Supply Chain Network Redesign at Vanderlande

Final report
25-04-2017

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Master Thesis Industrial Engineering & Management
University of Twente

UNIVERSITY OF TWENTE.

VANDERLANDE

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Version: Final report - Public version

Publication date: 25-04-2017

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VANDERLANDE

MANAGEMENT SUMMARY

Vanderlande is the global market leader in baggage handling systems and warehouse automation solutions. They operate in a project-based and engineer-to-order environment. This requires a responsive supply chain to handle their wide variety of products and enable a fast response to various demand quantities with short lead times, while delivering highly innovative products at a high service level. Responsiveness is a trade-off with efficiency, which implies that responsiveness comes at a price. A first analysis showed that the current network struggles to meet on-time delivery in this fast growing market. This is an urgent problem since it can obstruct growth ambitions and put Vanderlande's competitive position at stake. Thus, our main research question becomes:

''How can Vanderlande improve responsiveness in a growing market by redesigning the roles of facilities in their supply chain network?"

We first considered the current network and performed a literature study. Next, we proposed the network redesign. Hereafter, we constructed a mathematical model to quantify the impact.
The current network has five echelons: second tier suppliers, first tier suppliers, warehouse, site and the three Supply Chain Centers (SCCs). These SCCs are virtual facilities that coordinate the material flow. The literature study did not provide a direct solution: instead we constructed a three-step framework to guide our redesign. The first step is to operationalize responsiveness for the given context. We formulate three Key Performance Indicators (KPIs):

1) **Orderline fill rate** is the fraction of orderlines of which the item is available in the warehouse on time. The current value is 57%, thus almost half of the orderlines arrive later than requested.
2) **Activity fill rate** is the fraction of activities of which all orderlines are in the warehouse on time. The current value is 90%, meaning that 10% of the activities causes project delay.
3) **Average activity lead time** is the average duration in weeks to supply all items of an activity. The current KPI value is 10.6 weeks. Planning strives for an activity lead time of 8 weeks.

The second step is to determine the required level of responsiveness. The third step is to align your network design accordingly. We identified that all project items receive the same treatment, irrespective if these items are critical project specific items or standard items used in multiple projects. However, we show that the level of required responsiveness is different for these two product types, providing an opportunity to benefit from economies of scale (EOS) by aggregating demand over multiple projects. Thus, the basic concept for the redesign is to introduce 'item level split'. This advocates a different approach with respect to responsiveness and efficiency for items, dependent if an item is truly project specific or a standard, so-called EOS item.
The redesign results in two networks:

- The project specific network focusing on responsiveness.
- The EOS network focusing on efficiency by aggregating item demand over all projects.

We describe the new facility roles. We introduce a new facility to coordinate this EOS network, SCC EOS, implying organizational change. We estimate IT implementation costs to be €30,000.

We foresee three main impacts for this redesign:

- It provides a clear **strategic focus** for supply chain personnel: they must decide per item which network fits best, based on item characteristics.
- These EOS items are suitable for inventory management. Since EOS items can now be picked directly from stock, this provides the opportunity to increase **responsiveness**.
- Vanderlande can harvest growth as opportunity to realize economies of scale. This raises efficiency and enables **cost reductions** of EOS items. Demand aggregation allows Vanderlande to reduce the number of orderlines and realize discount on item price. We expect savings by material cost and orderline reduction. However, this results in extra inventory costs.

We construct a mathematical model and implement the formulas in Excel to quantify these impacts. Since the EOS network focuses on efficiency, the objective is to maximize total savings of the EOS network. We considered all project orderlines with request date in 2016, and classified these items accordingly. Model input are items that were ordered for more than one project, having more than 1 orderline per week. This holds for 725 items, which are 4% of the item population but represents 26% of material cost and 52% of orderlines. The table below compares the redesign with the current network. Numerical results show that 633 out of these 725 items would become EOS items, providing €4,094,526 savings. Most of these savings result from discounts on item price, emphasizing the importance of supplier collaborations. Savings of orderline reduction is lower than expected due to extra handling efforts. We compute how KPIs change when EOS items have a fill rate of 98%. Both orderline fill rate (57% to 78%) and activity fill rate (90% to 94%) improves. Thereby, the model quantifies the redesign impact of responsiveness and cost reductions.

	Current network	Redesign
Total savings	**€ -**	**€ 4,094,526**
Inventory costs	€ -	€ -1,248,941
Savings in material cost	€ -	€ 5,349,232
Savings in orderline reduction	€ -	€ -5,766
Responsiveness KPIs		
Orderline fill rate	57%	78%
Activity fill rate	90%	94%
Average activity lead time in weeks	10.6	10.6

Based on this work, we propose the following recommendations for Vanderlande:

- Start with a pilot to test this redesign and communicate results to involved departments.
- Continue with the implementation roadmap as suggested below to ultimately implement this redesign and change facility roles accordingly.

Step	Start	Finish	Milestone	Responsible actor
1. Convince key decision makers	2017 wk 22	2017 wk 22	* Go/no go meeting with key decision makers to agree on plan of approach	SC development
2. Assign team for SCC EOS	2017 wk 23	2017 wk 26	* Kick-off meeting with all SCC EOS team members	Key decision makers
3. Run pilot and inform	2017 wk 26	2017 wk 51	* Go/no go meeting with key decision makers to evaluate pilot results	Team SCC EOS
4. Implement SCC EOS	2018 wk 1	2018 wk 26	* Presentations * New IT system online * >50% of all EOS items sourced	Team SCC EOS
5. Evaluate changes	2018 wk 27	2018 wk 27	* Close-down meeting with key decision makers to evaluate implementation	Team SCC EOS, key decision makers

- To reduce implementation risks, we recommend to pay extra attention to change management and careful item selection.
- To identify opportunities and measure progress, we recommend to improve data quality, in specific related to unit price and item volume.
- To increase the potential of this redesign, we recommend to focus on supplier collaboration to realize discount and lower the replenishment lead times of EOS items.
- To reduce average activity lead time to the 8 weeks target, we recommend Vanderlande to investigate how to improve on-time delivery of project specific items.

Furthermore, we identify six interesting topics for further research. These relate to demand forecast and workload balancing, triggers to stimulate standardization, product postponement to reduce activity lead times, supplier selection, cooperation between departments to reduce project lead times and select the best approach to store, consolidate and ship EOS items to site locations.

GLOSSARY

Term	Description
Activity	BOM with all items and quantities needed for specific building block of a project
Activity fill rate	KPI: fraction of activities of which all orderlines are in the warehouse at the late finish date
Average activity lead time	KPI: average makespan of an activity in weeks
BOM	Bill of Materials
Calhoun	Place in America: location of a Vanderlande factory
CODP	Customer Order Decoupling Point: virtual point in the supply chain that separates the part that responds directly to customer demand from the part that uses forecast planning
EDC	European Distribution Centre: warehouse used by SCC EU, located in Veghel
EOS	Economies of scale: advantages that arise with increased output of a product
EOS items	Items that the EOS networks sources
ERP	Enterprise Resource Planning
ETO	Engineer to order: CODP is located at the design stage
FTE	Full Time Equivalent: hours worked by one employee on a full-time basis
GSC	Vanderlande's Global Supply Chain department
Hubble	Tool to extract orderline data from ERP system
JDEdwards	Vanderlande's ERP system
KPI	Key performance indicator: measurable value that demonstrates how a company performs on key business objectives
NPI	New Product Introduction
O1/O2	Internal order to transfer items from SCCs anonymous stock to SCC's project stock
O3	Internal order to transfer items from another SCC's anonymous stock to SCC's project stock
O4	Internal order to transfer items between two SCC's anonymous stocks
OF	Purchase order to Vanderlande's factory in Veghel
ON/OM	Order to replenish anonymous items
OP	Purchase order to subcontractor
Orderline	One orderline is used to purchase one SKU at a first tier supplier
Orderline fill rate	KPI: fraction of orderlines of which the item is available in the warehouse at request date
PO	Purchase Order
Santpedor	Place in Spain: location of a Vanderlande factory
SCC	Supply chain centre
SCC EOS	Supply chain centre that coordinates the EOS network; new virtual facility
SCC AP	Supply chain centre focusing on region Asia-Pacific
SCC EU	Supply chain centre focusing on region Europe
SCC NA	Supply chain centre focusing on region North America
Site	The customer location where Vanderlande installs the system
SKU	Stock Keeping Unit: a unique item
Slimstock	Tool that Vanderlande uses to forecast and control inventory
SPEC	Project specification; BOM that Engineering releases as demand for the SCCs
Supply chain centre	A virtual, organizational entity which coordinates the flow of materials at Vanderlande
VBA	Visual Basics: programming tool in Excel
Veghel	Location in the Netherlands where one of the three Vanderlande's factory is located, as well as the Headquarters

PREFACE

To complete the master Industrial Engineering & Management at the University of Twente, students perform an in-depth study on a real company problem and document their approach and findings in a master thesis. This thesis describes my graduation project at Vanderlande, where I provide a scientific and independent view to redesign Vanderlande's supply chain network. Since September 2016, I was engaged in this research at the Supply Chain Development department.

This research is initialized by my company supervisors E. Tielemans and W. van Beusekom. I would like to thank them for creating this opportunity and for their helpful comments. I feel privileged that I was able to work on this interesting, global, strategic, high impact research project. I would like to thank my colleagues for all good conversation and thank all interviewees for sharing their valuable time and providing interesting insights. It was a real pleasure to work with all of you.

I would like to thank my first supervisor M. van der Heijden, for his excellent guidance and support during this research project. His feedback always helped me forward, and I really experienced that he is willing to go the extra mile for his students. The same holds for my second supervisor P. Schuur. With his creative mind, he always finds illustrative metaphors to point out his opinion. Both supervisors provided me with extensive feedback, which allowed me to improve my work.

With this master thesis, my student life comes to an end. I would like to thank all my friends and colleagues that contributed to this unforgettable period. Special thanks to my boyfriend for his care and encouragements. Finally, I am grateful for my parents for their mental and financial support during my complete study time. Your wise and kind words have always helped me through.

I hope you enjoy your reading!

's-Hertogenbosch, April 25th, 2017

Femke van der Putten

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1. RESEARCH INTRODUCTION

To complete the master Industrial Engineering & Management at the University of Twente, students perform an in-depth study on a real company problem and document their approach and findings in a master thesis. This thesis describes my graduation project at Vanderlande, where I provide a scientific and independent view to redesign Vanderlande's supply chain network. This thesis starts with a chapter that introduces the company, the research problem and corresponding research question. The remainder of the chapters answer one sub question. Ultimately, we finalize this thesis with conclusions, recommendations and suggestions for further research.

1.1. Company introduction

Vanderlande Industries is the global market leader in baggage handling systems for airports and sorting systems for parcel and postal services, and leading supplier of warehouse automation solutions (Vanderlande, 2016). They include their automated material handling solutions with software and after-sales service to provide integrated and customer-specific solutions. Customers across the globe use these integrated systems: more than 600 airports have a Vanderlande system in place, as well as many leading parcel and postal companies. Together, their systems sort more than 8.8 million pieces of luggage and 20 million pieces of parcel per day. Figure 1.1 shows an impression of their systems.

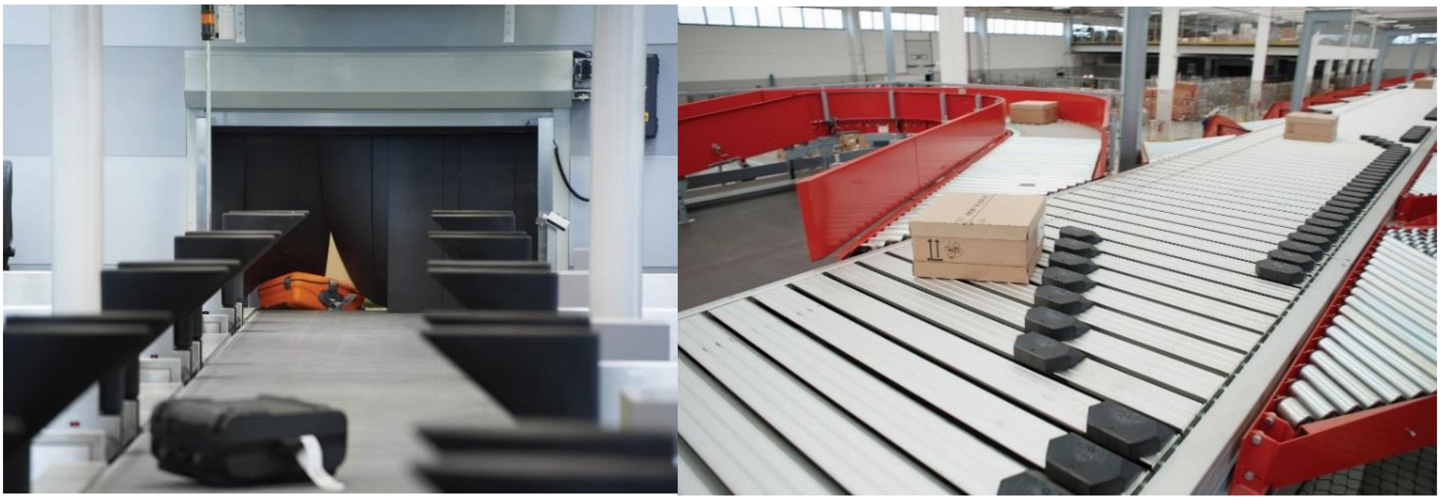

Figure 1.1 – Vanderlande provides solutions for baggage handling systems (left) and postal sorting (right)

Vanderlande operates in a project based and engineer-to-order (ETO) environment. In an ETO supply chain, the customer order penetrates to the design stage, which is often the case in large and complex project environments such as the construction or capital goods sector (Gosling and Naim, 2009). When a potential customer requests a new system, Vanderlande proposes a tailor-made design and quotes a lump sum price. If the customer accepts this bid and signs the contract, Vanderlande starts ordering the required materials. Duration, revenue and geographic location vary across projects: the timespan can be a few months up to several years, revenue starts at a few thousand up to half billion euros. Vanderlande builds at site locations on all continents. The company was founded in 1949 and the consistently increasing order intake recently exceeded one billion euros. Over 4,500 employees work at Vanderlande and these numbers are expected to grow. Vanderlande's headline *"reliable partner for value-added logistic process automation"* highlights their focus on automation of the entire logistics process of their customers.

Figure 1.2 shows the organizational structure. Our research focuses on the Global Supply Chain (GSC) department, which is part of the division Operations. GSC is responsible for material flow of all projects and consists of four sub departments. This research takes place at the Supply Chain Development department.

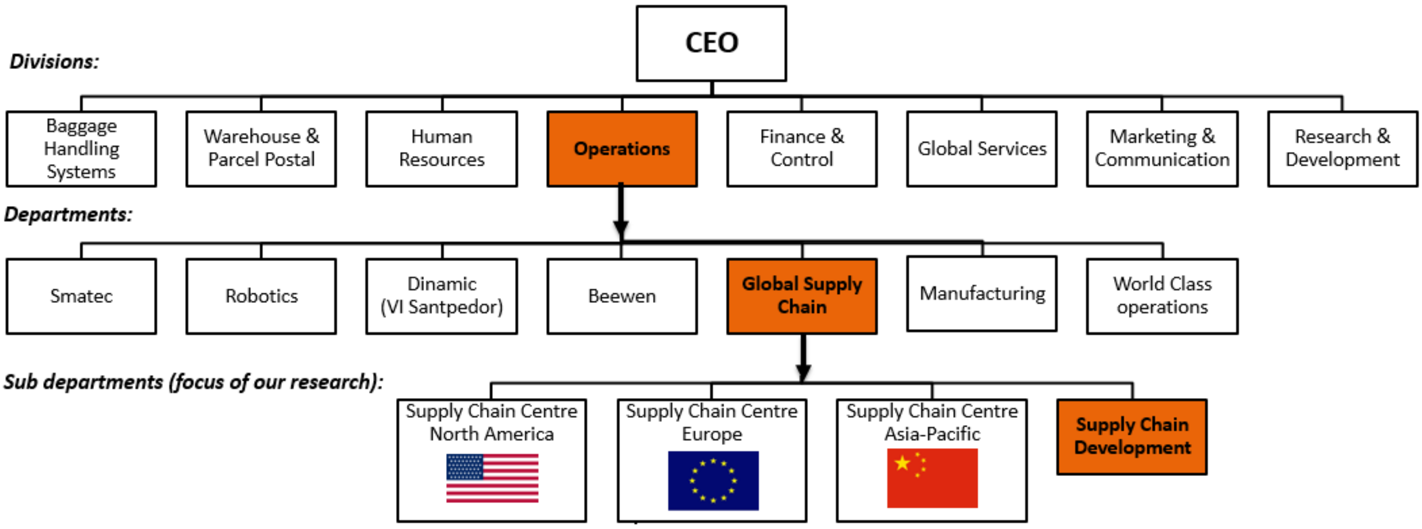

Figure 1.2 - Global Supply Chain in the Organization Hierarchy (Source: based on Annual report 2015). Other departments of Operations are former suppliers that Vanderlande recently acquired because of their specific product knowledge (Smatec, Robotics), as strategic partnership (Beewen), or to expand their production capacity (Dinamic).

GSC has three supply chain centres (SCCs) coordinating the material flow from the regions North America, Europe and Asia-Pacific. A *supply chain centre (SCC)* is a virtual, organizational entity which coordinates the flow of materials. The mission of the SCC is to "*deliver the right product, at the right moment to the right location at the right quality and cost".* In other words: the SCC must realize on-time delivery of complete activities to site. Engineers design the system layout and split it into building blocks, which Vanderlande calls 'activities' or 'specifications/SPECs', see Figure 1.3. For example, an activity can be a counter, a corner, a sorting machine or working hours. This activity split strives to optimize coordination, lead time, cost and installation on site since the project manager can decide per activity when it is delivered on site. Every activity has its own bill of materials (BOM) containing all items and quantities needed. All purchase orders (POs) are based on this BOM. POs are supplier specific and can have multiple orderlines (one line per item). Every orderline is linked to an activity such that the financial department can allocate all costs to the activity's budget. Ultimately, all activities of a project together result in one working system. Appendix A presents a simplified flowchart of all processes between different departments from project start to project delivery.

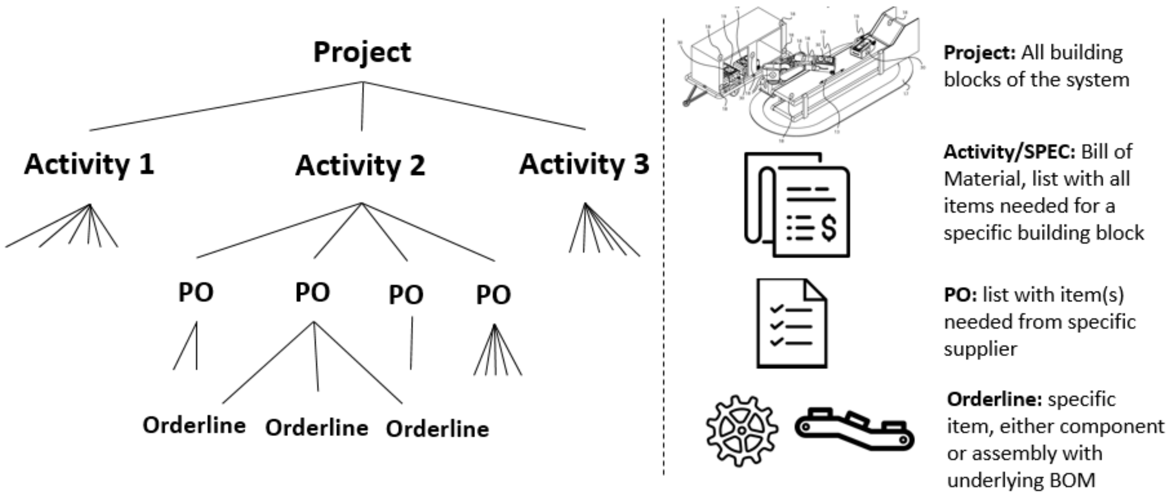

Figure 1.3 – Project breakdown into activities and purchase orders

This research specifically focuses on Vanderlande's global supply chain network. Different material flows exist to ultimately deliver all activities to site. The SCC orders necessary materials at their factories or subcontractors, who buy raw materials or subcomponents at second tier suppliers. The SCC first consolidates items in a warehouse and only sends complete activities to the geographically dispersed site locations. Not every SCC can order at every supplier, and only one SCC can source materials of a specific activity. The fast growth enables recent acquisitions of new SCCs and factories, but these are not yet fully supported by the ERP system. These ERP restrictions result in inflexibilities and causes material flow between the SCCs via 'internal orders'.

1.2. Problem identification and research goal

This network with three SCCs is in place since 2010, but it does no longer meet requirements of the growing organization. This is due to globalization, constant pressure to lower project lead times and costs, the acquisition of new factories and increased project sales on new geographic locations. Material flow and the project sizes increase year after year, thus Vanderlande has to act to enhance their competitive position in the flourishing market. The board supports this in the corporate strategy by introducing the 'fit for growth' programme, which strives to "*prepare for its rapid expansion in the coming years and keep pace with the growth of the markets in which it operates"* (annual report, 2015).

The current supply chain network offers many interesting problems to focus on, but due to time constraints we select one specific requirement that the current network cannot meet. To get acquainted with the problems, we conducted fourteen interviews with employees of several departments who are involved in the supply chain, see reference list. Based on these interviews, we cluster our observations on cause and consequences (Figure 1.4).The red boxes show the three main problems (symptoms) that the company currently faces: inability to meet on-time delivery, cost inefficiencies and undesirable workarounds in the ERP system.

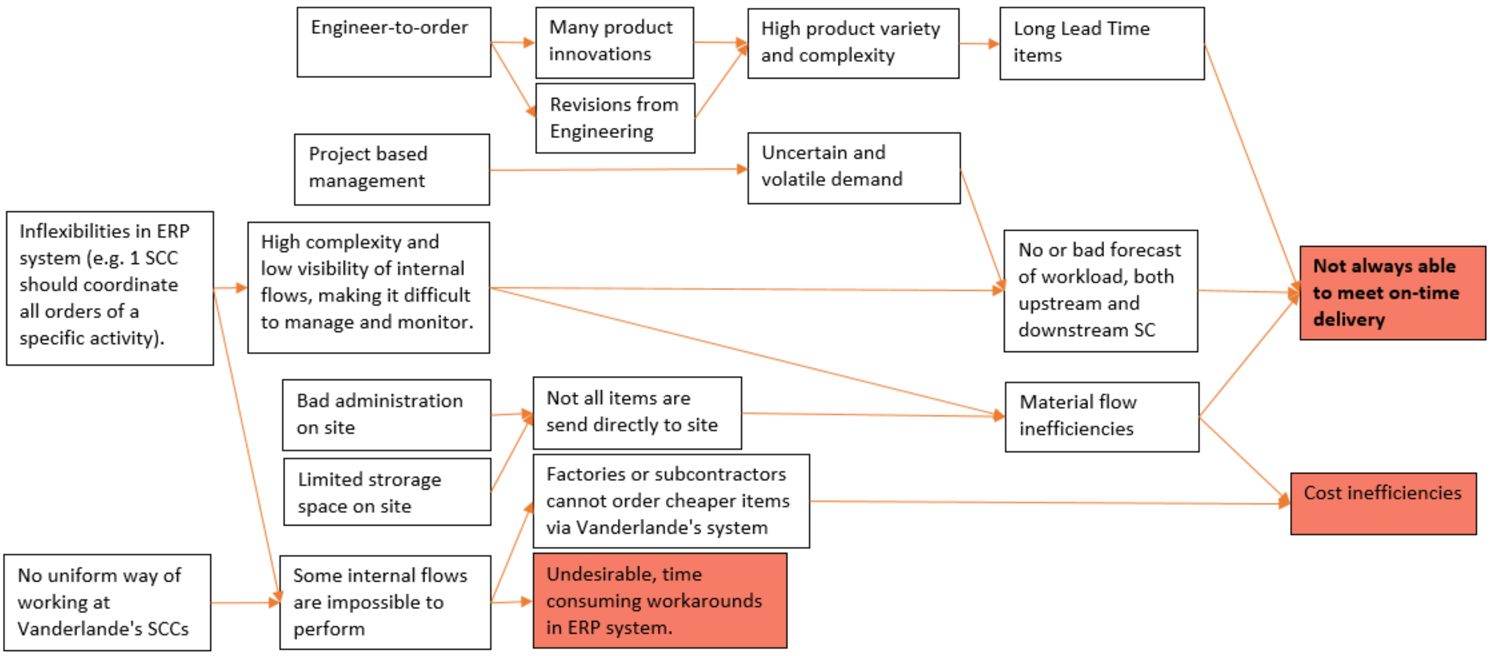

Figure 1.4 - Overview of problems identified during interviews

We prioritize the three symptoms based on the highest decision level: strategy. According to Chopra & Meindl (2016), a supply chain with uncertain demand fits a responsive strategy (Figure 1.5). A responsive supply chain is able to handle a wide variety of products and respond to various demand quantities, meet short lead times, build highly innovative products, meet a high service level and is able to handle uncertainty. This responsive supply chain strategy fits Vanderlande's ETO and project context, since demand is uncertain until Engineering releases the SPECs based on system layout. When we consider the three symptoms, we conclude that 'inability to meet delivery times' is an urgent problem for Vanderlande, since this violates responsiveness. This is an urgent problem, considering that workload over times only increases in a fast growing market. Although cost inefficiencies also obstruct their strategic objective of 'profitable growth', we focus on the strategic objective responsiveness.

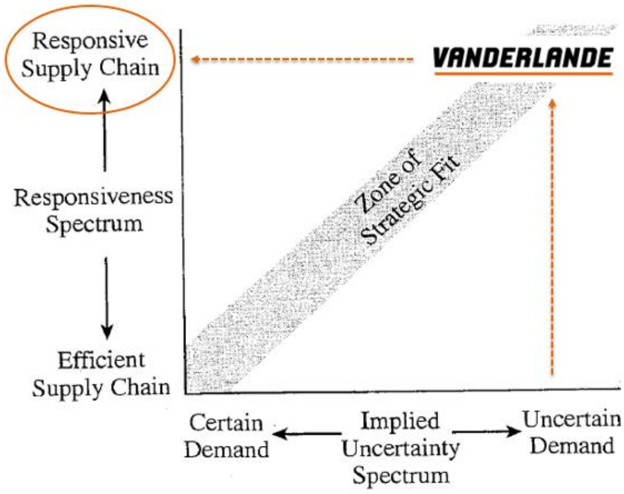

Figure 1.5 - Strategic Fit (Chopra & Meindl, 2016)

Also data shows this problem.

[Text and graph removed in public version]

Thus, we show that both interviews and data reveals that the current supply chain network struggles to meet on-time delivery in a fast growing market. This is an urgent problem since it could obstruct their growth ambitions. Vanderlande's corporate strategy stresses the need to become fit for growth.

