MASTER

Modeling and analysis of supply chain centralization at KMWE

Lastdrager, S.J.A.

Award date:
2016

Link to publication

Disclaimer
This document contains a student thesis (bachelor's or master's), as authored by a student at Eindhoven University of Technology. Student theses are made available in the TU/e repository upon obtaining the required degree. The grade received is not published on the document as presented in the repository. The required complexity or quality of research of student theses may vary by program, and the required minimum study period may vary in duration.

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
Modeling and Analysis of Supply Chain Centralization at KMWE

By
S.J.A. Lastdrager

Industrial Engineering & Innovation Sciences - 2011
Student identity number 0777423

in partial fulfilment of the requirements for the degree of

Master of Science in Operations Management and Logistics

Supervisors:
dr. T.G. Martagan, TU/e, OPAC
Prof. dr. ir. G.J. van Houtum, TU/e, OPAC
J. Langendonk, KMWE
E.Voncken, KMWE
Centralization, Supply Chain Clustering, Transportation Costs, Inventory Pooling, Demand Forecast Information, Lead Time
Abstract

In this research we quantify the impact of centralization on transportation costs, inventory, and lead time. The effects of supply chain centralization on those factors are investigated for the case of KMWE. The company will be launching customer at the Brainport Industries Campus (BIC), in which manufacturing companies are centralized on one location in Brainport Eindhoven. The transport practices are considered in an empirical and analytical way. Then, the suppliers and subcontractors of the company are analysed to get a vision on the best co-occupants at the BIC based on the transportation costs, by developing a transportation costs minimization model. Furthermore, the quantitative advantages of risk pooling on shared inventory are considered and compared with the results of the empirical research. Moreover, we considered the savings potential of demand information sharing. Finally, we analysed the current lead time, and we propose a potential for lead time reduction on the BIC.

Supply chain centralization will reduce the transportation costs, inventory levels, and lead time in the KMWE case on the BIC.
Executive Summary

Introduction

In this project the effects of supply chain centralization for KMWE on the Brainport Industries Campus (BIC) are modeled and analysed. KMWE is a specialist supplier in both the high-tech equipment industry and aerospace. The company operates in the high mix, low volume and high complexity machining environment. In this work we focus on two departments of KMWE Netherlands: KMWE Precision Components (PC) and KMWE Precision Systems (PS).

KMWE is the launching customer at the BIC in Eindhoven, where high-tech manufacturing industry will be located. The aim of the campus is to become a place where innovation and competitiveness in high-tech manufacturing will reach the highest level of excellence, due to the increase in collaboration between companies. Currently, the BIC management is in deliberations with other companies, who may be interested in moving to the BIC. At this time, KMWE is the only committed company.

In this research the following research question is defined, by focusing on the most important customer of PC and PS, ASML the Netherlands:

**What are the effects on the transportation costs, inventory, and lead time if companies of the supply chain are centralized?**

After a literature review the research question is divided into three sub-questions:

1. What is the effect on transportation costs if the supply chain is centralized on the BIC (in which the empirical research is serving as a benchmark for the analytical research)?
2. What are the effects when inventory is pooled and demand forecast is shared, due to centralization of the supply chain on the BIC?
3. What is the effect on the lead time of the supply chain if it is centralized on the BIC?

Supply Chain Centralization

Marshall (1890) developed the concept of clustering of economic activities. Clusters are defined as the geographic concentration of interconnected companies in a particular field (Porter, 1998). The main characteristics of clusters are physical proximity, core companies, and relationships.

According to many is the integration of suppliers a source of potential competitive advantage and improved performance of the supply chain (Eloranta and Hameri, 1991, Dyer, 1996, Frohlich and Westbrook, 2001 and Johnson, 2016). One of the main advantages of proximate suppliers is the reduction of transportation costs (Donnelly and Donnelly, 2004). Moreover, the centralization of companies will result in different transportation modes, transportation structures and transportation frequencies compared to the decentralized situation (Holweg, 2008).

Secondly, information input of orders from a downstream supply chain member could be a misleading parameter for production and inventory decisions of the upstream supply chain members. The bullwhip effect is observed if the orders to the supplier tend to have larger variance.
than the sales of the buyer (Lee, Padmanabhan, and Whang, 2004). Competitive advantage could be raised by sharing up-to-date logistics information (Ang, 1999). One possible way to coordinate the product’s physical flow and the information flow is centralization. The fact that the companies could easily arrange face-to-face meeting will increase the exchange of knowledge (Weterings and Ponds, 2009), which makes more intense relationships (Venables, 2004) and increase innovations (Gertler, 2003 and Oerlemans and Meeus, 2015).

The bullwhip effect will reduce by sharing information (Lee et al., 2004) with more upstream supply chain members. However, risk pooling is another way of reducing the bullwhip effect. Sucky (2009) shows that the bullwhip effect is reduced significantly if the risk is pooled. If risk is pooled the correlation between the demand is considered. Risk pooling causes a reduction of the total variability of demand and/or lead time by consolidation individual variabilities of demand and/or lead times (Oeser, 2015). Due to the reduction of the bullwhip effect, it is possible to reduce the safety stock level, because there are less variabilities in the orders.

The final effect considered is the lead time. Lead time is defined as a competitive advantage in most industries (Hummingbird, 1995 and Stalk, 1988). Time in the process is defined as a critical resource, on which “Time-Based Competition” is based (Holmstrom, 1995 and Blackburn, 1991). Lead time reduction will lead to an improvement in quality, reduces in costs, elimination in non-value-added waste, increases the company’s competitiveness, and market share because customer service is increasing (Suri, 1998). Dispersion of supply chain partners lead to longer lead times, caused by the transportation times (Patti, 2006) and the inventory holding times (Little, 1961).

### Effect of Supply Chain Centralization on Transport Costs

The current situation is compared with the BIC situation. The transport within the BIC will be executed by Automated Guided Vehicles (AGVs). Furthermore, there is a plan for a shared warehouse in the centre of the BIC.

First, the transport costs between PC and PS are investigated. In the current situation the transportation costs between PC and PS are low (a few thousands euro\(^1\) in 2015), due to good agreements and the short distance. In the BIC situation, the transport distance between PC and PS (from PC to the central warehouse, after that to PS) is higher than the distance in the current situation. The transportation costs in the BIC situation are calculated by using two methods: based on the current costs and based on the costs of an AGV system.

The first method is based on the requirement that the transport costs in the BIC must be equal or smaller than the cost in the current situation. The upper bound for the transport costs per movement is €0.89 per pallet per kilometer. The upper bound based on the current costs is equal to the current transportation costs.

The second method is based on the actual costs of an AGV system. Depending on the payback period of the AGV system, the transportation costs between PC and PS will change, in other words the costs per movement depends on the payback period. If the payback period is 5 years the costs of transport between PC and PS will increase by 55\% per year, however if the payback period is 9 years the transportation costs between the two companies in the BIC situation is 14\% lower per year than the current situation. A payback period of 20 years will result in savings of 61\% per year.

Then, the transport costs between KMWE and selected suppliers and subcontractors of the company are considered. In the current situation, three ways of accounting for the transport costs are identified: payment per run, payment per hour, and payment per weight. The total current transportation costs in 2015 are several thousands of euros\(^2\).

The current situation is compared with the situation where selected suppliers and subcontractors of KMWE are located on the BIC. Similar as before the transport costs in the BIC situation are determined by using the two methods (based on current costs and based on the AGV system

---

1. This number is masked, Appendix E.
2. This number is masked, Appendix E.
costs). The current transport costs are higher than the transport costs in the BIC situation, for most cases. Again, the upper bound of the transport costs based on the current costs is equal to the current costs. If we use the method in which the AGV costs are used, the change in cost is dependent on the payback period. The effect of supply chain centralization on transportation costs is that the total transportation costs will reduce. With a payback period of 5 years the difference between the current costs and the BIC costs is €169,965\(^3\) per year, this is a decrease of 57%. Considering a period of 9 years the difference is €227,298\(^3\) per year, which is a decrease of 76%, and 20 years €266,773\(^4\), a decrease of 89%. Here, different factors have to be taken into account: the possible changes in transport frequency and the costs per movement if another transport mode is used. For the AGV system the payback period is an important parameter for the costs per movement.

The suppliers and subcontractors of the company are analysed to get a vision on the best co-occupants at the BIC, by developing a transportation costs minimization model. We recommend to further analyse the suppliers and subcontractors that are selected. The selected suppliers have different product portfolios, therefore the companies have to be considered on an individual basis by the BIC management. KMWE, as first occupant of the BIC, could have an important role in this selection process.

**Effects of Inventory Pooling and Demand Forecasting**

The current situation is compared with two situations that may be executable at the BIC. The advantages of inventory pooling and demand information sharing are considered.

First, the improvement potential of inventory pooling between PC and PS on the BIC is analysed. Inventory pooling, is applicable if members of a supply chain network hold the same products in inventory and a base stock policy is used. When stock is treated in an aggregated way, rather than an isolated way, the variance of supply lead time and customer demand will reduce. This will result in lower safety stock levels, by maintaining the same service level. The decrease in safety stock levels will result in lower average inventory. By only considering the shared items of PC and PS in inventory for ASML NL a reduction of 7% in inventory amount is possible. This will reduce the inventory value by 10%.

The inventory policy change will bring an adjustment in business processes and responsibilities at KMWE, wherefore the relocation to the BIC is a good moment.

Secondly, we analysed the improvement potential of demand information sharing between KMWE and three suppliers (S2, S3, and S33\(^4\)). It became clear that there is a mismatch between the purchased orders at the suppliers and work orders for ASML NL in KMWE, the bullwhip effect. Demand information could be shared on the BIC to reduce the effect. A lower bound on the bullwhip effect is based on the lead time of the supply chain (Chen et al., 2000). The lower bound shows that there is a potential for reducing the bullwhip effect by (on average) 99%, for the three suppliers considered. A good BIC-wide information sharing system is necessary for communication on the BIC.

**Effect of Supply Chain Centralization on Lead Time**

The current situation, regarding to the lead time, is compared with the BIC situation. The lead time reduction is based on the fact that transport time and inventory holding time will reduce in the BIC situation compared to the current situation.

The reduction of the lead time is dependent on whether the suppliers and/or subcontractors are relocated to the BIC or stay at their current location. The current average lead time is 14 weeks. This could be reduced by 24% if KMWE, the suppliers, and the subcontractors are located on the BIC. The lead time could be reduced by 16% if KMWE and the suppliers are located on

\(^3\)This number is masked, Appendix E.

