            Sheet2.Range("C" & P + 3 & "").Select
            'ActiveCell.FormulaR1C1 = "=MAX(RC[-1]-(INVPOS!RC[1]-RC[1]),0)"
            ActiveCell.FormulaR1C1 = "=MAX(24075-(INVPOS!RC[-1]+INVPOS!RC[4]+R[-
2]C[0]-RC[-1]),0)"
            Sheet2.Range("E" & P + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=R[-1]C[-2]+INVPOS!RC[2]-'Quantities'!R[" & 30 - P +
P * 30 - 60 & "]C[2]"
            Sheet2.Range("G" & P + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=MAX(RC[-2]*1.5,0)"
            Sheet2.Range("F" & P + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=MAX(RC[-1]+RC[1]-INVPOS!RC[2],0)"
            Sheet2.Range("B" & P + 3 & ":G" & P + 3 & "").Select
           ' Selection.Copy
            'Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
             '   :=False, Transpose:=False
        End If

            'Fills in Quantities 30 periods
            For i = 1 To 30

                If Conta = 1 And i = 1 Then
                    'calculates Forecast Data one Period
                    Sheet2.Activate
                    Sheet2.Range("A" & 3 + P & "").Value = P
                    Sheet2.Range("B" & P + 3 & "").Select
                    ActiveCell.FormulaR1C1 = _
                        "=ROUNDUP((1/24)*SUM(Historical_data!R[-2]C[8]:R[21]C[8]),0)"
                    Sheet2.Range("D" & P + 3 & "").Select
                    ActiveCell.FormulaR1C1 = "=(RC[-2]*1.5)"
                    Sheet2.Range("C" & P + 3 & "").Select
```

```
        'ActiveCell.FormulaR1C1 = "=MAX(RC[-1]-(INVPOS!RC[1]-RC[1]),0)"
        ActiveCell.FormulaR1C1 = "=MAX(24075-(INVPOS!RC[-
1]+INVPOS!RC[4]+R[-1]C[0]-RC[-1]),0)"
        Sheet2.Range("E" & P + 3 & "").Select
        ActiveCell.FormulaR1C1 = _
           "=R[-1]C[-2]-'Input data'!R[6]C[-2]+'Input data'!R[9]C[-2]"
        Sheet2.Range("G" & P + 3 & "").Select
        ActiveCell.FormulaR1C1 = "=MAX(RC[-2]*1.5,0)"
        Sheet2.Range("F" & P + 3 & "").Select
        ActiveCell.FormulaR1C1 = "=MAX(RC[-1]+RC[1]+RC-INVPOS!RC[2],0)"
        Sheet2.Range("B" & P + 3 & ":G" & P + 3 & "").Select
        Selection.Copy
        Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
           :=False, Transpose:=False
        M_Hist_Qty = M_Hist_Qty + Sheet4.Range("B4").Value
        Sheet5.Activate

        'Preenche 1ª coluna A
        Sheet5.Range("C" & Conta + 3 & "").Select
        ActiveCell.FormulaR1C1 = _
           "=MAX('Input data'!R[7]C-'Demand&Leadtime data'!R4C2-'Input
data'!R[10]C,0)"
        Sheet5.Range("D" & Conta + 3 & "").Select
        ActiveCell.FormulaR1C1 = _
           "=IF(RC[-1]>0,0,RC[-2]+'Input data'!R[7]C[-1]-'Demand&Leadtime
data'!R4C2-'Input data'!R[10]C[-1])"
        Sheet5.Range("K" & Conta + 3 & "").Select
        ActiveCell.Formula = "='Forecast data'!F" & P + 2 & "/30"
        Sheet5.Range("E" & Conta + 3 & "").Select
        ActiveCell.Formula = "='Forecast data'!E" & P + 3 & "/30"
        Sheet5.Range("F" & Conta + 3 & "").Select
        ActiveCell.FormulaR1C1 = _
           "=IF('Input data'!R9C3+RC[5]>RC[-1],RC[-1],'Input data'!R9C3+RC[5])"
        Sheet5.Range("G" & Conta + 3 & "").Select
        ActiveCell.FormulaR1C1 = "='Input data'!R10C3+'Quantities'!RC[-1]-RC[3]"
        Sheet5.Range("H" & Conta + 3 & "").Select
        ActiveCell.FormulaR1C1 = _
            "='Input data'!R[9]C[-5]+'Quantities'!RC[-3]-'Quantities'!RC[-2]"
        Sea = Sheet4.Range("J2").Value
        Sheet5.Range("I" & Conta + 3 & "").Select
        If Sea = 1 Then
           Lead_time = Sheet4.Range("f4").Value
           ActiveCell.FormulaR1C1 = "=(RC[-3]+'Input data'!R10C3)/'Input
data'!R46C3"
           Sheet5.Range("J" & Conta + 3 & "").Select
           ActiveCell.FormulaR1C1 = _
              "=IF(RC[-1]>1,ROUNDDOWN((RC[-4]+'Input data'!R[6]C[-7])/'Input
data'!R[42]C[-7],0),0)"
           Sheet5.Range("L" & Conta + 3 & "").Select
           ActiveCell.FormulaR1C1 = _
              "='Input data'!R9C3+'Quantities'!RC[-1]-'Quantities'!RC[-6]"
```

