L-Pad case: Outsourcing the assembly of L-Pads

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1. Introduction

The management of the company you are working for, LogiXperience Ltd. (LX), is planning the launch of the brand-new L-Pad. The L-Pad is a revolutionary tablet with high functionality and tremendous ease to enjoy the Web, emails, photos and videos. Components of the L-Pad are produced worldwide. Assembly takes place in Shanghai.

The launch is planned in December 2011. Your team has been asked to develop the supply chain for this new tablet and investigate the required investments. The launch of the product, comprising the first two months after product introduction to the market is taken care of by another project team. Your team focuses on the remainder of the L-Pad product lifecycle, which is expected to be about a year. For this period you are supposed to set up and use a supply chain wide replenishment system that minimizes overall investments in inventory subject to operational customer service requirements, expressed in the so-called ready rate. The ready rate is defined as the fraction of time that the shelf is filled with product to satisfy customer demand.

Recently, LX management hired McQuincy Consultancy to advise them on their supply chain management and McQuincy proposed a new SCM concept: Customer Managed Inventory (CMI). The rationale behind this concept is that the L-Pad is built from a number of critical components and assembly steps that need to be coordinated (synchronized) carefully over time to ensure both an ideal flow of materials as well as high customer service at the end of the supply chain. The CMI concept assumes that every week all partners in the supply chain share information about Work-In-Process (WIP) and On-Hand Stock (OHS) of the critical components of the L-Pad. Together with contractual agreements on lead times and the new L-Pad forecasts this enables partners to respond quickly to changes in forecasts. The CMI concept has been implemented successfully in another High Volume Electronics environment under the heading of Collaborative Planning (cf. De Kok et al. (2005)).

The CMI concept employs multi-echelon inventory theory to propose material-feasible plans that can be modified when necessary. The basis of the planning logic is the use of so-called ‘echelon base-stock policies’: based on the sales plan it is easy to derive the cumulative requirements over each item’s cumulative lead times (including safety stock requirements)[1]. The base-stock level equals these cumulative requirements. Given the current total pipeline fill over the cumulative item lead time, it is easy to determine the quantity to be ordered to raise the overall pipeline fill to the item’s base stock level. In order to do so, simple but robust allocation policies are used.

The LX management has set up the required contractual relationships to share information on a weekly basis and have a joint meeting with all key players in its supply chain. However, an open question is how to parameterize the planning system, i.e. set safety stocks across the supply chain. Though the policies sketched above are quite simple, their parameterization under demand uncertainty constitutes a formidable problem. Fortunately new developments in multi-echelon inventory theory has led to tools to determine the safety stocks in *value networks* that minimize inventory capital investments subject to customer service level constraints. The optimization tool ChainScope has been validated in real-life situations to provide good estimates of value network performance given *average* physical inventory levels for all items in the value network. So it is an excellent candidate to answer the LX management questions.

[1] The cumulative lead time of an item is the lead time of the item (procurement or production) plus all its downstream process lead times.

McQuincy Consultancy pointed out that the ChainScope software not only provides the required safety stock parameters, but it also enables to develop the business case for possible redesign of the L-Pad supply chain. It provides annual cost information alongside capital investment information. It also provides the Du-Pont scheme that provides the break-down of *Return On Equity*.

The first step is to develop a model of the key components of the L-Pad and the key assembly steps. In order to do so you need information about the future market demand, the Bill-Of-Materials (BOM), the planned lead times of each item in the BOM, the added cost (or value) needed (created) to produce each item from its child items, and item batch sizes. The McQuincy company assists you in gathering the required information.

2. Invested stock capital vs. customer service level

For the design of Supply Chain Operations Planning (SCOP) you and your team have access to ChainScope. ChainScope is a computer program that is used to design the Supply Chain Operations Planning function in a company. ChainScope has been developed by Prof. Dr. Ton de Kok.

The objective of SCOP is to coordinate the release of materials and resources in the supply network under consideration such that customer service constraints are met at minimal cost.

Most companies have the objective to make as much profit as possible. ChainScope focuses on the capital spend in the supply chain and the service levels for customers. The amounts of capital spend on stock keeping affects the customer service level and will influence the cost or revenues. Based on these effects the invested stock capital and customer service level will influence the business performances.

ChainScope calculates the optimal situation where the invested stock capital and service level are balanced. With each value of the invested stock capital a maximum service level can be achieved but not the total amount of invested capital will automatically lead to this maximum service level. The allocation of this stock capital among the stock points is very important and will influence the achieved performance level.

You can find the ChainScope Quick Guide and links to the instruction videos in Appendix A.

3. L-Pad case

As mentioned above it is up to you and your team to advise your management about the L-Pad supply chain. Let us take a closer look at the L-Pad and its supply chain. Figure 1 maps the targeted supply chain.