\(^4\)See Appendix P.
the BIC. The lead time could be reduce by 12% if KMWE and the subcontractors are located on the BIC. The lead time could be reduced by 4% if PC and PS are located on the BIC.

As a conclusion, we can say that the centralization has impact on the lead time, due to reduction of transport time and inventory holding time.

Secondly, we investigated the ratio between the touch time and no touch time in the company, by developing a Manufacturing Critical-path Time (MCT) map. We found that the major part of the lead time is defined as no value adding time. We recommend the company to do further research on this observation.
Preface

This thesis is the result of my graduation project executed in partial fulfilment of the requirements for the Master of Science in Operations Management & Logistics (OML). I had the opportunity to conduct this thesis at KMWE Netherlands, in cooperation with Brainport Industries Campus (BIC).

Just like the saying goes; “Time flies when you are having fun!” My student life flew by so fast, five years of hard work, but pleasure at the same time. I am really glad that I made the choice to move to Eindhoven, and study Industrial Engineering.

First of all, I want to express my gratitude to Tugce Martagan, whose expertise and support guided me through this project. I am really glad we had a meeting every week, and your feedback was really supportive. You achieved a lot in the academic world, and I’m sure this is only the start of it.

Thanks to my second supervisor, Geert-Jan van Houtum, for sharing your knowledge and experience.

I want to express my acknowledgement to Edward Voncken, CEO of KMWE, for the opportunity to get involved with this interesting project. Furthermore, I want to thanks Jochem Langendonk and Arthur van Hout for their guidance during my project at KMWE. Besides I want to thank Helene Seibert for our lunch walks, I really enjoyed to talk and walk during our lunch breaks. Enjoy the coming period.

I want to express my gratitude to Erik Vermeulen, from BE2GROW, for involving me in the BIC project. Thanks for the insight-full meetings, and the several interesting gatherings about the BIC.

Furthermore, I want to thank my friends and sister Nienke. Thank you all for the fun nights, dinners, sport activities and your encouraging words.

Thanks to my parents, for their support during my entire life. It was always good to relieve from thesis stress at home. Delightful to have a well-prepared dinner, in the garden, and talk about life.

And last but not least, my lovely boyfriend Daan, thanks being my best friend. Thanks for our conversations and your support during my studies.

Sanne Lastdrager
# Contents

Contents \hspace{1cm} xi

List of Figures \hspace{1cm} xv

List of Tables \hspace{1cm} xix

## 1 Introduction

1.1 Description of KMWE \hspace{1cm} 1
1.2 Brainport Industries Campus \hspace{1cm} 2
1.3 Research Questions \hspace{1cm} 4
1.4 Scope of the Project \hspace{1cm} 4
1.5 Thesis Structure \hspace{1cm} 5

## 2 Scientific Literature on Supply Chain Centralization

## 3 Effect of Supply Chain Centralization on Transportation Costs

3.1 Empirical Research Transportation

3.1.1 Description Current Situation Transportation \hspace{1cm} 14
3.1.2 Transportation Costs Current Situation between PC and PS \hspace{18}
3.1.3 Transportation Costs Current Situation between KMWE and Suppliers \hspace{19}

3.2 Analytical Research Transportation

3.2.1 Description BIC Situation Transportation \hspace{20}
3.2.2 Transportation Costs BIC Situation between PC and PS \hspace{21}
3.2.3 Transportation Costs BIC Situation between KMWE and Suppliers \hspace{22}

3.3 Comparison Current Situation and BIC Situation

3.3.1 Considering KMWE \hspace{25}
3.3.2 Considering KMWE and Suppliers \hspace{26}

3.4 Transportation Costs Model

3.5 Sensitivity Analysis

3.5.1 Current Situation \hspace{29}
3.5.2 BIC situation \hspace{29}
3.5.3 Transportation Model \hspace{31}

3.6 Conclusions, Recommendations, and Future Research

3.6.1 Conclusions \hspace{31}
3.6.2 Recommendations \hspace{33}
3.6.3 Future Research \hspace{34}

## 4 Effects of Inventory Pooling and Demand Forecasting

4.1 Empirical Research Inventory

4.1.1 Analysis of Current On hand Inventory \hspace{35}
4.1.2 Inventory in Current Situation PC and PS \hspace{37}
4.1.3 Inventory in Current Situation KMWE and Suppliers \hspace{38}

---

Modeling and Analysis of Supply Chain Centralization at KMWE \hspace{1cm} xi
CONTENTS

4.2 Analytical Research Inventory ............................................. 39
  4.2.1 Description BIC Situation Inventory ................................ 39
  4.2.2 Inventory Pooling BIC Situation PC and PS ..................... 39
  4.2.3 Bullwhip Effect BIC Situation KMWE and Suppliers ............ 44
4.3 Conclusions, Recommendations, and Future Research ............... 47
  4.3.1 Conclusions ......................................................... 47
  4.3.2 Recommendations ................................................. 48
  4.3.3 Future Research .................................................. 49

5 Effect of Supply Chain Centralization on Lead Time ................. 51
  5.1 Empirical Research Lead Time ....................................... 51
    5.1.1 Broad Overview Current Situation Lead Time .................. 51
    5.1.2 Lead Time of Supply Chain in Current Situation .......... 52
    5.1.3 MCT Map Current Situation Lead Time ....................... 53
  5.2 Analytical Research Lead Time ..................................... 57
    5.2.1 Broad Overview BIC Situation Lead Time .................... 57
    5.2.2 Lead Time of Supply Chain in BIC Situation .............. 57
    5.2.3 MCT Map BIC Situation Lead Time ............................ 60
  5.3 Comparison Current Situation and BIC Situation .................. 62
  5.4 Conclusions, Recommendations, and Future Research ............ 63
    5.4.1 Conclusions ..................................................... 63
    5.4.2 Recommendations ............................................... 64
    5.4.3 Future Research ............................................... 64

6 Effects of Centralization in a Supply Chain ....................... 65
  6.1 Conclusions ......................................................... 65
  6.2 Recommendations .................................................. 66
  6.3 Future Research .................................................... 67

Appendix ................................................................................. 73
  A Turnover Distribution ................................................... 73
  B Suppliers KMWE ............................................................ 74
  C 80% supply and outside processes .................................... 75
  D Transportation Graphs & Tables ....................................... 76
  E Transport Confidential ................................................... 80
  F Background Calculations Transportation ............................ 81
  G Background Information: Automated Guided Vehicle ............. 82
  H Information about the 80% of supply Suppliers/Subcontractors ... 83
  I Total transport costs per payment method ........................ 84
  J Effect selection and transport costs ................................ 85
  K Solver Analysis ............................................................ 86
  L Table $S_\alpha$ ............................................................... 87
  M Inventory Graphs & Tables ............................................. 88
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>N Inventory Confidential</td>
<td>94</td>
</tr>
<tr>
<td>O Background Inventory</td>
<td>95</td>
</tr>
<tr>
<td>P 80% Suppliers Amount and Value Inventory</td>
<td>98</td>
</tr>
<tr>
<td>Q SQL queries</td>
<td>99</td>
</tr>
<tr>
<td>Q.1 Entire Inventory</td>
<td>99</td>
</tr>
<tr>
<td>Q.2 Entire Items</td>
<td>101</td>
</tr>
<tr>
<td>R Lead Time Graphs &amp; Tables</td>
<td>102</td>
</tr>
</tbody>
</table>
List of Figures

1.1 The structure of the KMWE Group, in this project the focus is on KMWE NL Precision Components (PC) and KMWE NL Precision Systems (PS), indicated by the black rectangle (KMWE, 2016k). ................................................................. 2

1.2 The intersection of a cluster on the BIC. The atrium is located in the middle, below the atrium the logistic zone will be created. Left and right are the plants of the companies (BIC, 2016). ................................................................. 2

1.3 Above, the traditional supply chain model. Below, the collaboration between the companies on the BIC (BIC, 2016). ................................................................. 3

1.4 The BIC will consist of five clusters, KMWE will be located at cluster one (BIC, 2016). Cluster one is indicated by the square. ................................................................. 3

1.5 The research question, with the three subjects of the sub-questions. It is indicated in which chapter the subjects are considered. ................................................................. 6

3.1 Visualization of the supply chain of KMWE for customer ASML NL. The flow of products is indicated for 2015 (KMWE, 2016a and KMWE, 2016e). ..................... 14

3.2 Visualization of the supply chain of KMWE for customer ASML NL. The number of shipment days is indicated for 2015 (KMWE, 2016a and KMWE, 2016e). ............. 15

3.3 Categorization of suppliers/subcontractors by number of products per pallet. Ranging from several products per pallet (category 1) to a lot of products per pallet (category 6). ................................................................. 19

3.4 Visualization of the transport situation in BIC. The shipments done by transportation mode AGVs are highlighted with green rectangles. The shipments done by one of the four other transportation modes are illustrated with the red rectangles. ........... 20

3.5 Model of the BIC, with the distance between KMWE and the central warehouse. ................................................................. 21

3.6 The distance between KMWE and the central warehouse is 1.15 kilometer, the distance between the central warehouse and a uniform distributed point on the BIC is 0.88 kilometer. ................................................................. 23

3.7 The relationship between the price per movement and the payback period. The price per movement creases if the payback period is longer. ................................................................. 25

3.8 Comparison between the current transportation costs between PC and PS and the transportation costs in the BIC situation between PC and PS, based on the current costs and the AGV system costs for different payback periods times. ................................................................. 26

3.9 The differences between the current transportation costs and the BIC transportation costs, for the four different scenario’s per supplier/subcontractor. ................................................................. 27

3.10 The results of the minimization function done by using Excel Solver, by using different values of $S_a$ and by varying the number of selected suppliers/subcontractors on the BIC ($I$). ................................................................. 28

3.11 The reduction of the transportation cost is depended on the number of selected suppliers/subcontractors in the BIC and on the costs determination method. The figure shows that if more suppliers/subcontractors are selected the higher the percentage reduction compared to the current costs is, however it seems to have a maximum. ................................................................. 29
LIST OF FIGURES

3.12 The effect on $T_β$ by changing the values a certain percentage of the original values, considering the current situation and transport between PC and PS. .......................... 30

4.1 The current inventory situation, all entities of the supply chain hold their own inventories to protect themselves from uncertainties. The suppliers, KMWE, and ASML NL are responsible for their own inventory. The dashed lines indicate the information flow, while the solid lines indicate the material flow. ......................... 36