This problem identification results in the following **problem statement:**
> *"Vanderlande's supply chain network struggles to remain responsive in a growing market."*

Based on this problem statement, we formulate the **research goal**:
> *"The research goal is to redesign Vanderlande's supply chain network to improve responsiveness and become fit for growth."*

1.3. Research scope

To be clear, we use the following definitions:

- **Supply chain network design** includes *"the assignment of facility role, location of manufacturing, storage and transportation-related facilities, and the allocation of capacity and markets to each facility"* (Chopra & Meindl, 2016).
- **Facilities** are "*physical locations where items are fabricated, assembled or stored"* (Chopra & Meindl, 2016).
- **Responsiveness** is *"a supply chain's ability to respond to a wide range of quantities demanded, meet short lead times, handle a wide variety of products, build highly innovative products, meet a high service level and handle supply uncertainty"* (Chopra & Meindl, 2016).

To narrow the research, we make some important scope decisions upfront:

- Facilities and their geographic locations are fixed. We consider the facilities of Vanderlande's current supplier base, the three Vanderlande factories situated in Veghel/Santpedor/Calhoun, the three SCCs situated in Veghel/Atlanta/Shanghai, the distribution centres situated in Veghel/Acworth and the project sites.
- We can change the roles of these facilities, thereby change the material and information flow.
- We consider reverse logistics, non-project related material flow and spare parts to be out of scope since they do not directly affect project lead time. We consider ERP restrictions to be out of scope, this to ensure creative thinking and redesign the network from scratch. Thus, we use a greenfield approach for facility roles, material flow and information flow. We also consider the recent acquired parties Smatec, Beewen and Robotics (Figure 1.2) out of scope.
- This thesis only focuses on activities related to material flow of Vanderlande equipment, which can be sourced via Vanderlande's factories or subcontractors. This equipment has a specific Vanderlande item number to enable purchasing via the ERP system.

1.4. Research question

Based on the research goal and scope, we formulate the **main research question:**

"How can Vanderlande improve responsiveness in a growing market by redesigning the roles of facilities in their supply chain network?"

We use sub questions to ultimately answer the main research question (Figure 1.6). We first zoom in on the current way of working and responsiveness performance (Q1). We perform a literature study (Q2) and apply this theory in Vanderlande's context, resulting in the network redesign (Q3). We use a mathematical model to quantify the impact of this redesign (Q4) and interpret results (Q5). We finalize by providing insights to ease implementation (Q6).

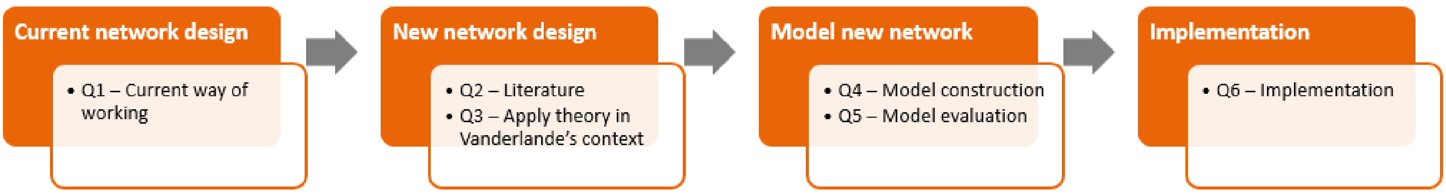

Figure 1.6 – Approach to answer main research question

Q1 - How does Vanderlande's supply chain network operate and how can we measure and explain current responsiveness performance?

- What are the main drivers in Vanderlande's supply chain network?
- What are the facility roles in Vanderlande's supply chain network?
- How do items flow in Vanderlande's supply chain network?
- What implications does the rapid growing market have on the network design?
- How is the total lead time built up and how can we explain and measure responsiveness?

Q2 - What theory does literature offer to improve responsiveness in an engineer-to-order oriented supply chain by changing facility roles in the network design?

- How do we perform our literature study?
- What knowledge do we subtract per research topics?
- What framework can we use to guide our redesign?

Q3 - How to apply this theory to redesign Vanderlande's supply chain network?

- How can we apply this framework in Vanderlande's context to redesign their network?
- How does this redesign change roles of facilities?
- How does this redesign change material flow and information flow?
- What is the impact of this redesign?

Q4 - How can we construct a model to quantify the impact of this redesign?

- How do we model this new network?
- What input do we use for our model?
- What output do we obtain from our model?
- How do we verify and validate our model?
- What are limitations of our model?

Q5 - How does this redesign perform compared to the current network design?

- What outcome does our model provide in terms of savings and responsiveness?
- How sensitive is the model for input parameters?
- What scenarios do we compare and what do we recommend based on their results?
- How can Vanderlande improve the potential of this redesign?

Q6 - How can Vanderlande implement this redesign?

- What are the first steps to take, by who and when?
- What is the opinion of managers of involved departments?
- What are the main risks and how can we manage these risks?

Every chapter answers one sub question. Table 1.1 shows the main data sources and time we devote to each sub question. We strived to answer all research questions within 20 weeks.

Table 1.1 - Approach to answer Research Questions

	Main data sources	**% of time devoted**	**Finish**
Q1	Interviews with Vanderlande stakeholders, Vanderlande documents on Vikipedia, observations, data extracted from ERP system via 'Hubble', industry benchmark, Annual reports	~ 25% (5 weeks)	Oct 2016
Q2	Scientific literature reviews (Scopus)	~ 25% (5 weeks)	Nov 2016
Q3	Output Q1, Q2, interactive session with management to define (dis)advantages		Dec 2016
Q4	Output Q1, Q2, Q3, literature, dataset from ERP system 'Hubble'	~ 40% (8 weeks)	Jan 2017
Q5	Output Q4		Feb 2017
Q6	Output Q5, interviews with management	~ 10% (2 weeks)	Mar 2017

2. CURRENT NETWORK DESIGN

This chapter answers the first research question: "How does Vanderlande's supply chain network operate and how can we measure and explain current responsiveness performance?". We first explain the supply chain drivers in Section 2.1 and current network with facility roles in Section 2.2. In Section 2.3, we analyze material flow. Section 2.4 explains the growth trends we identify, followed by lead time built up and current performance in Section 2.5.

2.1. Supply chain drivers

We introduce Vanderlande's current way of working in the supply chain by using the framework of Chopra & Meindl (2016) in Figure 2.1. This shows that a company should first formulate their competitive and supply chain strategy since this guides the choice of the logistical and cross-functional drivers. As mentioned in previous chapter, a company's supply chain should achieve a balance between responsiveness and efficiency that best meets the company's competitive strategy. This balance is influenced by the level of demand uncertainty; the more uncertainty, the more responsive a supply chain should be (Chopra & Meindl, 2016). Thus, there is a trade-off between efficiency and responsiveness, which implies that responsiveness comes at a price. Table 2.1 adds extra insight by comparing the behavior of these two strategies.

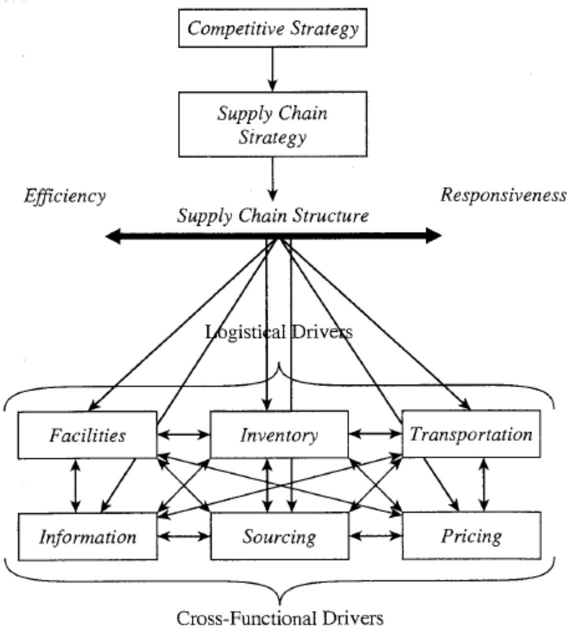

Figure 2.1 - Supply Chain Decision-Making Framework (Chopra & Meindl, 2016)

Table 2.1 - Chopra & Meindl (2016), adapted from "What is the right supply chain for your product?", Fisher, Harvard Business Review (March-April 1997), 83-93

	Efficient Supply Chain	Responsive Supply Chain
Primary goal	Supply demand at the lowest cost	Respond quickly to demand
Product design strategy	Maximize performance at a minimum product cost	Create modularity to allow postponement of product differentiation
Pricing strategy	Lower margins because price is a prime customer driver	Higher margins because price is not a prime customer driver
Manufacturing strategy	Lower costs through high utilization	Maintain capacity flexibility to buffer against demand/supply uncertainty
Inventory strategy	Minimize inventory to lower cost	Maintain buffer inventory to deal with demand/supply uncertainty
Lead time strategy	Reduce, but not at the expense of costs	Reduce aggressively, even if the cost are significant
Supplier strategy	Selection based on cost and quality	Selection based on speed, flexibility, reliability and quality

Figure 2.1 presents three logistical drivers (facilities, inventory, transportation) and three cross-functional drivers (information, sourcing and pricing). Choices regarding these drivers significantly influence the efficiency or responsiveness of a supply chain, since the interaction of the drivers determines the overall supply chain performance (Chopra & Meindl, 2016).

We explain every driver in Vanderlande's context to illustrate current operations.

Logistical driver: Inventory - A company can buffer inventory to deal with demand uncertainty (Chopra & Meindl, 2016), since higher product availability increases responsiveness. Vanderlande currently identifies two item types: project items and anonymous items. This results in two stock types: project stock with finished items related to an activity, and anonymous stock with bulk items that are not yet assigned to an activity. Eventually, the warehouse ships all items to a site location. SCC NA and SCC EU have their own warehouse to store and consolidate items. SCC AP has no warehouse and outsources this task to one of their subcontractors.

Logistical driver: Transportation - Transportation relates to the movement between stock points. Faster transportation is more expensive but positively contributes to responsiveness. Vanderlande transports activities to site by boat, truck, airplane or train. The choice of transportation is based on urgency of delivery, distance to site and product volume. To ease installation on site, Vanderlande only sends complete activities to site.

Cross-functional driver: Information - Information is the only driver that enables management to improve responsiveness and efficiency at the same time and directly influences performance of other drivers (Chopra & Meindl, 2016). Information with data of customers, facilities, inventories, prices and suppliers is essential for the supply chain performance. When management has access to the right information, it enables them to select lowest-cost alternatives (efficient) while meeting customer demand in time (responsiveness). Vanderlande stores information in the ERP system JDEdwards. Almost all Vanderlande's facilities use this ERP system, except for recently acquired factories. This results in ERP difficulties.

Cross-functional driver: Sourcing - Sourcing relates to decisions regarding which first tier supplier produces what equipment. In general, Vanderlande selects their first tier supplier based on three aspects: their ability to produce a product, the price and the available capacity, In a responsive supply chain, the firm select suppliers based on speed, flexibility, reliability and quality (see Table 2.1).

Cross-functional driver: Pricing - Pricing affects buying behavior. Vanderlande uses fixed prices in project quotation based on their sales pricing tool. The supply chain department does not take margins on their products to internal departments, since it is not their primary goal to make profit from their operations.

2.2. Facility roles

Due to the research scope, we provide extra information on logistical driver 'facility'. Facilities are physical locations where items are fabricated, assembled or stored. Firms can improve responsiveness by increasing the number of facilities (Chopra & Meindl, 2016) since it improves average responsive time. This improves average response time to the customer and lowers transportation cost, but increases facility costs. Thus, every supply chain must find its approprate trade-off. Firms should consider role (flexible versus dedicated, product versus functional focused), location (centralized versus decentralized) and capacity (high utilization versus excess capacity) of their facilities. Fabrication and assemblation of items occurs at Vanderlande's second tier and first tier suppliers. Vanderlande stores finished goods at their first tier suppliers, distribution centres or at site.

A set of facilities with the same role is an 'echelon', which results in a hierarchy of facilities (Melo et al., 2008). In this thesis, we consider facilities of five echelons, which we illustrate in Figure 2.2. These echelons are second tier suppliers, first tier suppliers, supply chain centres, warehouses & distribution centres, and sites. Although a SCC is a virtual and not necessarily a physical stock point, we treat the SCCs as facilities due to their coordinating role.

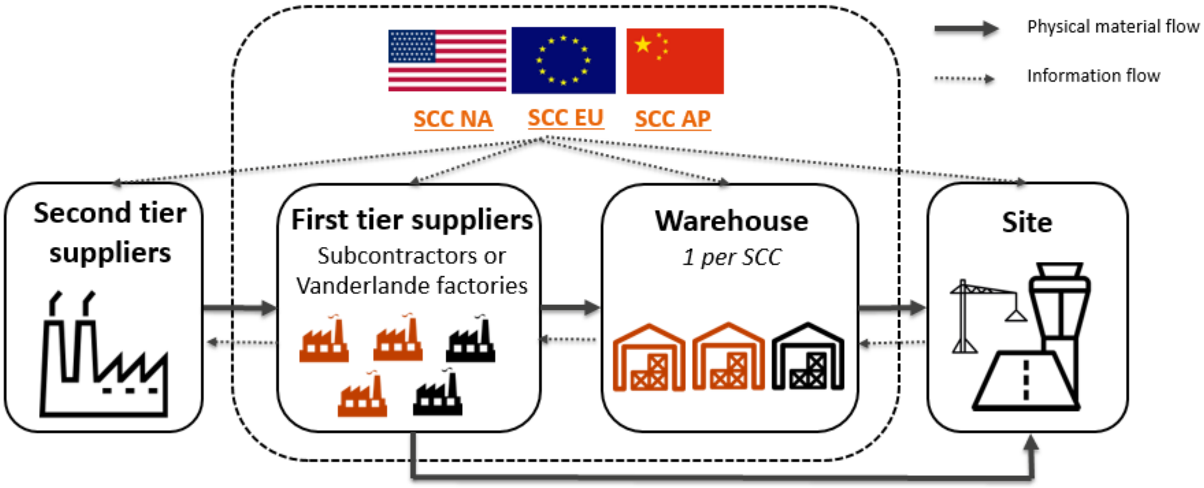

Figure 2.2 - Five echelons in the network and their relations (orange: facility owned by Vanderlande)

Second tier suppliers **-** The current role of second tier suppliers is to deliver raw materials and components for assemblies to the first tier suppliers. Vanderlande has close contacts with a limited number of second tier suppliers of some components, such as motors. In collaboration with this second tier supplier, engineering sets this specific motor in every BOM for Vanderlande equipment, stimulating first tier suppliers to buy this specific motor at the second tier supplier for a predetermined price. A second tier supplier can also be a first tier supplier for other Vanderlande items. Vanderlande's factories serve as second tier suppliers when they deliver subcomponents to each other, for example the factory in Veghel sends subcomponents to the factory in Santpedor.

First tier suppliers **-** The current role of the first tier suppliers is to deliver orders from SCCs at the right date, right amount and in good quality to the warehouses. A first tier supplier can be either a Vanderlande factory or a subcontractor. Vanderlande currently owns three factories; Appendix B evaluates their main differences. Veghel is located next to headquarters and is the oldest and largest of the three factories. This factory frequently communicates with Sourcing, Engineering and Research & Development and serves as the main playground for prototyping and new product introductions. To control factory workload, only SCC EU can order at Veghel, causing internal orders between the SCCs. Vanderlande has an extensive supplier base of subcontractors.

Supply chain centres **-** The current role of the SCCs is "*deliver the right product, at the right moment to the right location at the right quality and cost".* The SCC focuses on Vanderlande equipment, such as drives, sliderbeds and motors. Project procurement purchases all general equipment, such as scanners or screening machines, based on technical specifications. Appendix B evaluates the main differences of the three SCCs. We draw two conclusions. Firstly, SCC EU is the oldest and largest SCC in terms of personnel and workload. Secondly, every SCC has in some aspects a different way of working.

Warehouses & Distribution Centres **-** The current role of the warehouses is to receive, store, consolidate and ship items to site. Vanderlande has two warehouses: one for SCC EU in Veghel (European Distribution Centre, EDC) and one for SCC NA in Acworth. SCC EU consolidates most items first in the EDC and ship complete activities. SCC NA sends items directly to site based on geographical distance of supplier and site. SCC AP outsources warehousing to their subcontractor. Thus, every SCC has a different approach regarding storage and distribution of activities to site.

Sites **-** The current role of sites is to receive items, install and test the system. Sites are located at the customer's location, which can be any geographic location in the world. Every site is supervised by the site manager who coordinates the site team, assures quality and a safe working environment and communicates with both customer and Vanderlande's internal offices.

2.3. Material flow

Figure 2.3 provides an overview how materials flow from first tier supplier to site. We explained in Section 2.1 that every SCC has project stock and anonymous stock, which results in six 'business units' or 'branches' from where Vanderlande sends orders. The project branch coordinates the delivery of an activity to site. Vanderlande orders an item via a PO (purchase order) based on the activity BOM.

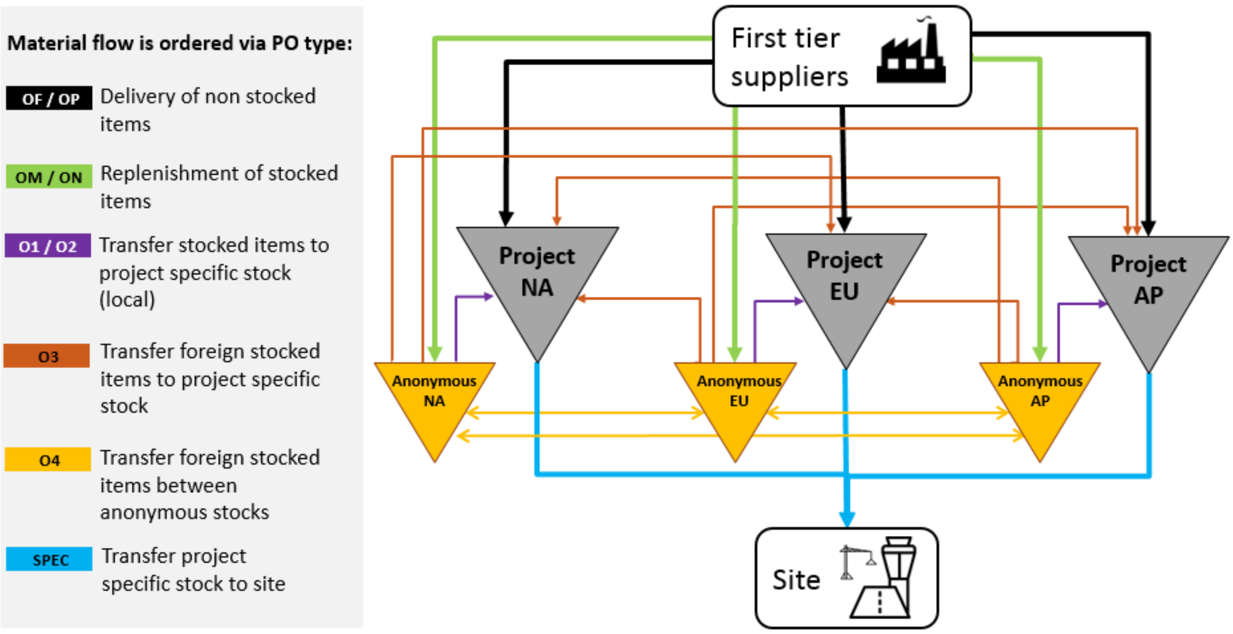

Figure 2.3 - Overview of all material flow with different type of Purchase Orders (Source: based on blueprint Vikipedia)

Let us now shortly explain the different order types that exist. The SCC orders project items from first tier suppliers via a Purchase Order (**OP,** to subcontractor) or via a Purchase Order Factory (**OF**, to Vanderlande's factories). The SCC can obtain items if they are available in the anonymous stock via **O1/O2** from their own anonymous stock, or at the anonymous stock of another SCC via **O3**. Items can be exchanged between SCC's anonymous stock via **O4**. These so called 'internal orders' between SCCs causes delay and requires extra communication efforts. Currently, this occurs via Skype, but interviews showed this is not sustainable when the number of orderlines grow. The difference between O1 and O2 is that O1 are bulk items belonging to a specific project but are built for multiple SPECs due to minimum order quantity, whereas O2 items are bought in larger quantities for multiple projects. These items are not yet assigned to a specific activity. Anonymous stock is replenished by orders from first tier suppliers (**OM** for O1, **ON** for O2). Eventually, an anonymous item is linked to a project activity, and the complete activity is shipped to site.

This three SCC network is in place since 2010. We perform a short analysis to illustrate current workload and the usage of anonymous versus project items.

The first insight we obtain is that most projects (89%) are still single SCC sourced, meaning that all project activities are sourced via the same SCC in our dataset. Because of ERP restrictions, an activity must completely be sourced by one SCC. But a project always consists of multiple activities, enabling double or triple sourcing of SCCs. This suggest that Vanderlande could make more use of their global supplier base.

The second insight of this analysis is that anonymous items are still a minor part of total material flow: only 2% of all SKUs belong to anonymous stock, and only 6% of all orderlines relate to anonymous items. Figure 2.4 shows the usage of anonymous versus project items, both in terms of stock keeping units (SKUs) and number of orderlines. We have several explanations why this number is lower than expected: 1) anonymous items are bulk, which logically lowers the number of SKUs compared than for tailor-made items. 2) Engineering is not restricted by GSC and can turn every equipment into new configurations, resulting in many new project item numbers. Appendix C illustrates an example with the Posisorter: although this sorter seems suitable for bulk production, Engineering can change many aspects. With this freedom, last year 1284 different SPECs were created, whereas 48 configuratoins would be enough to serve most customers. 3) The concept of anonymous items is introduced recently (2010); Vanderlande could still be exploring and developing these possibilities.

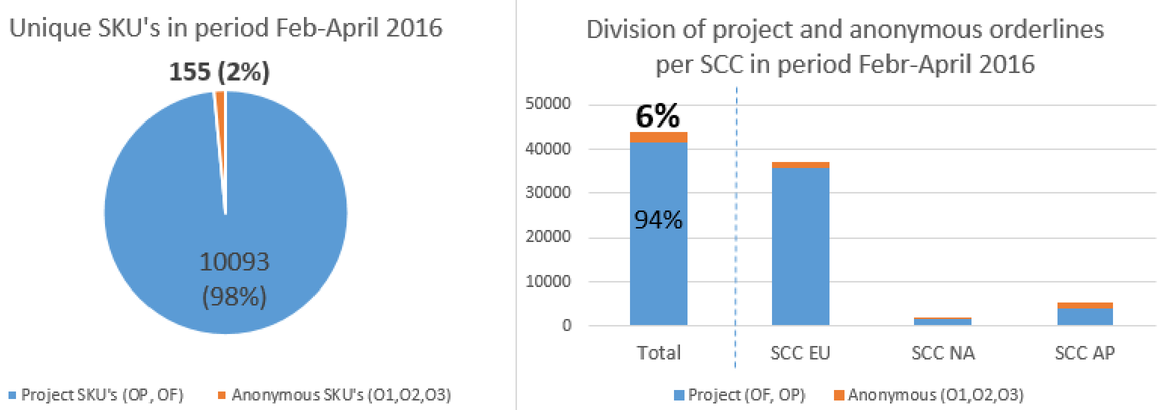

Figure 2.4 - Division of anonymous versus project items

The third insight is that SCC EU still places most orderlines, which can be explained by historic developments. In conclusion, this suggests that the current supply chain network can make more use of their global span and anonymous items.

2.4. Fit for growth

Looking at future prospects, Vanderlande must become 'fit for growth'. This has implications for the supply chain network. The board initiated this program to cope with the rapid expanding market. Since network design decisions last for several years, it is important to consider these growth trends. Vanderlande guides their growth ambitions based on three criteria, shows in the growth framework (Figure 2.5): key customers are leading (1), solutions are oriented on key customers (2) and geographic expansion is done by following these key customers (3). Vanderlande prioritizes projects based on the number of criteria it fulfills.

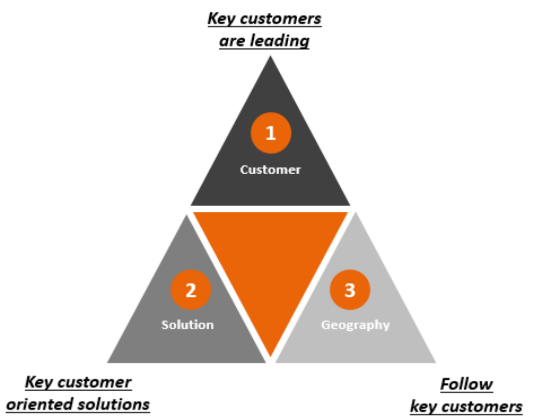

Figure 2.5 - Framework of the 'fit for growth' program (Source: Lockdown strategy presentation, 2016)

Key customers - Vanderlande expects all markets to grow the coming years. Airport passenger volumes stimulates the baggage handling system market (MarketsAndMarkets, 2016) and the rise of e-commerce sparks the warehouse automation and parcel & postal market. This expected annual sales increase is the first growth trend (I). Balancing the workload is challenging in a project organization because equipment supply is characterized by a 'high peak, long tail', which we elaborate on in appendix D. The second growth trend (II) is that key customers demand multiple warehouses to be built simultaneously while meeting shorter lead times, forcing Vanderlande to a new way or working.

Solutions – Vanderlande strives to do ongoing investments in R&D to serve these key customers. To stay competitive in a growing market, this results in a growth trend (III) of more New Product Introductions (NPIs) entering Vanderlande's supply chain.

Geographic expansion – Vanderlande evolved from a national operating company to a multinational. Currently, most revenue is created in Europe and North America, but they expect most growth in the Asia-Pacific region. This was the motivation for introducing these three SCCs. Vanderlande recently acquired four companies, spreading their global span. We identify two growth trends: increased international collaboration between SCCs (IV) and acquisition of external parties (V).

We translate these growth trends to network implications. To become fit for growth, the network should:

(I) Be able to tackle an annual workload increase for all SCCs.
(II) Facilitate key customer's desire to concurrently build projects within shorter lead times.
(III) Cope with more NPIs entering the supply chain.
(IV) Provide a more sustainable way to monitor internal orders between SCCs.
(V) Ease integration of new acquired facilities.

2.5. Lead time build up and current performance

We now provide extra insight in how lead times are build up. The planning department makes project planning on activity level. Every project has at least three milestones: contract award, mechanical layout approval and system handover. These are deadlines that must be finished before the other phase can start. In most projects, installation time is limited since the customer has only temporary building space, or a new building is still under construction. Therefore, they introduce the milestone 'Building Available'. After 'Mechanical Layout Approval', engineering starts releasing SPECs which creates the demand for the SCCs. Figure 2.6 shows a simplified project planning of a short project. All supply chain processes relate to phase 4 'equipment supply'. Although the duration of this project is rather short, it illustrates the milestones and planning sequence. Here, the equipment supply lasts 75 of the 210 days, which is 36% of the total project duration. Not all milestones are in control of Vanderlande; for example the customer determines the initial start date of 'Building Available'.