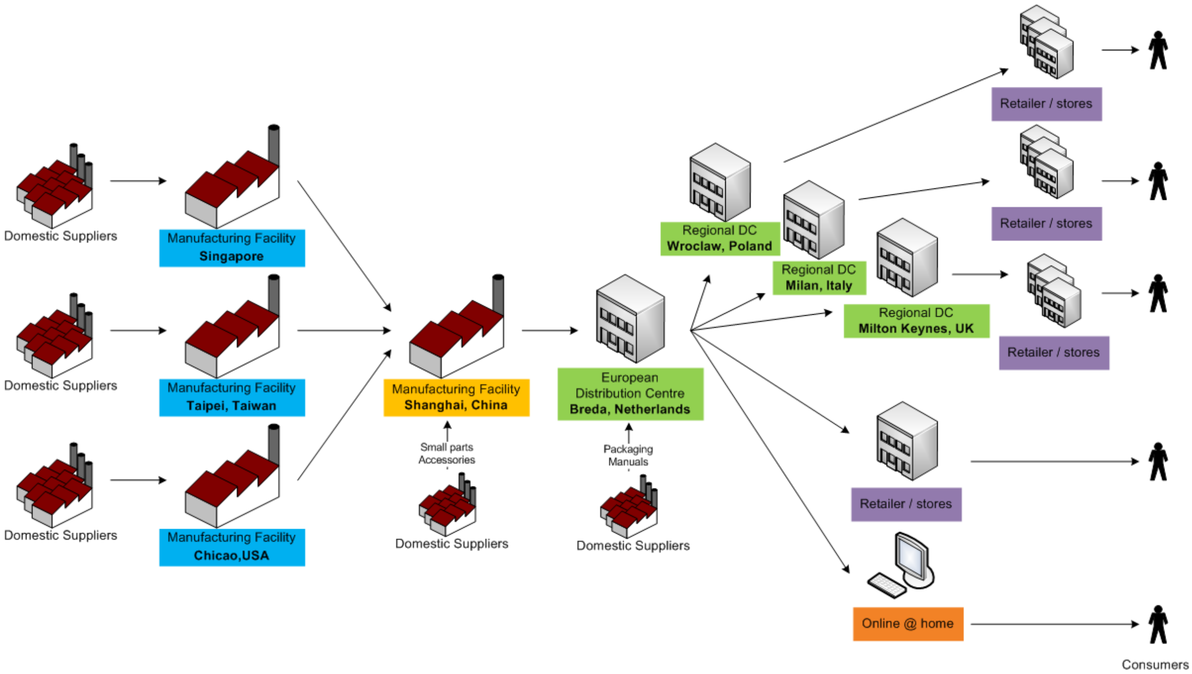


Figure 1 The supply chain of the L-Pad

Domestic supplies deliver components to the manufacturing facilities in Singapore, Taipei (Taiwan) and Chicago (USA). Each facility produces a different part of the L-Pad. The central manufacturing facility in Shanghai (China) assembles all these parts to a complete L-Pad. The L-Pad is distributed in Europe via the European Distribution Centre (EDC) in Breda (The Netherlands) and via three Regional Distribution Centres, namely Wroclaw (Poland), Milan (Italy) and Milton Keynes (United Kingdom). LX is responsible for the inventory of all four the distribution centres. Retailers and online stores sell the L-Pad to the customer.

Figure 2 maps the regular supply chain based on the L-Pad components. Each triangle represents a stage of the supply chain: either a supply or a process.