4.2 Number of unique items in inventory of PC and PS for ASML NL during 2015 and the number of items that are both in inventory of PC and PS for ASML NL during 2015 (KMWE, 2016j). .............................................................. 37

4.3 The current inventory situation, with suppliers S2, S3, and S33. Each entity has its own inventory holding point. The dashed lines indicate the information flow, while the solid lines indicate the material flow. ......................... 38

4.4 Illustration of the new inventory situation. The PC, PS and selected suppliers and subcontractors are present on the BIC. The central warehouse is used by all the entities on the BIC. There are suppliers and subcontractors that stay at their current location. ............................................................... 40

4.5 Figure 4.5a illustrates the isolated ordering method, while Figure 4.5b illustrates the consolidated ordering method. ............................................................... 40

4.6 The difference between ordering in an isolated or aggregated manner in terms of inventory target level of PC and PS for customer ASML NL during 2015, for items that are available in both inventories. ................................. 43

4.7 The difference between ordering in an isolated or aggregated manner in terms of inventory value of PC and PS for customer ASML NL during 2015, that are available in both inventories. ................................. 43

4.8 Illustration of the supply chain, demand from ASML, and required products for that demand to the suppliers. ............................................................... 44

4.9 The bullwhip effect is observed by the ordering policy of three products at three suppliers considered. The blue lines indicate the purchase orders, while the orange line indicate the work orders. ............................................................... 45

5.1 The current situation concerning the lead time in the supply chain. The products flow from a supplier to ASML NL is indicated. The entire process takes 14 weeks (KMWE, 2016g and KMWE, 2016h). ......................................................... 52

5.2 The MCT map of the current situation, the grey spaces indicate the actual touch time. The white spaces indicate the other elapsed time. The production time at the suppliers and subcontractors is assumed to be completely touch time. .......... 56

5.3 The BIC situation concerning the lead time in the supply chain. The products flow from a supplier to ASML NL, some suppliers/subcontractors are located at the BIC. The inventory time is depended on the lead time. .......................... 58

5.4 The MCT map of the BIC situation, the grey spaced indicate the actual touch time. The white spaces indicate the other elapsed time. The production time at the suppliers and subcontractors is assumed to be completely touch time. .......... 61

5.5 The comparison between the supplier lead times, for PC, PS and ASML NL. The lead time is depended on whether the suppliers/subcontractors are located in the current location or the BIC. ............................................................... 63

D.1 The total amount of products transported from PC to PS, specific for customer ASML NL in 2015 (KMWE, 2016e). ............................................................... 76

D.2 The number of incoming shipments per day at PC (Figure D.2a) and PS (Figure D.2b) (KMWE, 2016e). ............................................................... 77

D.3 Percentage difference between the current transportation costs and the BIC transportation costs per supplier (considered for the three pay back periods). A negative number indicates a decrease in costs if BIC transportation cost is used. .......... 79
F.1 The distribution of number of shipments per shipment day for products transported in 2015 from PC to PS. ................................................................. 81

M.1 The inventory amount (Figure M.1a) and inventory value (Figure M.1b) in items during the year 2015, for customer ASML NL in PC and PS. The figure shows that the value of inventory for ASML NL in PC is lower than in PS, during 2015 (KMWE, 2016j). ......................................................... 89

M.2 The inventory amount (Figure M.2a) and inventory value (Figure M.2b) of inventory on hand at PC for customer ASML NL during 2015 (KMWE, 2016j). ................................................................. 89

M.3 The inventory amount (Figure M.3a) and inventory value (Figure M.3b) of inventory on hand at PS for customer ASML NL during 2015 (KMWE, 2016j). ................................................................. 90

M.4 The number of items in inventory of PC, and the number of items that are in the shared inventory of PC and PS, for customer ASML NL during 2015 (Figure M.4a). The number of items in inventory of PS, and the number of items that are in the shared inventory of PC and PS, for customer ASML NL during 2015 (Figure M.4b)(KMWE, 2016j). ................................................................. 90

M.5 The unique items in inventory of PC and PS, during 2015 for three suppliers. The figure illustrates that the number of unique items in inventory of PC and PS are highest for supplier S3 (KMWE, 2016j). ................................................................. 91

M.6 The amount of items in inventory of PC and PS, during 2015 for three suppliers. The figure illustrates that the number of items in inventory of PC and PS are highest for supplier S3 (KMWE, 2016j). ................................................................. 91

M.7 The value items in inventory of PC and PS, during 2015 for three suppliers. The figure illustrates that the value of items in inventory of PC and PS are highest for supplier S3 (KMWE, 2016j). ................................................................. 92

M.8 The bullwhip effect is observed by the ordering policy of multiple products at three suppliers considered. ................................................................. 93

O.1 Illustration of the bullwhip effect, variability of the orders is high compared to the variability of the sales (Lee, Padmanabhan, and Whang, 2004). ................................................................. 96

O.2 The variance of orders is lower if inventory information is shared (Figure O.2b) compared to the situation where inventory information is not shared (Figure O.2a) (Croson and Donohue, 2006). ................................................................. 96

O.3 In Figure O.3a bullwhip effect without considering risk pooling, between the two retailers. The figure shows that the wholesaler’s orders vary more than the retailers’ periodical demand. In Figure O.3b the bullwhip effect with considering risk pooling, the variance is reduce significantly (Sucky, 2009) ................................................................. 97

R.1 Typical lead time of product produced at KMWE for ASML NL, in the current situation. The lead time of the entire process is 14 weeks (KMWE, 2016g and KMWE, 2016h). ................................................................. 103

R.2 Typical lead time of a product produced at KMWE for ASML NL, in the BIC situation. This is based the empirical research. ................................................................. 104
# List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>The parameter values for (3.1) for the transport between KMWE and suppliers and subcontractors pay per run.</td>
<td>16</td>
</tr>
<tr>
<td>3.2</td>
<td>The parameter values for (3.2) for the transport between PC and PS.</td>
<td>17</td>
</tr>
<tr>
<td>3.3</td>
<td>The parameter values for (3.2) for the transport between KMWE and suppliers and subcontractors.</td>
<td>17</td>
</tr>
<tr>
<td>3.4</td>
<td>The parameter values for (3.2) for the transport between KMWE and suppliers and subcontractors.</td>
<td>18</td>
</tr>
<tr>
<td>3.5</td>
<td>$T_a$ based on the AGV system costs, between KMWE and suppliers and subcontractors.</td>
<td>25</td>
</tr>
<tr>
<td>3.6</td>
<td>The effects of variables on the current transportation costs ((3.2) and (3.9)).</td>
<td>30</td>
</tr>
<tr>
<td>3.7</td>
<td>The effects of variables on the BIC transportation costs (3.5).</td>
<td>31</td>
</tr>
<tr>
<td>4.1</td>
<td>Gross requirements plan for productions ASML products using item 07130035 (KMWE, 2016) and KMWE, 2016c).</td>
<td>41</td>
</tr>
<tr>
<td>4.2</td>
<td>Required items for production at PC, $E(R_{1,t})$, $Var(R_{1,t})$ and (rounded) target inventory level $y_{1,t}$.</td>
<td>41</td>
</tr>
<tr>
<td>4.3</td>
<td>Required items for production at PS , $E(R_{2,t})$, $Var(R_{2,t})$ and (rounded) target inventory level $y_{2,t}$.</td>
<td>42</td>
</tr>
<tr>
<td>4.4</td>
<td>Target inventory level $y_{x,t}$ in isolated and aggregated manner.</td>
<td>42</td>
</tr>
<tr>
<td>4.5</td>
<td>The bullwhip effect according to calculation of Frank Chen, Drezner, Ryan, and Simchi-levi (2000), for the 12 months in 2015. $\frac{Var(q)}{Var(R)} &gt; 1$, this means that the variance of the items purchased at the suppliers is higher than the variance of the items demanded.</td>
<td>45</td>
</tr>
<tr>
<td>4.6</td>
<td>The lead time is divided into three parts (transport, inventory holding, and production), this is based on the analysis done in Chapter 5.</td>
<td>46</td>
</tr>
<tr>
<td>4.7</td>
<td>The BIC lead times are used to calculate the lower bound of bullwhip effect.</td>
<td>47</td>
</tr>
<tr>
<td>4.8</td>
<td>The BIC lead times (Table 4.7) are used to calculate the lower bound of bullwhip effect (4.8).</td>
<td>47</td>
</tr>
<tr>
<td>5.1</td>
<td>The supplier lead time per entity of the supply chain (KMWE, 2016g and KMWE, 2016h).</td>
<td>53</td>
</tr>
<tr>
<td>5.2</td>
<td>The subprocesses in the production of PC, with their frequency of occurring during 2015 (KMWE, 2016c).</td>
<td>54</td>
</tr>
<tr>
<td>5.3</td>
<td>The actual run time and fixed lead time per subprocess in PC (KMWE, 2016c). The average fixed lead time is the average of the planned lead time of the subprocess.</td>
<td>54</td>
</tr>
<tr>
<td>5.4</td>
<td>The subprocesses in the production of PS, with their frequency of occurring during 2015 (KMWE, 2016c).</td>
<td>54</td>
</tr>
<tr>
<td>5.5</td>
<td>The actual run time and fixed lead time per subprocess in PS (KMWE, 2016c). The average fixed lead time is the average of the planned lead time for the subprocess.</td>
<td>54</td>
</tr>
<tr>
<td>5.6</td>
<td>Summary of the ratio between the touch time and no touch time in the supply chain.</td>
<td>55</td>
</tr>
<tr>
<td>5.7</td>
<td>The lead time of PC, for three different situations. Depending on the location the lead time is changed.</td>
<td>59</td>
</tr>
<tr>
<td>Table</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>-------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>5.8</td>
<td>The lead time of the suppliers and the PC lead time. Depending on the location the lead time is changed.</td>
<td>59</td>
</tr>
<tr>
<td>5.9</td>
<td>The lead time of PS, for five different situations.</td>
<td>60</td>
</tr>
<tr>
<td>5.10</td>
<td>The total lead time of the supply chain per entity.</td>
<td>60</td>
</tr>
<tr>
<td>5.11</td>
<td>The total touch time and no touch time for the BIC situation, in hours.</td>
<td>62</td>
</tr>
<tr>
<td>D.1</td>
<td>The capacity and percentages used per transportation mode.</td>
<td>76</td>
</tr>
<tr>
<td>D.2</td>
<td>Indices used in Chapter 3.</td>
<td>77</td>
</tr>
<tr>
<td>D.3</td>
<td>Fixed variables used in Chapter 3.</td>
<td>78</td>
</tr>
<tr>
<td>D.4</td>
<td>Input parameters used in Chapter 3.</td>
<td>78</td>
</tr>
<tr>
<td>D.5</td>
<td>Decision variables used in Chapter 3.</td>
<td>78</td>
</tr>
<tr>
<td>D.6</td>
<td>Output parameters used in Chapter 3.</td>
<td>78</td>
</tr>
<tr>
<td>R.1</td>
<td>The comparison between the lead time in the current situation and in the BIC situation.</td>
<td>105</td>
</tr>
</tbody>
</table>
List of Abbreviations