```
                        Sheet5.Calculate
                    Else
                        Lead_time = Sheet4.Range("e4").Value
                        ActiveCell.FormulaR1C1 = "=(RC[-3]+'Input data'!R10C3)/'Input
data'!R45C3"
                        Sheet5.Range("J" & Conta + 3 & "").Select
                        ActiveCell.FormulaR1C1 = _
                            "=IF(RC[-1]>=1,ROUNDDOWN((RC[-4]+'Input data'!R[6]C[-7])/'Input
data'!R[41]C[-7],0),0)"
                        Sheet5.Range("L" & Conta + 3 & "").Select
                        ActiveCell.FormulaR1C1 = _
                            "='Input data'!R9C3+'Quantities'!RC[-1]-'Quantities'!RC[-6]"
                        Sheet5.Calculate
                    End If
                    Act_Linha = Sheet5.Range("A" & Conta + 3 & "").Value
                    If Sheet5.Range("J" & Conta + 3 & "").Value <> 0 And Lead_time + Act_Linha
< Periodos Then
                        Q1 = Sheet5.Range("J" & Conta + 3 & "").Value
                        ActiveSheet.Columns("A:A").Select
                        Selection.Find(What:=Lead_time + Act_Linha, After:=ActiveCell,
LookIn:=xlFormulas, LookAt _
                            :=xlPart, SearchOrder:=xlByRows, SearchDirection:=xlNext, MatchCase:=
_
                            False, SearchFormat:=False).Activate
                        Linha_Update = ActiveCell.Row
                        Old_update_value = 0
                        Old_update_value = ActiveSheet.Range("b" & Linha_Update & "").Value
                        'ActiveSheet.Range("b" & Linha_Update & "").Select
                        ActiveSheet.Range("b" & Linha_Update & "").Value = Q1 +
Old_update_value
                    End If
                    Sheet5.Range("A" & Conta + 3 & ":L" & Conta + 3 & "").Select
                    Selection.Copy
                    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
                        :=False, Transpose:=False
                    Conta = Conta + 1
                    Sheet4.Calculate
                ElseIf Conta < Periodos + 1 Then
                    Sheet5.Activate
                    M_Hist_Qty = M_Hist_Qty + Sheet4.Range("B4").Value


                    'Preenche 1ª coluna C
                    Sheet5.Range("C" & Conta + 3 & "").Select
                    ActiveCell.FormulaR1C1 = _
                        "=MAX(R[-1]C+RC[-1]-'Demand&Leadtime data'!R4C2-R[-1]C[1],0)"
                    Sheet5.Range("D" & Conta + 3 & "").Select
                    ActiveCell.FormulaR1C1 = _
                        "=IF(RC[-1]>0,0,ABS(R[-1]C[-1]+RC[-2]-R[-1]C-'Demand&Leadtime
data'!R4C2))"
                    Sheet5.Range("K" & Conta + 3 & "").Select
```