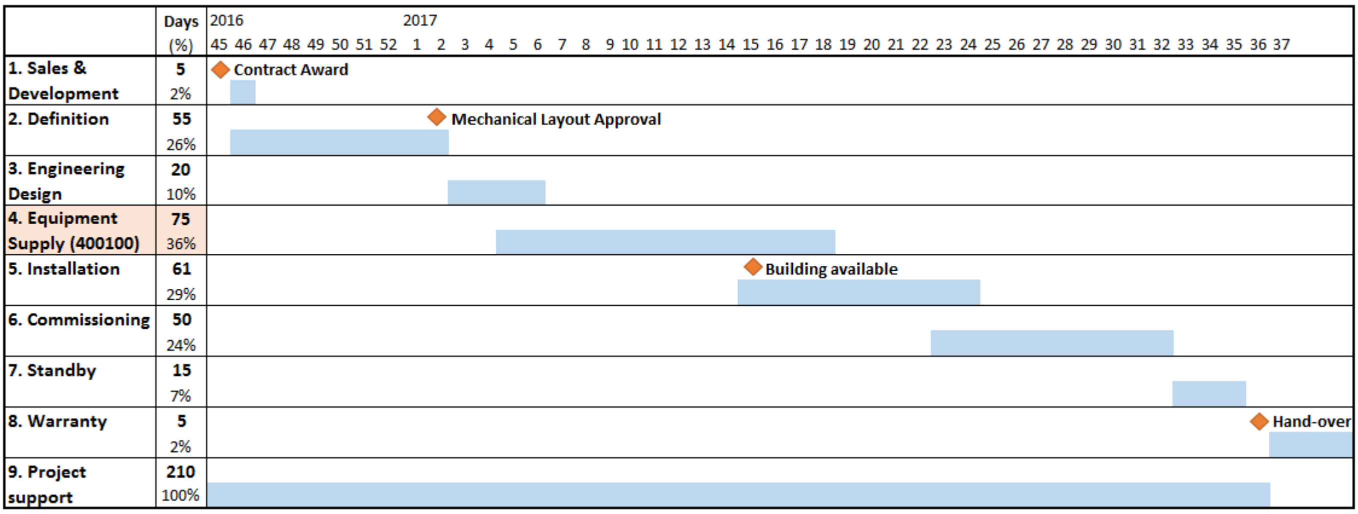

Figure 2.6 - Gantt chart based on Project 1408365

These milestones set the initial boundaries for the total project duration since they are located on the *critical path*. The critical path is the longest sequence of processes in a project and this determines the minimum project duration (*makespan*). These processes cannot start until its predecessor is completed. Total product duration is the time between contract award and hand-over. If installation phase delays due to too late delivery of activities on site and the installation team cannot speed up their processes, the hand-over moment shifts to a later moment in time. This increases the total project duration due to Vanderlande's performance, which can result in high penalty costs and dissatisfied customers.

We illustrate the critical path via a simplified network diagram. Figure 2.7 shows the equipment supply phase for a project with just three activities. Equipment supply of an activity can only start when SPEC is released (predecessor): Engineering releases the SPECs on different moments in time: in week 0, 2 and 4. Activity C is located on the critical path due to the longest duration: the makespan 4+8=12 weeks. This means that activity A has a slack or 'float' of 4 weeks. Order delay in activity A does not change the makespan until delay exceeds 4 weeks, and speeding up supply of activity A does not shorten the total makespan. But if equipment supply of activity A delays more than the float (for example 5 weeks), a new critical path is created (0+8+5>12). Moreover, if the customer informs the supply chain department that the building is available in 20 weeks instead of the promised 10 weeks due to for example construction errors, all equipment supply obtain extra float. Then, the makespan increases without Vanderlande to blame.

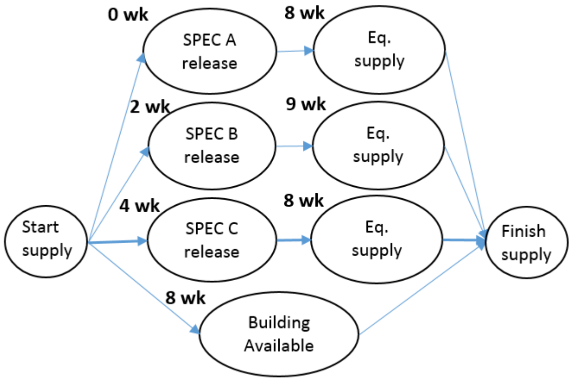

Figure 2.7 – Network diagram to illustrate critical path in equipment supply phase (makespan = 12 weeks)

This illustration shows that orderline delay is harmful if it increases the activity makespan. Early delivery is helpful if it shortens the activity makespan. Every item provides in essence a possibility to increase the makespan and thereby delay projects. Therefore, we focus our responsiveness performance on orderline level.

The SCC quotes a fixed activity lead time of eight weeks, which the planning department uses for the equipment supply phase. This means that the SCC promises that an activity is delivered in the warehouse at most eight weeks after SPEC release (this excludes shipping to site). The SCC may extend this quotation if the BOM contains long lead time items or exceeds certain financial thresholds. Figure 2.8 shows the processes within these eight weeks: this shows that Vanderlande's responsiveness performance is influenced by multiple echelons, meaning that a delay from a second tier supplier also influences lead time performance. After SPEC release, the SCC uses one week to prepare and release all orders of the activity. Then, the first tier supplier has a maximum of seven weeks to deliver the items to the warehouse; this includes engineering of manufacturing planning, order and receive sub items at second tier suppliers, assemble and deliver the item to the warehouse.

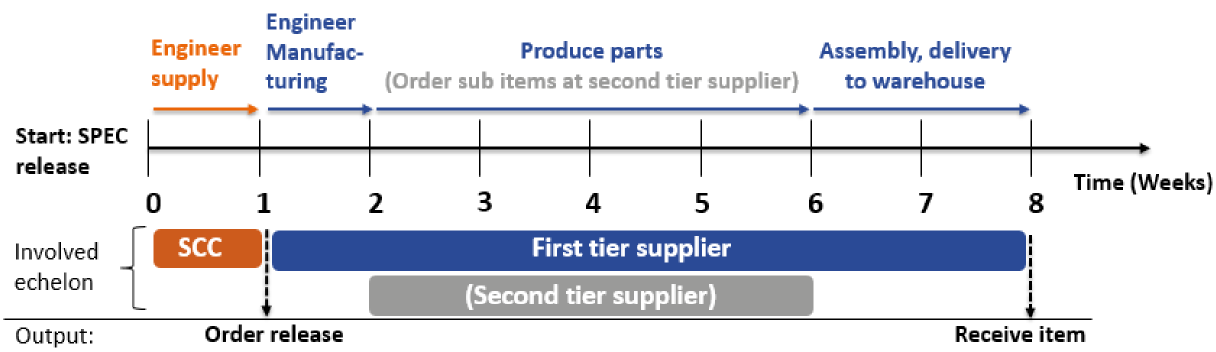

Figure 2.8 – Lead time from order release to item receive

We now explain how we operationalize responsiveness. Companies can measure performance based on Key Performance Indicators (KPIs). Although the goal of SCCs is to be responsive with supply of activities towards projects, we focus on orderline level and request date instead of just activity level and late finish date, since every orderline can extend the critical path.

Every activity has a late finish date which indicates project's critical path. Every orderline has five data points that we can use for KPI calculations (Figure 2.9):

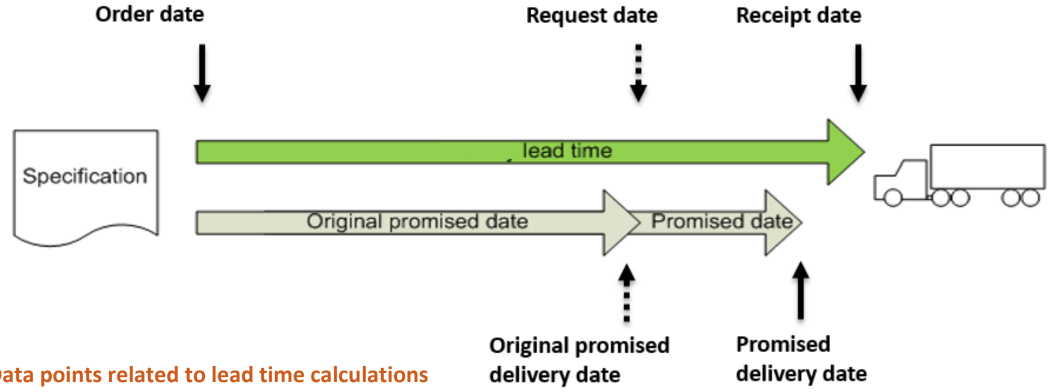

Figure 2.9 - Data points related to lead time calculations

- **Order date:** moment that Vanderlande places the order in ERP system and informs supplier.
- **Request date:** moment that Vanderlande would like to receive the order at warehouse.
- **Original promised delivery date:** initial delivery date quoted by supplier.
- **Promised delivery date:** latest delivery date communicated by supplier.
- **Receipt date:** moment that Vanderlande receives item at warehouse. This can be before, exactly on or after the request date.

When the SCC sends an order to a first tier supplier, the operational buyer enters three dates: request date, original promised delivery date and promised delivery date. Initially, all three fields are set on the request date, which is based on (but not necessarily equal to) the late finish date of the activity. When a supplier informs the SCC that an item is delivered earlier or later than requested, the operational buyer changes the original promised delivery date. If the supplier quotes a new delivery date, the operational buyer only changes the promised delivery date. This way, the three fields can have different values in the end. The warehouse only sends complete activities to site; if all orderlines of the activity are delivered on or before the request date (receipt dates $\leq$ request dates), the activity is shipped on time. Delay can occur when an orderline arrives later than requested: receipt date > request date.

Vanderlande has no performance measurements in place to measure responsiveness. To provide insight in current responsiveness performance, we formulate three KPIs: orderline fill rate, activity fill rate and average activity lead time. We use these KPIs later on in this thesis to show how the redesign performs compared to the current network.

1) **Orderline fill rate** is the fraction of orderlines of which the item is available in the warehouse at the request date. For example: an orderline fill rate of 80% means that 80% of the orderlines, the item is in the warehouse at request date, 20% is later than request date. Ideally, this fill rate is close to 100%.

$$Orderline\ fill\ rate = \frac{(\#\ orderlines\ where\ receipt\ date\ \leq request\ date\ in\ period)}{Total\ \#\ orderlines}$$

2) **Activity fill rate** is the fraction of activities of which all orderlines are available in the warehouse at the late finish date. Ideally, this is 100%, meaning that no activity caused project delay. The lower the activity fill rate is, the more hinder a project experiences. Therefore, we consider this activity fill rate as an important indicator for supply chain responsiveness in Vanderlande's context.

$$Activity\ fill\ rate = \frac{(\#\ activities\ where\ all\ orderlines\ have\ receipt\ date\ \leq late\ finish\ date)}{Total\ \#\ activities}$$

3) **Average activity lead time** is the average makespan of an activity. We divide by 7 since we express lead time in weeks. We add one week since the SCC uses one week to prepare the order (see Figure 2.8). The activity is completed when the last order arrives in the warehouse, therefore we take the maximum receipt date of all activity's orderlines. Ideally, this KPI value is equal to Vanderlande's activity lead time quotation of 8 weeks.

$$Activity\ lead\ time\ in\ weeks = \frac{\max(receipt\ date) - \min(order\ date)\ of\ activity's\ orderlines}{7} + 1$$

$$Average\ activity\ lead\ time = \frac{\sum_{all\ activities} Activity\ lead\ time}{Total\ \#\ activities}$$

Ideally, we would also add a financial KPI for penalty cost of delay if an item extends the critical path, but these penalty costs heavily depends on the customer and only occurs when the installation team comes to a complete shutdown. We are not able to track this in the ERP system and we cannot generalize penalty costs. We limit our analysis to six projects since considering all projects is too exhaustive. To provide a complete view, we select a sample of projects of different size and sector. Table 2.2 presents the current responsiveness performance. This analysis shows that orderline fill rate is 57%, meaning that first tier suppliers deliver their orderlines in almost half of the instances later than requested. This explains why the number of incomplete activities increases over time, see Chapter 1. The activity fill rate of 90% implies that in these six sample projects, 10% of the activities were later than the late finish date, causing hinder for the installation team on site. The average activity lead time is 10.6 week, which is 2.6 weeks longer than the desired 8 weeks of planning department. This shows room for improvement.

Table 2.2 - Responsiveness KPIs

Current performance	Overall	1473602	1407772	1404242	1407063	1408305	1408744
# orderlines	33508	11705	10355	2772	1505	2048	5123
# orderlines on time	19094	8042	6241	1901	355	1062	1493
Orderline fill rate	**57%**	69%	60%	69%	24%	52%	29%
# activities	982	514	162	142	27	67	70
# activities on time	886	476	147	123	24	55	61
Activity fill rate	**90%**	93%	91%	87%	89%	82%	87%
Average activity lead time	**10.6**	10.4	11.8	9.9	11.3	10.4	11.2

2.6. Conclusion

This chapter allows us to answer the first research question: *"How does Vanderlande's supply chain network operate and how can we measure and explain current responsiveness performance?"*

Responsiveness is a trade-off with efficiency. We explain how Vanderlande's network currently operates by evaluating drivers inventory, transportation, information, sourcing and pricing. The network consists of five echelons: second tier suppliers, first tier suppliers, warehouse & distribution centres, sites and the three coordinating SCCs. We analyze material flow and all types of orderlines, also internal orderlines between SCCs. We identify that to become fit for growth, the SCCs should be able to tackle a workload increase, facilitate key customer's desire to concurrently build projects within shorter lead times, cope with more NPIs, provide a more sustainable way to monitor internal orders between SCCs and ease integration of new acquired facilities. The makespan of the critical path determines total project lead time. We measure responsiveness based on three KPIs and compute their values based on six sample projects. This results in an orderline fill rate of 57%, activity fill rate of 90% and average activity lead time of 10.6 weeks, which is 2.6 weeks more than the quotation of 8 weeks. We show reasons that can explain this performance. One could think of internal orders, high peaks instead of stable workload, freedom from Engineering, internal orders between SCCs and only sending complete activities to site.

3. LITERATURE STUDY

We explained in the previous chapter how the current network operates. This chapter takes a closer look on scientific literature to see what solutions they provide. This chapter answers the second research question: "What theory does literature offer to improve responsiveness in an engineer-to-order oriented supply chain by changing facility roles in the network design?" Section 3.1 explains how we perform our study, Section 3.2 summarizes each research topic and Section 3.3 presents our conceptual framework.

3.1. Literature review selection

This section explains the methodology of our literature study. Since time is limited and researchers already have written many excellent reviews, we prefer an explorative study instead of an exhaustive literature review. We execute our literature study in three steps:
1) Select relevant literature reviews
2) Summarize theory on research topics to get the reader acquainted with theory.
3) Develop a framework to apply theory in Vanderlande's context.

To ultimately answer the sub question, we demarcate our analysis with four research topics: supply chain network, facility role redesign, engineer-to-order and responsiveness. This is called 'purposive sampling' (Randolph, 2009), where the researcher examines only central or pivotal articles in the field. No review exists that combines all four topics together. To overcome this issue, we look for reviews that combine two topics (keyword combinations A, B, C) or on facility role redesign in specific (combination D). Figure 3.1 visualizes this overlap. We use Scopus as database and only include papers with a minimum journal rate of 1 to ensure high quality. Appendix E shows the specific search queries and the list of ten selected reviews. We use forward and back tracking to find additional information if necessary. We first summarize each research topic individually, followed by the development of our framework to apply this theory in Vanderlande's context.

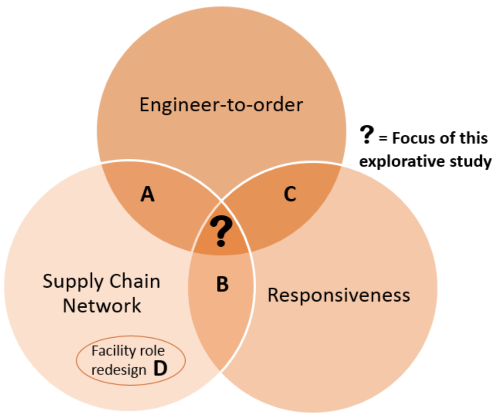

Figure 3.1 - Overlap of research topics

3.2. Summary per research topic

Research topic 'Supply chain network'
According to Melo et al. (2008), supply chain management is concerned with planning, implementing and controlling all operations, movements and storages of the supply chain from point-to-origin to point of consumption. Movements can be categorizes in flow of products, information and funds. The goal is to satisfy customer needs and generate profit from this only revenue source. Supply chain management decisions can have serious impact on a firm's performance (Chopra & Meindl, 2016). Historically, nodes in the network were optimized separately based on the false assumption that linking these local optima would result in the global optimum for the whole supply chain (Bicheno & Holweg, 2008). But recent literature move to a holistic network perspective. To compete in the globalizing market, companies must extend integration beyond their own boundaries (Banderjee et al., 2011) and management of only single relationships should be avoided (Arantes et al., 2015). Collaborative efforts in the network result in many benefits such as cost reductions and quality increase (Arantes et al., 2015), so key is to consider the entire network and aim for synergy (Bicheno & Holweg, 2008).

Research topic 'Facility role redesign'

Redesign is often triggered by market expansion or mergers (Melo et al., 2008). Facility role redesign is a network design decision and therefore strategic: it sets the structure for years to come and thus have a long-lasting effect on the company (Melo et al., 2008). Many factors complicate these decisions, since strategic decisions have a long term impact on the company's performance (Melo et al., 2008). It must anticipate on future, uncertain activity levels over a long time horizon to ensure a robust value-creating network (Klibi et al., 2010). Since managerial decision making is involved, human factors complicate network design decision making (Olhager et al., 2015). Therefore, emotional and cultural influences may be strong inhibitors or enablers of design decisions (Engelhardt-Nowitzki, 2012). The multinational and global coverage introduces exchange rate risk, tariffs, tax regulations and trade barriers (Klibi et al., 2010). The selection of performance indicators to assess the network design quality is another important challenge (Klibi et al., 2010). Another challenge is that often there is an old network in place, resulting in existing relationships and power dynamics. Thus, we conclude that when redesigning facility roles, we should consider the long term impact, human factors, global coverage, selection of new performance indicators and the old network that is in place.

The supply chain can achieve a given level of responsiveness by adjusting facility role of each stage: making one stage more responsive allows other stages to focus on efficiency (Chopra & Meindl, 2016). The idea is that implied uncertainty can be allocated in different ways across supply chain stages, resulting in different roles while obtaining the desired level of responsiveness (Figure 3.2). In this figure, most uncertainty in Supply Chain II is allocated to the manufacturer, thus allowing other stages to focus on efficiency (Chopra & Meindl, 2016). The best role combination depends on the available flexibility and efficiency capabilities at each stage.

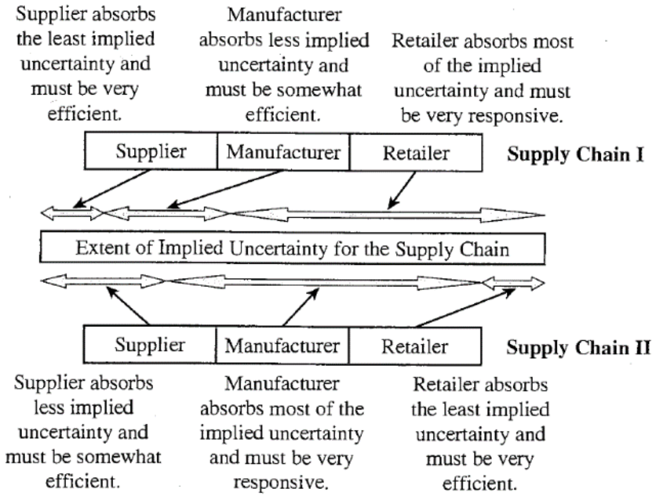

Figure 3.2 - Two network configurations (Chopra & Meindl, 2016)

A facility can take different roles for different product types (Olhager et al., 2015). Lee (2004) state that networks should be designed around primary supply chain entities which are relatively robust to market changes. He states that the best supply chains identify and adapt to environmental changes before they occur and develop a network with more than one structure in place. Long-term relationships must be established between these primary, robust entities to reduce uncertainty. The supporting and inter-changeable supply chain entities can be linked with short-term relationships, this to ensure easy reconfiguration (Stevenson & Spring, 2007). One can include softer aspects such as site competences, existing facility relationships and power dynamics (Olhager et al., 2015).

Research topic 'Engineer-to-order'

Many articles discuss supply chain structure classification, aiming to define specific characteristics. A well-known way to classify supply chains is based on the location of the customer order decoupling point (CODP). The CODP, also called 'order penetration point', is a virtual point in the supply chain that separates the part that responds directly to customer demand from the part that uses forecast planning (Gosling & Naim, 2009). Pull processes are initiated by the customer order, whereas push processes are initiated to anticipate on customer orders (Chopra & Meindl, 2016). It is important to identify the appropriate push/pull boundary to match supply and demand. Inventory exists at the CODP to counter forecast errors caused by mismatch in supply and demand (Bicheno & Holweg, 2008). The position of the CODP is affected by market, product and production; it is important to consider these factors since they influence the network design (Olhager et al., 2015). They state that a network in an ETO context should most likely be designed different than a network for high volume, standardized products.

We summarize five ETO characteristics from these reviews:

1. Decoupling point at the design stage. Orders are postponed until customer orders have been fixed (Engelhardt-Nowitzki, 2012), making it difficult to forecast and amplifies the bullwhip effect. Delayed information flow increases demand variability as orders move along a supply chain: the preceding tier has to react more strongly to changes in demand.
2. High level of customization. ETO products are typical 'high mix, low volume'.
3. High product complexity. ETO products often have a deep and complex BOM structure.
4. Project environment. This results in different supplier partnerships from project to project. Arantes et al. (2015) mention in their review that trust, openness and honesty is needed for successful partnerships, but state that these attitudes often lack in the construction sector.
5. Non-fixed site locations. Customers can be located at different geographical locations, which causes extra transportation issues and possible lead time increase.

Research topic 'Responsiveness'

Researchers have not yet reached consensus about a comprehensive definition of supply chain responsiveness. Underlying terms such as flexibility, agility and adaptability are used heterogeneously (Engelhardt-Nowitzki, 2012), causing inconsistency. Since researchers lack a comprehensive definition of responsiveness, it is no surprise that there is no agreement on how to measure responsiveness. As Stevenson & Spring (2007) quote: *"Until adequately defined, it cannot be measured",* referring that this research field is still in its infancy. Measuring flexibility is difficult and studies about flexibility measurements are often criticized for being subjective and too specific. Flexibility is a measure of potential behaviour so it does not have to be demonstrated to be real (Stevenson & Spring, 2007), which makes it difficult to measure in the first place. Engelhardt-Nowitzki (2012) use a three-step framework to improve flexibility, which we explain in more detail in appendix F. Her first step is to operationalize flexibility for the given context, then identify the sources of uncertainty and develop improvement means. We cannot use the framework directly in our situation since it is too generic: it relates to flexibility in general, not supply chain responsiveness in specific. What we do consider valuable information is her three-step approach and insight of first operationalizing for the given context, something that other authors also empathize. We add this insight of a three-step approach and operationalization in our framework.

Stevenson & Spring (2007) state that the importance of flexibility concepts varies per supply chain: the ability to quickly act to customers' orders plays a strategic role in markets with volatile demand and high product variety. In volatile markets, manufacturers cannot longer hedge with finished goods inventory so a more flexible production strategy is needed (Chou et al., 2011). Thus, before we redesign a network to improve responsiveness, it is important to first consider the reasons why responsiveness is needed in the first place. The framework of Reichhart & Holweg (2007) helps identifying these causes of uncertainty. Appendix F provides extra explanation. These authors list four 'external requirements' that stimulate the need to be responsive in the first place:

- Demand uncertainty.
- Demand variability.
- External product variety.
- Lead time compression.

Key in their framework is that they use two types of responsiveness: demonstrated responsiveness (what your environment forces you based on the external requirements) and potential responsiveness (which your firm can improve by changing internal determinants). One should first determine the level of demonstrated responsiveness that is really needed, and then change internal determinants to align potential responsiveness with demonstrated responsiveness, this to avoid unnecessary costs. We add this insight of first determining uncertainty from external requirements and then aligning the internal determinants in our framework.

The supply chain decision framework of Chopra & Meindl (see Chapter 2, Figure 2.1) shows that responsiveness is a trade-off with efficiency. A company should decide where flexibility is needed and where uncertainty can be reduced, while considering "*both the benefits and penalties associated with flexibility"* (Engelhardt-Nowitzki, 2012). Some authors argue that a limited amount of flexibility can already achieve many of the benefits of 'overall flexibility' (Stevenson & Spring, 2007). This was proved in a recent study of Chou et al. (2011), showing that partial plant flexibility can be nearly as effective as full flexible systems. Chopra & Meindl (2016) support this by stating that a key strategic choice of any supply chain is the level of responsiveness it seeks to provide, given this cost trade-off. But "*questions about how many flexibility an ETO firm requires and which type, remain unsolved*" (Gosling & Naim, 2009). When relating this trade-off to network design, a close collaboration with every facility in the network would be impractical and expensive. In conclusion, studies show that partial responsiveness can already obtain most benefits of 'overall flexibility'.

Due to the cost trade-off, a company should decide where responsiveness is most needed and where uncertainty can be reduced. This again relates to the external requirements of Reichhart & Holweg (2007), which structures the causes of uncertainty a company faces. When a company serves many customer segments with a wide variety of products across multiple channels, a tailor supply chain is required that is efficient when implied uncertainty is low and responsive when uncertainty is high (Chopra & Meindl, 2016). These authors state that "*creating strategic fit is all about designing a supply chain whose responsiveness aligns with the implied uncertainty it faces",* what we can relate to Reichhart & Holweg's approach to align potential with demonstrated responsiveness.

3.3. Framework development

Literature does not provide us with a direct solution to improve responsiveness in an ETO environment by redesigning the facility roles in the supply chain network. During our study we observe two frameworks that we can combine to serve our particular need. Thus, we use the frameworks of Engelhardt-Nowitzki and Reichhart & Holweg (appendix F) as inspiration. The strong point of Engelhardt-Nowitzki's framework is that she uses a clear three-step approach and first operationalizes for the given context. Since flexibility is too generic for our research we change this to the more specific term 'supply chain network responsiveness'. The strong point of Reichhart and Holweg is that they identify demonstrated and potential responsiveness, stating that one should first consider uncertainty created from external requirements, and then align potential responsiveness by changing internal determinants. Their framework focuses on a wide range of internal determinants, stating that *"responsiveness is a goal that can be achieved through multiple means"*. This shows that tailored solutions are needed based on a company's restrictions, preferences and specific circumstances. Since we focus on network design in specific, we change the internal determinants according to the classification of Chopra & Meindl (2016).