3PL    Third Party Logistics
ASML   ASM Lithography
BIC    Brainport Industries Campus
BOM    Bill Of Material
DAP    Delivery at Place
DDO    Delivery Duty Paid
EBIT   Earnings Before Interest and Tax
EXW    Ex Works
FTE    Fulltime-Equivalent
ICT    Information and Communication Technologies
JIT    Just-In-Time
KMWE   Small Mechanical Workshop Eindhoven (Klein Mechanische Werkplaats Eindhoven)
MCT    Manufacturing Critical-path Time
OEM    Original Equipment Manufacturer
OML    Operations Management and Logistics
PC     KMWE Precision Components
PS     KMWE Precision Systems
QRM    Quick Response Manufacturing
ROIC   Return On Invested Capital
SCM    Supply Chain Management
SQL    Structured Query Language
## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base stock policy</strong></td>
<td>Inventory order policy in which a minimum level of inventory is kept in stock.</td>
</tr>
<tr>
<td><strong>Centralization</strong></td>
<td>In this research centralization is used to indicated the act of bringing individual companies together into one location. The companies are placed together to share common facilities. Every company maintains its decision-making power.</td>
</tr>
<tr>
<td><strong>Item</strong></td>
<td>A product in inventory (raw material, work in process, and finished products).</td>
</tr>
<tr>
<td><strong>Item Portfolio</strong></td>
<td>The collection of different items in the inventory of a company.</td>
</tr>
<tr>
<td><strong>KMWE</strong></td>
<td>In this research KMWE is used to indicate KMWE Precision Components and KMWE Precision Systems.</td>
</tr>
<tr>
<td><strong>KMWE NL Group</strong></td>
<td>In this research KMWE NL Group is used to indicate KMWE NL, Dutch Aero, KMWE 3DP, and KMWE Projects.</td>
</tr>
<tr>
<td><strong>Lead Time</strong></td>
<td>The amount of time between the start of a process and its completion. In manufacturing, lead time is defined as the time between the moment that the customer places an order and the time that the product is delivered. The total time required to manufacture an item consists of preparation time, queue time, setup time, run time, move time, inspection time, put-away time and the shipment time.</td>
</tr>
<tr>
<td><strong>Make-to-order</strong></td>
<td>In the make-to-order strategy the manufacturer only manufactures the end product once the customer places the order. This creates additional wait time for the consumer to receive the product but it allows for more flexible customization compared to purchasing directly from retailers’ shelves</td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>A finished products bought at a supplier or sold to a customer.</td>
</tr>
<tr>
<td><strong>Supply Chain</strong></td>
<td>A network that consists of a set of geographical dispersed facilities (suppliers, plants, and warehouses). The network of facilities and distribution options performs the functions of procurement of materials, transformation of the materials into intermediate and finished products, and the distribution of these finished product to customers. The materials flow through those facilities; from supplier to end customer. A supply chain in which a product passes through multiple sites before it is finally delivered to an outside customer is called a multi-echelon supply chain.</td>
</tr>
<tr>
<td><strong>Touch Time</strong></td>
<td>The actual time spent on developing a product with the ultimate goal to add value to the end consumer.</td>
</tr>
<tr>
<td><strong>Turnover</strong></td>
<td>The annual sales volume net of all discounts and sales taxes.</td>
</tr>
</tbody>
</table>
Chapter 1

Introduction

In this project, the effects of supply chain centralization on transportation, inventory, and lead time are modeled and analysed for the KMWE case. Company KMWE is the launching customer at Brainport Industries Campus (BIC), a campus where the high-tech manufacturing industry of Brainport Eindhoven will be located at a central location. The aim of the campus is to become a place where innovation and competitiveness in high-tech manufacturing will reach the highest level of excellence, caused by the increase in collaboration between companies.

First, the company is introduced (Section 1.1). Followed by the description of the BIC in Section 1.2. In Section 1.3 the problem considered in this report is represented. In this section the research questions are identified. Furthermore, the scope is determined in Section 1.4. Finally, in Section 1.5 the thesis structure is given.

1.1 Description of KMWE

KMWE, established in 1955, has grown to be a high-tech company with locations in Eindhoven, the Netherlands and in Penang, Malaysia. The KMWE Group is a specialist supplier in both the high-tech equipment industry and aerospace. The company operates in the high mix, low volume and high complexity machining environment. To meet the demand of the various customers, the company produces over 3,000 different products classified in four markets. The markets are: Aerospace & Defense, Semiconductor, Medical & Analytical and Science & Industry.

The KMWE Group consists of four subsidiaries: KMWE Netherlands (KMWE NL), Dutch Aero, KMWE Malaysia (KMWE MY) and KMWE Projects. Besides that, the company has two joint ventures; KMWE 3DP and IDEAS. In KMWE Netherlands, Dutch Aero, and KMWE Malaysia there are several departments: Precision Components (PC), Precision Systems (PS), Sheet Metal Fabrication, and Thermal Spraying. In Figure 1.1 the structure of the KMWE Group is given. The departments work as individual companies, with one coordinating management team.

KMWE Group has 550 employees. Currently, KMWE Netherlands has 282 employees, in total 255 FTEs.

KMWE headquarters is located at Croy 11 in Eindhoven. The production facility of PC is here located as well. PS is located at Croy 47 in Eindhoven, while Dutch Aero is located at Zwaanstraat 1 in Eindhoven.

In 2014 the company had a turnover of 61 million euro. The average grow between 2010-2014 was 15.4%, the earnings before interest and tax (EBIT) was 5.9% during that same time period. The return on invested capital (ROIC) in period 2010 till 2014 was 8.7% (Group, 2016).
CHAPTER 1. INTRODUCTION

Figure 1.1: The structure of the KMWE Group, in this project the focus is on KMWE NL Precision Components (PC) and KMWE NL Precision Systems (PS), indicated by the black rectangle (KMWE, 2016k).

1.2 Brainport Industries Campus

KMWE will be the first factory at the Brainport Industries Campus (BIC) in Eindhoven. The BIC is a business area in development for high-tech manufacturing industry in Brainport Eindhoven. Within the campus companies will be centralized at one location, while every company maintains its own decision-making power. According to the founders of the BIC, companies on the BIC will use each others strength and specialism (Figure 1.3), and are therefore able to deal with the changes in the market environment. Besides the innovations and the development of new business cases will BIC create a representative work environment. The BIC will have an open structure; in the atrium could employees, visitors, and students meet each other.

As you can see in Figure 1.2 the atrium is central located in the BIC. One floor below the atrium a logistic zone will be created. The companies are located next to the atrium.

In the future, the BIC will consist of five clusters (Figure 1.4). The plant of KMWE will cover almost half of the first cluster.

The BIC will be established in the north-west of Eindhoven, near Eindhoven Airport, and in between the highway A2/N2 and the Beatrix canal.

KMWE will be located at the BIC in 2017, according to the current planning. The other clusters and surroundings will be completed after that. Depending on the market demand, the expectation is that the entire campus will be completed by 2035.

Figure 1.2: The intersection of a cluster on the BIC. The atrium is located in the middle, below the atrium the logistic zone will be created. Left and right are the plants of the companies (BIC, 2016).
Figure 1.3: Above, the traditional supply chain model. Below, the collaboration between the companies on the BIC (BIC, 2016).

Figure 1.4: The BIC will consist of five clusters, KMWE will be located at cluster one (BIC, 2016). Cluster one is indicated by the square.
CHAPTER 1. INTRODUCTION

1.3 Research Questions

The goal of this project is to get insight on the value of centralization. In this project the aim is to quantify the impact of centralization on transportation costs, inventory costs, and lead time.

The research question is defined as:

**What are the effects on the transportation costs, inventory, and lead time if companies of the supply chain are centralized?**

By doing this project KMWE wants to get more insight in the advantages of centralization of their supply chain at the BIC. Currently, it is unclear whether the centralization will result in a decrease in manufacturing costs. Centralization is defined as the act of bringing individual companies together into one location. The companies are place together to share common facilities, while every company maintains its own decision-making power.

The research question is divided into three sub-questions:

1. What is the effect on transportation costs if the supply chain is centralized on the BIC (in which the empirical research is serving as a benchmark for the analytical research)?
2. What are the effects when inventory is pooled and demand forecast is shared, due to centralization of the supply chain on the BIC?
3. What is the effect on the lead time of the supply chain if it is centralized on the BIC?

The research question is divided into three parts; transport, inventory and lead time. We use the empirical study of the current transport situation as a benchmark for the analytical study of the BIC situation. Then, we compare the empirical research with the analytical research. By answering sub-question 2 we compare the results of the empirical research of the inventory situation of KMWE with the results of two different kinds of analytical researches. The subjects of the analytical researches are inventory pooling and demand information sharing. The last sub-question is again a comparison between the empirical research of the current lead time situation in KMWE, and the analytical research of the lead time in the BIC.

1.4 Scope of the Project

We analysed the turnover, costs of the products in inventory, amount of products in inventory, and the purchased order volume of PC and PS. One customer is outstanding: ASML Netherlands (ASML NL).

First the turnover of PC and PS is analysed. In PC ASML NL is accountable for 15% of the turnover during 2015 (KMWE, 2016d)(Appendix A). In PS ASML NL is accountable for 61% percent of the turnover during 2015 (KMWE, 2016d)(Appendix A).

In PC is ASML NL accountable for 19% of the inventory on hand during the time observed in 2015 (KMWE, 2016i). In PS is ASML NL accountable for 34% of the inventory on hand during the time observed in 2015 (KMWE, 2016i).

In PC is ASML NL accountable for 26% of the inventory value during the time observed in 2015 (KMWE, 2016i). In PS is ASML NL accountable for 50% of the inventory value during the time observed in 2015 (KMWE, 2016i).

In PC is ASML NL accountable for 1% of the purchased orders during 2015 (KMWE, 2016e). In PS is ASML NL accountable for 12% of the purchased orders during 2015 (KMWE, 2016e).