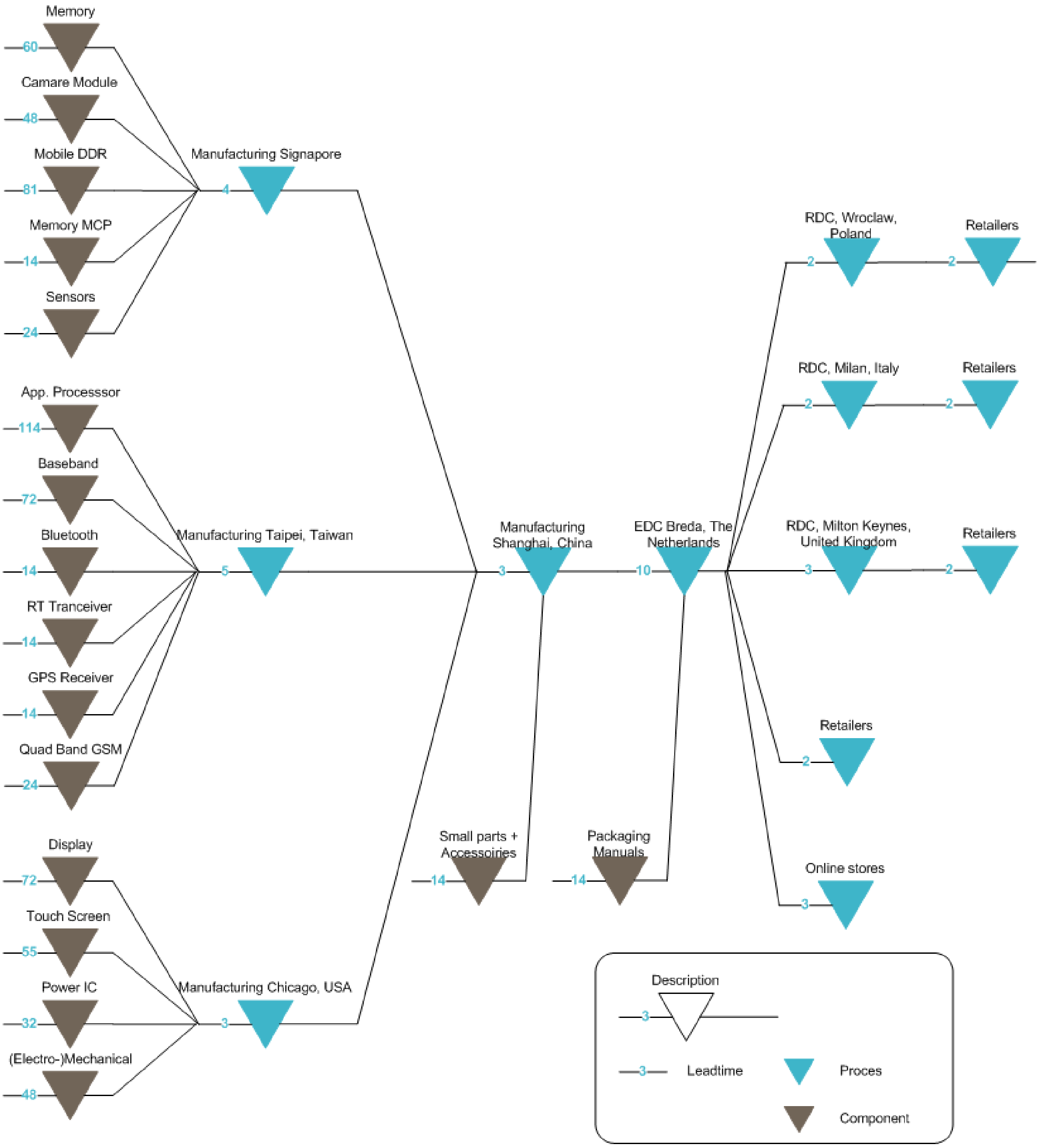


Figure 2 The supply chain of the L-Pad with lead time. The lead time drawn in front of a process or component indicates the lead time it takes for that process or component to fill an order.

Components
Table 1 provides the parameters of the components for the L-Pad, namely the nominal lead time and the added costs. It can be seen that the L-Pad itself consists of 17 components. The total cumulative cost of the L-Pad itself is $ 326.61. Eleven components are generic, whereas only six components are L-Pad specific. The generic components can be ordered via the OEM and via a distributor. The specific components can only be sold via the producer.

	Stage name	Type	Stage cost	Nominal Stage lead-time (days)	Manufacturing Location
ME	Memory (Samsung NAND, 32 GB, MLC)	Generic (1)	$ 43.00	60	Singapore
CM	Camera module (Infineon, 1280 x 800, 720p)	Generic (3)	$ 4.30	48	Singapore
MD	Mobile DDR (Samsung, 4Gb SDRAM)	Specific	$ 15.70	81	Singapore
MM	Memory MCP	Generic (5)	$ 7.00	14	Singapore
SE	Sensors (Gyroscope, Accelerometer, Light Sensor)	Generic (10)	$ 11.90	24	Singapore
DP	Display (LG 9,7" Diagonal, Color IPC-LED)	Generic (2)	$ 74.50	72	Chicago, USA
TS	Touch Screen (LG)	Specific	$ 52.50	55	Chicago, USA
PI	Power IC (Li-Ion, 6930mAh)	Generic (8)	$ 35.20	32	Chicago, USA
EM	Mechanical/Electro-Mechanical	Generic (11)	$ 7.00	48	Chicago, USA
AP	App. Processor (Samsung, ARM Cortex A8)	Specific	$ 14.00	114	Taipei, Taiwan
BB	Baseband (Infineon, HSFPA, Dual ARM926)	Specific	$ 11.69	72	Taipei, Taiwan
BT	Bluetooth	Generic (4)	$ 4.94	14	Taipei, Taiwan
RT	RT Transceiver	Generic (6)	$ 2.20	14	Taipei, Taiwan
GPS	GPS Receiver	Generic (7)	$ 1.87	14	Taipei, Taiwan
QB	Quad Band GSM	Generic (9)	$ 7.01	24	Taipei, Taiwan
SP	Small parts + accessories	Specific	$ 20.20	14	Shanghai, China
PM	Packaging Manuals	Specific	$ 13.60	14	Breda, The Netherlands
	Cumulative cost of the L-Pad		$ 326.61		

Table 1 Parameters of the components of the L-Pad

Manufacturing & Distribution
Table 2 shows the costs for manufacturing and the different transportation steps. After manufacturing the different components are sent to the assembly location in China. The European distribution centre (EDC) adds region specific packaging and manuals. The L-Pad is distributed via four distribution centres: one European Distribution Centre and three Regional Distribution Centres. Retailers and online stores sell the L-Pad to the customer. The total costs for handling and additional parts are between ten to twelve dollars. It can be concluded that most costs are made in the first stage (components costs are much higher than the packaging and handling costs).