This results in four new internal determinants: **facility roles, facility location, capacity allocation** and **market & supply allocation.** The insight we include in our framework is uncertainty allocation, making one facility focussing on responsiveness and the other on efficiency. We mainly focus on facility roles, so we only shortly explain the other internal determinants. Many researchers focus on facility location. Simply said, centralized locations are preferred for efficient supply chains, whereas decentralized is preferred for responsive supply chains, being close to the customer. Capacity allocation can improve potential responsiveness since excess capacity enables responsiveness (Chopra & Meindl, 2016). Collaborative relationships with other facilities can be used to reduce uncertainty by developing inter-organizational trust and commitment (Stevenson & Spring, 2007). Market and supply allocation influences responsiveness by choosing fast, reliable and flexible suppliers. Supplier involvement can *"reduce development time, product complexity and costs while improving parts commonality, ease of manufacturing and quality"* (Stevenson & Spring, 2007).

Figure 3.3 presents our framework. We use this in Chapter 4 to guide our redesign.

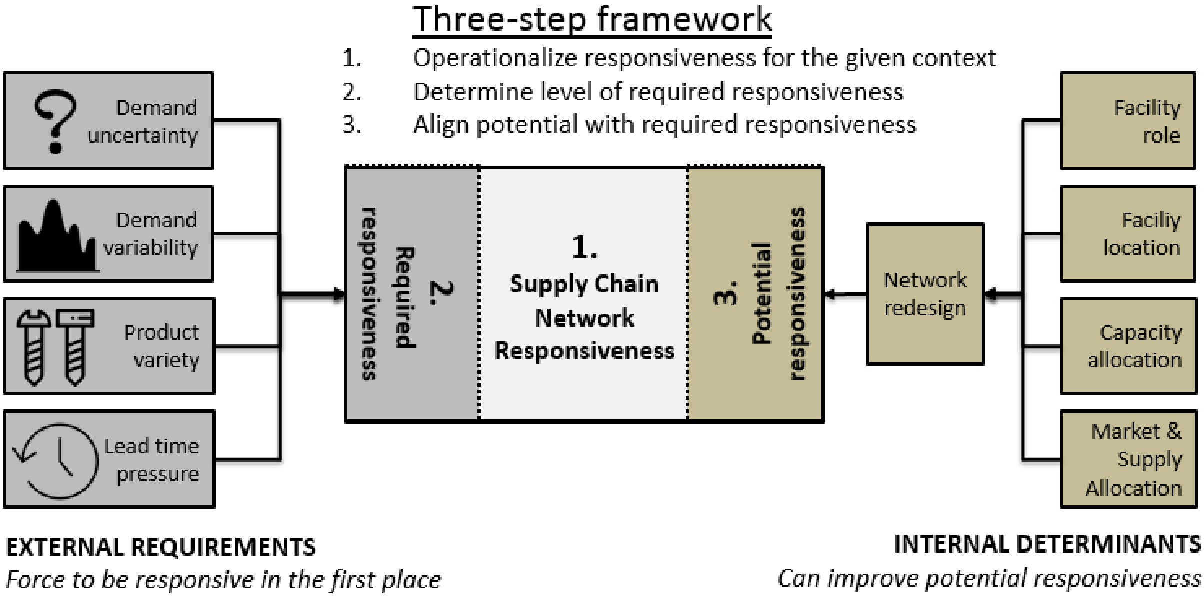

Figure 3.3 - Our framework, inspired by Engelhardt-Nowitzki (2012) and Reichhart & Holweg (2007)

The first step is to **operationalize** responsiveness for the given context, as emphasized by Engelhardt-Nowitzki. The second step is to **determine** why responsiveness is needed in the first place and where uncertainty from external requirements can be reduced. Based on this step, we find the level of required responsiveness. We highlight some examples which are relevant for our supply chain. One way to reduce uncertainty is by information sharing, which decreases the bullwhip effect (Stevenson & Spring, 2007) and thereby the external determinants 'demand variability'. The location of the customer order decoupling point heavily influences uncertainty since it determines the product characteristics (Stevenson & Spring, 2007). Hence, another way to reduce uncertainty is to move the location of the CODP downstream by standardization, which reduces uncertainty from the external determinant 'product variety'. Once the level of required responsiveness is defined, the third step is to **align** potential responsiveness with this required responsiveness by redesigning the network. We changed the term 'demonstrated' to 'required' responsiveness since we believe that this term better describes its function.

We contribute to literature by designing a three-step framework based on academic literature reviews. There was no such framework in place yet. This framework can be adjusted to fit other companies that face responsiveness problems. They can adapt the framework to their own restrictions, preferences and circumstances. We refer to the paper of Reichhart & Holweg (2007) if the company is interested in other internal determinants.

3.4. Conclusion

This chapter allows us to answer the second research question*: "What theory does literature offer to improve responsiveness in an engineer-to-order oriented supply chain by changing facility roles in the network design?".*

We evaluate ten literature reviews on four research topics. Since literature does not offer a direct solution, we design a three-step framework inspired by the work of Engelhardt-Nowitzki (2012) and Reichhart & Holweg (2007). The first step is to operationalize responsiveness for the given context. Then, we must determine the level of required responsiveness based on the four external requirements. The last step is to align potential responsiveness by changing internal determinants.

4. NETWORK REDESIGN

This chapter answers the third research question: "How to apply this theory to redesign Vanderlande's supply chain network?". In Section 4.1 we apply the three step framework of the literature study in Vanderlande's context, which results in the network redesign. Hereafter, Section 4.2 shows how facility roles change and Section 4.3 how material and information flow change. Section 4.4 provides us with the three main impacts of this redesign.

4.1. Apply framework in Vanderlande's context.

Step 1: Operationalize responsiveness for the given context

The first step of our framework is to operationalize; define responsiveness and determine how to measure this for the given context. We already performed this step in Chapter 2 by introducing the three KPIs and compute current performance based on six sample projects: orderline fill rate (57%, target ~100%), activity fill rate (90%, target 100%) and activity lead time (10.6 weeks, target 8 weeks). We also mention in Chapter 2 that in a project organization, the critical path determines the total project makespan. Since every orderline could potentially increase this project makespan, we measure KPIs on orderline level.

Step 2: Determine level of required responsiveness

In this second step, we first determine the level of required responsiveness on system level. We consider the four external requirements and match these with the five ETO characteristics of our literature study (Section 3.2). Table 4.1 shows this match. We see that all five ETO characteristics apply in Vanderlande's context, which results in a high level of required responsiveness on system level.

Table 4.1 – Required responsiveness is high on system level

		Vanderlande's complete system: <u>high</u> level of required responsiveness
External requirements	**Demand uncertainty**	**High;** Demand is uncertain until SPEC release; the CODP is located at the design stage since Vanderlande offers tailor-made customer solutions (<u>ETO characteristic 1</u>). From that moment, SCC has eight weeks to deliver all items to the warehouse. Demand can change in the rolling horizon due to SPEC revisions or changes in planning.
	Demand variability	**High;** The workload for the SCC is expressed in orderlines. Due to the project environment (<u>ETO characteristic 4</u>), this workload is characterized by a high peak and long tail as shown in the Oslo example, appendix D.
	Product variety	**High;** Engineering has the freedom to make every equipment project specific, resulting in high level of customization (<u>ETO characteristic 2</u>) as we showed in the posisorter example in appendix C. Also NPIs and products with complex underlying BOM structures (<u>ETO characteristic 3</u>) raise uncertainty of this external requirement.
	Lead time pressure	**High;** Vanderlande cannot buffer the customized items in finished good inventory, which pressures the lead time performance of all echelons involved. Non-fixed site locations all over the globe (<u>ETO characteristic 5</u>) also create lead time pressure.

However, as we just mentioned above, we measure KPIs on orderline level since every orderline can potentially increase the project makespan, causing project delay. Thus, responsiveness at Vanderlande applies not just on activities (system) but on orderline (item) level. Vanderlande's system consists of two type of items: project specific items (specials, one-offs) and more standard items. Both item types have different product characteristics, resulting in different levels of uncertainty. We show this by matching both item types with the external requirements.

Table 4.2 – Required responsiveness is high for project specific items but low for standard items

		Project specific items: <u>high</u> level of required responsiveness	Standard items: <u>low</u> level of required responsiveness
External requirements	Demand uncertainty	**High;** project specific items are specified in SPEC release, so CODP is located at the design stage.	**Low;** demand can be aggregated over multiple projects, enabling a reliable demand forecast.
	Demand variability	**High;** no demand aggregation possible, so demand variability is high.	**Low;** demand aggregation creates a more stable workload, which lowers the demand variability.
	Product variety	**High;** Project specific is characterized by 'high mix, low volume'.	**Low;** Standard items are characterized by 'low mix, high volume'.
	Lead time pressure	**High;** High customization hinders a buffer with finished good inventory, pressuring lead times.	**Low;** Forecast enables sourcing before SPEC release and inventory management, lowering the lead time pressure.

This table shows that the level of required responsiveness differs on item level. However, currently all items receive almost the same treatment, irrespective if these items are critical project specific items or standard items used in multiple projects. However, these standard components can require a lower level of responsiveness. Due to the responsiveness trade-off which we explained in Section 2.1, these standard items better fit an efficient strategy. The annual sales increase in this growing organization offers the opportunity to benefit of economies of scale (EOS).

Step 3: Align potential with required responsiveness

We use this insight in the third step to redesign the network. These different levels of required responsiveness ask for two supply chain strategies, which we call 'item level split'. Project specific items have a high level of required responsiveness and fit a responsive strategy. However, standard items have a low level of required responsiveness. Due to the responsiveness trade-off, an efficient strategy fits these items. We introduce <u>two</u> networks: the project specific network focusing on responsiveness, the EOS network focusing on efficiency by aggregating demand over all projects. This is in line with Chopra & Meindl's (2016) strategic fit, stating that a tailored supply chain is required to be efficient when implied uncertainty is low and responsive when implied uncertainty is high. The item level split results in two networks:

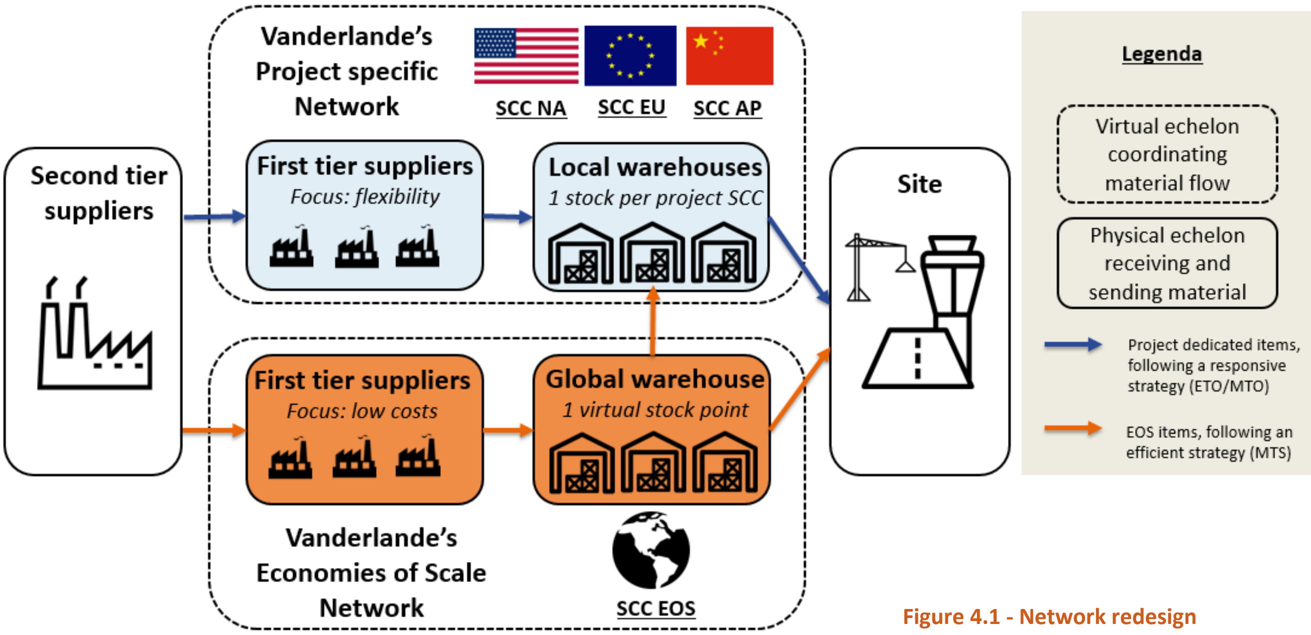

Figure 4.1 - Network redesign

The project specific network follows a responsive strategy and sources the so called 'project specific items'. This network serves the ETO environment where the CODP is located at the design stage. The economies of scale (EOS) network follows an efficient strategy and sources what we call 'EOS items'. The CODP is shifted downstream and demand is aggregated over multiple projects. In Chapter 5, we provide an item classification scheme to identify which items are suitable to become EOS items. We provide an illustrative example which we found in the book of Chopra & Meindl (2016). A company that successfully applied this item level split is fashion retailer Zara. They apply a responsive strategy for new season clothes ('project specific items') and an efficient strategy for basic clothes ('EOS items') and adjust the supply chain drivers that we showed in Section 2.1 accordingly. For example, Zara produces basic clothes in low-cost countries but new season clothes at local factories to ensure fast shipment to stores.

This redesign allocates most uncertainty to the project specific network. Key is that this redesign provides strategic focus: GSC selects per item the best supply chain strategy based on the item characteristics. The goal of the project specific network is to be responsive towards projects: coordination still occurs by the current three SCCs. On the other hand, the goal of the EOS network is to realize economies of scale by aggregating item demand over all projects. They must ensure item availability against lowest costs. Since the EOS network aggregates demand, there is one global virtual stock points which can have different physical locations. EOS items can be sent via separate shipments to site or first be consolidated at the local warehouse.

In our network design, we deliberately make a clear separation of two networks. We believe that if every facility focuses on one strategy that fits item characteristics, Vanderlande can deliver their systems faster ánd more cost efficient while still designing customer-specific solutions. The project specific network enables the customer-specific solutions, whereas the EOS network can apply proper inventory management and realize economies of scale, thereby being faster and more cost efficient. In Chapter 5, we shows this statement with a mathematical model.

4.2. Change in facility roles

This redesign provides a clear focus and role division for involved facilities of echelons of first tier supplier, SCC and warehouse. The role of second tier suppliers and site remains unchanged. As we explained in the literature study, a supply chain can achieve a given level of responsiveness by adjusting the facility roles of each echelon. Since we distinguish two strategies, we formulate two roles per echelon. We also introduce a new facility at Vanderlande to coordinate the EOS items: SCC EOS.

For Vanderlande, this redesign implies an organizational change. Currently, employees of SCCs manage all item types and must realize both on-time delivery ánd cost reductions. In the redesign, we provide employees with a specific strategic focus: "two teams". The employees that work for SCC EOS focus purely on efficiency and only source the EOS items. Their main tasks are aggregating demand, enabling cost reductions, standardization efforts and proper inventory management. They select suppliers based on cost and quaintly. On the other hand, employees that work for the three project SCCs can shift their focus purely on responsiveness of project specific items. They select suppliers based on speed, flexibility, reliability and quality (see table 2.1).

Table 4.3 shows the new facility roles per echelon.

Table 4.3 - Facility roles for project specific network and EOS network

Echelon	Facility role in project specific network	Facility role in the EOS network
Second tier supplier	Deliver raw materials and sub items to first tier suppliers.	Deliver raw materials and sub items to first tier suppliers.
First tier supplier	Deliver project specific items at the request date of project SCCs and provide flexibility. The facility focuses at on-time delivery, facilitate prototype testing and reserve excess capacity. Reduce lead times, even if costs are significant.	Deliver EOS items to warehouse at the request date of SCC EOS against lowest costs, providing reliable replenishment lead times. The facility lowers costs through high utilization. Reduce lead times, but not at the expense of costs.
SCC	Strategic focus is **responsiveness**: respond quickly to demand of project specific items. Select suppliers based on speed, flexibility, reliability and quality.	Strategic focus is **efficiency**: supply demand at the lowest costs while ensuring product availability. This by aggregating demand, realize economies of scale, lower risk of obsolescence by standardization and proper inventory management. Select suppliers based on cost and quality.
Warehouse	Receive and consolidate all project specific items and add the required EOS items, prepare on-time shipment of complete activities to site.	Receive and stock all EOS items against lowest inventory and distribution costs. Pick EOS items from stock and consolidate to activity when requested.
Site	Receive all items, install system, test system.	Receive all items, install system, test system.

We now specify how roles of Vanderlande's facilities change in more detail. As explained above, the redesign implies an organizational change that enables strategic focus. The employees of the three project SCCs shift their focus to responsiveness, whereas the employees of SCC EOS focus on efficiency. Regarding Vanderlande's three factories, Vanderlande has to decide which network they service, based on their flexibility and efficiency capabilities. A facility can take different roles for different product types (Olhager et al., 2015), this implies that Vanderlande's factories could serve both networks if they apply this item level split in their processes. To give an illustration, one part of the factory can focus on efficiency (high utilization, long production runs, realize Economies of Scale, low-cost suppliers) while the other part focus on responsiveness (prototyping, short production runs, excess capacity, flexible suppliers). Vanderlande can provide the supplier with a base load via the EOS network and use flexibility for the project specific network.

We recommend factory Veghel to become a flexible factory in the project specific network, due to their capabilities in prototype testing and geographic location close to headquarters. As shows in appendix B, factory Santpedor is specialized in high mix, low volume equipment. We recommend factory Santpedor to also become a flexible factory in the project specific network. Factory Calhoun produces conveyors and carrousels for the American market. Since this equipment is suitable for bulk production, we recommend factory Calhoun to become a low-cost factory in the EOS network. We recommend Vanderlande to adjust the KPIs of these factories accordingly, since currently their KPIs mainly focus on utilization instead of their flexibility capabilities. Vanderlande's current warehouses remain their role: receive, store, consolidate and ship items to site. However, both warehouses get an extra task of receive, store, pick and consolidate EOS items.

4.3. Change in material and information flow

This new SCC EOS has one global virtual stock point. Vanderlande can merge EOS items at the local warehouses or send them via separate shipments to site, which eliminates the need of internal orders. To lower complexity and raise transparency, we recommend to eliminate OM and OF orders since project specific SCCs buy via OP and SCC EOS via ON orders. This results in a new blueprint (Figure 4.2):

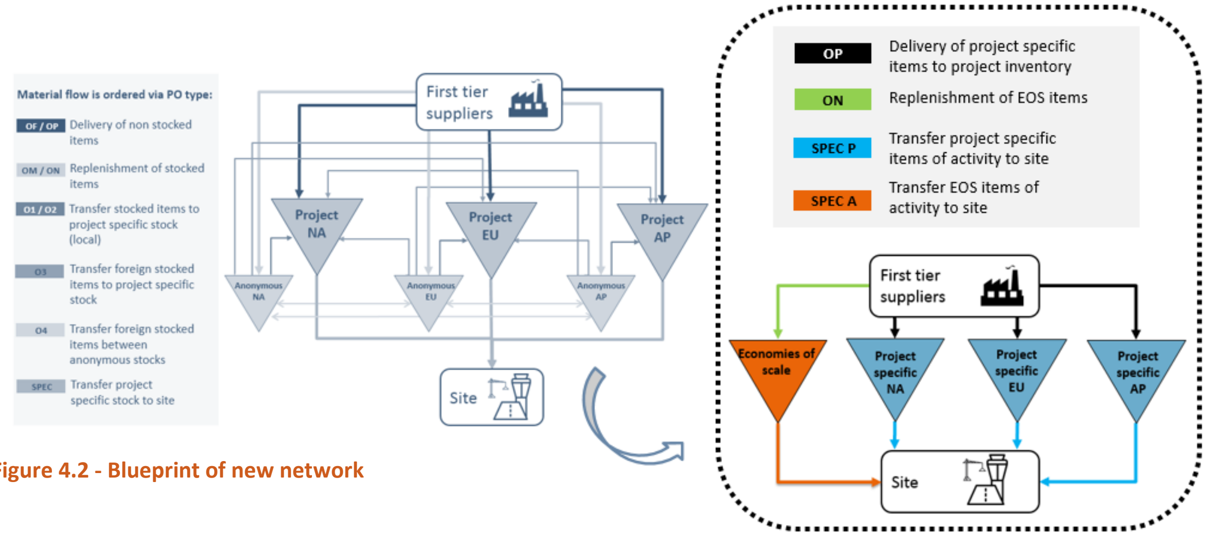

Figure 4.2 - Blueprint of new network

Vanderlande must apply three major changes in IT system JDEdwards to implement this blueprint:

1) Add new branch for SCC EOS and delete current 'anonymous' branches (11001, 60001, 70001).
2) Ensure that activities can be shipped to site by two flows.
3) Ensure that all items can be ordered via OP or ON orders and delete the OF, OM, O1, O2, O3 and O4 orders. Every SCC must be able to order at every first tier supplier, including own factories.

Vanderlande can use the forecasting tool 'Slimstock' to aggregate demand and apply proactive inventory management of EOS items. Licenses and hardware for both JDEdwards as well as Slimstock are already in place. Thus, IT implementation costs apply to the personnel cost of the three changes in JDEdwards. We asked two IT specialists at Vanderlande to estimate these costs: they both estimate this effort to take six weeks of one IT consultant. With consultant costs being €1000,- per day, the IT implementation costs are €30,000. We recommend Vanderlande to implement this new blueprint; it eliminates internal orders and complexity and eases the integration of new facilities. This helps the network to become fit for growth, since it can realize the growth trend IV and V we explained in Section 2.4.

4.4. Expected impact

We foresee three main impacts with this redesign:

1) Supply chain personnel must decide per item which network fits best, based on item characteristics. This enables a clear **strategic focus** as explained in Section 4.2.
2) These EOS items are suitable for inventory management. Since EOS items can now be picked directly from stock, this provides the opportunity to improve **responsiveness**.
3) Vanderlande can harvest growth as opportunity to realize economies of scale. This raises efficiency and enables **cost reductions** of EOS items.

We now explain in more detail where and why we expect this impact to occur. This EOS network introduces a product focus in this project minded organization. We presented this redesign to management of GSC, who received this with enthusiasm and immediately started a pilot. They requested extra insight in the potential of this EOS network. Quantifying this potential becomes the focus of Chapter 5 and 6.

In Chapter 5 we construct a mathematical model that quantifies the impact of cost reductions (3) and responsiveness (2). The model first maximizes total financial savings. This may sound strange since the focus of this research is to improve responsiveness, but we do this since the strategic focus on the EOS network is efficiency. This way, we only include items that contribute to this strategy. The model results in a list of EOS items, which we use to compute where and how much responsiveness improves.

Let us now explain why we expect cost reductions and responsiveness. The EOS network aggregates item demand over all projects to realize economies of scale. This demand aggregation reduces the number of orderlines, reduces material cost and raises responsiveness of EOS items.

Orderlines
Instead of placing separate orders per item per activity, SCC EOS places one replenishment order on a regular basis. This way, demand aggregation **reduces the number of orderlines** for items that are ordered on a frequent basis. However, when EOS items must be consolidated to a project activity, it involves extra handling for the warehouse due to the picking task. Figure 4.3 shows an example of the current approach versus the EOS network regarding orderlines.

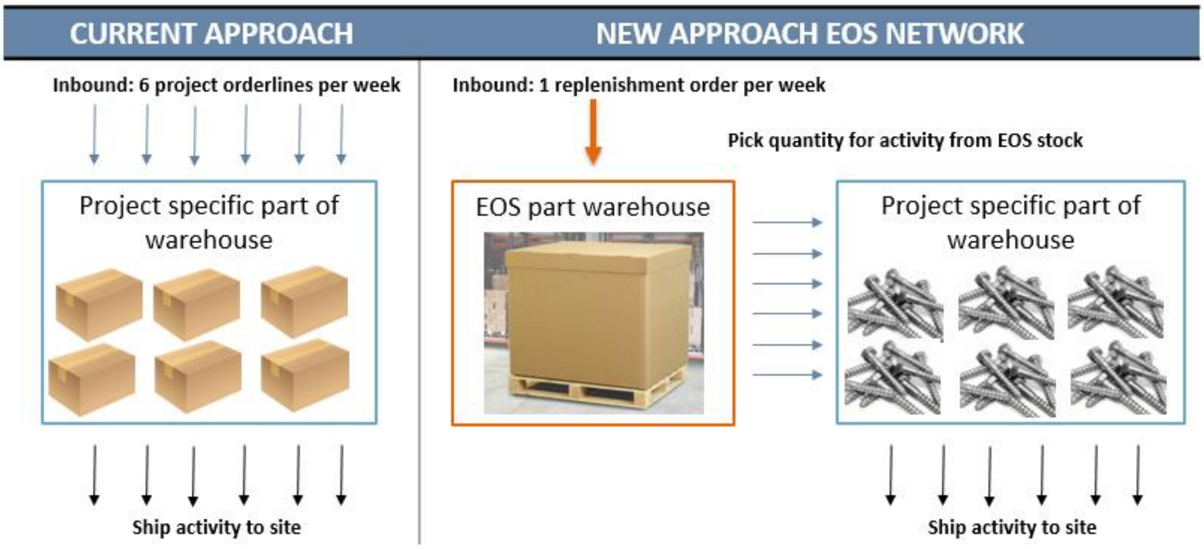

Figure 4.3 - Current compared to new approach related to orderlines

Material cost
Demand aggregation allows Vanderlande to provide their suppliers with a reliable and stable workload. This involves mutual benefits. Vanderlande benefit since they can offer suppliers with an accurate forecast and reserve a base load capacity via contractual agreements. This enables them to carefully select suppliers based on cost and quality. Suppliers benefit from this fixed base load: they can optimize their own production process and capacity planning accordingly. As can be seen in Figure 4.3, items in the EOS network arrive in bulk by one truck delivery instead of separate collies by frequent transports. This offers the supplier with handling and transportation advantages. We assume that based on these supplier advantages, Vanderlande can improve supplier collaboration and negotiate to realize a discount on EOS item prices. This supplier collaboration **reduces material cost**.

Responsiveness
To make sure these EOS items can be delivered on time, SCC EOS must apply proper inventory management. Chapter 5 explains which inventory policy we apply. This inventory policy raises the orderline fill rate for EOS items close to 100%, which **improves responsiveness** of EOS items. However, this inventory creates extra inventory costs.

4.5. Conclusion

This chapter allows us to answer the third research question: *"How to apply this theory to redesign Vanderlande's supply chain network?"*

By using our three-step framework, we identify that all project items receive the same treatment, while their level of required responsiveness differs. These different levels of required responsiveness ask for two networks, each with a different strategic focus, which we call 'item level split'. The project specific network focuses on responsiveness and the EOS network focuses on efficiency by aggregating demand over all projects. We formulate new facility roles per echelon and introduce a new facility SCC EOS that coordinates the EOS network. This extra SCC implies an organizational change: we provide employees of GSC with a clear strategic focus. This redesign results in a new blueprint that is fit for growth, with IT implementation costs being €30,000. We expect three main impacts with this redesign: clear strategic focus, opportunity to improve responsiveness and cost reductions. The EOS network provides cost reductions when savings from orderline reduction and material cost exceed the extra costs of inventory. Responsiveness improvement occurs since EOS items can be picked directly from stock. In Chapter 5 we construct a model to quantify the impact in terms of responsiveness and cost reductions.