Furthermore, it is noticeable that PS is the major customer of PC. The turnover of PC consists for 25% of sales to PS during 2015 (KMWE, 2016d). As a result of that PC is the major supplier of PS. In PS 31% of the supplier turnover is related to PC (KMWE, 2016b). Specific for customer ASML NL is PC associated with 24% of the supplier turnover in PS during 2015.
We state, as a conclusion, that ASML NL is the major customer of the companies. On top of that is PC the major downstream supplier of PS producing for ASML NL. Therefore, in this thesis the focus is on that supply chain. In this report the structure is described, the scope could be changed in the future in which all the products of KMWE are included. On top of that, other companies could be included.

1.5 Thesis Structure

The research starts with the consideration of the related literature in Chapter 2.

This thesis is divided into three main chapters. The chapters are divided into an empirical part, analytical part, a part where the comparison between the two is made, and a conclusion.

Chapter 3 answers the question what the effect is on transportation costs if the supply chain is centralized. In this chapter the results of the empirical study serves as a benchmark for the analytical study of the BIC situation. First, we wrote down the results of the empirical research (Section 3.1). Then, the analytical research is described, in which the benchmark is base on the empirical research (Section 3.2). Then we compare the two studies in Section 3.3. Furthermore, we use the studies to develop a transportation costs model (Section 3.4). In Section 3.5 a sensitivity analysis is described. Finally, we draw the conclusions in Section 3.6.

In Chapter 4 we answer sub-question 2. Here, we describe the effects of inventory pooling and demand forecast sharing due to centralization of the supply chain. This chapter is divided into 3 sections. In the first section we describe the results of the empirical study about the inventory (Section 4.1). Then, we have done two kinds of analytical studies in Section 4.2, one related to the effects of inventory pooling (Section 4.2.2) and the other related to the demand information sharing (Section 4.2.3) possibilities in the BIC. Finally, we draw the conclusion in Section 4.3.

Chapter 5 answers what the effect is on lead time if a supply chain is centralized. Again, we start with the empirical research about the lead time in KMWE (Section 5.1). Then, the results of the analytical research are given in Section 5.2. In Section 5.3 we compare the empirical study and the analytical study. Finally, we draw the conclusion in Section 5.4.

Chapter 6 gives the overall conclusions, recommendations, and future research directions. In Figure 1.5 a summary of the above mentioned is made.
What are the effects if companies of a supply chain are centralized?

Figure 1.5: The research question, with the three subjects of the sub-questions. It is indicated in which chapter the subjects are considered.
Chapter 2

Scientific Literature on Supply Chain Centralization

The concept clustering of economic activity dates back to Marshall (1890), he investigated the concentration of specialized trades in certain localities. The regional or local concentrations of trades are referred to as a triad of external economies. Porter (1998) reinvented Marshall’s cluster concept. A cluster is defined by Porter (1998) as the geographic concentration of interconnected companies and institutions in a particular field. It is defined as an alternative way of organising the supply chain. Porter (1998) identified three key characteristics of clusters: physical proximity, core companies, and relationships. Clusters affect competition in three broad ways: the increase of productivity of companies based on the area; driving the direction and pace of innovations, which results in future productivity growth; and stimulating the formulation of new businesses.

Production in many industries, such as assembling of automobiles or the weaving of textiles, occur often in centralized locations. The tendency of companies to locate close to each other in markets where transportation costs of raw material or end products are substantial high, seems logical. More general, the integration of suppliers is referred as a source of potential competitive advantage and improved performance of the supply chain (Eloranta and Hameri, 1991, Dyer, 1996, Johnson, 2016 and Frohlich and Westbrook, 2001). Several case studies in the automotive industry concluded that logistical concerns are the major factor behind supplier location (Cowburn, 1998 and Larsson and Larsson, 2002).

Bennett and Klug (2012) analysed explanatory case studies about supplier integration in the automotive industry. They identified five principal conditions of supplier integration as their main findings: geographical proximity; delivery contents, volume and sequence shared investment and asset specificity; information sharing and IT systems integration; and transport systems.

Transportation and Centralization

In today’s competitive environment logistical costs are of growing interest in supply chain management. In the literature, there are different definitions of logistical costs. However, there are four main components identified; transport, warehousing, inventory carrying, and logistics administration costs (Engblom, Solakivi, Juuso, and Ojala, 2012).

In the past, costs of transportation services were relatively low compared to the inventory holding costs. This led to the tendency to transport as fast and frequently as possible, as in just-in-time delivery (JIT). Due to changes in the last decade, such as the increase of oil prices and imbalance of supply and demand for freight transport service, the transportation methods are gaining more interest in supply chain management (Russell, Coyle, and Thomchic, 2014).

Location models aim to find the optimal facility location, because the success or failure of facilities depend in a part on the location chosen for those facilities. The location models answer the questions how many facilities should be sited, where each facility must be located, how large each
CHAPTER 2. SCIENTIFIC LITERATURE ON SUPPLY CHAIN CENTRALIZATION

facility should be, and how demand should be allocated to the facilities (Daskin, 1995). Traditional location models deal with location, transportation, and inventory decisions in a fragmented way (Ballou, 1999).

The paper of Syam (2002) extends traditional facility location models by introduction several logistical cost components such as holding, ordering, and transportation costs in a multi-commodity, multi-location framework. According to Syam (2002), the transportation costs are highly interrelated with the facility locations, therefore an integrated model is developed. The model minimizes the physical distribution costs by simultaneously determining optimal locations, flows, shipment compositions, and shipment cycle times. Syam (2002) used two heuristic methodologies, based on the Lagrangian relaxation and simulated annealing, which are compared in an extensive computational experiment.

One of the main advantages of proximate suppliers is the reduction of transportation costs (Donnelly and Donnelly, 2004). Patti (2006) performed a case study in which Porter’s economic cluster theory is used. The researcher compares two different situations: in the first situation used the US petrochemical firm outsourced raw materials from a firm about 200 miles away. While in the second situation the firm got its supply from a plant across the street. The transportation costs are reduced by using the neighbour firm instead of the other firm.

Cowburn (1998) performed a case study in the motor components industry. In this research the emphasis is placed on the on-site location of component suppliers by leading motor assemblers. It is showed that the placement of the supply on site of the OEM offers significant reduction in transport costs and improved delivery reliability. The reduction of transport costs in this case is mainly due to the savings of packaging costs.

Furthermore, the risk of delayed or disrupted deliveries as a result of weather, road congestions, or vehicle breakdown is reduced if a supplier is located close to the company (Svensson, 2000).

Larsson and Larsson (2002) performed another case study in the automotive industry, in this research it is stated that the higher the delivery frequencies are, the more important the geographical and temporal supplier proximity is in order to minimize the transportation costs and maximize the reliability.

Another advantage of centralization, is the bundling of transport volumes to similar customers, which reduces transportation cost. The centralization of companies will result in different transportation modes, transportation structures and transportation frequencies compared to the decentralized situation (Holweg, 2008).

Inventory and Centralization

The orders from a downstream supply chain member are the information input for production and inventory decisions of the upstream supply chain member. However, information input of orders from a downstream supply chain member could be misleading parameters for production and inventory decisions of the upstream supply chain member (Lee, Padmanabhan, and Whang, 2004). This phenomenon, which is often occurring, is introduced by Forrester (1961) as the bullwhip effect. The bullwhip effect suggests that the variability of orders increase as we move more upstream in the supply chain from retail to manufacturing. The orders to the supplier tend to have larger variance than the sales to the buyer, and the distortion propagates upstream in an amplified form (Lee et al., 2004).

According to research of Lee et al. (2004) four major causes of the phenomenon can be identified. They identify the first cause as the demand signal processing, which is based on the fact that demand is not stationary over time, and is updated based on the observed demand. The rationing game is identified as the second cause, this means that customers may start to increase their orders if demand exceeds supply. Order batching, the third cause of the bullwhip effect, occurs if the costs for frequent order processing are high. The last cause, identified as price variance, is caused by price fluctuations. Then the downstream member’s buying pattern do not reflect its consumption patterns anymore.
CHAPTER 2. SCIENTIFIC LITERATURE ON SUPPLY CHAIN CENTRALIZATION

The closer the supply chain members are integrated the more important is information sharing. One of the solutions of the bullwhip effect is to grant the manufacturer access to the demand data at the retail outlet. Electronic data interchange systems between retailers and manufacturers are becoming fairly common in the grocery industry. (Lee et al., 2004). The aim of those systems is to facilitate quick and easy transmission of demand data to upstream members of the chain. Companies could collaborate in which they agree on sharing information. The collaboration is based on mutual trusts, openness, and shared risks and rewards which could lead to competitive advantages (Soosay, Hyland, Ferrer, and Soosay, 2008). The competitive advantages could lead to better performance than the companies would have without the collaboration (Hogarth-Scott, 1999).

Scarf (1960) proposed to have a single member of the supply chain performing forecasting and ordering for other members, which is known as centralized multi-echelon inventory control system. However, Frank Chen, Drezner, Ryan, and Simchi-levi (2000) points out that the bullwhip effect still exists even though that all demand information is shared, every stage of the supply chain uses the same forecasting techniques, and every stage uses the same inventory policy. The lower bound of the bullwhip effect is based on the lead time between the different members of the supply chain. According to Fangruo Chen (1998) the value of centralized demand information depends on several key systems parameters, such as the number of stages, lead times, batch sizes, demand variability, and the desired level of customer service. It is found that the value of information seems to exhibit an upward trend as the number of stages, the lead time or the base quantity increases. Furthermore, increases in the coefficient of variation of the demand leads to a decrease in the value of information. Moreover, the value of the information is the highest for the extreme (high or low) values of the back order level, according to the research.

As said the long (replenishment) lead times contribute to the bullwhip effect, this makes that shortening the lead time is a direct and effective counter-measure of the effect (Fisher, 1994). An example, in the case study of Patti (2006) is that the neighbour supplier is more preferable compared to the supplier further away. Inventory is needed to deliver during the supplier lead time and to protect the plant from delivering uncertainties.

Because of the bullwhip effect entities more upstream in the supply chain hold higher inventories to deal with the variability in demand of downstream supply chain members. Classical inventory theory illustrates that the level of inventory and customer service are directly related. Moreover, due to uncertainties in the demand for products and supply it is required for members of the supply chain to maintain safety stock for its products (Silver, Pyke, and Peterson, 1998). Higher safety stock levels lead to higher customer service level. But on the other hand; higher safety stock levels increase the warehousing expenses. In other words, lower safety stock levels decrease the average inventory on hand, and therefore warehousing expenses.