	Stage name	Stage cost	Nominal Stage lead-time (days)
MAS	Manufacturing Singapore	$ 1.50	4
MAT	Manufacturing Taipei, Taiwan	$ 0.50	5
MAC	Manufacturing Chicago, USA	$ 2.00	3
MC	Manufacturing Shanghai, China	$ 3.50	3
EDC	European Distribution Centre Breda, The Netherlands	$ 2.00	10
RDCP	Regional Distribution Centre, Wroclaw, Poland	$ 1.30	2
RDCI	Regional Distribution Centre, Milan, Italy	$ 1.80	2
RDCU	Regional Distribution Centre, Milton Keynes, United Kingdom	$ 1.50	3
RT	Retailers	$ 0.75	2
OS	Online Stores	$ 0.30	3

Table 2 Parameters of supply chain stages of the tablet

Demand
The expected demand characteristics per distribution step are given in the following table. Assume 260 selling days per year. In total, LogiXperience expects to sell 790,400 L-Pads in 2012. The daily demand is expected to be highly variable: its standard deviation is assumed to be equal to the expected daily sales. Selling price is $ 499.00

Item code	Expected Daily Demand in 2012	Expected Standard deviation of demand
European Distribution Centre Breda, The Netherlands	*	*
Regional Distribution Centre, Wroclaw, Poland	*	*
Regional Distribution Centre, Milan, Italy	*	*
Regional Distribution Centre, Milton Keynes, UK	*	*
Online Stores	*	*

Table 3 Expected demand for the L-Pad in 2012

*) The missing necessary information (expected daily demand and expected standard deviation of demand) for Assignment 2 and 3 will be provided at the start of the case at EVO in Zoetermeer.

4. Assignments

In order to get acquainted with the ChainScope tool the ChainScope Quick Guide has been provided in Appendix A. This Quick Guide describes how to install and run ChainScope.

Appendix A provides also links to the instruction videos on the internet.

Important note: The instructional video covers a different case than the case in the assignment below.

Use ChainScope to execute the assignments below. Assignment 1 is for homework and intended to become acquainted with the software and is based on a different scenario then Assignment 2 and 3. Assignment 2 and 3 are based on the L-Pad case described above.

Assignment 1 – Homework Exercise
Assignment 1 allows you and your team to learn more about ChainScope and its features. Assignment 1 uses a different scenario compared to the described L-Pad case. In this scenario there is one product which consist of two components. The product is manufactured at one location.

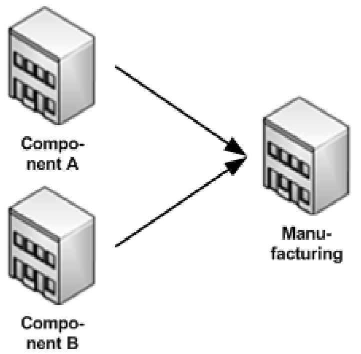


Figure 3 Supply chain Assignment 1

The underlying policies employed in ChainScope for this situation are so-called (R,S)-policies[2], i.e. periodic review order-up-to-policies. The results can be verified, assuming you know how to determine average inventories at the end of arbitrary periods and service levels for such systems under gamma distributed demand. Based on extensive empirical research it has been shown that the gamma distribution adequately represents exogenous demand. This distribution is determined by its mean and standard deviation. These are the parameters used as input for market demand in ChainScope.

The expected demand characteristics are given in the following table. Assume 260 selling days per year. The daily demand is expected to be highly variable: its standard deviation is assumed to be equal to the expected daily sales. Selling price is $ 200.00

	Item code	Expected Daily Demand in 2012	Expected Standard deviation of demand
MF	Manufacturing	30	30

Table 4 Expected demand for Assignment 1

[2] See http://www.advanced-planning.eu/advancedplanninge-237.htm to get an impression how (R,S)-inventory policies work

Table 5 shows the stage costs and nominal stage lead-time for each stage.

	Stage name	Stage cost	Nominal Stage lead-time (days)
CA	Component A	$ 85.00	2
CB	Component B	$ 80.00	6
MF	Manufacturing	$ 25.00	5

Table 5 Parameters of supply chain stages

Analyze the base case situation and manually deploy the supply chain inventory. Only use evaluation.

Steps	
1.	Open ChainScope. Open “L-Pad Assignment1” scenario
2.	Try to change the “current stock”[3] parameter. Your goal: • Actual ready rate of 95% • The dead stock value as close to 0 as possible *Hint: It is possible to decrease the total investment by nearly 6%.*

[3] The current stock of an item is the average on hand inventory (as resulting from the use of a base-stock policy).

Note: The missing necessary information (expected daily demand and expected standard deviation of demand) for Assignment 2 and 3 will be provided at the start of the case at EVO in Zoetermeer. This also applies to the Excel files to import scenarios.