```
            ActiveCell.Formula = "='Forecast data'!F" & P + 2 & "/30"
            Sheet5.Range("E" & Conta + 3 & "").Select
            ActiveCell.Formula = "='Forecast data'!E" & P + 3 & "/30"
            Sheet5.Range("F" & Conta + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=IF(R[-1]C[6]+RC[5]>RC[-1],RC[-1],R[-
1]C[6]+RC[5])"
            Sheet5.Range("G" & Conta + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=R[-1]C+RC[-1]-RC[3]"
            Sheet5.Range("H" & Conta + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=R[-1]C+RC[-3]-RC[-2]"
            Sea = Sheet4.Range("J2").Value
            Sheet5.Range("I" & Conta + 3 & "").Select
            If Sea = 1 Then
               Lead_time = Sheet4.Range("f4").Value
               ActiveCell.FormulaR1C1 = "=(RC[-3]+R[-1]C[-2])/'Input data'!R46C3"
               Sheet5.Range("J" & Conta + 3 & "").Select
               ActiveCell.FormulaR1C1 = _
                  "=IF(RC[-1]>=1,ROUNDDOWN(((RC[-4]+R[-1]C[-3])/'Input
data'!R46C3),0)*'Input data'!R46C3,0)"
               Sheet5.Range("L" & Conta + 3 & "").Select
               ActiveCell.FormulaR1C1 = "=R[-1]C+RC[-1]-RC[-6]"
               Sheet5.Calculate
            Else
               Lead_time = Sheet4.Range("e4").Value
               ActiveCell.FormulaR1C1 = "=(RC[-3]+R[-1]C[-2])/'Input data'!R45C3"
               Sheet5.Range("J" & Conta + 3 & "").Select
               ActiveCell.FormulaR1C1 = _
                  "=IF(RC[-1]>1,ROUNDDOWN(((RC[-4]+R[-1]C[-3])/'Input
data'!R45C3),0)*'Input data'!R45C3,0)"
               Sheet5.Range("L" & Conta + 3 & "").Select
               ActiveCell.FormulaR1C1 = "=R[-1]C+RC[-1]-RC[-6]"
               Sheet5.Calculate
            End If
            Act_Linha = Sheet5.Range("A" & Conta + 3 & "").Value
            If Sheet5.Range("J" & Conta + 3 & "").Value <> 0 And Lead_time + Act_Linha
< Periodos Then
               Q1 = Sheet5.Range("J" & Conta + 3 & "").Value
               ActiveSheet.Columns("A:A").Select
               Selection.Find(What:=Lead_time + Act_Linha, After:=ActiveCell,
LookIn:=xlFormulas, LookAt _
                  :=xlPart, SearchOrder:=xlByRows, SearchDirection:=xlNext, MatchCase:=
_
                  False, SearchFormat:=False).Activate
               Linha_Update = ActiveCell.Row
               Old_update_value = 0
               Old_update_value = ActiveSheet.Range("b" & Linha_Update & "").Value
               'ActiveSheet.Range("b" & Linha_Update & "").Select
               ActiveSheet.Range("b" & Linha_Update & "").Value = Q1 +
Old_update_value
            End If
            Sheet5.Range("A" & Conta + 3 & ":L" & Conta + 3 & "").Select
```

```
                    Selection.Copy
                    Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
                        :=False, Transpose:=False
                    Conta = Conta + 1
                    Sheet4.Calculate
                End If
            Next i

        If P <> 1 Then
            'calculates InvPos One Period
            Sheet3.Activate
            Sheet3.Range("A" & 4 + P & "").Value = 30 * P
            Sheet3.Range("B" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = "=Quantities!R[" & 29 - P + P * 30 - 30 & "]C[1]"
            Sheet3.Range("C" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = "=Quantities!R[" & 29 - P + P * 30 - 30 & "]C[1]"
            Sheet3.Range("D" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = "=RC[-2]+RC[1]-RC[-1]"
            Sheet3.Range("E" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = "=SUM('Forecast data'!R[" & -1 - P & "]C[-2]:R[-2]C[-
2])-SUM(Quantities!R[" & -P & "]C[-3]:R[" & 29 - P + P * 30 - 30 & "]C[-3])"
            Sheet3.Range("F" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = "=Quantities!R[" & 29 - P + P * 30 - 30 & "]C[6]"
            Sheet3.Range("G" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = _
                "='Forecast data'!R[-2]C[-4]-SUM(Quantities!R[" & -1 - P + P * 30 - 29 &
"]C[3]:R[" & 29 - P + P * 30 - 30 & "]C[3])+R[-1]C"
            Sheet3.Range("H" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = "=RC[-2]-Quantities!R[" & 29 - P + P * 30 - 30 & "]C"
        Else
            Sheet3.Activate
            Sheet3.Range("A" & 4 + P & "").Value = 30 * P
            Sheet3.Range("B" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = "=Quantities!R[" & 29 - P + P * 30 - 30 & "]C[1]"
            Sheet3.Range("C" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = "=Quantities!R[28]C[1]"
            Sheet3.Range("D" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = "=RC[-2]+RC[1]-RC[-1]"
            Sheet3.Range("E" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = "=SUM('Forecast data'!R[" & -1 - P & "]C[-2]:R[-2]C[-
2])-SUM(Quantities!R[" & -P & "]C[-3]:R[" & 29 - P + P * 30 - 30 & "]C[-3])"
            Sheet3.Range("F" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = "=Quantities!R[28]C[6]"
            Sheet3.Range("G" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = _
                "='Forecast data'!R[-2]C[-4]-SUM(Quantities!R[-1]C[3]:R[28]C[3])+R[-1]C"
            Sheet3.Range("H" & 4 + P & "").Select
            ActiveCell.FormulaR1C1 = "=RC[-2]-Quantities!R[28]C"
        End If