Information flows and systems must be synchronised to get a seamless and effective supply chain (Childerhouse and Towill, 2003 and Voisin, 1996). Furthermore the sharing of up-to-date logistics information such as production-plans and capacities, delivery-orders and stock levels in real time are important factors in raising to competitive advantage (Ang, 1999). Lalonde (1998) refers to the sharing of information as one of the main factors in a good supply chain relationship. The information sharing leads to the tendency to work as a single entity, which lead to better understanding the end customers.

Proximity is a way to coordinate the product’s physical flow and the information flow. Companies that share the same location, centralized companies, could easily arrange face-to-face meeting (Weterings and Ponds, 2009) to exchange knowledge. The exchange could contribute to make intense relationships between the companies (Venable, 2004) and increase the innovations (Oerlemans and Meeus, 2015 and Gertler, 2003). However, Bathelt (2008) and Torre (2008) conclude that if companies are not located close to each other frequent face-to-face meetings and the use of information and communication technologies (ICT) systems contributes to make firms feel close to each other, which facilitates the relations. However, then the need for coordination is high, compared to the situation where companies are centralized.
When companies are centralized on one location, the physical inventory locations could reduce from several decentralized locations into fewer central locations. Aggregated safety stock could reduce by this consolidation. Maister (1976) states that there is a rule of thumb for measuring the effect of inventory centralization on aggregate safety stock. The so-called square root law is used to approximate the changes in aggregate safety stock resulting from changes in the number of stocking locations used in the distribution of a product. The higher the number of stocking locations, the higher the safety stock required to maintain a certain customer service level.

The reasoning behind the above is explained as follows. The average amount of demand at the centralized location is the sum of the average demand faced by each of the individual (decentralized) locations. Furthermore, the variability of the demand of the centralized location, measured by the standard deviation, is proven to be smaller than the combined variabilities of the individual (decentralized) locations. In other words, risk pooling reduces underlying uncertainty through aggregation of the stock (Cai and Du, 2009). Risk pooling is a way to cope with uncertainty, the idea behind risk pooling is to redesign the supply chain, or production process or product, to better deal with uncertainties faced (Cachon and Terwiesch, 2013). When uncertainties in inventory are shared, we call this inventory pooling. Inventory pooling causes a reduction of the total variability of demand and/or lead time by consolidation individual variabilities of demand and/or lead times (Oeser, 2015).

In the article of Sucky (2009) the principles of inventory pooling and bullwhip effect are combined. In the supply chain described in the article of Sucky (2009) there are two retailers, one wholesaler, and a manufacturer, which results in a three-stage supply chain. Similar to the research of Lee et al. (2004), Sucky (2009) quantifies the variance of the retailer demand and orders placed by the wholesaler which results in the bullwhip effect.

In an illustrative example Sucky (2009) shows the difference between the bullwhip with and without risk pooling. It is showed that the wholesaler’s orders vary more than the retailers’ periodic demands (bullwhip effect). In the situation where the order-up-to-levels and the orders placed to satisfy retailers’ demand are based on the isolated manner, risk is not pooled, the correlation between the demand is neglected. However, when the retailers demand is statistically correlated, and considered in the aggregated manner, risk is pooled. Sucky (2009) shows that the bullwhip effect is reduced significantly in that case.

Summarized, when risk pooling is applied, the demand of members of the supply chain to more upstream members of the supply chain are considered together. Then, the correlation between the demand is considered. This results in a significant decrease of the bullwhip effect. Due to the reduction of the bullwhip effect, it is possible to reduce the safety stock level, because there is less variabilities in the orders. The reduction of the safety stock levels lead to a decrease in average inventory on hand. Therefore, warehousing expenses will reduce. A decrease in average inventory will result in the increase of the inventory turnover ratio.

### Lead Time and Centralization

Lead time is defined as a competitive advantage in most industries (Hummingbird, 1995 and Stalk, 1988). Time in the process is defined as a critical resource, on which “Time-Based Competition” is based (Blackburn, 1991 and Holmstrom, 1995). Based on this Suri (1998) developed the manufacturing strategy called Quick Response Manufacturing (QRM), that addresses the implementation of lead time reduction in manufacturing companies. The lead time is reduced by integrating all aspects of the operations. In QRM the mathematical relationship between bottleneck utilization, lot sizes, and variability to lead time is used to reduce the lead time.

Lead time reduction will lead to an improvement in quality, reduces in costs, elimination in non-value-added waste, increases the companies competitiveness, and market share because customer service is increasing (Suri, 1998). Therefore, an analysis of the status quo must be made, in which the flow of material and information are identified, and the processes are divided into different elements. Often, time is wasted because of serialization of independent activities, non-synchronization of dependent activities in the production process, unacceptable quality, or
inefficient work flows (Hummingbird, 1995). Traditionally, the focus of lead time reduction strategies was only on the area of production and operations. While supplier and customer integration in the lead time reduction strategies is the key (Hummingbird, 1995).

Dispersion of supply chain partners lead to longer lead times. In the case of Patti (2006) lead time reduces because of the use of the supply from the neighbour firm is one of the main drives behind the inventory level reduction. In this case study the re-order levels are set based on the forecasted demand during the lead time. Based on the principles of Little (1961) we can say that the inventory time will reduce because of the increase in arrival time.

Longer lead time, lead to higher supply chain disruption risks due to higher forecast errors, transportation delays and shorter recovery times (Chopra, Reinhardt, and Mohan, 2007 and Peck, 2004). By doing a regression analysis Habermann, Blackhurst, and Metcalf (2015) found that lead time, and especially supplier lead time, is significantly related with higher levels of supply chain disruption risk. Moreover, the clustering of supplier has a beneficial effect on the reduction of the disruption duration. The use of a local supplier reduces the lead time variations. Which results in lower safety stock requirements.

Furthermore, shorter lead times reduce the forecasting horizon, which causes a more accurate forecast (Patti, 2006).

In this research another case study is performed. In this research we focus on multiple effects of supply chain centralization. The effects on transportation costs, inventory, and lead time are investigated. The aim of this research is to conclude whether the centralization is a source of potential competitive advantage and improved performance in the future.

We focus on transport because this is becoming one of the major interests in supply chain management. Similar as Patti (2006) in this thesis the advantages of local suppliers and subcontractors and good relations with them are investigated. In contrast to the case studies described in Bennett and Khag (2012) and Cowburn (1998) the suppliers are not integrated with the OEM. In our case the OEM stays at its current location, according to the current information. In the transportation model it becomes clear that the higher the delivery frequencies are, the more important the geographical proximity is in order to minimize the transportation costs, similar as Larsson and Larsson (2002). As described in Holweg (2008) the transportation modes, structures, and transportation frequencies will change in the centralized situation.

According to Soosay et al. (2008) and Hogarth-Scott (1999) collaboration could lead to competitive advantages, therefore we focus on this factor. Information could be shared more easily if companies are centralized (Weterings and Ponds, 2009 and Venables, 2004). To calculate the advantages of information sharing for the inventory practices we used the principles of Forrester (1961), Lee et al. (2004), and Fangruo Chen (1998). Moreover, we used the principles of Sucky (2009) to calculate the improvement potential of inventory pooling of the aggregated stock. When companies have the same physical inventory point, this sharing of aggregated stock is easier.

Lead time is defined as a competitive advantage (Hummingbird, 1995 and Stalk, 1988), therefore we want to focus on this factor. Lead time will increase the customer service, which could be of major importance in the “Time-Based Competition” of the OEM. A centralization of the supply chain, will reduce the lead time, because of the reduction of the transportation time. This will result in a reduction of the re-order levels of the inventory (Patti, 2006), inventory time (Little, 1961), disruption risks (Chopra et al., 2007 and Peck, 2004), disruption duration (Habermann et al., 2015) and forecasting horizon (Patti, 2006).
Chapter 3

Effect of Supply Chain Centralization on Transportation Costs

Transportation is one of the major cost drivers in a supply chain. In this chapter the transportation practices of the current situation are analysed. Additionally, the BIC situation is considered. The current situation serves a benchmark for transportation practices on the BIC. In this chapter the following research question is answered:

What is the effect on transportation costs if the supply chain is centralized on the BIC (in which the empirical research is serving as a benchmark for the analytical research)?

The first section (Section 3.1) is the result of the empirical research done on the transportation in KMWE. In this section we first consider the transport between PC and PS. Secondly, we consider the transport between KMWE and the suppliers and subcontractors.

The second section (Section 3.2) is the result of the analytical research done on the transportation in the BIC. The BIC situation is not established yet, therefore the current situation serves as benchmark. Again we first focus on the transport between PC and PS, after that on transport between KMWE and the suppliers and subcontractors.

In the third section (Section 3.3) we compare the outcomes of Section 3.1 and Section 3.2. In the fourth section (Section 3.4) we develop a transportation costs model. The model determines the best set of suppliers in the BIC, if the aim is to minimize the total transportation costs.

In section (Section 3.5) a sensitivity analysis is performed, there we test the values that we used in the calculations and the model. The final section is the conclusion (Section 3.6). In which conclusions are drawn, recommendations are made, and directions for further research are given.

3.1 Empirical Research Transportation

In this section the transport practices of the current situation are considered, in an empirical way. The current situation serves as a benchmark for the BIC situation (Section 3.2), because the BIC case is not completely elaborated yet.

First, in Section 3.1.1 we describe the current situation of the transport of goods. We focus on the product flow in the supply chain, the modes of transport, and the payment methods. In Section 3.1.2 we calculate the current costs for the transport between PC and PS. Section 3.1.3 is similar as Section 3.1.2, but here we consider the case in which we include the transport between KMWE and its suppliers and subcontractors.
3.1.1 Description Current Situation Transportation

In this section we describe the current situation concerning transport. In this section we focus on the product flow in the supply chain. The modes of transport are described, as well as the payment methods. Furthermore, we classify the suppliers according to the number of products per pallet.

### Product Flow in Supply Chain

In this section we describe the product flow of the supply chain (Figure 3.1 and Figure 3.2). Within the supply chain of KMWE products are shipped several times. First, products are shipped from suppliers to the plants of KMWE. PC bought their supply for ASML NL at 71 different suppliers, during 2015 (Appendix B). PS bought their supply for ASML NL at 170 suppliers (Appendix B). According to the database of KMWE, 23,443 items are bought by PC during 2015 for ASML NL. PS bought 270,244 items for ASML NL during 2015 (indicated by arc 2 in Figure 3.1) (KMWE, 2016e). The supply is delivered during 250 working days at PC, and 254 working days at PS during 2015 (indicated by arc 2 and 3 in Figure 3.2) (KMWE, 2016e)(Figure D.2a and Figure D.2b, Appendix D).