5. MODEL CONSTRUCTION

In the previous chapter, we provide the network redesign by using the three-step framework. The item level split advocates two networks, each with a strategic focus. This chapter answers the fourth research question: "How can we construct a model to quantify the impact of this redesign?" As explained in Section 4.4, we quantify the impact of responsiveness improvement and cost reductions. Due to the strategic focus of the EOS network, the goal of the model is to maximize total savings of the EOS network. This provides us with a list of EOS items, which we use to compute the impact on responsiveness. Section 5.1 explains the inventory policy and all formulas we use to ensure EOS items can be picked directly from stock. Section 5.2 elaborates on the model input in terms of item selection and parameter values. Section 5.3 shows how we use the model output to show the effect on responsiveness. Finally, we validate and verify the model in Section 5.4 and show limitations in Section 5.5. Chapter 6 provides numerical results and the sensitivity analysis on input parameters.

5.1. Model description

This section describes all formulas, variables and parameters of the model. Let us consider a single stock point at the central warehouse. Our model determines stock level per item to ensure product availability with a given service level, allowing us to compute inventory cost and ultimately show the effect on responsiveness. We assume items are backordered if an item is not on stock on the request date since eventually all items are needed to construct the system on site. Formulas relate to the inventory position, which is defined as:

$$Inventory\ position = inventory\ on\ hand + on\ order - backorders$$

As explained in Section 4.4, we assume that Vanderlande can realize discount on the average unit price by supplier collaborations. In Chapter 6, we show that this discount becomes an important parameter in determining total savings. Although suppliers in real life have a maximum capacity, we assume that suppliers have unlimited capacity to simplify the model. Due to this unlimited capacity, we can state that replenishment lead times are fixed and the supplier can always meet demand. We assume backorder cost may be ignored since these are marginal costs. We assume there is no correlation between items since demand over subsequent weeks is independent. For EOS items, we apply periodic review with review period R being 1 week. We consider 1 week since SPECs are released on a weekly basis and also shipping is arranged per week. This is in line with Silver et al. (2017) saying that "*the value of R is often dictated by external forces*". If desired, Vanderlande can adjust this review period to for example one month. In Section 2.5 we explained that the supply chain has eight weeks from SPEC release to delivery at the warehouse. Taking into account the review period of one week, SCC EOS has a customer order lead time of seven weeks. When the replenishment lead time of an EOS items is less than these seven weeks, SCC EOS can simply satisfy demand to order. However, when the replenishment lead time exceeds seven weeks, SCC EOS must satisfy demand from stock. For this purpose, we introduce an inventory control policy. Every week, SCC EOS raises per EOS item the inventory to the predefined order-up-to level S by sending one replenishment order. This (R,S) system is commonly used at companies without sophisticated computer control or when items are ordered at the same supplier (Silver et al., 2017). Safety stock can buffer for fluctuations in demand. We use the fill rate as target service level, which we define as 'percentage of demand satisfied from stock in hand'. The model computes per item the average stock necessary to reach this target service level, enabling us to compute inventory costs.
Since management is interested in yearly savings based on historic performance, we use historic order data of all project orderlines requested in 2016. We convert all valuta based on 2016's average exchange rates: 1 Chinese yuan = €0.14, 1 American dollar = €0.88.

Let us introduce the following notation:

Indices
i = item 1 … I , with I being the total number of candidate items we use as input of our model. In Section 5.2, we explain which items are candidate items.

Decision variable	
y_i	Boolean: y_i=1 if item i is sourced by SCC EOS, else y_i=0
Output variables	
TCI_i	Total cost of inventory of item i per year if SCC EOS is used
TSM_i	Total savings of material cost of item i per year if SCC EOS is used
TSO_i	Total savings of order cost of item i per year if SCC EUS is used
Variables	
k_i	Safety factor of item i, based on the value of P_2
α_i	Shape parameter gamma distribution of item i
β_i	Scale parameter gamma distribution of item i
SS_i	Safety stock of item i in units
S_i	Order-up-to level of item i in units
Parameters	
R	Duration of review period. In our model, we take R = 1 week, same for all items i
P_2	Volume fill rate, expressed as percentage of demand satisfied from stock in hand, same for all items i
h	Inventory carrying charge in €/€/year, same for all items i
v	Internal cost of placing one project orderline, same for all items i
w	Handling cost from EOS stock to consolidate to activity, same for all items i
δ	Discount on average unit price in the dataset, same for all items i
L_i	Replenishment lead time of item i in weeks
x_i	Mean demand of item i in units per week
s_i	Standard deviation of demand of item i in units per week
$x_{(L+R)i}$	Expected demand over a review interval plus replenishment lead time of item i in units
$\sigma_{(L+R)i}$	Standard deviation of errors of forecast over a review interval plus a replenishment lead time of item i in units
A_i	Unit price of item i if sourced via EOS network
C_i	Average unit price of item i in the dataset
TOL_i	Total # orderlines of item i in the dataset
$G(k_i)$	Normal loss function, used to find safety factor k of item i

As mentioned above, the goal of the model is to maximize total savings of the EOS network over all candidate items I resulting from orderline reduction and lower material price, while taking into account extra inventory costs. We express this in the objective function:

$$Max \sum_{i=1}^{I} \left(y_i * (-TCI_i + TSM_i + TSO_i)\right) \qquad [Objective]$$

We use formulas [1]-[13] to compute TCI, formula [14] to compute TSM and formula [15] to compute TSO. If an item provides positive savings, decision variable y turns 1. This way, we can find the total savings (-TCI+TSM+TSO) to compute impact of **cost reductions**, and we find which candidate items become EOS items (y=1), which we use to quantify the impact of **responsiveness**.
The remainder of Section 5.1 shows all formulas necessary to find the costs and savings for our objective function. We exclude index i in the formulas to facilitate reading. In appendix G we provide a numerical example to illustrate the formulas.

The expected demand during replenishment lead time and review period must cover L+R weeks of average demand. The same holds for standard deviation of demand, where we take the square root because variation is σ^2. We find these values as follows:

$$\hat{x}_{L+R} = x * (L + R) \quad [1]$$
$$\sigma_{L+R} = s * \sqrt{(L + R)} \quad [2]$$

With this information, we can determine which demand distribution to use. Silver et al. (2017) argue that most items can be represented by normal demand distribution, which is an adequate approximation when the coefficient of variation is less than 0.5:

$$Coefficient\ of\ variation\ CV_{L+R} = \frac{\sigma_{L+R}}{x_{L+R}} \quad [3]$$

However, if [3] is higher than 0.5, they advocate the use of gamma distribution because, with such a high value of CV, a normal distribution would lead to a significant probability of negative demands (Silver et al., 2017). Thus, we can model every item in the EOS network by either Normal distribution (when $CV_{L+R} \leq 0.5$) or Gamma distribution (when $CV_{L+R} > 0.5$). Hence, we use two sets of formulas to find safety stock SS and order-up-to level S. We refer to appendix II of Silver et al. (2017) for density function and table of the normal probability distribution. We refer to the paper of Burgin (1975) for density function and approximations of the gamma distribution. We use appendix III of Silver et al. (2017) for spreadsheet implementation of the gamma distribution.

Formulas to find SS and S for NORMAL DISTRIBUTION

We select the safety factory k that satisfies:

$$G(k) = \frac{x * R}{\sigma_{L+R}} * (1 - P_2) \quad [4]$$

With help of the Solver in Excel, we find the value of k for which equation [4] holds. This enables us to compute the safety stock:

$$SS = k * \sigma_{(L+R)} \quad [5]$$

We find the order-up-to level S since it must cover demand during L+R weeks and include safety stock:

$$S = \hat{x}_{(L+R)} + SS \quad [6]$$

Formulas to find SS and S for GAMMA DISTRIBUTION

Silver et al. (2017) also provide formulas to determine safety stock and order-up-to levels for gamma distributed demand. We describe the gamma distribution with shape parameter α and scale parameter β, implying a mean of $\alpha\beta$ and standard deviation of $\sqrt{\alpha}\beta$ (Silver et al., 2017). We calculate α and β by:

$$\alpha = \frac{x_{L+R}^2}{\sigma_{L+R}^2} \quad and \quad \beta = \frac{\sigma_{L+R}^2}{x_{L+R}} \quad [7]$$

We find the order-up-to level and expected shortages per replenishment cycle (ESPRC) by using the gamma distribution. In Excel, we can find $F(S; \alpha; \beta)$ by using the formula GAMMA.DIST(S;α;β;TRUE). We first find the value of expected shortages per replenishment cycle (ESPRC) with formula [8]:

$$P_2 = 1 - \frac{ESPRC}{x * R} \quad [8]$$

The solver in Excel helps us to find the value of S for which equation [9] holds:

$$ESPRC = \alpha\beta[1 - F(S; \alpha + 1; \beta)] - S[1 - F(S; \alpha; \beta)] \quad [9]$$

With the order-up-to level resulting from [9], we can simply compute the safety stock:

$$SS = S - \hat{x}_{(L+R)} \quad [10]$$

The remaining formulas are equal for both demand distributions. We find backlog per week by:

$$Expected\ backlog\ per\ week = x * R * (1 - P_2) \quad [11]$$

Assuming the mean demand rate is constant over time, the expected stock on hand is simply half of the demand per week, plus safety stock, minus the backlog:

$$Expected\ stock\ on\ hand\ = \frac{x * R}{2} + SS - backlog \quad [12]$$

We only pay carrying cost on the average physical stock on hand, so we multiply carrying cost, unit price and the outcome of [12] to compute the total cost of inventory per year:

$$TCI = h * A * \ expected\ stock\ on\ hand \quad [13]$$

Our dataset covers data of one year; 52 weeks. Cost reductions occur due to reduce of material costs. We source EOS items for the discounted price ‘A’ instead of average price C. Therefore, we save (C-A) euro per unit by supplier collaborations and negotiations. To compute total savings per item per year, we multiply demand per week with 52 weeks:

$$TSM = (C - A) * 52 * x \quad [14]$$

Since SCC EOS places a replenishment order on a weekly basis, we save (TOL-52) orderlines per year with internal cost of v per orderline. However, an orderline via the EOS network involves one extra handling effort as shown in Section 4.4. This picking task to consolidate an EOS item to the activity results in extra handling costs of w*TOL. We provide a visualization and example in appendix I. Note that savings TSO can turn out negative because of these extra handling efforts. Thus, when the dataset considers one year, we compute total savings by orderline reduction via:

$$TSO = v * (TOL - 52) - w * TOL \quad [15]$$

With the costs [13] and savings [14, 15] we now can determine whether it is beneficial to source a candidate item via the EOS network (y=1) or not (y=0):

$$y\ = \begin{cases} 1\ if\ (TSM + TSO\ > TCI) \\ 0\ if\ (TSM + TSO\ \leq TCI) \end{cases} \quad [16]$$

Let us recall the goal of the model, which results in our objective function. As mentioned in the introduction of this Chapter, the goal of the model is to maximize total savings of the EOS network resulting from reduction of orderlines (TSO) and material cost (TSM), taking into account the extra inventory costs (TCI). Decision variable y enables us to maximize total savings of the EOS network over all items I, leading to the following objective function:

$$Max \sum_{i=1}^{I} \left(y_i(-TCI_i + TSM_i + TSO_i) \right) \quad [17]$$

5.2. Model input

Item classification

As explained in Section 5.1, total savings of our model are annual savings based on historic performance. We consider the dataset of ~200,000 project orderlines with request date in 2016. This dataset incorporates ~20,000 unique item numbers, which we refer to as 'item population'. To make sure we only include relevant input in our model, we first classify this item population. Classification allows clustering items in homogeneous classes. We use the work of Bachetti et al. (2013) as inspiration, since they explicitly mention that their approach is "*easy enough to be understood by management*", what we highly value. Appendix H provides more insight in their approach. We apply four criteria to classify our item population in Figure 5.1.

- **Commonality.** This criterion relates to obsolescence risk, which is higher for project specific items. We should source items via the project specific network when the item only occurs in one project. Therefore, we start classifying with this criterion, with cut-off value being 1.
- **Frequency.** We focus on fast movers since high repetition of orders provides orderline reduction. But above all, it provides a more reliable demand forecast. Although it is arbitrary which cut-off value to use, we set the cut-off value of >1 orderline per week (TOL>52) since from here on, a weekly replenishment order reduces the number of orderlines. However, we include a cut-off value of >1 orderline per two weeks (TOL>26) in our sensitivity analysis in Section 6.2.
- **Customer order lead time.** When the response lead time is larger or equal to the replenishment lead time, it is not necessary to keep inventories (Bachetti et al., 2013). Thus, we only keep inventory for items with replenishment lead time larger than the customer order lead time. Considering the eight weeks from SPEC release to warehouse delivery and review period being one week, the cut-off value is seven weeks.
- **Demand characteristics.** Finally, we classify on demand distribution since we have two sets of formulas. We model demand by either normal or gamma demand distribution. We classify based on the coefficient of variation as explained in equation [3], with cut-off value of 0.5.

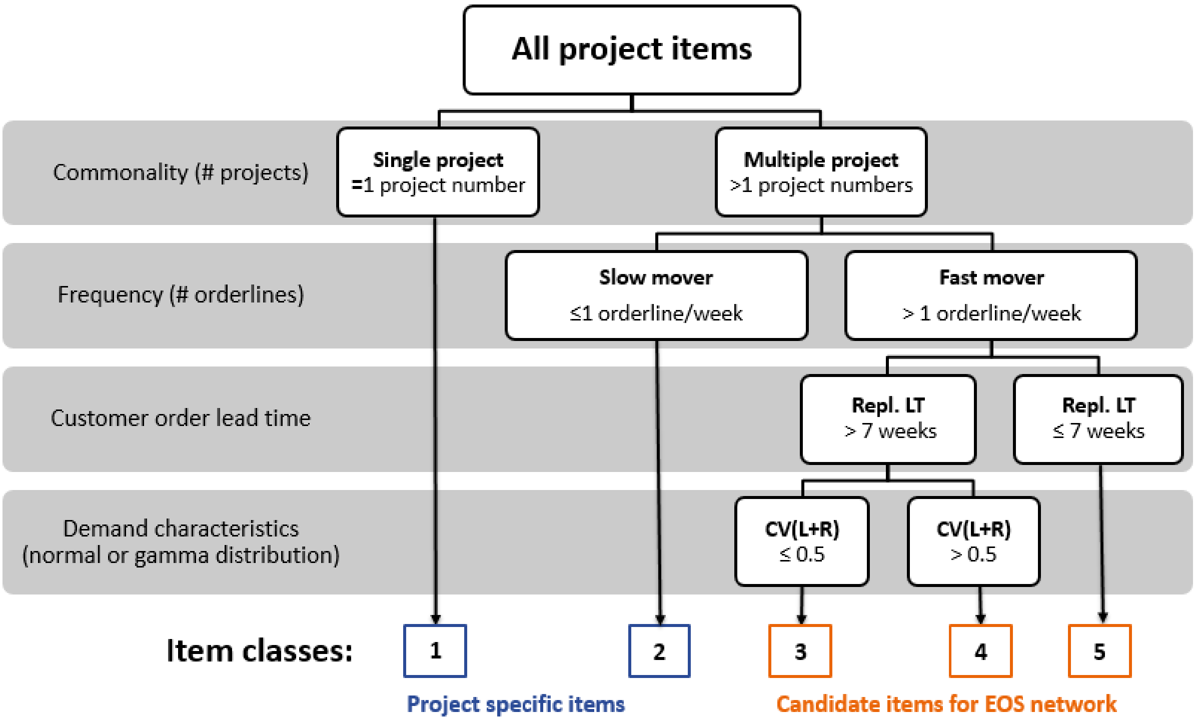

Figure 5.1 - Item classification scheme

This item classification gives five item classes. Items of class 3, 4 and 5 become candidate items for the EOS network. For class 3 and 4 we apply the (R,S) inventory policy. For class 5 we can satisfy demand to order since replenishment lead times are smaller than the customer order lead time; we only use formulas [14]-[17] for class 5 items. Descriptive statistics in Table 5.1 shows that the candidate items are just 4% of the item population, but represents 26% of material cost and 52% of all orderlines of the dataset. We notice that 7605 items of class 1 (40% of item population) only have one orderline, clearly showing the need for a project specific network. These 725 candidate items are input of our model.

Table 5.1 - Descriptive statistics per item class

[This table is left out in public version]

Parameters

Per candidate item, we provide the model with the following item specific parameters based on 2016's performance: replenishment lead time L, mean demand x, standard deviation s, average unit price C, total number of orderlines TOL. We need these item specific parameters to compute the average stock on hand (L, x, s), inventory cost (C), savings in material cost (A, C) and savings in order cost (TOL). We find all item specific parameters using Excel VBA.

- **Replenishment lead time L_i:** average of (receipt date – order date). In the model, we take the effective replenishment lead time, which is replenishment lead time – customer order lead time. Since demand of class 5 items can be satisfied to order, effective replenishment lead time is 0 weeks. We emphasize that we compute this value of L based on historic performance and not on actual ability of the supplier. Historically, suppliers were never encourages to deliver their items faster than eight weeks. This explains why there are only 9 items in Class 5. But when requested, suppliers could optimize their processes and strive for lower lead times, which most likely results in a shift from class 3 and 4 items to class 5.
- **Mean demand x_i, standard deviation s_i:** in Excel, we list the quantity that was requested per week. From this data, we compute the average and standard deviation.
- **Unit price if sourced via EOS network A_i:** this value is based on the average unit price C and discount we obtain from suppliers δ: $A_i = (1 - \delta)C_i$.
- **Average unit price C_i:** we use VBA to find the average unit price in the dataset. Per orderline, we multiply order quantity with the given unit price. Ultimately, we sum this amount over all item's orderlines and total order quantity. Since Vanderlande orders an item at different quantities, prices and suppliers, the average unit price differs from the lowest unit price.
- **Total orderlines TOL_i:** we use VBA to count the number of orderlines per item in the dataset.

To give a first impression of total savings, we consider certain parameters to be item independent: review period R, target fill rate P_2, inventory carrying charge h, internal orderline cost v, handling cost w and discount δ. Looking at items in more detail, these parameters could differ in real life between items. For example, screws most likely have less handling cost than motors. Therefore, we recommend Vanderlande to carefully select items by interpreting model results.

As motivated in Section 5.1, we fix values of R=1 week and P_2=0.98. In the sensitivity analysis of Chapter 6, we show the effect of a lower (0.90) or higher value (0.995) of P_2 in terms of savings and responsiveness performance. We now provide extra attention in the values of h, v, w and δ.

The **inventory carrying charge h** consists of storage, capital cost and risk. Normally, this percentage is between 20-25% of the item value per year (Nevi, 2014). Although storage, handling and obsolescence risk differs per item, we generalize this value for all candidate items since we do not have item specific data on volume, handling effort or location in the life cycle. Management of Vanderlande estimates h to be 0.15: 3% capital, 7% storage & handling and 5% risk. In our model, we set the inventory carrying charge on 0.15 €/€/year and we incorporate the benchmark of 0.25 in our sensitivity analysis.

The **internal orderline cost v** consists of orderline process cost and the invoice process cost. Industry benchmark is €21.06 per order (The Hackett Group, 2015), but at Vanderlande this cost per orderline is unknown. To the best of our knowledge, we estimate the minimum costs by only evaluating personnel efforts. This results in €9.40 per orderline, see appendix I. Management estimations of internal cost per orderline are €200,- per order. One order contains on average 9.2 orderlines, therefore we add the value of v= €21.74 per orderline in our sensitivity analysis.

The **handling cost w** occurs since a person has to count the quantity requested from the EOS stock and move it to the project racking. We visualize this in Figure 4.3. The manager of EDC estimates cost per pick at €6.25. When we recall the formula [15] of Section 5.1, we see that TSO is positive when is has more than 155 orderlines with input parameters v=€9.40 and w=€6.25: €9.40*(156-52)>€6.25*156.

The **discount δ** results from supplier collaborations as explained in Section 4.4. Let us recall these supplier benefits: with a fixed base load they can optimize their production process and capacity planning, and they also benefit from transportation advantages. Vanderlande can arrange this discount via contractual agreements. In Chapter 6, we reveal that this value of δ is an important parameter with impact on total savings. In our model, we take the value of δ=15% as input based on our supervisor's expectation and our analysis. We compute the relative difference between lowest and average unit price per candidate item and rank them from lowest to highest relative difference: Figure 5.2. However, we notice data pollution due to typos (see Section 5.5). If we only consider the candidate items with <50% price difference, the average difference between lowest and average unit price (blue line) is 17%. This is discount that can be realized by just choosing the supplier with lowest unit price: this did not yet take into account the supplier collaboration we explained in Section 4.4! This supports that 15% discount is a realistic assumption. Again, we generalize this parameter for all items i to give a first impression. Ultimately, this value of δ can be higher or lower per item based on the actual benefits the supplier can realize and the margins he currently makes. Therefore, we again recommend careful item selection.

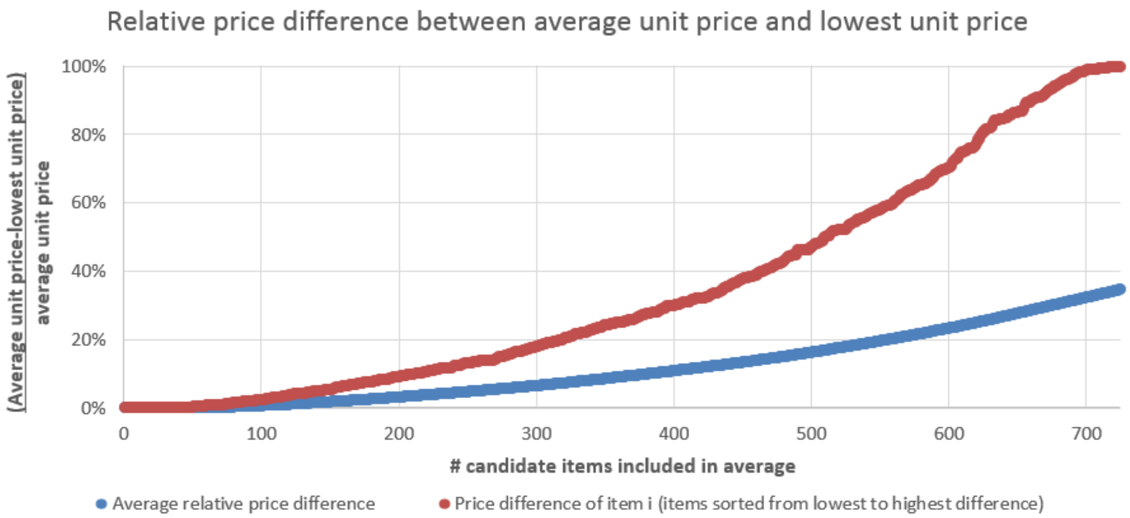

Figure 5.2 - Graph that shows relative price difference of the 725 candidate items

In summary, the following parameters are item independent and input in Chapter 6:

P_2 = 0.98	**h = 0.15 €/€/year**	**v = €9.40 per orderline**	**w = €6.25 per pick**	**δ = 0.15**

5.3. Model output

We implement all formulas of Section 5.1 in Excel and use the input as specified in Section 5.2. The output of our model is twofold:

- Total savings of the EOS network based on the 725 candidate items. This allows us to quantify the impact of cost reductions.
- List of EOS items, which are candidate items for which decision variable y_i is 1. This allows us to quantify the impact on responsiveness.

With this list of EOS items, we compute the effect on responsiveness performance. We refer to Figure 2.9 in Section 2.5 for definition of receipt and request date and formulas for KPI calculations. Let us recall the three KPIs we explained in Section 2.5: **Orderline fill rate** is the fraction of orderlines of which the item is available in the warehouse at the request date. **Activity fill rate** is the fraction of activities of which all orderlines are available in the warehouse at the late finish date. **Average activity lead time** is the average makespan of an activity in weeks. We compare historic performance of the six sample projects that we also used for measuring the current performance in Section 2.5, who vary in both project size and sector. Since our model uses a fill rate of 98% (P_2), we change for 98% of the orderlines the receipt date to the request date. This implies that the EOS item is delivered when requested, being on time. For 2% of the orderlines, we change the receipt date to request date + 4 days. For class 5 items, we always change receipt date to request date since demand can be satisfied to order. Appendix J presents an example of this approach.

5.4. Validation and verification

We perform validation and verification of our model to ensure correct and reliable outcomes. Verification is concerned with correctness of the model during coding, whereas validation is concerned if the model presents reality in a correct manner (Law, 2015). We visualize this relation in Figure 5.3.

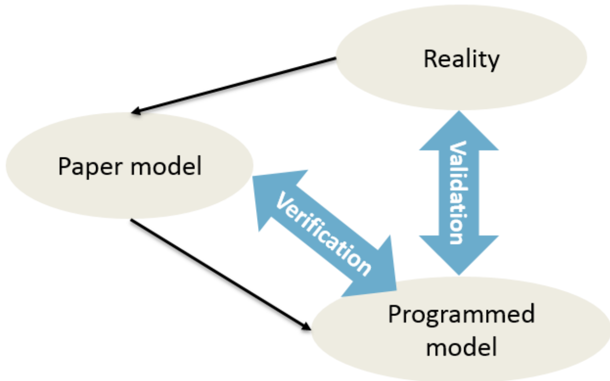

Figure 5.3 - Verification and validation

We perform model verification while coding by:

- Using an incremental approach. We start with a simple dataset and gradually add more data and formulas with increased complexity.
- Debugging with breakpoints in the VBA code and with the 'iferror' function in the worksheet.
- Recalculating results via pivot tables and by hand, see example in appendix G.
- Always check that percentages add up to 100%.
- Structured walk through the VBA code with company supervisor E. Tielemans. We also provide Vanderlande with an extensive Excel manual to check our code and way of working.
- Compare parameter values with Hubble reports per item. For example, we can compare the lowest unit price and total orderlines with Hubble.

We validate our model in multiple ways:

- We use real company data instead of benchmarks. We subtract data from ERP system Hubble and we estimate orderline cost and holding cost based on company specific values and perform sensitivity analysis on these parameters in Chapter 6.

- We validate the input of candidate items and their characteristics with a list provided by Slimstock. We obtained this list via our supervisor after we performed the item classification; we executed our analysis independently. This tool identified a list of ~1500 item numbers suitable for bulk production, based on historic demand and item characteristics. Because of our classification criteria, we were more selective, resulting in less items. For example, Slimstock did not consider the number of projects and total number of orderlines. Of our 725 candidate items, 686 items overlap with this Slimstock list. This is overlap of 95% (Figure 5.2) showing that our item classification and VBA code works properly.