        'calculate Hist data one period
```

```
        Sheet8.Activate
        Sheet8.Range("H" & 25 + P & "").Select
        ActiveCell.Value = 30 * P
        Sheet8.Range("I" & 25 + P & "").Select
        ActiveCell.Value = P
        Sheet8.Range("J" & 25 + P & "").Select
        ActiveCell.Value = M_Hist_Qty
'        Selection.Copy
'        Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
'            :=False, Transpose:=False

        'puts to 0 the Monthly qty after update historical data
        M_Hist_Qty = 0
        Calculate
        Sheet4.Calculate


    Next P

    'Builds up Costs sheet
    Sheet6.Select
    Sheet6.Range("B3:I3").Select
    Selection.AutoFill Destination:=ActiveSheet.Range("B3:I65100")
    'connects automatic recalculation
    With Application
        .Calculation = xlAutomatic
        .MaxChange = 0.001
    End With
    ActiveWorkbook.PrecisionAsDisplayed = False

End Sub

Private Sub Worksheet_SelectionChange(ByVal Target As Range)

End Sub
```

```
Private Sub Cmd_RunSim_Click()
'P counts period to be updated
Dim P As Long

'For y = 1 To Sheet2.Range("B2").Value

        'Cleans the file before starting a new simulation
        Sheets("Quantities").Select
        ActiveSheet.Range("A4:T4").Select
        ActiveSheet.Range(Selection, Selection.End(xlDown)).Select
        Selection.ClearContents
        Sheets("Forecast data").Select
        ActiveSheet.Range("A4:D4").Select
        ActiveSheet.Range(Selection, Selection.End(xlDown)).Select
        Selection.ClearContents
        Sheets("Historical_data").Select
        ActiveSheet.Range("I26:J26").Select
        ActiveSheet.Range(Selection, Selection.End(xlDown)).Select
        Selection.ClearContents
        Sheets("= Costs").Select
        ActiveSheet.Range("B4:I4").Select
        ActiveSheet.Range(Selection, Selection.End(xlDown)).Select
        Selection.ClearContents
        ActiveSheet.Range("A3").Select
        ActiveSheet.Range(Selection, Selection.End(xlDown)).Select
        Selection.ClearContents
'        ActiveSheet.Range("I4").Select
'        ActiveSheet.Range(Selection, Selection.End(xlDown)).Select
'        Selection.ClearContents


    '' disconnects automatic recalculation
        With Application
            .Calculation = xlManual
            .MaxChange = 0.001
        End With
        ActiveWorkbook.PrecisionAsDisplayed = False

        'Reads number of periods to create
        Periodos = Sheet2.Range("B3").Value

        If Periodos > 65000 Then
            MsgBox "Simulation can only run to a maximum of 65000 periods", vbCritical,
"Error"
            End
        End If

        'Fills in t periods defined in sheet Input data
        For J = 4 To Periodos + 3
            Sheet6.Range("A" & J & "").Value = J - 3
            If J < Periodos + 4 Then
```

```
        Sheet7.Range("A" & J - 1 & "").Value = J - 3
      End If
    Next J

    'calulates number of periods for Hist data and forecast data
    If Periodos Mod 30 = 0 Then
      m_periodos = Periodos / 30
    Else
      m_periodos = Round(Periodos / 30) + 1
    End If

    Conta = 1

    For P = 1 To m_periodos

      If Conta <> 1 Then
        'calculates Forecast Data one Period
        Sheet3.Activate
        Sheet3.Range("A" & 3 + P & "").Value = 30 * P + 1 - 30
        Sheet3.Range("B" & P + 3 & "").Select
        'ActiveCell.FormulaR1C1 = _
        '    "=ROUNDUP((1/24)*SUM(Historical_data!R[-2]C[8]:R[21]C[8]),0)"
        ActiveCell.FormulaR1C1 = "= R[-1]C[4]+R[-1]C[5]"
        Sheet3.Range("D" & P + 3 & "").Select
        'ActiveCell.FormulaR1C1 = _
        '    "=RC[-
2]/30*(IN!R19C3+1)+2.33*SQRT((IN!R19C3+1)*IN!R28C3*IN!R28C3)"
        'new line
        ActiveCell.Value = 9455
        'Sheet3.Range("C" & P + 3 & "").Select
        'ActiveCell.FormulaR1C1 = _
        '    "=RC[-
1]/30*(IN!R28C8+1)+2.33*SQRT((IN!R28C8+1)*IN!R28C3*IN!R28C3+IN!R27C3*IN!R2
7C3*IN!R23C3*IN!R29C8)"
        'new line
        'ActiveCell.Value = 13950
'        Sheet3.Range("B" & P + 3 & ":D" & P + 3 & "").Select
'        Selection.Copy
'        Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
'          :=False, Transpose:=False
         Sheet3.Range("F" & P + 3 & "").Select
         ActiveCell.FormulaR1C1 = "= 'Forecast data'!R1C7 * 'Historical_data'!R[21]C[4]
+ (1-'Forecast data'!R1C7)*(R[-1]C+R[-1]C[1])"
         Sheet3.Range("G" & P + 3 & "").Select
         ActiveCell.FormulaR1C1 = "= 'Forecast data'!R1C9 *(RC[-1]-R[-1]C[-1]) + (1-
'Forecast data'!R1C9)*R[-1]C"
      End If