Assignment 2 – Optimize the base case manually
Turn to the supply chain described in the L-Pad case above. This is a multiple tier supply chain.

Analyze the base case situation and manually deploy the supply chain inventory. Only use the ChainScope 'evaluation' mode.

Steps	
1.	Open the ChainScope. Open "L-Pad-base.xls".
2.	Try to change the "current stock" parameter. Your goal is to keep the total investment as low as possible. Keep in mind that the desired value for "Actual ready rate" is 95%. Also, try to keep the dead stock value as close to 0 as possible.

Assignment 3 – Choose the best option
Your management requires you to compare the following three options:

- Remain in charge of the entire supply chain (AS-IS)
- Shorten the supply chain via the distributor
- Outsource the entire production of the L-Pad

Steps	
1	Analyze the base case: optimize this situation (using ChainScope and the scenario "L-Pad base", which can be found by opening "L-Pad-base.xls"). Pay attention to the investments, costs and ready rate.
2	A large Chinese distributor offers to provide the 11 generic components within two days, with an equal quality. This significantly decreases the lead-time, but the procurement prices will be 20% higher. Evaluate and optimize the proposal of the distributor in terms of investments, costs and ready rate. Execute the following steps: Open the scenario "Distributor" in ChainScope. (using ChainScope and the scenario L-Pad Distributor, which can be found by opening "L-Pad_Distributor.xls" Note: both structures can now be found under the ChainScope option "Manage projects"). Optimize and analyze this situation using ChainScope.
3	A large Chinese manufacturing company, called Foxconn, proposes to assemble and deliver the tablet at the European Distribution Centre for an additional $ 16.95 per tablet. The total cost price will become $ 343.56 In this situation, LogiXperience will solely remain in charge of the distribution network. Execute the following steps: Open the files "L-Pad_Out.xls" and "L-Pad_Foxconn-In.xls". Optimize and analyze this situation using ChainScope.
4	Now it's up to you and your team to advise your management about the supply chain with low investment in inventory capital and high operational customer service! Which scenario do you prefer under which circumstances? Write down five arguments. Please take both the quantitative and qualitative aspects into account.

5. The results

The final ranking consists of two parts, namely:

- Assignment 2 – The results of the manually optimized supply chain
- Assignment 3 – The advise about the supply chain scenario to use for the L-Pad.

Assignment 2 – The results of the manually optimized supply chain
In assignment 2 every group manually optimizes the supply chain. The group closest to the optimum situation receives the highest ranking. In this comparison the following three parameters are taken into account, namely.

1. actual ready rate
2. total Investment
3. dead stock

The higher the number the more important that parameter is.

Assignment 3 – Advise about the supply chain scenario to use for the L-Pad.
In assignment 3 every group chooses its preferred scenario, and explains why this choice was made by writing down five arguments. It is important to not only mention quantitative aspects. Also take qualitative aspects into account. The group with the best arguments, judged by a jury, receives the highest ranking.

The final ranking
The final ranking is made by combining the results of assignment 2 (50%) and assignment 3 (50%). Each group gets a number of points per assignment. The higher the ranking, the more points a group gets. Points are allocated as follows:

Rank	Points
1	20
2	19
3	18
4	17
5	16
6	15
7	14
8	13
9	12
10	11
11	10
12	9
13	8
14	7
15	6
16	5
17	4
18	3
19	2
20	1

Table 6 Point allocation

Total score = Points Assignment 2 + Points Assignment 3.

Appendix A – ChainScope Quick Guide

In this briefly description of ChainScope we take a closer look at the following items:

- Installation
- Launch ChainScope → Instruction videos on internet available
- Import scenario
- Evaluate scenario
- Change parameters
- Optimize parameters
- Reporting
- Analyze data
- Change scenario
- Copy scenario

For a full description we refer you to the ChainScope User Manual.

Installation
ChainScope requires Microsoft Windows XP or later

Instruction videos on YouTube:

Part 1: http://www.youtube.com/watch?v=bIEKk42voPI

Part 2: http://www.youtube.com/watch?v=1zPUvdv3dNI

Part 3: http://www.youtube.com/watch?v=1Cea3uRS51g

Launch ChainScope
Execute the following steps to launch ChainScope

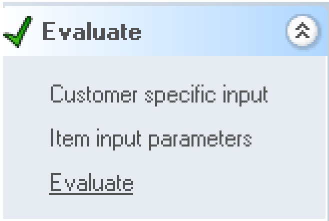
- Run “Scope.exe”
- When prompted for a username and a password:
  Username: student ***Password: student***

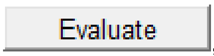
Import scenario
Execute the following steps to import a scenario

- In ChainScope click at the “import scenario” button
- Select an Excel file(.xls) and click “Open”
- Wait until you see the “Scenario loaded” message and click “Ok”

Evaluate scenario
After loading a scenario, execute the following steps to evaluate a scenario.