Then, products are produced in the KMWE companies, often production processes are outsourced to a subcontractor. Specific for customer ASML NL PC outsourced 17,936 processes in 2015, and PS outsourced 490 processes specific for customer ASML NL (KMWE, 2016e)(indicated by arc 3 in Figure 3.1). For all the subcontractors the distance travelled, is two times the actual distance.

After that the production process continuous, then the products are shipped to ASML NL or to PS. PC delivered 9,679 products specific for ASML NL at PS (indicated by arc 1 in Figure 3.1), during 213 days (indicated by arc 1 in Figure 3.2) in 336 shipments (Appendix F)(KMWE, 2016e).

PC delivered 3,401 products to ASML NL during 2015. PS delivered 5,277 products to ASML NL during 2015 (indicated by arc 4 in Figure 3.1) (KMWE, 2016a). PC delivered the products during 130 days in 2015 to ASML NL. PS delivered the products during 247 days in 2015 to ASML (indicated by arc 4 in Figure 3.2) (KMWE, 2016a).

### Supplier and Subcontractor Selection

We made a selection of the most important suppliers and subcontractors. For this purpose four different sets are identified. Suppliers of PC that deliver 80% of the material to the company are selected in the most important supplier list of PC. The subcontractors of PC that perform 80% of the outside processes to the company are selected in the most important subcontractor list of PS. The same procedure is used to find the most important suppliers and subcontractors of PS.
CHAPTER 3. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON TRANSPORTATION COSTS

Suppliers

Subcontractors

KMWE

Precision Components

ASML

Netherlands

250 days

254 days

213 days

130 days

247 days

1

2

2

3

3

4

Suppliers

Subcontractors

KMWE

Precision Components

KMWE

Precision Systems

ASML

Netherlands

250 days

254 days

213 days

130 days

247 days

1

2

2

3

3

4

Figure 3.2: Visualization of the supply chain of KMWE for customer ASML NL. The number of shipment days is indicated for 2015 (KMWE, 2016a and KMWE, 2016e).

Several suppliers are both in the 80% material list of PC as in the list of PS. The lists are added in Appendix C.

Only one of the suppliers is located abroad. This company is not considered in the analysis. The selection consists of 26 suppliers and 11 subcontractor.

Modes of Transport

In the supply chain of KMWE, several types of vehicles are used for the shipments from suppliers, to and from subcontractors, between the KMWE companies, and to customers. The four types of vehicles used are mini van, van, tail-lift truck, and curtain side truck.

The transport modes have different capacities and costs. During two weeks in May 2015, it is counted which vehicles are loaded and unloaded. According to the material handling department, the numbers obtained represent the current situation during 2015. The percentages and the capacities are added to Table D.1 (Appendix D) (KMWE, 2016m). It is clear that the van is the vehicle that is used most often. The van has a capacity of 5 EURO-pallet (Logistics, 2016).

Payment methods

In this section the different procedures of payments for shipments are considered. First we consider the delivery agreements made with the other members of the supply chain. After that we consider the contract types. KMWE made different agreements with several third party logistics providers, who perform the shipments.

The three major delivery agreements are “Delivery at Place” (DAP), “Delivery Duty Paid” (DDP), and “Ex Works” (EXW). For approximately 85% of the purchased supply of KMWE the agreement DAP/DDP is used (KMWE, 2016l). Here the agreement is made that the seller (supplier or subcontractor) delivers the goods to the buyer (KMWE). However, for 15% of the cases, the agreement EXW is made. In this agreement the seller (supplier or subcontractor) is required to make the goods ready for pickup at their own place of business (KMWE, 2016l). In other words, by the contract type DAP/DDP it is not immediately clear which part of the selling price is caused by the transport. The assumption is made that the costs for transport is not significantly different between the two contract types, the transport costs are similar, but only invoiced in a different way.

Most (over 90%) of the transport is performed by logistic providers (KMWE, 2016f). Currently KMWE has four different contracts with the logistic providers, which are pay per run, pay per hour, pay per weight, and pay per loading meter.

This number is not specific for the supply of customer ASML NL, no distinction is made between the customers in this data.
CHAPTER 3. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON TRANSPORTATION COSTS

Table 3.1: The parameter values for (3.1) for the transport between KMWE and suppliers and subcontractors pay per run.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Parameter Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_\beta$</td>
<td>Fixed fee per run</td>
<td>Appendix E</td>
</tr>
<tr>
<td>$F_{x,y}$</td>
<td>Frequency of shipments</td>
<td>$89 \times 2 = 178$</td>
</tr>
</tbody>
</table>

The contract type pay per hour is used for the transport between PC and PS. For the selected suppliers and subcontractors we consider the payment per run method, the payment per hour method, and the payment per weight method (Appendix H). The contract type pay per loading meter is not used for the selected suppliers and subcontractors.

The transportation of goods is coordinated on a day to day basis, in which a lot of fluctuations exist. The demand fluctuates but also packaging and size differences exist. KMWE makes thousands of different product types, with a high variety of packaging methods and sizes. The packaging methods are numerous (but not always product specific), there are different paper boxes, pallets and wooden bins. Unfortunately, the company does not count the amount of different packaging methods. The same is true for the sizes, the products’ sizes made in the company ranges from some centimeters to several meters.

In succession we consider the four contract types. Starting with pay per run and ending with pay per loading meter.

**Pay per Run**

In general, we can say that pay per run is used for the transportation of goods near the facility, within a radius of 60 kilometer from Eindhoven.

Third party logistic (3PL) provider 3PL1 (Appendix E) is used for the transport. The fee for this run is fixed (Appendix E). KMWE makes this run almost every work day.

The transport pay per run is in general de-centrally coordinated. The KMWE companies call a courier on a day to day basis.

**Transport between KMWE and Suppliers/Subcontractors**

This contract type is used for the transport between KMWE and one of the 11 subcontractors, S1.

The total transportation costs paid per run ($T_\beta$) are calculated by (3.1). The parameter and parameter values are given in Table 3.1. The total transportation costs of the selected suppliers and subcontractors are added to Appendix I.

$$ T_\beta = R_\beta \times F_{x,y} $$ (3.1)

**Pay per Hour**

For the transport which is paid per run KMWE uses different third party logistic (3PL) providers; 3PL2 and 3PL3. The fee per hour is fixed (Appendix E). In general, we can say that pay per hour method is used for the transportation of goods near the facility.

Similar as the payment method per run the transportation of the goods is coordinated on a day to day basis, in a de-centrally coordinated manner.

**Transport between PC and PS**

All the transport between PC and PS is paid per hour. This transport is done by 3PL2. The shipments are performed by using a van, that is owned by 3PL2.

The total amount paid for transport between PC and PS in the current situation ($T_\beta$) is given in (3.2). The parameter and parameter values are given in Table 3.2. The $T_\beta$ is given in Appendix E.

$$ T_\beta = \left( \frac{2 \times D_{x,y}}{K_\beta} + U_\beta \right) \times F_{x,y} \times S_\beta $$ (3.2)

16 Modeling and Analysis of Supply Chain Centralization at KMWE
Table 3.2: The parameter values for (3.2) for the transport between PC and PS.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description Parameter</th>
<th>Parameter Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{x,y}$</td>
<td>Distance between $x$ is PC and $y$ is PS</td>
<td>0.3 kilometer</td>
</tr>
<tr>
<td>$K_β$</td>
<td>Average speed</td>
<td>Assumed to be 10km/h</td>
</tr>
<tr>
<td>$U_β$</td>
<td>Average (un)loading time</td>
<td>$\frac{1}{2}$ hour (KMWE, 2016m)</td>
</tr>
<tr>
<td>$F_{x,y}$</td>
<td>Frequency of shipments between $x$ is PC and $y$ is PS</td>
<td>336</td>
</tr>
<tr>
<td>$S_β$</td>
<td>Fixed fee per hour</td>
<td>Appendix E</td>
</tr>
</tbody>
</table>

Table 3.3: The parameter values for (3.2) for the transport between KMWE and suppliers and subcontractors.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description Parameter</th>
<th>Parameter Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{x,y}$</td>
<td>Distance between $x$ is KMWE and $y$ is a supplier or subcontractor</td>
<td>Dependent on the supplier or subcontractor location (Appendix H)</td>
</tr>
<tr>
<td>$K_β$</td>
<td>Average speed</td>
<td>Assumed to be 70 km/h</td>
</tr>
<tr>
<td>$U_β$</td>
<td>Average (un)loading time</td>
<td>$\frac{1}{2}$ hour (KMWE, 2016m)</td>
</tr>
<tr>
<td>$F_{x,y}$</td>
<td>Frequency of shipments between $x$ is KMWE and $y$ is a supplier or subcontractor</td>
<td>Dependent on demand per supplier or subcontractor (Appendix H)</td>
</tr>
<tr>
<td>$S_β$</td>
<td>Fixed fee per hour</td>
<td>Appendix E</td>
</tr>
</tbody>
</table>

Transport between KMWE and Suppliers/Subcontractors

This contract is often used during 2015, 26 times of the 37 selected suppliers and subcontractors. The total transportation costs paid per hour ($T_β$) is calculated by (3.2). The total transportation costs of the selected suppliers and subcontractors is added to Appendix I. The parameter values are added in Table 3.3.

Pay per Weight

In general, we can say that pay per weight is used for the transportation of goods further away from the facility, within a radius of 200 km from Eindhoven. The 3LP used for this transport are 3PL4 and 3PL5 (Appendix E).

While KMWE produces thousands of different products, the differences in weight are numerous. This results in high variety of fees for the transport (Nederland, 2015) (Appendix E). This fee is not dependent on the kilometer travelled (Appendix E).

Transport between KMWE and suppliers/subcontractors

This payment method is used for 10 of the 37 selected suppliers and subcontractors. Currently, the company has no data about the weight or volume of the supply. In this section we consider an EURO-pallet sized parcel. The dimensions of the EURO-pallet are 1.2 meter by 0.8 meter (123pallets.nl, 2014) and it is assumed that the height is 0.8 meter. The national transportation fee of logistics providers is the maximum of the real total weight or volume weight. Because the real weight is not tracked in the company, we take the volume weight. A shipment within the Netherlands has a volume factor of 300. The volume weight is calculated by multiplying the dimensions by the volume factor ($(1.2 \times 0.8 \times 1.2) \times 300 = 245.6$). The transportation fee for a parcel with volume weight 245.60 is a fixed amount (Appendix E) (Nederland, 2015).