        'Fills in Quantities 30 periods
        For i = 1 To 30
          rand_dema = Sheet5.Range("B4").Value
```

```
          If Conta = 1 And i = 1 Then
            'calculates Forecast Data one Period
            Sheet3.Activate
            Sheet3.Range("A" & 3 + P & "").Value = P
            Sheet3.Range("B" & P + 3 & "").Select
           ' ActiveCell.FormulaR1C1 = _
           '     "=ROUNDUP((1/24)*SUM(Historical_data!R[-2]C[8]:R[21]C[8]),0)"
            ActiveCell.FormulaR1C1 = "= R[-1]C[4]+R[-1]C[5]"
            Sheet3.Range("D" & P + 3 & "").Select
            'ActiveCell.FormulaR1C1 = _
            '    "=RC[-
2]/30*(IN!R19C3+1)+2.33*SQRT((IN!R19C3+1)*IN!R28C3*IN!R28C3)"
            'new line
            ActiveCell.Value = 9455
            'Sheet3.Range("C" & P + 3 & "").Select
            'ActiveCell.FormulaR1C1 = _
            '    "=RC[-
1]/30*(IN!R28C8+1)+2.33*SQRT((IN!R28C8+1)*IN!R28C3*IN!R28C3+IN!R27C3*IN!R2
7C3*IN!R23C3*IN!R28C8)"
            'new line
            'ActiveCell.Value = 13950
'           Sheet3.Range("B" & P + 3 & ":D" & P + 3 & "").Select
'           Selection.Copy
'           Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks
_
'               :=False, Transpose:=False
            M_Hist_Qty = M_Hist_Qty + Sheet5.Range("B4").Value
            Sheet3.Range("F" & P + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=R[-3]C[1]* 'Historical_data'!R[21]C[4] + (1-R[-
3]C[1])*(R[-1]C+R[-1]C[1])"
            Sheet3.Range("G" & P + 3 & "").Select
            ActiveCell.FormulaR1C1 = "= 'Forecast data'!R1C9 *(RC[-1]-R[-1]C[-1]) +
(1-'Forecast data'!R1C9)*R[-1]C"
            Sheet6.Activate
            'Fills sheet quantitites with values
            Sheet6.Range("C" & Conta + 3 & "").Select
            ActiveCell.FormulaR1C1 = _
               "=IN!R[7]C-" & rand_dema & "+RC[-1]"
            Sheet6.Range("D" & Conta + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=IF(RC[-1]>0,RC[-1],0)"
            Sheet6.Range("K" & Conta + 3 & "").Select
            'ActiveCell.FormulaR1C1 = "=IF(RC[-7]<'Forecast data'!R4C3/4,1,0)"
            ActiveCell.FormulaR1C1 = "1"
            Sheet6.Range("E" & Conta + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=IF(RC[-2]<0,-RC[-2],0)"
            Sheet6.Range("F" & Conta + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=IF(RC[-2]-RC[-1]<14655,192,0)"
            'ActiveCell.FormulaR1C1 = "=MAX('Forecast data'!R4C3-Quantities!RC[-
2],0)"
            Sheet6.Range("G" & Conta + 3 & "").Select
```