Table 5.2 - Overlap of candidate items with Slimstock list

		Overlap with Slimstock list	
	# candidate items	#items	% of candidate items
Class 3	129	129	100%
Class 4	587	550	94%
Class 5	9	8	89%
Total	**725**	**687**	**95%**

- Also the two items that GSC independently selected for their pilot both become candidate items in our model and provide positive savings.
- We validate our formulas of (R,S) inventory by checking if we get same results when using an example calculation of Silver et al. (2017). Gamma and normal distribution should provide similar values for low CV_{L+R}, enabling us to validate our formulas. We indeed validate the formulas since these provide comparable results. Appendix G shows these calculations: normal demand results in an average inventory level of 120, gamma distribution in 127.

5.5. Limitations

Unfortunately, we encountered two data related limitations while developing this model. The first relates to **data unavailability.** In our dataset, some orderlines do not contain a unit price: all OF orderlines have a default unit price of 0 euro, since it is an intercompany order. We solved this issue by matching the unit price per item number with the factory pricelist, using a VLOOKUP. However, also some OP orderlines do not contain prices. We could not solve this issue. Therefore, we had to exclude 1503 items of our item population (7%). Although this data unavailability is not desirable, it does not influence our results since this 7% is responsible for just 1% of all orderlines. Another aspect of data unavailability was that Vanderlande is not aware of cost per orderline v or inventory carrying charge h. We solve this issue by estimating the values to the best of our knowledge and include both parameters in the sensitivity analysis. Also, it was not possible to determine volume per item number. As a result, we had to compute inventory costs based on financial value instead of total inventory volume per item.

The second limitation relates to **data pollution**. In first instance, we tried to find the lowest unit price in the dataset to become the EOS item price ‘A’. VBA provides us with the lowest unit price in the dataset per item. However, we noticed that some candidate items have an unrealistic difference between the lowest unit price and average unit price C. Our VBA code works perfectly, but the data is polluted due to typos. For example: we found a class 3 item with lowest unit price of €0.14 and average unit price C of €150. This relative difference of 99.9% results from a typo. Although our code works perfectly, we concluded that this data pollution results in unrealistic outcomes. With parameter δ, we overcome this problem. We recommend Vanderlande to improve their data quality of unit prices to prevent unrealistic results in the future. To motivate this effort, we perform our analysis in Section 6.1 also with the polluted data, see appendix K. Since δ has a high impact on material cost and therefore total savings, we include this in our sensitivity analysis of Chapter 6. Vanderlande can influence this parameter by increased efforts in supplier collaborations.

5.6. Conclusion

This chapter allows us to answer the fourth research question: *"How can we construct a model to quantify the impact of this redesign?"*

We construct a mathematical model with the objective to maximize total savings of the EOS network. For EOS items with replenishment lead time larger than seven weeks, we introduce the (R,S) inventory control policy. Every week, SCC EOS raises per EOS item the inventory to the predefined order-up-to level S by sending one replenishment order. We provide formulas to compute average stock levels per item and implement them in Excel. The model computes total cost of inventory, total savings in material cost and total savings in orderline reduction.

Input of our model are 725 candidate items, which are the result of item classification based on four criteria: commonality, frequency, customer order lead time and demand characteristics. Candidate items were ordered for more than 1 projects and have more than one orderline per week. These 725 items are 4% of the item population but represents 26% of material cost and 52% of all orderlines of the dataset. The model calculates which of these items have positive savings, making it an EOS item. Output of our model is total savings of the EOS network and the list of EOS items. With the fill rate per EOS item of 98%, we compute how responsiveness KPIs change. In the sensitivity analysis of Chapter 6, we perform a sensitivity analysis on criterion 'frequency', raising the number of candidate items. We also perform sensitivity analysis on parameters δ, h and v.

6. MODEL EVALUATION: NUMERICAL RESULTS

We now show the numerical results of the model we constructed in previous chapter. Chapter 6 answers the fifth research question: "How does this redesign perform compared to the current network design". We start with showing the numerical results of the model. Section 6.2 provides the sensitivity analysis and in Section 6.3 we compare different scenarios with the current network design. Hereafter, we provide recommendations in Section 6.4 how to further improve potential of the EOS network.

6.1. Numerical results

Section 5.2 explained the input of our model: we include 725 items with item specific parameters, and the following parameters, which are same for all candidate items:

P_2 = 0.98	**h = 0.15 €/€/year**	**v = €9.40 per orderline**	**w = €6.25 per pick**	**δ = 0.15**

Table 6.1 shows the results when using these input parameters on 725 candidate items:

Table 6.1 - Model output

	TOTAL	Class 3	Class 4	Class 5
# candidate items	**725**	129	587	9
Positive savings:	**633**	123	501	9
	87%	95%	85%	100%
Total savings	**€ 4,094,526**	€ 1,069,403	€ 2,980,710	€ 44,413
TCI	**€ -1,248,941**	€ -132,255	€ -1,116,685	€ -
TSM	**€ 5,349,232**	€ 1,150,636	€ 4,151,561	€ 47,035
TSO	**€ -5,766**	€ 51,022	€ -54,166	€ -2,623

With these input parameters, the model shows that 633 of the 725 candidate items provide positive savings, leading to a total saving of **4 million euros**. The table shows costs and savings per item class, providing us with three insights:

- Total cost of inventory (TCI) mainly arise in class 4. Class 5 has no inventory costs since replenishment lead time is less than 7 weeks. This is the ideal situation, since class 5 items can realize the savings by supplier collaboration but do not have inventory cost. Items can move from class 3 or 4 to class 5 by lowering the replenishment lead time, supporting our conviction that supplier collaboration is important in the context of EOS network. We determine replenishment lead times based on historic average, but suppliers were never encouraged to deliver faster than 8 weeks. This explains why there are only 9 items in class 5, but also suggests that there is potential to move more items to class 5 by lowering replenishment lead times. We elaborate on this interesting insight in Section 6.4.
- Total savings in material cost (TSM) contributes most to total savings. This indicate that δ is an important parameter in determining total savings. Vanderlande can influence this value of δ themselves by increased supplier collaborations. Therefore, we include δ in our sensitivity analysis of Section 6.2.
- Total savings in orderline reduction (TSO) is negative due to extra handling in the warehouse, while initial expectation of management was that reduction in orderlines would result in financial benefits. This is a valuable insight for management. As explained in Section 5.2, TSO is only positive when an item has more than 155 orderlines. However, our dataset contains candidate that have at least 52 orderlines, explaining why TSO can result in negative savings.

Section 5.3 explained how we compute lead time calculations based on the list of EOS items. Table 6.2 shows the lead time performance when including these 633 EOS items with fill rate of 98%.

Table 6.2 - Responsiveness performance: comparing current performance with redesign performance (include EOS items)

		Overall	1473602	1407772	1404242	1407063	1408305	1408744
	# orderlines	33508	11705	10355	2772	1505	2048	5123
	# activities	982	514	162	142	27	67	70
	Project makespan weeks	82	267	52	61	37	46	30
	Total EOS items on list	633						
	# EOS items in project		200	372	372	148	238	183
	% of EOS item list	93%	32%	59%	59%	23%	38%	29%
Historic	# orderlines on time	19094	8042	6241	1901	355	1062	1493
	Orderline fill rate	**57%**	69%	60%	69%	24%	52%	29%
	# activities on time	886	476	147	123	24	55	61
	Activity fill rate	**90%**	93%	91%	87%	89%	82%	87%
	Average activity LT (wks)	**10.6**	10.4	11.8	9.9	11.3	10.4	11.2
EOS items	# orderlines on time	26047	9268	8698	2155	685	1504	3737
	Orderline fill rate	**78%**	79%	84%	78%	46%	73%	73%
	# activities on time	919	486	153	128	25	61	66
	Activity fill rate	**94%**	95%	94%	90%	93%	91%	94%
	Average activity LT (wks)	**10.6**	10.5	11.5	10.0	11.4	10.3	10.9

Almost all EOS items (93%) are present in this sample of six projects, showing the commonality. We see improvements on orderline fill rate (57% to 78%) and activity fill rate (90% to 94%). This is a valuable improvement: it shows that EOS items indeed caused activity delay in these six projects! We conclude that EOS items do improve responsiveness in terms of orderline fill rate and activity fill rate. However, average activity lead time remains 10.6 weeks. Project specific items still delay activities, leaving room for improvement to lower activity lead time to 8 weeks.

The model quantified the impact of **cost reductions** and **responsiveness**. However, the model could not quantify the impact of the third impact we mentioned in Section 4.4: increased **strategic focus**. Yet, we do expect that this increased strategic focus improves performance in the project specific network as well, which ultimately results in lower activity lead times. Due to the scope of this research, we only consider shippable items and not the subcomponents that Vanderlande's factories order at second tier suppliers. These subcomponents are not incorporated in the model. Considering this increased strategic focus, the business impact can be more than 'just' the 4 million savings. However, we cannot proof this statement in this thesis. We recommend Vanderlande to perform a separate study to quantify the effect of increased strategic focus in the project specific network. Considering the growth trends of Section 2.4, we already showed in Section 4.3 that the new blueprint supports growth trend IV and V. In addition, this increased strategic focus could also support growth trend I, II and IV, making this redesigned network fit for growth.

6.2. Sensitivity analysis

Let us now consider the sensitivity analysis. As explained in Chapter 5, we include several aspects in our sensitivity analysis. We first look at item classification, followed by sensitivity on the input parameters. To perform item classification sensitivity analysis, we change the cut-off value of criterion 'frequency' to >1 orderline per two weeks as explained in Section 5.2. Class 2 items with more than 26 orderlines now become candidate items. This results in 1478 candidate items, which is 8% of the item population, 37% of material cost and 65% of all orderlines. Appendix L shows the detailed table with descriptive statistics.

	TOTAL	Class 3	Class 4	Class 5
# candidate items	**1478**	132	1300	46
Positive savings:	**1169**	126	1002	41
	79%	95%	77%	89%
Total savings	**€ 5,267,361**	€ 1,072,102	€ 4,074,501	€ 120,758
TCI	**€ -2,135,268**	€ -133,052	€ -2,002,216	€ -
TSM	**€ 7,529,689**	€ 1,154,926	€ 6,244,564	€ 130,199
TSO	**€ -127,060**	€ 50,228	€ -167,847	€ -9,441

Hereby, we double the amount of candidate items, but we do not see this doubling effect in the total savings. There is an increase from 4.1 million to 5.3 million. Orderline fill rate also shows an improvement from 78% to 83%, but activity fill rate remains 94%. More input logically results in more output. It shows that potential can be increased by raising the number of candidate items. However, it also shows that our item classification already selected the most promising items.

Let us now perform the sensitivity analysis on input parameters. Since Vanderlande had no exact numbers for holding cost or cost per orderline, we perform sensitivity analysis on h (0.15 or 0.25) and v (9.40 or 21.74). We also include δ in this sensitivity analysis ranging from 0% to 25% as mentioned in Section 5.2. Figure 6.1 shows these results: we refer to the legend to see which parameters we change.

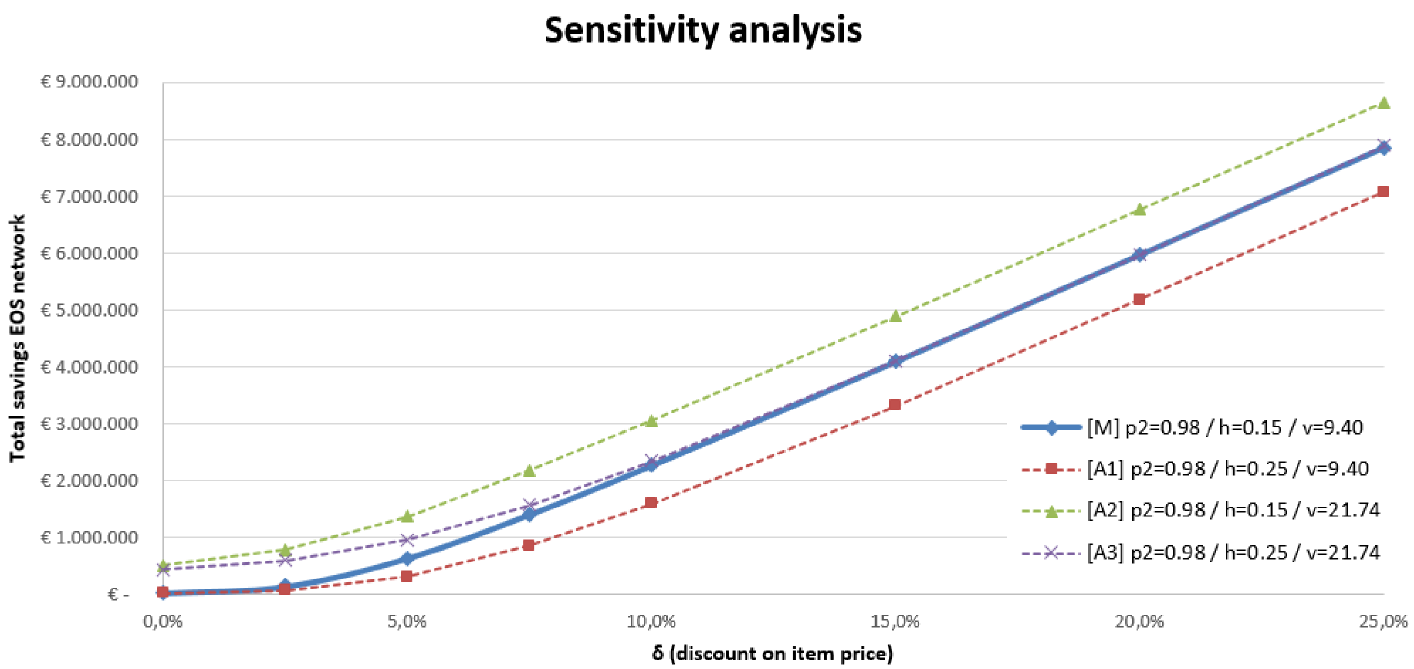

Figure 6.1 - Sensitivity analysis on input parameters

This graph brings us three insights:

- When Vanderlande does not obtain discount at suppliers (δ = 0%), the EOS network still provide positive savings, varying from €27,551 for A1 to €513,195 for A2. Since no savings occur due to material costs when δ = 0%, these total savings of EOS network only relate to orderline reduction. We explained that savings of orderlines is only positive when an item has more than 155 orderlines in our dataset when v=€9.40 and w=€6.25.
- With δ from 0-10%, we see that all lines increase: more candidate items become EOS items. We see that A3 approaches the model line.
- From δ = 10% and higher, all graphs show the same linear trend, showing that δ has most influence in total savings. This is in line with our results in Section 6.1, where most savings occur due to TSM, not TSO. We recommend Vanderlande to put most effort in supplier collaborations. As explained in Section 6.1, this can affect TSM by realizing discount but also TCI by moving more items to class 5 by providing lower replenishment lead times.

6.3. Scenarios

To interpret our model results, we compare several scenarios with the current network who serves as baseline. Scenario 1 is the redesign with numerical results as computed in Section 6.1, allowing us to compare how the redesign performs with the current network. Hereafter, we consider scenarios 2 and 3 where management selects a lower or higher value of P_2. This provides management insight in the effect of choosing another fill rate. We consider scenario 4 to show the maximum responsiveness improvement caused by the 725 candidate items. Table 6.3 presents the results per scenario.

Current network	Management does not change network. Responsiveness KPIs are equal to those we computed in Section 2.5.
1: Maximize savings with P_2=0.98	Redesign equal to the numerical results of Section 6.1
2: Maximize savings with P_2=0.90	Redesign, but with lower value of P_2
3: Maximize savings with P_2=0.995	Redesign, but with higher value of P_2
4: Include all candidate items	Redesign, but we turn all candidate items in EOS items, regardless of their savings. We change formula [16] to y_1=1.

Table 6.3 - Comparison of scenarios with current network

	Current network	**Scenario 1 Redesign, P_2=0.98**	**Scenario 2 Redesign, P_2=0.90**	**Scenario 3 Redesign, P_2=0.995**	**Scenario 4 Include all candidate items**
Item population					
Total # items	18862	18862	18862	18862	18862
Candidate items	0	725	725	725	725
EOS items	0	633	647	616	725
		87%	89%	85%	100%
Total savings					
TCI	€ -	€ -1,248,941	€ -847,949	€ -1,518,714	€ -1,319,321
TSM	€ -	€ 5,349,232	€ 5,395,243	€ 5,266,686	€ 5,415,685
TSO	€ -	€ -5,766	€ -9,478	€ -1,895	€ -29,691
Total savings	**€ -**	**€ 4,094,526**	**€ 4,537,949**	**€ 3,746,078**	**€ 4,066,673**
Responsiveness					
Orderline fill rate	57%	78%	74%	78%	79%
Activity fill rate	90%	94%	94%	94%	94%
Activity lead time	10.6	10.6	10.7	10.6	10.6

We see that in none of the scenarios the average activity lead time improves. In scenario 2, we see a slight increase, which is undesirable. To prevent EOS items cause project delay, we recommend management to select a value of P_2 of 0.98 or higher. Scenario 3 shows that a higher fill rate results in less savings, but no necessarily in responsiveness improvements. Scenario 4 reveals that candidate items are not able to reduce activity lead time to the desired 8 weeks. These scenarios show that the redesign results in higher savings and responsiveness improvements. Therefore, we recommend Vanderlande to implement this redesign with a fill rate of at least 0.98.

6.4. Increase redesign potential

Based on the formulas and numerical results of the model, we provide recommendations how to increase potential of the EOS network in terms of cost reductions and responsiveness performance. We explain why we expect increased potential and how to realize this. The recommendations relate to supplier collaborations, standardization efforts and warehouse consolidation.

Supplier collaborations
As shown in the sensitivity analysis of Section 6.2, δ is an important parameter. Supplier collaborations can realize this discount. Let us recall why we expect supplier benefits, as explained in Section 4.4. Demand aggregation allows Vanderlande to provide suppliers with a reliable and stable workload. They can optimize their production process and capacity planning accordingly. Also, bulk transport results in handling and transportation advantages. But Vanderlande can also ask suppliers to lower replenishment lead times when possible. Faster replenishment implies lower safety stock, and ultimately move more candidate items to class 5. We expect that it is realistic that more items can move to class 5, having a replenishment lead time lower than 7 weeks, since our model determines replenishment lead times based on historic performance. In this time period, suppliers were given 8 weeks to deliver their materials to the warehouse. We cannot see the capability of a supplier to deliver faster. We already described in Section 6.1 that this explains why only 9 of the 725 candidate items are class 5 items. Redesign is needed to obtain these benefits for suppliers: this allows Vanderlande to identify and select EOS items and offer the reliable forecast and baseload to suppliers. However, the inventory costs are now over 1 million euro. These costs can be reduced to a minimum when Vanderlande manages to shift candidate items to class 5. When SCC EOS selects their suppliers, they should therefore not only consider who provides the lowest discount, but also value their ability to deliver within 7 weeks.

Standardization efforts
The sensitivity analysis on item classification showed that more input of candidate items logically results in more savings. But when we fix the cut-off value on 52 orderlines per year, Vanderlande can increase the number of candidate items by standardization efforts. In our dataset, there were no such standardization efforts and we only evaluated project items of Vanderlande Equipment. A product that currently exists with different item numbers can be excluded from our model. For example: an item that currently exists in 6 different item numbers, each ordered 15 times a year for multiple projects, becomes class 2 items. However, if we standardize this to one item number, this item has 90 orderlines, making it a candidate item. Standardization efforts can be realized by collaboration with Engineering and R&D. Supply chain can provide Engineering insight in their drawing program in which items are EOS items, for example by colours. Introducing the EOS network and the EOS item terminology can help to create awareness. Another way to increase the number of candidate items is to include subcomponents of assemblies that Vanderlande's factories purchase at second tier suppliers. We cannot see these subcomponents in our dataset since we only look at SCCs orderlines. Component commonality in assemblies provides the opportunity of product postponement. Postponement is the ability of a supply chain to delay product differentiation or customization until closer to the time the product is sold (Chopra & Meindl, 2016). Since second tier suppliers also influence the activity lead time (Figure 2.8), this suggest that lead times can be reduced. We include this as suggestion for further research.

Warehouse consolidation

In our model, EOS items are consolidated to a project activity in the warehouse (Figure 4.3), resulting in extra handling efforts of €6.25 per orderline. This consolidation was a requirement set by management. As showed in Section 6.1, this explains why savings or orderline reduction is less than expected. However, these savings can be increased with a different approach regarding shipment of EOS items to site to lower handling efforts. For example, this inventory can also be held and managed at the supplier, applying Vendor Managed Inventory (VMI). Or Vanderlande can ask suppliers to deliver in separate collies, which results in less handling efforts for the warehouse. However, suppliers do not benefit of transportation and handling advantages as mentioned in Section 4.4, which can imply a lower discount. Another approach is to not consolidate EOS items to activities, but just send one container with EOS items to site. This approach was suggested during an interview with a former site manager. As inspiration, we refer to the paper of Montreuil et al. (2012), who provide the breakthrough concept 'Physical internet'. This is a metaphor of the digital internet, reshaping the real world where *"physical objects are currently being moved, stored, realized, supplied and used in inefficient and unsustainable ways".* In Section 8.3 we provide suggestions for further research. Here, we also recommend to investigate which approach is best to store, consolidate and ship EOS items to site.

6.5. Conclusion

This chapter allows us to answer the fifth research question: *"How does this redesign perform compared to the current network design?"*

The numerical results of the model show that 633 of the 725 items provide positive savings, of which most savings occur due to savings in material cost. When we compare the current network with this redesign, we see that it reduces costs with 4 million euros and improves responsiveness in terms of orderline fill rate (raising from 57% to 78%) and activity fill rate (raising from 90% to 94%). However, average activity lead time remains 10.6 weeks since project specific items still increase the critical path. The model thereby quantified the impact of cost reductions and responsiveness performance.

Sensitivity analysis shows that the number of candidate items can be increased by include items of class 2 which are ordered more than once per two weeks. We include twice as much items in the model, but savings only rise with 1.3 million, showing that our model already selects most promising items. Sensitivity analysis also shows that discount has most impact on total savings. We emphasize that supplier collaborations are important, not only to obtain discount and thereby raise savings of material cost, but also to lower replenishment lead times to reduce inventory costs. This could further increase the potential of this redesign.

7. IMPLEMENTATION

In the previous chapter, we showed the numerical results of our model. This chapter answers the sixth research question: "How can Vanderlande implement this redesign?". We provide the implementation roadmap in Section 7.1. We also interviewed managers of different departments to ask their opinion of this redesign and what risks they expect. This management opinion and risk management is the focus of Section 7.2 and Section 7.3.

7.1. Implementation process

Figure 7.1 shows the five steps we identify to guide the implementation process.

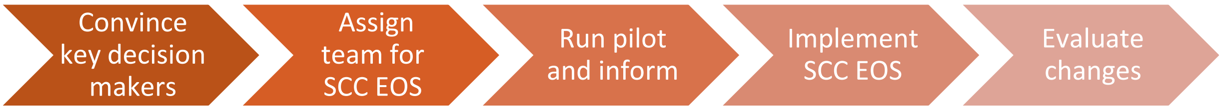

Figure 7.1 - Five steps of the implementation process

Convince key decision makers - The goal of this step is to inform decision makers about the redesign and convince them to support this implementation process. Decision makers can provide feedback and recommend employees for the implementation team. Ultimately, they must agree on the plan of approach. Supply Chain Development takes the lead in convincing the following key decision makers:

> **Managers of Global Supply Chain**
> **Management of other departments, in specific Engineering and R&D.** To realize the full potential of this new network, these departments should cooperate in standardization and allow early involvement. This high dependency is also emphasized during interviews with management.

Assign team for SCC EOS - When the key decision makers are convinced, Vanderlande can assign employees to the SCC EOS implementation team. We identify six functions in the team:

> **Team leader:** focuses on successful implementation of SCC EOS by keeping track of the progress, KPIs and communication with the key decision makers.
> **Sourcing manager:** focuses on supplier selection for EOS items and contractual agreements.
> **Stock controller:** focuses on inventory management: high product availability against lowest costs.
> **Integrator:** focuses on collaboration and involvement of other Vanderlande departments.
> **Data & IT specialist:** focuses on data accuracy and IT adaptations necessary to implement SCC EOS.
> **Continuous improver:** focuses on identifying and utilizing new opportunities to improve efficiency.

Run pilot and inform - The team start with a pilot on a selected group of EOS items, for example the top 10 items with highest expected savings. This enables them to keep track of performance, start collaborations with first tier suppliers, and apply the lessons learned for the implementation of SCC EOS. During this pilot, they can prepare IT adaptations. This pilot also allows to communicate results to involved departments and see how they react on this redesign.

Implement SCC EOS - When the pilot is evaluated with the key decision makers, they can agree to continue with the full implementation of SCC EOS. Vanderlande assigns the manager to SCC EOS. Now, the team starts sourcing all EOS items via the EOS network. Also the IT adaptations are executed. In the meanwhile, the SCC EOS manager can identify new candidate items and start new improvement projects to raise efficiency.

Evaluate changes - The team leader of SCC EOS should develop KPIs to measure and evaluate progress and update key decision makers. Also KPIs for first tier suppliers should be adjusted according to which network they serve: KPIs should focus on either flexibility or efficiency, depending on the network.

Table 7.1 shows the implementation roadmap with milestones and responsible actors.

Table 7.1 – Roadmap of the implementation process

Step	Start	Finish	Milestone	Responsible actor
1. Convince key decision makers	2017 wk 22	2017 wk 22	* Go/no go meeting with key decision makers to agree on plan of approach	SC development
2. Assign team for SCC EOS	2017 wk 23	2017 wk 26	* Kick-off meeting with all SCC EOS team members	Key decision makers
3. Run pilot and inform	2017 wk 26	2017 wk 51	* Go/no go meeting with key decision makers to evaluate pilot results	Team SCC EOS
4. Implement SCC EOS	2018 wk 1	2018 wk 26	* Presentations at departments * New IT system online * >50% of all EOS items sourced	Team SCC EOS
5. Evaluate changes	2018 wk 27	2018 wk 27	* Close-down meeting with key decision makers to evaluate implementation	Team SCC EOS, key decision makers

7.2. Management opinion of involved departments

To reach the full potential of the EOS network, Vanderlande departments have to cooperate. In March 2017, we interviewed 11 managers of various departments: R&D (2x), Sales (2x), Engineering (2x), Supply Chain (2x), Spare parts (1x), Warehouse (1x), and Finance (1x). During a 30-minute semi-structured interview, we asked the interviewee for the advantages and disadvantages of this redesign in perspective of their own department as well as company-wide. Table 7.2 shows the summary of the (dis)advantages they expect. Appendix M provides the complete and detailed table with quotes per interviewee.