- In ChainScope select “Evaluate”

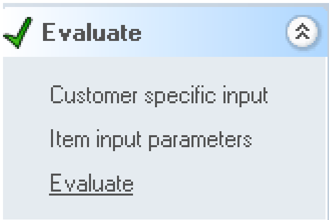


- Click the evaluate button  , to start evaluation.

Note: see “Analyze date” for a brief description of the data presented.

Change parameters
Execute the following steps to manually change a scenarios parameters:

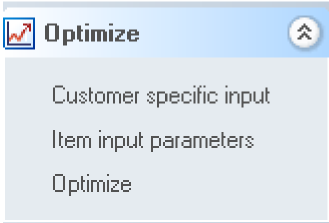
- In Chainscope select “Customer specific input” or “Item input parameters”
- Click on a value you want to change, and fill in the new value

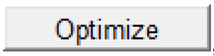


- Evaluate the scenario to see the changes

Optimze parameters
Instead of manually change a scenarios parameters, you can use ChainScope to calculate the optimal values. Execute the following steps to optimize a scenario.

- In ChainScope select “Optimize”



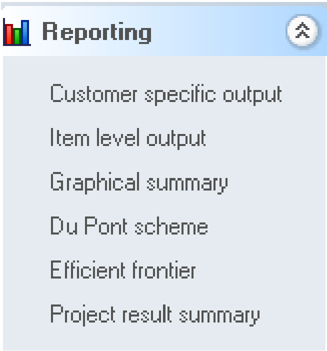
- Click the optimize button 

, to start optimizing.

Note: See “Analyze date” for a brief description of the data presented.

Reporting
In ChainScope it is possible to compare two different scenarios. To do this, use the “Reporting” function. Execute the following steps to compare two (or more) scenario’s.

- Select “Reporting” → “Project result summary”



- Select the scenarios you want to compare
- Choose the “Graphs” or “Results” tab, to see the report you want to see.

Note: See “Analyze date” for a brief description of the data presented.

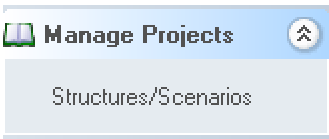
Analyze data

Parameter	Description
Annual capital cost	The annual capital costs are the costs for holding inventory in the stock points and the “stock” in the pipelines
Annual material cost	The annual material cost is the total costs in one year for producing all the expected demand in one year.
Annual dead capital cost	The annual dead capital cost is the interest paid over the dead stock and is calculated with the number of dead stock items multiplied with the cumulative value of the item and multiplied with the interest rate.
Annual release cost	For each order of an item one has to pay the release cost. If one releases 100 orders a year one has to pay the release costs100 times.
Stock on hand investment	The stock on hand investment is the average value of your total stock. If there is only one stock point with on average 10 number of items in stock and the cumulative value of one item is 10€ the stock on hand investment will be 100€.
Dead stock	Dead stock is surplus inventory of items and thus useless items in a stock point. The dead stock does not contribute to customer service and in the output table the dead stock is expressed in time, value and number.
Remnant stocks	The remnant stock value is the number of items which are in the stock point because other items are not available and also needed for a transformation process.
Pipeline	The pipeline investment is the average number of items in the pipeline multiplied with the average value of one item in the pipeline. For items with no input items the pipeline value is equal to the total added value of the item and for items with input items that pipeline value is equal to the sum of the added values of all the input items plus half of the added value of the item.
Supply chain	The supply chain investment is the stock on hand investment plus the pipeline investment.
Fixed asset	The fixed asset investment is the sum of all the investments in fixed assets and can be inserted in the evaluation or optimization screens. If different scenarios have different fixed assets this is an influential parameter, for example the fixed asset for an extra distribution centre.
Actual ready rate	The actual ready rate is the fraction of time during which the net stock is positive.
Actual fill rate	The actual fill rate is the target fraction of customer demand that is met routinely, without backordering.

Table 7 ChainScope parameters

Change scenario
In ChainScope it is possible to load more than one scenario at a time. When there is more than one scenario loaded, you can choose which scenario you want to evaluate or optimize. Execute the following steps to change the active scenario.

- Select “Manage Projects” → “Structures/Scenarios”



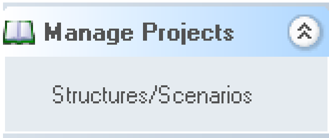
- Activate a scenario by clicking on it.

Note: the arrow in front of the scenario indicates that it is active.

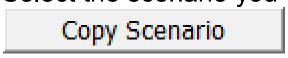
Copy scenario
ChainScope automatically saves every change you make. A selected scenario can be copied with the "Copy Scenario" button. After entering the new scenario name the selected scenario will be identically copied. In this copy of the original scenario you can make changes in the input data or supply chain structure. The different scenarios can be evaluated or optimized to compare these different scenarios. The date of the last evaluation can be found in the last column of the scenarios table.

To copy a scenario, execute the following steps:

- Select "Manage Projects" → "Structures/Scenarios"



- Select the scenario you want to copy, and click the "Copy Scenario' button



Note: the arrow in front of the scenario indicates that it is active.