```
            ActiveCell.FormulaR1C1 = "=RC[-1]"
              If P = 1 Then
                Sheet6.Range("S" & Conta + 3 & "").Select
                ActiveCell.FormulaR1C1 = "=IN!R16C3/30"
              Else
                Sheet6.Range("S" & Conta + 3 & "").Select
                ActiveCell.FormulaR1C1 = "=R[30]C[-2]"
              End If
            Sheet6.Range("H" & Conta + 3 & "").Select
            ActiveCell.FormulaR1C1 = _
              "=IF(IN!R[6]C[-5]>Quantities!RC[-1],0,IF((ABS(IN!R[6]C[-5]-
Quantities!RC[-1]))<IN!R[5]C[-5]+RC[11],(ABS(IN!R[6]C[-5]-Quantities!RC[-
1])),IN!R[5]C[-5]+RC[11]))"
            Sheet6.Range("I" & Conta + 3 & "").Select
            'ActiveCell.FormulaR1C1 = "=IN!R[6]C[-6]+Quantities!RC[-1]"
            ActiveCell.FormulaR1C1 = "=MAX(IN!R10C3+ RC[-1]-RC[5],0)"
            Sheet6.Range("J" & Conta + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=MAX(RC[-3]-RC[4],0)"
            Sheet6.Range("L" & Conta + 3 & "").Select
            'ActiveCell.FormulaR1C1 = "=IF(RC[-8]>('Forecast data'!R4C3)/4,1,0)"
            ActiveCell.FormulaR1C1 = "0"
            Sea = ActiveCell.Value
            Sheet6.Range("M" & Conta + 3 & "").Select
            'ActiveCell.FormulaR1C1 = _
            '   "=IF(RC[-6]<IN!R48C3,0,IF(RC[-5]+IN!R[6]C[-10]>RC[-
6],Quantities!RC[-6]/IN!R48C3,0))"
            ActiveCell.FormulaR1C1 = _
              "=IF(RC[-2]=1,IF(RC[-6]<=IN!R48C3,0,RC[-6]/IN!R48C3),IF(RC[-
6]<=IN!R49C3,0,RC[-6]/IN!R49C3))"
            Sheet6.Range("N" & Conta + 3 & "").Select
            ActiveCell.FormulaR1C1 = "=IF(RC[-1]>=1,IF(RC[-3]=1,IF(RC[-6]+
IN!R10C3>=rounddown((RC[-6]+IN!R10C3)/IN!R48C3,0)*IN!R48C3,rounddown((RC[-
6]+IN!R10C3)/IN!R48C3,0)*IN!R48C3,0),IF(RC[-6]+IN!R10C3>=rounddown((RC[-
6]+IN!R10C3)/IN!R49C3,0)*IN!R49C3,rounddown((RC[-
6]+IN!R10C3)/IN!R49C3,0)*IN!R49C3,0)),0)"
              If Sea = 1 Then
                Lead_time = Sheet5.Range("f8").Value
                Sheet6.Calculate
              Else
                Lead_time = Sheet5.Range("e8").Value
                Sheet6.Calculate
              End If
            Act_Linha = Sheet6.Range("A" & Conta + 3 & "").Value
              If Sheet6.Range("N" & Conta + 3 & "").Value <> 0 And Lead_time +
Act_Linha < Periodos Then
                Q1 = Sheet6.Range("N" & Conta + 3 & "").Value
                ActiveSheet.Columns("A:A").Select
                Selection.Find(What:=Lead_time + Act_Linha, After:=ActiveCell,
LookIn:=xlFormulas, LookAt _
                  :=xlPart, SearchOrder:=xlByRows, SearchDirection:=xlNext,
MatchCase:= _
```

```
'                                    False, SearchFormat:=False).Activate
                                Linha_Update = ActiveCell.Row
                                Old_update_value = 0
                                Old_update_value = ActiveSheet.Range("b" & Linha_Update & "").Value
                                ActiveSheet.Range("b" & Linha_Update & "").Value = Q1 +
Old_update_value
                            End If
                        Sheet6.Range("P" & Conta + 3 & "").Select
                        'ActiveCell.FormulaR1C1 = "=IN!R17C3"
                        ActiveCell.FormulaR1C1 = "=RC[-2]-RC[-14]"
                        Sheet6.Range("Q" & Conta + 3 & "").Select
                        ActiveCell.FormulaR1C1 = "=MAX('Forecast data'!R4C4-IN!R9C3-RC[-
9]+RC[2]-RC[-9]+RC[2],0)"
                        Sheet6.Range("R" & Conta + 3 & "").Select
                        ActiveCell.FormulaR1C1 = "=RC[-1]-RC[1]"
                        Sheet6.Range("T" & Conta + 3 & "").Select
                        ActiveCell.FormulaR1C1 = _
                            "=IN!R[5]C[-17]+Quantities!RC[-1]-Quantities!RC[-12]"
'                       Sheet6.Range("A" & Conta + 3 & ":T" & Conta + 3 & "").Select
'                       Selection.Copy
'                       Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks
_
'                           :=False, Transpose:=False
                        Conta = Conta + 1
                        Sheet5.Calculate
                        Sheet6.Calculate
                    ElseIf Conta < Periodos + 1 Then
                        Sheet6.Activate
                        M_Hist_Qty = M_Hist_Qty + Sheet5.Range("B4").Value