Table 7.2 - (Dis)advantages identified by managers of involved departments

	Advantage (mentioned x times)	Disadvantage (mentioned x times)
Vanderlande company-wide	+ Cost reductions (10x) + Clear product focus (6x) + Increase supply chain performance (6x) + Stimulates standardization (5x) + Better able to balance workload (4x) + Shorten lead times (3x) + Enables supplier involvement (3x)	- Dependent on other departments / hard to change mindset (6x) - IT adaptations needed (5x) - Higher error cost / risk of obsolescence (4x) - Project specific items can still cause delay (2x) - Projects always feel less flexible when GSC sets restrictions (1x)
R&D	+ Enabling faster prototyping + Stimulates 'first time right' mindset	- High inventory level can delay time to market - Customers can see different item versions
Sales	+ Competitive position + Trigger customers to choose standard	None
Engineering	+ Better supports current way of working for baggage projects	- No direct lead time reductions since most items still flow through project specific network
Supply Chain	+ Able to provide stable workload to suppliers + Opportunity to extend to subcomponents of specials and long lead time items	- More inventory costs
Spare parts	+ Use same suppliers of EOS network	None
Warehouse	+ Transport advantages for supplier + Better predict workload inbound	- Extra picking task
Finance	+ Less invoices, opportunity for e-invoicing	None

As explained in Section 7.1, managers of involved departments are also key decision makers. We received positive reactions during the interviews. Table 7.2 shows that management sees more advantages than disadvantages, justifying to continue with the pilot. We recommend Vanderlande to involve these departments during the implementation process and pay extra attention to these disadvantages they expect. Communicate pilot results can help to convince these key decision makers.

7.3. Risks

We also ask these 11 managers what they see as main implementation risk and what solution they see to manage this risk. We summarize three risks in random order and solutions provided by management.

Risk	Solutions provided by management to manage this risk:
1) Other departments are not willing to collaborate	*"Use (financial) triggers and provide insight"* *"Use ESOT to provide engineers with insight and guidance"* *"Start with small steps/pilot"* *"Explain to management why this is a better world: what's in it for you"* *"Sales can help forecasting to reach full potential"*
2) Difficult to change mindset in project organization	*"Introduce stakeholder with ownership"* *"Start small and communicate financial results to all involved departments"* *"Involve Engineering"* *"Make this a shared problem of R&D, Sales, Engineering and Supply chain"*
3) Too high risk of obsolescence or error cost of quality issues	*"Stimulate first time right mindset to make this a success"* *"Carefully choose which products become EOS items"* *"Closer collaboration with R&D"* *"Quality issues: reduce impact by introducing Track & Trace tooling"* *"Choose items that are suitable for picking and direct shipment"*

It is important to consider these risks for a successful implementation. We recommend Vanderlande to pay extra attention to change management (risk 1 and 2) and to careful item selection (risk 3).

7.4. Conclusion

This chapters allows us to answer the sixth and last research question: *"How can Vanderlande implement this redesign?"*

We identify five steps in the implementation process. Important is to convince all decision makers and start with a pilot. We also provide an implementation roadmap with milestones and responsible actor. Interviews with managers of involved departments provides us with positive reactions which encourages to start the pilot. To manage the three main risks, we recommend Vanderlande to pay extra attention to change management and careful item selection during the implementation process.

8. CONCLUSIONS & RECOMMENDATIONS

This final chapter concludes this research. Section 8.1 answers the main research question: "How can Vanderlande improve responsiveness in a growing market by redesigning the roles of facilities in their supply chain network?". Section 8.2 presents the recommendation that follows from this research and we finalize this thesis with discussion and suggestions for further research.

8.1. Conclusions

We conclude that Vanderlande can improve responsiveness in a growing market by implementing our proposed network redesign. We identify that all project items receive the same treatment in the current network, irrespective if these items are critical project specific items or standard items used in multiple projects. We show that their level of required responsiveness differs, advocating the 'item level split'. The redesign consists of two networks, each having a specific strategic focus. The project specific network follows a responsive strategy, whereas the economies of scale (EOS) network follows an efficient strategy by aggregating demand over all projects. This redesign involves new facility roles for echelons 'first tier supplier', 'SCC' and 'warehouse', depending on which network they serve. We refer to Section 4.2 for the detailed description per facility. We introduce a new virtual facility to coordinate the EOS network: SCC EOS. The goal of this SCC is to supply demand against lowest cost and select suppliers based on cost, reliability and quality. The current three SCCs shift their focus purely on responsiveness: their goal is to respond quickly to demand and select suppliers based on speed, flexibility, reliability and quality. The new blueprint implies IT implementation costs of €30,000.

The impact of this redesign is threefold: it provides a clear strategic focus, improves responsiveness and reduces costs. We construct a model to quantify these impacts to show the potential of the EOS network. We classify the item population and include 725 items (4%) in our model. Demand aggregation of these EOS items results in savings of material cost of €5,349,232 but extra inventory cost of €1,248,941. Savings of orderline reduction result in cost of €5,766 due to extra handling efforts of item consolidation. The model quantifies the impact of cost reductions to be 4 million euros, where discount of unit price has most impact. Our inventory policy provides EOS items with a fill rate of 98%. We compute responsiveness KPIs and show that this redesign improves responsiveness in terms of orderline fill rate (raising from 57% to 78%) and activity fill rate (raising from 90% to 94%). This is a valuable insight: it shows that EOS items indeed caused project delay! Thereby, we improve responsiveness with EOS items. However, average activity lead time remains 10.6 weeks. We emphasize that supplier collaborations are important, not only to obtain discount and thereby raise savings of material cost, but also to lower replenishment lead times. This could further increase the potential of this redesign.

8.2. Recommendations

Based on this work, we propose the following recommendations for Vanderlande:

- We recommend to start with a pilot to test this redesign and communicate results to involved departments.
- To improve responsiveness and realize cost reductions, we recommend Vanderlande to ultimately implement our proposed network redesign and change facility roles accordingly.
- To reduce implementation risks, we recommend to pay extra attention to change management and careful item selection.
- To increase the potential of this redesign, we recommend to focus on supplier collaboration to realize discount and lower the replenishment lead times of EOS items.

- To identify opportunities and measure progress, we recommend to improve data quality, in specific related to unit price and item volume.
- The model did not quantify the impact of having increased strategic focus. To reduce average activity lead time to the 8 weeks target, we recommend Vanderlande to investigate how to improve on-time delivery of project specific items.

8.3. Suggestions for further research

Due to the scoping and data unavailability, we could not evaluate every aspect of the supply chain, leaving many interesting research topics to investigate. We identify six interesting research topics which we present in random order. First, as explained in Section 5.2, we compute item demand based on historic data to show the potential of the EOS network. An interesting opportunity for Vanderlande is to include information of Sales and Engineering to improve their forecast and to balance their workload.

- **Topic 1: How can Vanderlande improve demand forecast and balance workload?**

Our analysis is performed from supply chain department perspective. It could be interesting to use the savings as triggers to stimulate standardization at other departments, customers or suppliers. As explained in Section 6.4, this can further increase the redesign potential.

- **Topic 2: How can Vanderlande use (financial) triggers to stimulate standardization?**

In Section 6.4, we also highlighted the opportunity of product postponement. Our dataset does not include subcomponents of underlying BOM and item classification excludes long lead time items of class 1 and 2. However, providing proper inventory management could reduce the replenishment lead times of these assemblies or long lead time items, providing extra opportunities to improve responsiveness. For example: instead of one item number per colour, Vanderlande can set one default colour on stock and apply the right colour one week before shipment.

- **Topic 3: Where and how can Vanderlande apply product postponement to reduce lead times?**

We explained in Section 6.1 that the low number of class 5 items can be explained since suppliers were never triggered to deliver faster than eight weeks. Vanderlande can contact all suppliers for actual replenishment lead times and ask to what extend the supplier can benefit from this new way of working, obtaining the discount. This allows SCCE EOS to select their key suppliers.

- **Topic 4: Which suppliers become the key suppliers of the EOS network?**

The focus of this research was on equipment supply phase of the project as we showed in Section 2.5. However, many other departments influence total project lead time. Working more in parallel by increased cooperation provides an interesting opportunity to reduce the total project lead time.

- **Topic 5: How can Vanderlande departments cooperate to shorten total project lead time?**

In our model, EOS items are consolidated to a project activity in the warehouse, resulting in extra handling efforts. As explained in Section 6.4, is would be interesting to see how these handling efforts can be reduced. Vanderlande could ask suppliers to manage EOS stock (Vendor Managed Inventory) or send EOS items in one container to site. Also, sending incomplete activities to site could speed up installation, providing an opportunity to improve responsiveness.

- **Topic 6: What is the best approach to store, consolidate and ship EOS items to site?**

To conclude this thesis, we contributed to Vanderlande by providing a network redesign that not only improves responsiveness but also realizes cost reductions.

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Documents

Vanderlande Documents obtained via Vikipedia:	Documents and information obtained via emails:
Annual report Calendar Year 2010-2015	Bahrain Organisation Chart V7
Blueprint	Internal Vacancy site manager
Corporate Strategy PowerPoint 2014	Lockdown strategy presentation
Supply Chain Process	Mail GSC Manager
Split-up rules	NPI overview Oct 2016
Supply Centres page	Supplier list
Supply Chain Process	
Sustainability Report 2015	

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http://www.marketsandmarkets.com/Market-Reports/baggage-handling-systems-market-955.html
https://www.vanderlande.com/about-vanderlande/acquisitions

Overview of relevant interviews, meetings & presentations

	Date	Type	Department	Initials	Function
Interviews to get acquainted with problems and way of working in current supply chain network					
1	12-08-2016	Interview	SC Development	BL	Supply Chain Coordinator
2	08-09-2016	Interview	SC Development	ET	Senior Supply Chain Coordinator
3	08-09-2016	Interview	SC Development	WB	Senior Manager
4	08-09-2016	Interview	Production Planning	HB	Senior Team leader
5	12-09-2016	Interview	SC Development	JH	Specialist Supply Chain
6	13-09-2016	Interview	SC Development	DB	Lead Buyer
7	14-09-2016	Interview	Corporate Procurement	BP	Sourcing Manager II
8	14-09-2016	Interview	Corporate Procurement	GG	Supply Chain Coordinator II
9	22-09-2016	Interview	SCC AP	TL	Supply Chain Support Specialist
10	26-09-2016	Interview	Logistical Support	SV	Senior Team Leader
11	27-09-2016	Interview	SCC AP	IT	Cost Engineer II
12	28-09-2016	Interview	Logistic Warehouse	RS	Supply Chain Coordinator II
13	29-09-2016	Interview	SCC AP	JY	Manager SCC AP
14	05-10-2016	Interview	Corporate Procurement	DE	Junior Supply Chain Coordinator
15	02-11-2016	Interview	SC Development	WB	Senior Manager
Meetings to get extra insight in current supply chain network					
1	28-10-2016	Interview	VMI Group (benchmark)	BB	Vice-president logistics
2	26-09-2016	Guided tour	Factory Veghel		
3	07-10-2016	Guided tour	EDC		
4	05-12-2016	Presentation	SCC EU: supply plan update		
5	13-12-2016	Meeting KPI	Operational buyers		
6	16-01-2017	Presentation	GSC: recap performance 2016		
Weekly meetings					
1	Weekly	Update	Weekly update with supervisors Vanderlande		
2	Weekly	Question hour	Meetings with E. Tielemans for extra explanation Hubble, Slimstock, validation		
Presentations & discussions about new network design					
1	16-12-2016	Presentation	GSC involved employees	WB, ET, JH, GB, NG, DE, RS, JP, GG, BP, HB, FO	
2	12-01-2017	Presentation	Management GSC	GB, JH, KS, RV	
3	26-01-2017	Discussion	Management GSC	RV, EN	
4	31-01-2017	Discussion	World Class Operations	JS	
5	09-02-2017	Discussion	Engineering	IK, PV	
6	22-03-2017	Coffee conversation	Shared Service Centre	RB	
7	22-03-2017	Coffee conversation	Engineering	JM	
8	31-03-2017	Coffee conversation	Data Management	GJV	
9	19-04-2017	Presentation	SC Development		
10	20-04-2017	Presentation	Global Supply Chain		
11	24-04-2017	Presentation	Global Supply Chain		
Interviews to ask management opinion of involved departments					
1	27-03-2017	Interview	Sales	FD	Director Sales Engineering WPP
2	28-03-2017	Interview	Supply Chain	RV	Manager SCC EU
3	28-03-2017	Interview	Supply Chain	EN	Executive manager Sourcing
4	28-03-2017	Interview	Spares	AV	Group leader Spares
5	28-03-2017	Interview	Finance	PB	Executive BU WPP Controller
6	29-03-2017	Interview	Engineering Parcel	MJV	Senior manager
7	29-03-2017	Interview	R&D	HB	Executive director R&D
8	29-03-2017	Interview	R&D	JB	Program manager
9	30-03-2017	Interview	Warehouse	SA	Senior Manager
10	30-03-2017	Interview	Engineering Baggage	RD	Executive Manager
11	31-03-2017	Interview	Sales	JF	Director Sales Engineering Baggage

APPENDICES

Appendix A: Flowchart of supply processes from project start to project delivery

The simplified flowchart in Figure 0.1 clarifies the processes related to project start to project delivery from involved departments. We emphasize processes that relate to procurement, first tier suppliers and distribution since the supply chain department is responsible for material flow from SPEC release to delivery on site.

Creation of specifications
A project is sold when the customer signs the contract. A project manager is assigned to the project and relevant system requirements are sent to the **Engineering** department. Engineering designs the system, both functional as well as layout engineering. Engineering can include new products from the **Research & Development (R&D)** department in this design. Engineering is responsible for dividing the complete system into activities. Based on these activities, **Shared Service Centre** creates budget and hours and assigns a SCC. **Project planning** is responsible for the time and resource control during the project and adapts the planning accordingly. Finally, Engineering creates and releases SPECs.

Procurement
These SPECs are the input (demand) for the supply chain department. Based on the SPECs, **procurement** starts ordering the required project items. They have to make many decisions regarding outsourcing, the selection of subcontractors, price and due date determination. Based on all these decisions, procurement sends the order to a first tier supplier.

First tier supplier
Vanderlande's factories or **subcontractors** are both first tier suppliers. They receive the order and in some cases negotiate about the due date and price (however, most prices are fixed). When they reach agreement with procurement, they confirm the order and start manufacturing. If necessary, the first tier supplier orders extra items at second tier suppliers. Interesting is that these second tier suppliers can be a first tier supplier for other items, depending on the items requested. They send finished goods to Vanderlande's distribution centres or directly to site.

Distribution
Vanderlande owns two **distribution centres**: in Acworth (USA) and Veghel (NL). The warehouse receives and stores items from first tier suppliers. When all items of an activity are received, items are picked from the shelves, merged ('consolidation') and prepared for outbound. They send activities to site by air, boat, train or truck: this depends on urgency of delivery, distance to site and product volume.

Site
The **site** manager supervises item inbound, the installation and testing of the system. If all quality checks are approved and the system works as designed, he delivers the project to the customer. From here, the global service department takes over.

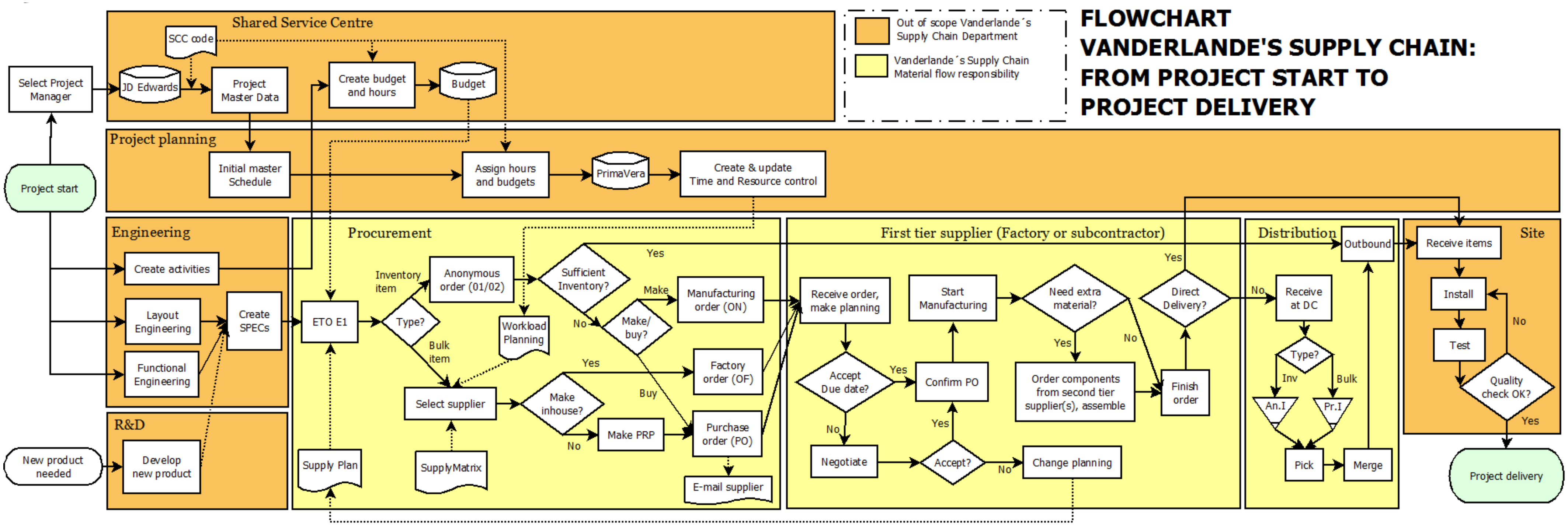

Figure 0.1 – Flowchart (simplified version of an outdated flowchart. Source: Supply Chain Process, Vikipedia)

Appendix B: Main differences between Vanderlande's factories and SCCs

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Appendix C: SPEC creation of Engineers (Posisorter example)

We illustrate the possible reason for low usage of anonymous items with the Posisorter (SPO). The SPO consists of six sections (Figure 0.2) and performs the function of moving parcels to another belt by moving the black 'shoes' over aluminium frames (Figure 0.3). These six sections are the entry (A) where products are placed on the belt, followed by a pre-sort (B) and sorting section (C). The SPO ends with the exit section (D) and controls (E). The sixth section is the transportation unit (F) which includes the carrier mats, wheels, chains and shoes.

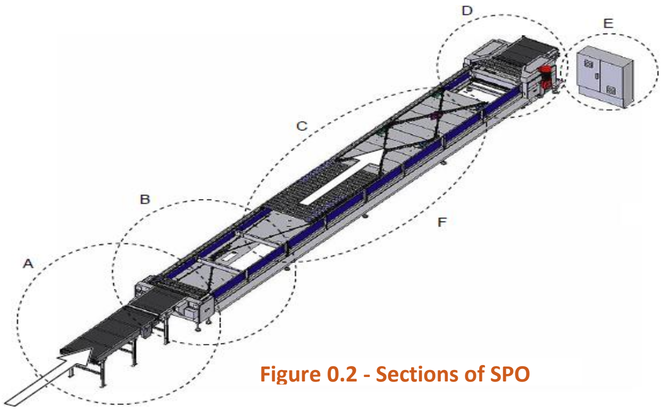

Figure 0.2 - Sections of SPO

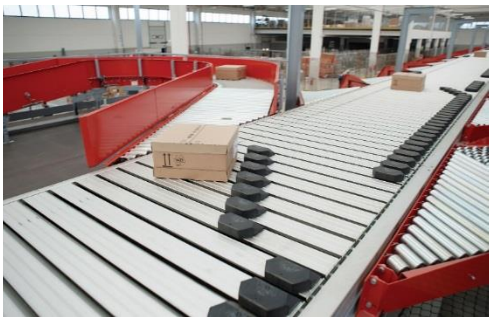

Figure 0.3 - SPO in working

In this simple example, the SPO can vary on four ways to make it applicable for almost every customer system: section B can vary the exit (dual or single) and degree of the shoe (20 or 30), section C the size (900, 1000, 1100, 1200, 1300 or 1400 mm). Assuming that other sections remain fixed, Vanderlande would need 2*2*2*6=48 SPO configurations in their layout (see Figure 0.4).

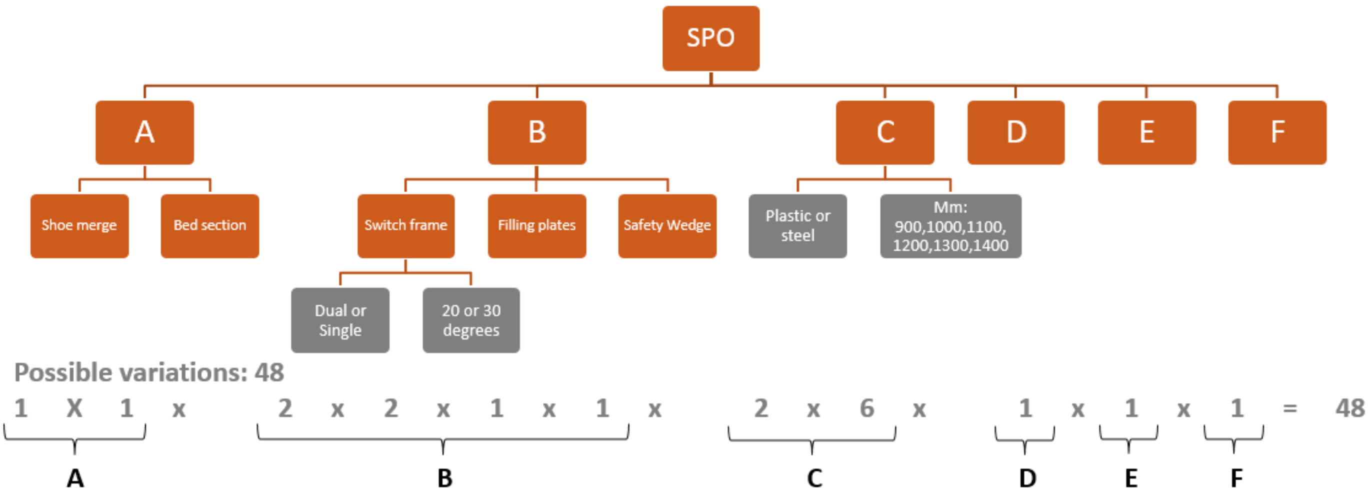

Figure 0.4 - The 48 configurations of the SPO

However, data analysis shows that last year 1284 different dashes (SPECS) were released to specify a SPO, which is clearly more than these 48 standard configurations! This is because Engineering can vary the SPO on more ways. The length can be any value between 50 and 3000 mm, resulting in 48^{2500} extra options! Image what happens if the colour can change or the motor power. This ultimately results in unlimited number of options, making this equipment very project specific instead of standard.

Appendix D: High peak long tail project workload (Oslo example)

Figure 0.5 shows the workload measured in orderlines of the Oslo project. The workload is characterized by a high peak in 2015 to supply all activities and followed by a long tail for the supply of extra materials. According to the supply chain coordinator, the high peak and long tail characteristic applies to other projects as well. This complicates workload distribution for the SCCs, since they execute many projects simultaneously. This results in multiple peaks at the same time, pressuring the SCCs workload.

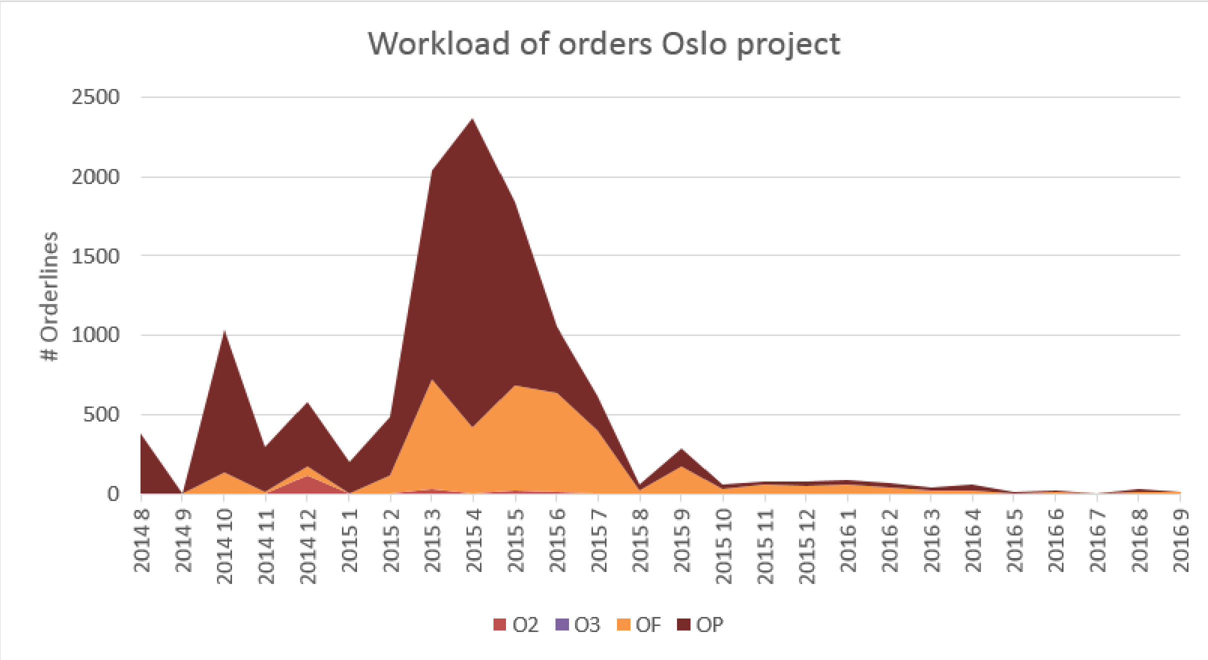

Figure 0.5 - Workload of specific project with high peak and long tail (Source: Hubble)

Appendix E: Keyword analysis of literature study

We use four keyword combinations for our literature study, see Table 0.1. From the initial query results, only relevant articles are selected based on the following inclusion criteria:
> Is the title relevant for this explorative study?
> If yes: Is the abstract relevant and does it match keywords?
> If yes: Does the journal have a Scientific Journal Rate higher than 1 to ensure high paper quality?
When all inclusion criteria are met, we select the review.

Table 0.1 - Keyword combinations

Keywords review combination A	**Keywords review combination B**	**Keywords review combination C**	**Keywords review combination D**
ETO / engineer-to-order / Construction sector	Supply Chain Network	ETO / engineer-to-order / Construction sector	Supply Chain Network Design
Supply Chain	Responsiveness / flexibility	Responsiveness / flexibility	Facility role
Literature review	Literature review	Literature review	Literature review

Query combination A: **TITLE-ABS-KEY((supply chain) AND (ETO or engineer-to-order OR construction sector) AND (literature review)) AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"re"))**
Initially 20 results. Relevant articles based on the inclusion criteria: 3 relevant articles.
Query combination B: **TITLE-ABS-KEY((supply chain network) AND (responsive* OR flexib*) AND (literature review)) AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"re"))**
Initially 16 results. Relevant articles based on the inclusion criteria: 5 relevant articles.
Query combination C: **TITLE-ABS-KEY((ETO or engineer-to-order OR construction sector) AND (responsive* OR flexib*) AND (literature review)) AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"re"))**
Initially 10 results. Relevant articles based on the inclusion criteria: 0 relevant articles.
Query combination D: **TITLE-ABS-KEY((supply chain network design) AND (facilit* AND role) AND (literature review)) AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"re"))**
Initially 3 results. Relevant articles based on the inclusion criteria: 2 relevant articles.