Appendix B – Model and analysis

Note: this appendix only serves as background information and is not needed to run the software. We outline the generic model that describes a value network and the algorithm that generates feasible plans for materials for each item in the network. De Kok and Visschers (1999) and De Kok and Fransoo (2003) discuss the underlying ideas from stochastic multi-echelon inventory theory supporting the model and the algorithm we refer to. Based on the algorithm we describe below, we can operationally manage value networks, but we can also develop exact probabilistic expressions for long-run performance measures and costs, under the assumption of stationary demand. The ChainScope software uses these expressions and resulting optimality equations to compute close-to-optimal target base stock levels (cf. below).

The model

We consider an acyclic value network structure with *M* items. The value network can be described by means of the following sets and their mutual relationships:

M set of all items;

N set of all end-items, i.e. items sold to customers of the value network;

C_i the set of immediate successors or parent set of item *i*, $i \in \mathrm{M}$;

P_i the set of immediate predecessors or child set of item *i*, $i \in \mathrm{M}$;

F_i the set of end-items delivered by item *i*, $i \in \mathrm{M}$.

With each item $i \in \mathrm{M}$, we associate a number of parameters:

a_{ij} number of items *i* required to produce one unit of item *j*, $j \in \mathrm{M}$ *.*

L_i lead time of a work order of item *i.*

L^*_{ij} sum of lead times associated with all items on the path between item *i* and item *j* (both items inclusive), $j \in \mathrm{M}$.

ST_i safety lead time associated with item *i.*

ST^*_{ij} sum of safety lead times associated with all items on the path between item *i* and item *j* (both items inclusive), $j \in \mathrm{M}$.

The lead times L_i exclude the safety lead times ST_i. For ease of presentation, we assume that $a_{ij} \in \{0,1\}$. Clearly the (safety) lead times associated with items are parameters that have a major impact on the decisions generated. Within the context of this operational planning model, we assume (safety) lead times to be exogenous parameters. The lead times must be derived from actual measurements. Theoretically speaking, the safety lead times may be derived from the analysis of stochastic multi-echelon inventory systems (de Kok and Fransoo 2003). In the project users set the safety lead times used in the planning software environment.

We assume that, in each review period, a work order is released for all items of the value network. The work order release quantities are the decision variables, whose value must be determined. We assume no lot sizing restrictions for released quantities. We define the following variables for all $i \in \mathrm{M}$ and $t \geq 1$:

$D_i(t)$	forecast of demand for end-item *i* in period *t.*
$I_i(t)$	net stock of item *i* at the start of period *t.*
$IP_i(t)$	inventory position of item *i* at the start of period *t.*
$EIP_i(t)$	echelon inventory position of item *i* at the start of period *t.*
$SR_i(t)$	scheduled receipt of item *i* planned to arrive at the start of period *t.*
$PO_i(t)$	work order of item *i* released at the start of period *t*.

Important to the solution sought is that only feasible work orders for materials are released. This implies that the net stock of all non end-items is non negative immediately after all orders have been released, i.e.

$$I_i(t) \geq 0,\ i \in \mathrm{M} \setminus \mathrm{N},\ t \geq 1.$$

We derive inventory positions and echelon inventory positions from the following equations:

$$IP_i(t) = I_i(t) + \sum_{s=1}^{L_i-1} SR(t+s),\ i \in \mathrm{M},\ t \geq 1.$$

$$EIP_i(t) = IP_i(t) + \sum_{j \in C_i} EIP_j(t),\ i \in \mathrm{M},\ t \geq 1.$$

In the first of the above equations, we assume that the scheduled receipt arriving at the start of period *t* is consolidated in $I_i(t)$. We assume that demand forecasts not satisfied from (planned) end-item stocks are backlogged. Without loss of generality, we may assume that we are at the start of period 1, that is, at time 0. At this epoch, the exogenous input to determine the initial state of the system can be described as follows:

$$SR_i(t+s),\ t = 1,\ldots,L_i - 1,\ i \in \mathrm{M}.$$

$$D_i(t),\ t = 1,\ldots,T.$$

Despite the fact that in principle only the immediate work order release decisions are relevant, below we present an algorithm that generates both immediate work order release decisions and planned work order release decisions. The latter provide insight into possible future item shortages and overages, which is quite relevant in an environment with short product life cycles and high volatility in demand and supply. Thus, we assume that we have to determine $PO_i(t)$ for all items *i* until some period *T*, which as a result is the planning horizon. We assume that *T* is long enough to accommodate all immediate planning decisions. This implies that

$$T \geq \max_{i,j}\left(L_{ij}^{*} + ST_{ij}^{*}\right) + 1,\ i, j \in \mathrm{M}.$$

In what follows, we assume that (planned) events occur in the following order:

(1) Facilities receive scheduled or planned items immediately at the start of a period;
(2) They release work orders for each item immediately after this;
(3) They fulfill customer demand forecasts and internal work orders just before the end of the period.