                        'Preenche 1ª coluna C
                        Sheet6.Range("C" & Conta + 3 & "").Select
                        ActiveCell.FormulaR1C1 = "=R[-1]C+RC[-1]-" & rand_dema & ""
                        Sheet6.Range("D" & Conta + 3 & "").Select
                        ActiveCell.FormulaR1C1 = "=IF(RC[-1]>0,RC[-1],0)"
                        Sheet6.Range("E" & Conta + 3 & "").Select
                        ActiveCell.FormulaR1C1 = "=IF(RC[-2]<0,-RC[-2],0)"
                        Sheet6.Range("F" & Conta + 3 & "").Select
                        ActiveCell.FormulaR1C1 = "=IF(RC[-2]-RC[-1]+R[-1]C[10]-RC[-
4]<14655,192,0)"
                         ' If (ActiveCell.Row - 4) Mod 30 = 0 Then
                                'ActiveCell.FormulaR1C1 = "='Demand&Leadtime data'!R4C2+'Forecast
data'!R" & 3 + P & "C3-'Forecast data'!R" & 2 + P & "C3"
                                'ActiveCell.FormulaR1C1 = "=" & rand_dema & "+'Forecast data'!R" & 3
+ P & "C3-'Forecast data'!R" & 2 + P & "C3"
                            '   ActiveCell.FormulaR1C1 = "=IF(" & rand_dema & "+'Forecast data'!R"
& 3 + P & "C3-'Forecast data'!R" & 2 + P & "C3 > 0," & rand_dema & "+'Forecast data'!R"
& 3 + P & "C3-'Forecast data'!R" & 2 + P & "C3,0)"
                            '   Selection.Copy
'                               Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone,
SkipBlanks _
```

```
'                :=False, Transpose:=False
            'Else
              'ActiveCell.FormulaR1C1 = "='Demand&Leadtime data'!R4C2"
            '  ActiveCell.Value = rand_dema
'              Selection.Copy
'              Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone,
SkipBlanks _
'                :=False, Transpose:=False
            'End If
          Sheet6.Range("G" & Conta + 3 & "").Select
          ActiveCell.FormulaR1C1 = "=R[-1]C+RC[-1]-R[-1]C[7]"
            If P = 1 Then
              Sheet6.Range("S" & Conta + 3 & "").Select
              ActiveCell.FormulaR1C1 = "=IN!R16C3/30"
            Else
              Sheet6.Range("S" & Conta + 3 & "").Select
              ActiveCell.FormulaR1C1 = "=R[-30]C[-2]"
            End If
          Sheet6.Range("H" & Conta + 3 & "").Select
          ActiveCell.FormulaR1C1 = _
            "=IF(R[-1]C[1]>RC[-1],0,IF((ABS(R[-1]C[1]-RC[-1]))<R[-
1]C[12]+RC[11],(ABS(R[-1]C[1]-RC[-1])),R[-1]C[12]+RC[11]))"
          Sea = Sheet5.Range("J2").Value
          Sheet6.Range("I" & Conta + 3 & "").Select
          ActiveCell.FormulaR1C1 = "=MAX(R[-1]C+RC[-1]-RC[5],0)"
          Sheet6.Range("J" & Conta + 3 & "").Select
          ActiveCell.FormulaR1C1 = "=MAX(RC[-3]-RC[4],0)"
          Sheet6.Range("K" & Conta + 3 & "").Select
          'ActiveCell.FormulaR1C1 = "=IF(RC[-7]<'Forecast data'!R[" & P - 1 - Conta +
1 & "]C[-8]/4,1,0)"
          ActiveCell.FormulaR1C1 = "1"
          Sheet6.Range("L" & Conta + 3 & "").Select
          'ActiveCell.FormulaR1C1 = "=IF(RC[-8]>('Forecast data'!R[" & P - 1 - Conta
+ 1 & "]C[-9])/4,1,0)"
          ActiveCell.FormulaR1C1 = "0"
          Sea = ActiveCell.Value
          Sheet6.Range("M" & Conta + 3 & "").Select
          ActiveCell.FormulaR1C1 = _
            "=IF(RC[-2]=1,IF(RC[-6]<=IN!R48C3,0,RC[-6]/IN!R48C3),IF(RC[-
6]<=IN!R49C3,0,RC[-6]/IN!R49C3))"
          Sheet6.Range("N" & Conta + 3 & "").Select
          ActiveCell.FormulaR1C1 = "=IF(RC[-1]>=1,IF(RC[-3]=1,IF(RC[-6]+r[-1]c[-
5]>=rounddown((RC[-6]+r[-1]c[-5])/IN!R48C3,0)*IN!R48C3,rounddown((RC[-6]+r[-1]c[-
5])/IN!R48C3,0)*IN!R48C3,0),IF(RC[-6]+r[-1]c[-5]>=rounddown((RC[-6]+r[-1]c[-
5])/IN!R49C3,0)*IN!R49C3,rounddown((RC[-6]+r[-1]c[-5])/IN!R49C3,0)*IN!R49C3,0)),0)"
            If Sea = 1 Then
              Lead_time = Sheet5.Range("f8").Value
              'Sheet6.Calculate
            Else
              Lead_time = Sheet5.Range("e8").Value
              'Sheet6.Calculate
```