In conclusion, 10 literature reviews are the fundament for this chapter, see Table 0.2. We may use references of these literature reviews by performing back-tracking.

Table 0.2 - Final selection of literature reviews

Author	**Year**	**Combi**	**SJR score**	**Title**
Arantes, Ferreira, Costa	2015	A	3.127	Is the construction industry aware of supply chain management? The Portuguese contractors' perspective.
Banerjee, Sarkar, Mukhopadhyay	2012	B	1.359	Multiple decoupling point paradigms in a global supply chain syndrome: A relational analysis.
Chou, Chua, Teo, Zheng	2011	B	3.781	Process flexibility revisited: the graph expander and its applications.
Engelhardt-Nowitzki, Hammervoll, Jensen	2012	B	1.193	Improving value chain flexibility and adaptability in build-to-order environments.
Gosling & Naim	2009	A	2.033	Engineer-to-order supply chain management: A literature review and research agenda.
Klibi, Martel, Guitouni	2010	B	2.713	The design of robust value-creating supply chain networks: a critical review.
Melo, Nickel, Saldanha da-Gama	2009	D	2.540	Facility location and supply chain management – A review.
Olhager, Pashaei, Sternberg	2015	D	1.694	Design of global production and distribution networks: a literature review and research agenda.
Palma-Mendoza, Neailey, Roy	2014	A	1.168	Business process re-design methodology to support supply chain integration.
Stevenson & Spring	2007	B	1.262	Flexibility from a supply chain perspective: Definition and review.

Appendix F: Frameworks Engelhardt-Nowitzki (2012) and Reichhart & Holweg (2007)

Engelhardt-Nowitzki (2012) offer a framework to guide improvement of flexibility, see Figure 0.6. First, flexibility needs to be defined and operationalized for the given context and the target customer (1). Then, the company must select where it wants to be flexible based on the trade-off (2) and then develop and implement improvement means (3).

Flexibility operationalization	Flexibility-driven segmentation	Development of improvement means
• definition of flexibility and adaptability for the given context • uncertainty source identification • identification of occasions that require flexibility • uncertainty reduction potential analysis	• selection of the most relevant flexibility dimensions of the concrete practical context (incl. prioritization) • allocation of observed/perceived evidence to selected dimensions • segmentation of value flow areas into well-directed fields of action	• twofold creation of improvement ideas: - uncertainty reduction - flexibility alignment (clear focus) and enhancement • definition of measurement mode (e.g. performance indicator, qualitative scale) • measure selection and implementation
⇒ flexibility & adaptability landscape	⇒ points of action are identified	⇒ implemented improvement means

Figure 0.6 - Framework of Engelhardt-Nowitzki (2012)

Reichhart & Holweg (2007) develop a framework for clear distinction between factors that require a supply chain to be responsive in the first place and factors that enable them to be responsive, see Figure 0.7. These external requirements result in demonstrated responsiveness, so how much responsiveness is really required due to the external environment. The internal determinants enable potential responsiveness. One must align potential and demonstrated responsiveness to avoid unnecessary costs. The first step is to reduce uncertainty of external requirements and thereby lower demonstrated responsiveness; the need to be responsive in the first place. Then, adjust internal determinants to match potential responsiveness with demonstrated responsiveness.

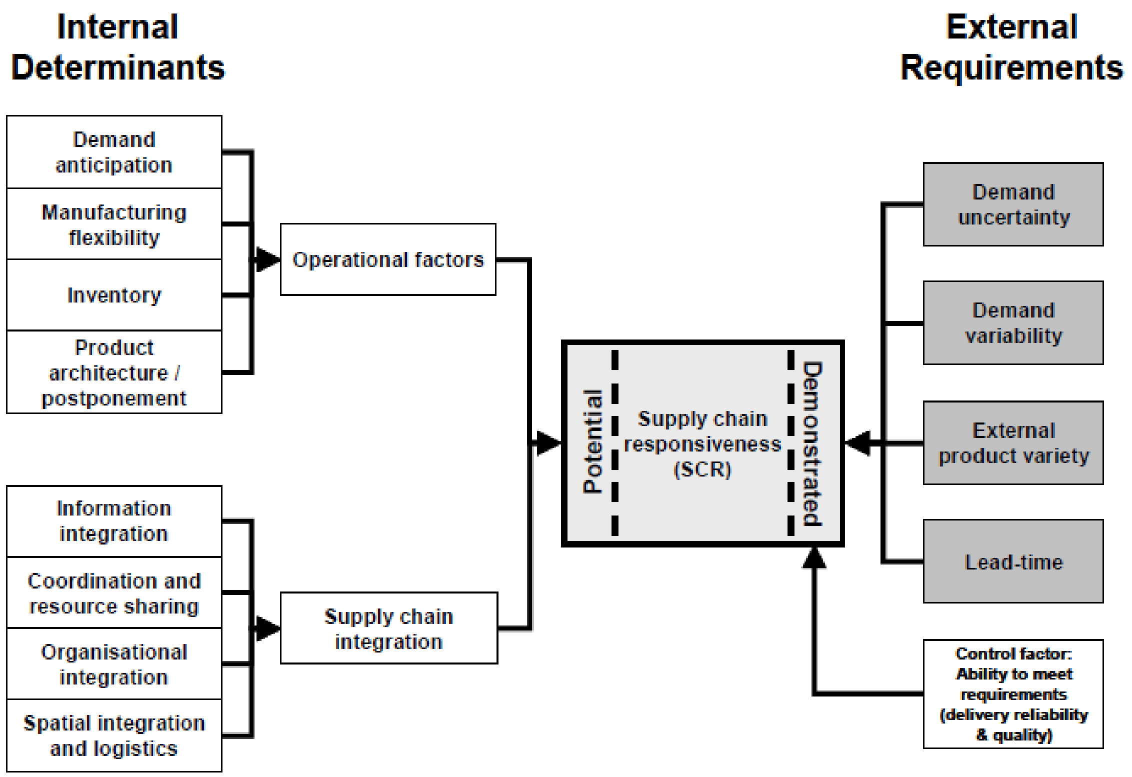

Figure 0.7 - Framework of Reichhart & Holweg, 2007

Appendix G: Numerical examples of formulas

NUMERICAL EXAMPLE NORMAL DEMAND DISTRIBUTION

We illustrate the formulas with an example item with the following characteristics: R = 1 week, L = 2 weeks, x = 100, s = 30, A = €3.00, h = € 0.15 / € / period, P_2 = 0.98, C = €3.10, v = €6.58 and TOL = 111 during 52 weeks. With [1] and [2] we find $\hat{x}_{L+R}$ is 300 and σ_{L+R} is 52. The CV_{L+R} is 0.17 [3], so we take formulas for normal distribution. We find k=1.38 [4], resulting in SS of 72 [5] and S of 372 [6]. With the backlog of 2 [11], we find the expected stock on hand of 120 units [12]. This results in total inventory cost of €54,- per year [13], while savings €520,- on material cost [14] but negative savings on orderline reduction of -€139,- [15]. Total savings are positive (€327,-), thus y=1 and we include this item in the EOS list [16].

[1] $\hat{x}_{L+R} = 100 * (2+1) = 300$

[2] $\sigma_{L+R} = 30 * \sqrt{(2+1)} = 52$

[3] $Coefficient\ of\ variation\ CV_{L+R} = \frac{52}{300} = 0.17$

[4] $G_u(k) = \frac{100*1}{52} * (1 - 0.98) \quad \rightarrow \quad k = 1.38$ (solver)

[5] $SS = k * \sigma_{(L+R)} = 1.38 * 52 = 72$

[6] $S = \hat{x}_{(L+R)} + SS = 300 + 72 = 372$

[11] $Expected\ backlog\ per\ week = x * R * (1 - P_2) = 100 * 1 * (1 - 0.02) = 2$

[12] $Expected\ stock\ on\ hand = \frac{x*R}{2} + SS - backlog = \frac{100*1}{2} + 72 - 2 = 120$

[13] $TCI = h * A * expected\ stock\ on\ hand = 0.15 * €3.00 * 120 = €54$

[14] $TSM = (€3.10 - €3.00) * 100 * 52 = €\,520$

[15] $TSO = v * (TOL - 52) - w * TOL = €9.40 * (111 - 52) - €6.25 * 111 = -€139$

[16] $TSM_i + TSO_i > TCI_i \quad since\ 54 < 381\ so\ y_i = 1$

[17] $Total\ savings\ of\ EOS\ network = 1 * (327) = €327$

NUMERICAL EXAMPLE GAMMA DEMAND DISTRIBUTION

For small values of CV_{L+R}, the gamma distribution is almost equal to the normal demand distribution. Therefore, we validate these outcomes by using the formulas of the gamma distribution and compare results. Formula [1] and [2] are equal to our approach above: we find $\hat{x}_{L+R}$ is 300 and σ_{L+R} is 52 and the CV_{L+R} of 0.17. Note that in our model, we only apply gamma distribution to CV_{L+R}>0.5: we use this example to validate our results. We find alpha of 33.3 and beta of 9.0 [7]. With [8] we find ESPRC = 2.0. Since we know the value of ESPRC, alpha and beta, we can find the value of S using the gamma distribution [9]. This results in S of 379 and SS of 79 [10]. When looking at [11]-[17], we see comparable results as for normal demand distribution, validating our approach.

[7] $\alpha = \frac{x_{L+R}^2}{\sigma_{L+R}^2} = \frac{300^2}{52^2} = 33.3 \qquad \beta = \frac{\sigma_{L+R}^2}{x_{L+R}} = \frac{52^2}{300} = 9.0$

[8] $P_2 = 1 - \frac{ESPRC}{x*R} \rightarrow 0.98 = 1 - \frac{ESPRC}{100*1} \quad so\ ESPRC = 2.0$

[9] $ESPRC = \alpha\beta[1 - F(S; \alpha+1; \beta)] - S[1 - F(S; \alpha; \beta)] \quad We\ know\ ESPRC, \alpha\ and\ \beta\ so\ S = 379$

[10] $SS = S - \hat{x}_{(L+R)} = 379 - 300 = 79$

[11] $Expected\ backlog\ per\ week = x * R * (1 - P_2) = 100 * 1 * (1 - 0.02) = 2$

[12] $Expected\ stock\ on\ hand = \frac{x*R}{2} + SS - backlog = \frac{100*1}{2} + 79 - 2 = 127$

[13] $TCI = h * A * expected\ stock\ on\ hand = 0.15 * €3.00 * 127 = €57$

[14] $TSM = (€3.10 - €3.00) * 100 * 52 = €\,520$

[15] $TSO = v * (TOL - 52) - w * TOL = €9.40 * (111 - 52) - €6.25 * 111 = € - 139$

[16] $TSM_i + TSO_i > TCI_i \quad since\ 57 < 381\ so\ y_i = 1$

[17] $Total\ savings\ of\ EOS\ network = 1 * (324) = €324$

Appendix H: Classification scheme of Bachetti et al. (2013)

Figure 0.8 shows an overview of classification criteria with suggested cut-off values. The references in this table can be found in the reference list of the paper of Bachetti et al. (2013).

Part/unit cost	Several papers consider this criterion jointly with others: threshold values are defined in conjunction with other criteria (Ernst and Cohen, 1990; Partovi and Anandarajan, 2002; Chen et al., 2006; Ramanathan, 2006; Zhou and Fan, 2007; Ng, 2007). It is also common that two or three levels/classes are proposed (Petrovic and Petrovic, 1992; Nagarur et al., 1994; Huiskonen, 2001; Braglia et al., 2004; Cavalieri et al., 2008), which are determined qualitatively (e.g. high/low) with unspecified cut-off values. Porras and Dekker (2008) propose a five-level classification based on cut-off values related to a case study organisation
Part Criticality	The criterion is qualitative in nature. Most papers suggest the definition of two or three criticality levels based on a direct judgmental evaluation (Flores and Whybark, 1988; Petrovic and Petrovic, 1992; Huiskonen, 2001; Persson and Saccani, 2009), or the evaluation of sub criteria (Cavalieri et al., 2008). In some cases an Analytical Hierarchy Process (AHP) methodology is proposed (Gajpal et al., 1994; Braglia et al., 2004), clustering (Duchessi et al., 1988; Ernst and Cohen, 1990) or weighted average methods (Chen et al., 2006; Ramanathan, 2006; Chu et al., 2008)
Demand volume/value	Generally, ABC classifications are used on the cumulative annual demand volume or value, based on ad-hoc Pareto-based threshold values (Flores and Whybark, 1988; Syntetos et al., 2009b), or on clustering techniques (Duchessi et al., 1988), or on qualitative characterisations (e.g. high/low—Huiskonen, 2001; Persson and Saccani, 2009). Several papers consider this criterion jointly with others: threshold values are defined in conjunction with the other criteria (Ernst and Cohen, 1990; Partovi and Anandarajan, 2002; Chen et al., 2006; Ramanathan, 2006; Zhou and Fan, 2007; Ng, 2007). Some papers address demand frequency (Gelders and Van Looy, 1978; Porras and Dekker, 2008) with ad-hoc cut-off values, or take a reliability perspective (Petrovic and Petrovic, 1992; Braglia et al., 2004)
Supply characteristics/ uncertainty	The evaluation is based on the supply lead time (Gajpal et al., 1994) or supplier distance (Nagarur et al., 1994) with unspecified or ad-hoc cut-off values. In Braglia et al. (2004) several sub-criteria are considered through an AHP methodology. Eaves and Kingsman (2004), considering lead time variability, state: "*the choice of boundaries between each of the categories is essentially a management decision*" (p. 432). Persson and Saccani (2009) report the part availability on the market from competitors as a classification criterion
Demand characteristics	Lead-time demand variability is addressed by Williams (1984) and Eaves and Kingsman (2004). Syntetos et al. (2005) categorise demand according to the squared coefficient of variation of the demand sizes and the average demand interval. Both the parameters and cut-off values are obtained analytically and are further empirically validated on 3000 real-intermittent demand data series (SKUs) suggesting their robustness in a variety of contexts. Boylan et al. 2008 showed through a case study analysis with a software manufacturer the insensitivity of the average inter-demand interval cut-off value in the range 1.18–1.86
Life cycle phase	The criterion is suggested by Yamashina (1989). In the case described by Persson and Saccani (2009) four phases are considered, with case-based cut-off values depending on the number of years from which the equipment is being manufactured, or by the time passed since the production ended

Figure 0.8 - Classification criteria resulting from a literature study performed by Bachetti and Saccani (2012)

Figure 0.9 shows the classification scheme of Bachetti et al. (2013).

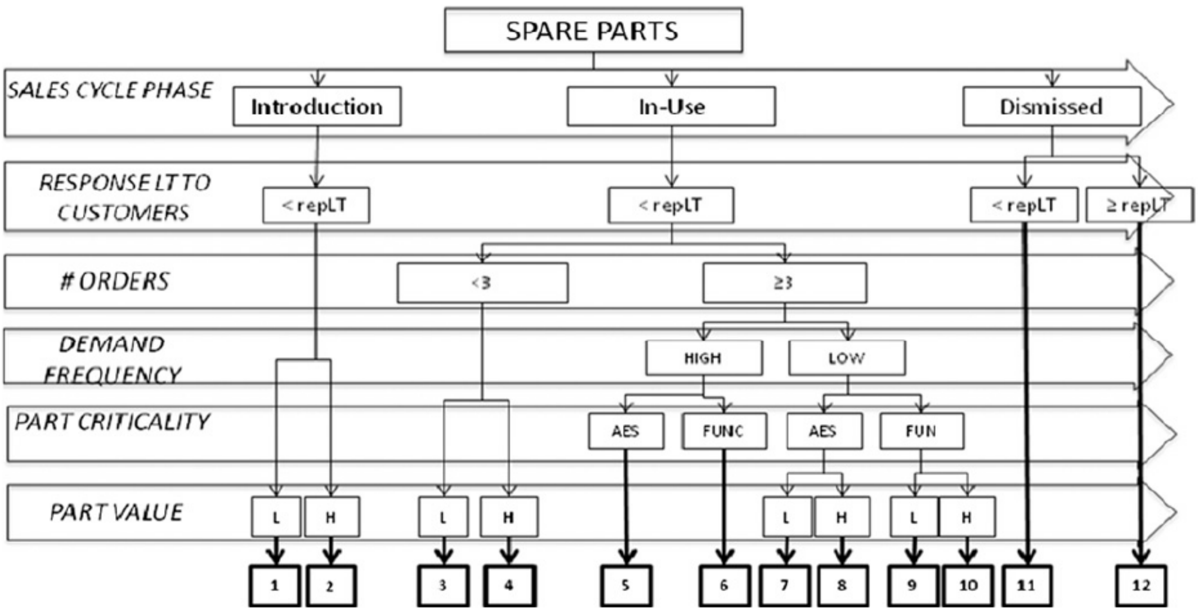

Fig. 2. The proposed classification scheme.

Figure 0.9 - Classification scheme of Bachetti et al. (2013)

Appendix I: Cost per orderline

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Appendix J: Simplified example to calculate responsiveness KPIs

We use a simplified example on project 'Istanbul' and 14 EOS items to show how we calculate lead time performance. As Figure 0.10 shows, 3 of the 14 EOS items were used in the Istanbul project. In four occasions, this item receipt date exceeded the activities late finish date: two times for item 002370-88010 and two times for item 002763-00010.

We marked the delayed orderlines of item 002370-88010 yellow, see Table 0.3. In the first activity (1402931476440, containing 8 orderlines), we see that there are more items exceeding the late finish date. Item 006002-11070 (sourced by Lapp Benelux B.V., no EOS item) increases the activity makespan with 31 days. In this activity, **the EOS item does not improve activity fill rate or activity lead time.**

ISTANBUL

EOS item	In Istanbul?	#orderlines	# > late finish?
007011-22201		0	0
006002-13668		0	0
004405-10032	1	306	0
004420-05031		0	0
N44401-05024		0	0
000420-01406		0	0
002370-88010	1	198	2
012632-292-00001		0	0
012632-015-17016		0	0
012632-683-00001		0	0
012632-998-00001		0	0
004422-02212		0	0
002763-00010	1	201	2
002315-01412		0	0

Figure 0.10 - EOS items in Istanbul project

However, in the second activity (1402931490120), this EOS item was the only cause to increase activity makespan. We pick the EOS item from stock, changing receipt date to request date. This decreases the activity makespan with 12 days. For this activity, **the EOS item does improve activity fill rate and reduces average activity lead time.**

Table 0.3 - EOS item 002370-88010 in project Istanbul

Supplier	Item	Order date	Requested Date	Receipt Date	Late Finish Date	Lot	Too late?	Days later than late finish
1402931476440								
Supplier A	006002-11070	10-06-2016	22-07-2016	05-09-2016	05-08-2016	1402931476440	1	31
Supplier B	006002-12509	10-06-2016	22-07-2016	22-07-2016	05-08-2016	1402931476440	0	
Supplier B	006002-12508	10-06-2016	22-07-2016	22-07-2016	05-08-2016	1402931476440	0	
Supplier B	006002-11609	10-06-2016	22-07-2016	19-08-2016	05-08-2016	1402931476440	1	14
Supplier C	002315-01408	10-06-2016	05-08-2016	08-08-2016	05-08-2016	1402931476440	1	3
Supplier C	002370-88010	10-06-2016	05-08-2016	08-08-2016	05-08-2016	1402931476440	1	3
Supplier C	002723-39025	10-06-2016	05-08-2016	08-08-2016	05-08-2016	1402931476440	1	3
Supplier C	002761-00010	10-06-2016	05-08-2016	08-08-2016	05-08-2016	1402931476440	1	3
1402931490120								
Supplier C	002763-00010	15-07-2016	01-08-2016	09-09-2016	09-09-2016	1402931490120	0	
Supplier C	002763-00112	15-07-2016	01-08-2016	09-09-2016	09-09-2016	1402931490120	0	
Supplier C	002370-88010	15-07-2016	01-08-2016	21-09-2016	09-09-2016	1402931490120	1	12
Supplier C	0P5302-00055	15-07-2016	01-08-2016	09-09-2016	09-09-2016	1402931490120	0	
Supplier C	002931-052-00100	15-07-2016	01-08-2016	09-09-2016	09-09-2016	1402931490120	0	
Supplier C	002931-052-10100	15-07-2016	01-08-2016	09-09-2016	09-09-2016	1402931490120	0	
1402931476260								
Supplier D	006005-00690	25-11-2016	20-01-2017	20-01-2017	20-01-2017	1402931476260	0	
Supplier E	006002-07161	25-11-2016	20-01-2017	13-01-2017	20-01-2017	1402931476260	0	
Supplier F	0L0119-00595	25-11-2016	20-01-2017	19-01-2017	20-01-2017	1402931476260	0	
Supplier G	0G0094-049-00000	25-11-2016	20-01-2017	20-01-2017	20-01-2017	1402931476260	0	
1402931476310								
Supplier G	002931-065-00000	21-10-2016	16-12-2016	21-11-2016	16-12-2016	1402931476310	0	

We measure responsiveness performance by three KPIs: orderline fill rate, activity fill rate, average and activity lead time.

$$Orderline\ fill\ rate = \frac{(\#\ orderlines\ where\ receipt\ date\ \leq request\ date\ in\ period)}{Total\ \#\ orderlines\ in\ dataset}$$

$$Activity\ fill\ rate = \frac{(\#\ activities\ where\ all\ orderlines\ have\ receipt\ date\ \leq late\ finish\ date)}{Total\ \#\ activities\ in\ dataset}$$

$$Activity\ lead\ time\ in\ weeks = \frac{\max(receipt\ date) - \min(order\ date)\ of\ activity's\ orderlines}{7} + 1$$

$$Average\ activity\ lead\ time = \frac{\sum_{all\ activities} Activity\ lead\ time}{Total\ \#\ activities\ in\ dataset}$$

Assuming this project 'Istanbul' solely consists of these four activities, we find the following KPIs:

KPI	Current performance	EOS network performance
Orderline fill rate	$\frac{11\ on\ time}{19\ orderlines} = 63\%$	$\frac{14\ on\ time}{19\ orderlines} = 74\%$
Activity fill rate	$\frac{3\ on\ time}{4\ activities} = 75\%$	$\frac{4\ on\ time}{4\ activities} = 100\%$
Average activity lead time	$\frac{13.4 + 10.7 + 9.0 + 5.4}{4} = 9.6\ weeks$	$\frac{13.4 + 9.0 + 9.0 + 5.4}{4} = 9.2\ weeks$

This shows that orderline fill rate (63% to 74%), activity fill rate (75% to 100%) and activity lead time (9.6 to 9.2 weeks) improve.

Activity	Max receipt date	Min order date	Lead time current (weeks)	Max receipt date	Min order date	Lead time EOS network (weeks)
1402931476440	05-09-2016	10-06-2016	13.4	05-09-2016	10-06-2016	13.4
1402931490120	21-09-2016	15-07-2016	10.7	09-09-2016	15-07-2016	9.0
1402931476260	20-01-2017	25-11-2016	9.0	20-01-2017	25-11-2016	9.0
1402931476310	21-11-2016	21-10-2016	5.4	21-11-2016	21-10-2016	5.4
Average activity lead time current:			**9.6 weeks**	**In EOS network:**		**9.2 weeks**

Appendix K: Numerical results model without considering data pollution

[Left out in public version]

Appendix L: Descriptive statistics of item classification sensitivity analysis

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Appendix M: Management expectation of redesign

Table 0.4 - Management expectation of network redesign

	Mentioned by our interviewees
Advantages Vanderlande	+ **Clear focus.** **“**Shift from project focus to product focus” (EN, RV, MJV, RD), “Clear distinction: which product is mainstream, which customer-specific” (AV), “Best of both worlds: stable flow of efficient production while still being able to deliver customer-specific systems” (RV) + **Cost reductions.** (AV,PB,MJV, HB), lower product price (JB, SA) , “lower cost price” (RD, FD), “Increase shareholder value: profit” (RB), “Less orderlines” (SA) + **Shorten lead times.** “Better able to fulfill customer’s desire of shorter lead times” (EN) “Opportunity to source long lead time items via EOS network” (PB), “Able to start production before layout approval” (MJV) + **Increase SC performance**. “Better delivery performance” (FD), “More reliable delivery” (RD), “Faster delivery” (JF), “Less panic in supply chain” (FD), “Prevent surprises” (RD), “Better delivery performance, improve customer satisfaction” (FD), + **Stimulates/forces standardization.** “Use what we have” (RV), “Competitive advantages” (HB), “Create awareness” (SA), “Less revisions” (SA), “Enables bulk SPECs and extra stock on site” (JF) + **Supplier involvement.** “Involve suppliers, use Vendor Managed Inventory” (PB), “Supplier enjoys transport advantages” (SA), “Supplier advantages by combining base load with flexibility” (JB) + **Able to balance workload**. “Better plan workload” (SA), “Produce at different speeds: Supply chain has to accelerate” (HB), “Provide base load to supplier (JB), “Prevent peaks to suppliers by offering base load” (RD)
Per department	**Sourcing:** “Able to provide base load to suppliers” **Supply chain:** “Able to fulfill supplier’s request to provide stable workflow. Improves QLTC: higher quality, faster deliveries, cheaper products” “Opportunity to extend this to underlying components of specials by product postponement” **Spares:** “Able to use the same suppliers of EOS network” **Finance:** “None, but I’m interested who benefits from these cost reductions” **Shared service Centre:** “Less invoices, opportunity to introduce e-invoicing” **Engineering:** “Better supports current way of working Baggage” **R&D:** “Focus for supply chain employees: enabling faster prototyping because of dedicated project specific network” “Product is faster in Product Lifecycle Management” “Stimulates mindset of first time right” “Easier to stimulate standardization of equipment in PLM” **Sales**: “Better competitive position because of lower cost price” “Able to shorten lead times with long lead time items on stock” “Better able to balance workload of SPO” “Trigger customer” **Warehouse:** “Better able to balance workload” “Transport advantages for supplier” “Better able to predict workload at inbound”
Disadvantages Vanderlande	- **IT adaptations needed** (EN, RV, SA), “Not all data yet available which is needed for proactive inventory management: Slimstock can help” (AV), “Takes long to implement” (EN) - **High dependency of other departments** (R&D, sales, Engineering) to make this a success (PB), “You need R&D and Engineering to reach full potential” (RD) - **Risk of obsolescence.** (EN, FD) - **Projects could feel less flexibility** because of supply chain restrictions (RV) - **Mindset has to change**. “Project thinking is the DNA of our company” (RD), “We are not yet ready for this new way of working” (RV) - **Higher error cost**. “Higher impact of revisions” (JB), “High impact with quality issues” (RD) - **Inventory and adding an extra line could hide the real problems** (HB), “Critical path is often steelwork” (JF)
Per department	**Supply Chain:** “More inventory costs” **Engineering:** “No direct lead time reductions: most items still via project specific network” **R&D:** “Inventory can delay new product releases” “We could have to wait with release when stock is still available” “Different versions of items can occur, which customer may not accept” **Sales:** “None, but we need to maintain our flexibility” **Warehouse:** “Extra picking task” “Fire in warehouse has more impact”