Below we describe how to compute the immediate work-order-release decisions. Next we update the (planned) state of the value network by “executing” these decisions, assuming that scheduled and planned receipts arrive according to their planned lead times and assuming that demand realizations equal demand forecasts. Next we apply the procedure described below to the new (planned) state of the value network. We repeat this process until the end of the planning horizon. The state-updating procedure can be described as follows:

$$SR_i(t + L_i) = PO_i(t),\ i \in \mathrm{M},\ t \geq 1.$$

$$I_i(t+1) = I_i(t) - D_i(t) + SR_i(t),\ i \in \mathrm{N},\ t \geq 1.$$

$$I_i(t+1) = I_i(t) - \sum_{j \in C_i} a_{ij} PO_j(t) + SR_i(t),\ i \in \mathrm{M} \setminus \mathrm{N},\ t \geq 1.$$

Determining material feasible work orders

Important to a proper sequencing of the decisions to be taken at the start of a particular period *t*, *t*=1,…,*T*, is the acyclic structure of the value network. The computations start with the most upstream items of the value network, that is, items with no predecessors. With a proper low-level coding procedure of the acyclic network, we can recursively determine all subsequent decisions. Our procedure is based on a combination of base-stock policies and linear allocation rules. The procedure yields release decisions that may be inefficient in the sense that the solution proposed may result in unused child items that could be used to satisfy immediate parent item demand. However, in a multi-item multi-echelon system under stochastic demand, this inefficiency need not harm the system’s performance, since such residual stock can (should) be used in future periods (de Kok and Visschers 1999). In what follows, we drop the argument *t* referring to the current period.

Dynamic base stock levels
The first step in the algorithm is to determine target base stock levels. Since the echelon stock of an item *i* indicates the cumulative stock available to cover demand over the lead times $L^*_{i,k}+1,\ k \in F_i$, including safety stocks, we define the target base stock levels S_i as follows:

$$S_i = \sum_{k \in F_i} \left\{ \sum_{s=1}^{L^*_{i,k}+ST^*_{i,k}+1} D_k(s) \right\},\ i \in \mathrm{M}.$$

The cumulative safety stock in the echelon of *i*, SS_i, is defined as

$$SS_i = \sum_{k \in F_i} \left\{ \sum_{s=1}^{L^*_{i,k}+ST^*_{i,k}+1} D_k(s) \right\} - \sum_{k \in F_i} \left\{ \sum_{s=1}^{L^*_{i,k}+1} D_k(s) \right\},\ i \in \mathrm{M}.$$

Ordering, allocation, and work-order release
Standard base-stock policies do not guarantee material feasibility. When an order for an item *j* derived from the base-stock policy can be satisfied from the available stock of an item $i \in P_j$, then we allocate the required quantity of item *i* to the order. If this is not the case, because the total required quantity of item *i* exceeds its available stock I_i, we apply consistent appropriate share (CAS) allocation policies (Van der Heijden et al. 1997) to allocate all available stock.

However, this procedure tackles only the availability issue for item *i* and all of its successors *j*. Since we must guarantee that the order from *j* is feasible for all the children $n \in P_j$, we take PO_j as a minimum of all the quantities allocated from its predecessors. This reasoning can be translated into the following steps:

Let q_j be the unconstrained order from item *j*, i.e.

$$q_j = \left(S_j - EIP_j\right)^+.$$

Let us consider item $i \in P_j$. We want to determine the quantity $Q_j^{(i)}$, which is the order released for item *j* if item *i* would be the only predecessor of item *j*. Let us assume that for all $m \in C_i$ the unconstrained orders have been determined. Now we can distinguish between two situations, $\sum_{m \in C_i} q_m \le I_i$ and $\sum_{m \in C_i} q_m > I_i$.

(1) $\sum_{m \in C_i} q_m \le I_i$.
In this case, we satisfy all orders for item *i*. Thus we find

$$Q_j^{(i)} = q_j.$$

(2) $\sum_{m \in C_i} q_m > I_i$

In this case, we must allocate available stock I_i. Van der Heijden et al. (1997) discuss the consistent appropriate share rationing policy. The main idea is to allocate the shortage of item *i* according to the cumulative safety stocks of items $m \in C_i$. Defining EIP_j^+ as the echelon inventory position of *j* immediately after allocation of the available stock of item *i*, we find

$$EIP_j^+ = S_j - \frac{SS_j}{\sum_{m \in C_i} SS_m} \left(\sum_{m \in C_i} q_m - I_i \right).$$

It is well known that due to imbalance, it may be possible that $EIP_j^+ < EIP_j$, which implies that a negative quantity would be allocated to item *j*. Taking this into account, we calculate $Q_j^{(i)}$ in this case as

$$Q_j^{(i)} = \frac{\max\left(0, EIP_j^+ - EIP_j\right)}{\sum_{m \in C_i} \max\left(0, EIP_m^+ - EIP_m\right)} I_i.$$

Thus, we have found $Q_j^{(i)}$ for the two possible cases. Then we determine the order released for item *j* from

$$PO_j = \min_{n \in P_j} Q_j^{(n)}.$$

This concludes the algorithm.

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