```
                    End If
                Act_Linha = Sheet6.Range("A" & Conta + 3 & "").Value
                    If Sheet6.Range("N" & Conta + 3 & "").Value <> 0 And Lead_time +
Act_Linha < Periodos Then
                        Q1 = Sheet6.Range("N" & Conta + 3 & "").Value
                        ActiveSheet.Columns("A:A").Select
                        Selection.Find(What:=Lead_time + Act_Linha, After:=ActiveCell,
LookIn:=xlFormulas, LookAt _
                            :=xlPart, SearchOrder:=xlByRows, SearchDirection:=xlNext,
MatchCase:= _
                            False, SearchFormat:=False).Activate
                        Linha_Update = ActiveCell.Row
                        Old_update_value = 0
                        Old_update_value = ActiveSheet.Range("b" & Linha_Update & "").Value
                        'ActiveSheet.Range("b" & Linha_Update & "").Select
                        ActiveSheet.Range("b" & Linha_Update & "").Value = Q1 +
Old_update_value
                    End If
                Sheet6.Range("P" & Conta + 3 & "").Select
                ActiveCell.FormulaR1C1 = "=R[-1]C+RC[-2]-RC[-14]"
                Sheet6.Range("Q" & Conta + 3 & "").Select
                ActiveCell.FormulaR1C1 = _
                    "=MAX('Forecast data'!R[" & P - 1 - Conta + 1 & "]C[-13]-Quantities!R[-
1]C[3]-RC[-9]-RC[2]-R[-1]C[1],0)"
                Sheet6.Range("R" & Conta + 3 & "").Select
                ActiveCell.FormulaR1C1 = "=MAX(R[-1]C+RC[-1]-RC[1],0)"
                Sheet6.Range("T" & Conta + 3 & "").Select
                ActiveCell.FormulaR1C1 = "=R[-1]C+RC[-1]-RC[-12]"
'               Sheet6.Range("A" & Conta + 3 & ":T" & Conta + 3 & "").Select
'               Selection.Copy
'               Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks
_
'                   :=False, Transpose:=False
                Conta = Conta + 1
                Sheet5.Calculate
                Sheet6.Calculate
            End If
        Next i

    Sheet7.Select
    Sheet7.Range("H" & Conta + 1 & "").Select
    ActiveCell.FormulaR1C1 = _
        "=IF(SUM('Quantities'!R[-28]C:R[1]C)>'Forecast data'!R[" & -30 - (P * 30 - 30) +
P & "]C[-6],(SUM('Quantities'!R[-28]C:R[1]C)-'Forecast data'!R[" & -30 - (P * 30 - 30) + P
& "]C[-6])*IN!R39C3*IN!R38C3,0)"

    'calculate Hist data one period
    Sheet1.Activate
    Sheet1.Range("I" & 25 + P & "").Select
    ActiveCell.Value = P
    Sheet1.Range("J" & 25 + P & "").Select
```

```
            ActiveCell.Value = M_Hist_Qty
'            Selection.Copy
'            Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
'                :=False, Transpose:=False

            'puts to 0 the Monthly qty after update historical data
            M_Hist_Qty = 0
            Calculate
            Sheet5.Calculate


        Next P

        'Builds up Costs sheet
        Sheet7.Select
        Sheet7.Range("B3:G3").Select
        Selection.AutoFill Destination:=ActiveSheet.Range("B3:G" & Periodos + 2 & "")
        Sheet7.Range("I3").Select
        Selection.AutoFill Destination:=ActiveSheet.Range("I3:I" & Periodos + 2 & "")
        Sheet7.Range("I1").Select
        ActiveCell.FormulaR1C1 = "=SUM(R3C9:R" & Periodos + 2 & "C9)"
        'connects automatic recalculation
        With Application
            .Calculation = xlAutomatic
            .MaxChange = 0.001
        End With
        ActiveWorkbook.PrecisionAsDisplayed = False

'        ActiveWorkbook.SaveAs Filename:="C:\Tests\SCmodel_V2_test" & y & ".xls" _
'        , FileFormat:=xlNormal, Password:="", WriteResPassword:="", _
'        ReadOnlyRecommended:=False, CreateBackup:=False
'
'Next y

End Sub
```