The total transportation costs ($T_β$) for the contracts pay per weight can be calculated by using (3.3). The parameter and parameter values are given in Table 3.4. The total transportation costs to/from the selected suppliers and subcontractors in this method is added to Appendix I.
CHAPTER 3. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON TRANSPORTATION COSTS

Table 3.4: The parameter values for (3.2) for the transport between KMWE and suppliers and subcontractors.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description Parameter</th>
<th>Parameter Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{x,y}$</td>
<td>Pallets transported</td>
<td>Dependent on the demand at suppliers and subcontractors (Appendix H)</td>
</tr>
<tr>
<td>$W_\beta$</td>
<td>Fixed fee per pallet</td>
<td>Appendix E</td>
</tr>
</tbody>
</table>

$$T_\beta = P_{x,y} \times W_\beta$$ (3.3)

Pay per Loading Meter

The last transportation contract is made for the transport of goods further away as the third option, for example to Spain, Turkey, or England. There are different fees for the import and the export, and differences per country (Appendix E). The selected suppliers and subcontractors are located in the Netherlands, therefore no more detailed calculation is performed in this section.

Products per Pallet

Currently, the company keeps track of their company-wide transportation costs only, there is no distinction between products, suppliers, subcontractors, customers. To perform better analysis in the future, it could be useful to track the data more specific. To perform further calculations, we made an assumptions for the average number of products per pallet.

The suppliers and subcontractors deliver a lot of different products, and those products have different sizes. This means that sometimes only one product fits in a pallet, and sometimes there fit 500 products. In this section it is assumed that the products from one supplier or subcontractor are similar sized, then data is used to make several categories in number of products per pallet.

The entire list of 80% suppliers and subcontractors is considered (Appendix C), for each payment method there is another method for deriving the number of pallets. Subsequently, we consider the three payment methods.

The number of pallets and number of products per pallets are added in Appendix H. By using that table we can create Figure 3.3, in which the number of products per pallet are clustered into six different categories. Ranging from several products per pallet (category 1) to a lot of products per pallet (category 6). For each transport contract another procedure is used to derive the number of products per pallet.

Payment per run

To derive the average number of products in the van we divide the total demand (for S1) by the total frequency. This is the average number of products per shipment ($\frac{422}{86} = 16$). So, on average there are 16 products in the van, and the capacity of a van is 5 pallets. This means that a pallet consists on average 4 products.

Payment per hour

The total number of pallets is calculated by multiplying the frequency of shipments by the capacity of a van. Here, the assumption is made that the van is 100% loaded. The number of products per pallet are calculated by dividing the total demand with the total number of pallets.

Payment per weight

The number of parcels delivered are equal to the number of pallet transported. If we divide the demand by the number of pallets, we get the number of products per pallet.

3.1.2 Transportation Costs Current Situation between PC and PS

The above mentioned is summarized in this section. For the transport between PC and PS the company uses the pay per hour method. The formula used to calculate the total transportation
costs in 2015 is (3.2) (Appendix E).

From the total transportation costs we derived the costs per shipment and the costs per pallet (Appendix E).

In the total transportation costs the costs associated with the administration process and the material handling are not included.

### 3.1.3 Transportation Costs Current Situation between KMWE and Suppliers

The above mentioned is summarized in this section. For the transport between suppliers/subcontractors and KMWE, the company uses the pay per run, hour, and weight method.

The current transportation costs for a specific supplier or subcontractor is calculated by using (3.4)

\[ T_{\beta} = Z_A * (R_{\beta} * F_{x,y}) + Z_B * ((2 * D_{x,y}) / K_{\beta} + U_{\beta}) * F_{x,y} * S_{\beta} + Z_C * (P_{x,y} * W_{\beta}) \]  

(3.4)

In Appendix D the meanings of the variables are defined. For each payment method another formula is used to calculate the total transportation costs. The total transportation costs of all suppliers and subcontractors is given in Appendix E.

### 3.2 Analytical Research Transportation

In this section the proposed transportation practices on the BIC are described. Currently, the issues related to the logistics in the BIC are not determined yet. Therefore, estimations are made in this section. The current situation will serve as a benchmark of the BIC situation.

This section consists of a description of the BIC situation. Furthermore, the transportation costs in the BIC are calculated by using several assumptions. This is done for the two situations; PC and PS on the BIC, and KMWE and the selected suppliers and subcontractors on the BIC.
CHAPTER 3. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON TRANSPORTATION COSTS

Figure 3.4: Visualization of the transport situation in BIC. The shipments done by transportation mode AGVs are highlighted with green rectangles. The shipments done by one of the four other transportation modes are illustrated with the red rectangles.

3.2.1 Description BIC Situation Transportation

In this section a description is given of the transportation in the BIC situation. In this section we made clear what the differences are between the BIC situation and the current situation.

In the BIC situation the entire KMWE NL Group will be situated in the same facility, in cluster one on the BIC. Moreover, in the BIC situation several suppliers or subcontractors are able to move to the same location. On top of that, it is possible that other companies, not part of the KMWE supply chain, move to the BIC. This will effect different factors considering transport; such as the decrease in travelling distance, enhancement transportation mode by an automated guided vehicle (AGV) (Appendix G), and the transportation frequency will increase.

The BIC situation is similar to the current situation for the suppliers that do not move to the BIC. The companies still use one of the four transportation modes (Section 3.1.1). However, the transportation distance is adjusted, KMWE’s plant is not longer situated at Croy, but at the new location. Moreover, it is possible that shipment frequencies will change if BIC suppliers and KMWE order together from non BIC suppliers.

In the BIC situation AGVs will be used for transportation from a supplier or subcontractor located on the BIC to the central warehouse and after that to KMWE. Moreover, the AGVs can be used to perform internal transports. The internal shipments are out of scope.

Furthermore, transport to ASML NL is in the BIC situation the same as in the current situation. The transportation is done by one of the four transportation modes (Section 3.1.1). However, the transportation distance is adjusted. Moreover, shipment frequencies could be changed if BIC companies and KMWE deliver together to the same customer. The BIC situation is visualised in Figure 3.4.
CHAPTER 3. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON TRANSPORTATION COSTS

3.2.2 Transportation Costs BIC Situation between PC and PS

In this section potential reductions of the transport costs are identified if PC and PS are both located on the BIC.

The transportation cost ($T_\alpha$) in the BIC situation is calculated by multiplying the pallets transported between company $x$ and $y$ ($P_{x,y}$) by the transportation cost per kilometer on the BIC ($S_\alpha$) by the distance travelled on the BIC ($D_\alpha$). In this case company $x$ is PC and PS is company $y$ (3.5).

$$T_\alpha = P_{x,y} \cdot S_\alpha \cdot D_\alpha$$ (3.5)

In this section the costs for shipment of ASML NL products from PC to PS is calculated. First we consider the distance of transport on the BIC, $D_\alpha$, after that the transportation costs per kilometer, $S_\alpha$.

Distance of Transport on BIC between PC and PS

The BIC will consist of five clusters in the future (Figure 1.4). The BIC will cover 200 hectares, of which 65 hectares are reserved for the companies. Currently, there are ideas to establish a central warehouse in the middle of the BIC. KMWE will cover 22,000m$^2$ of the first cluster.

Currently, there is time between the purchasing of supply at PC and the assembling at PS. It is assumed that this policy will not change in the BIC situation. Therefore, after production in PC products will be transported to the central warehouse and then transported back if PS is ready for further processing. It could be possible that KMWE decides to use an inventory hub at their site on the BIC, this will effect the distance travelled ($D_\alpha$). For now we took the distance between KMWE and the central warehouse, because this is the highest of the two.

By using a model of the BIC, we conclude that the distance between cluster one and the middle of the BIC is 1.15 kilometer. So, the two-way movement is 2.3 kilometer ($2 \times 1.15$) (Figure 3.5).

Estimation of Transportation Cost BIC between PC and PS

Currently, the contract policy and payment method is unclear, however, the pay per use policy is often mentioned and discussed. Accordingly, in this section we made some estimations of this policy.

The estimates are based on two methods:

1. The new costs paid for transportation must not exceed the current total transportation costs. We call this the pay per use policy based on the current costs.

2. The costs of an AGV system. We call this the pay per use policy based on the costs of an AGV system.
CHAPTER 3. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON TRANSPORTATION COSTS

Based on the Current Costs

The new costs paid for transportation can not exceed the current total transportation costs. This means that the estimated number in this section is an upper limit of the pay per use based on the current costs. The company should not pay more than this amount per movement.

To calculate the upper bound based on the current costs (3.6) is developed.

\[
\text{Current costs} \geq \text{BIC costs} \rightarrow \left( \frac{2 \cdot D_{x,y} \cdot U_\beta}{K_\beta} \right) \cdot F_{x,y} \cdot S_\beta \geq P_{x,y} \cdot S_\alpha \cdot D_\alpha
\]  
(3.6)

The left part of the equation calculates the current costs, while the left part calculates the BIC costs. In Appendix D the meaning of the variables are defined.

In the situation where PC is the supplier of PS the following parameters are obtained (Appendix E).

The current costs for the shipments of the products from PC to PS for customer ASML NL, during 2015 are calculated by using (3.2) (Section 3.1.1 and Appendix I).

\[
T_\beta \geq P_{x,y} \cdot S_\alpha \cdot D_\alpha
\]  
(3.7)

\[
S_\alpha \leq 0.89 \text{ per pallet per kilometer}
\]  
(3.8)

In equation (3.7) the upper bound of the fee per pallet per kilometer in the BIC situation is calculated, based on the requirement that the BIC transport costs are lower than the current transport costs. \( S_\alpha \leq 0.89 \) for the AGV transport between PC and PS.

Based on Costs AGV system

After calculating the costs per driving kilometer on the BIC based on the AGV system costs, it became clear that it is not significant to dedicate an AGV for shipments between PC and PS, for ASML NL products. This is concluded because of the fact that the utilization of the AGV will be below an acceptable level (Approximately 6\%, \( \frac{1,613}{26,280} \)). Therefore, in this section the costs per driving kilometer based on the more broader scope is used in this calculation. The calculation is done in Section 3.2.3.

The total costs in the BIC situation can be calculated by using (3.5) both the costs based on the current costs and the costs based on the AGV system are calculated (Appendix E).

The \( S_\alpha \) of the pay per use based on the current costs is \( S_\alpha \leq 0.89 \). The \( S_\alpha \) of the pay per use based on the current costs is \( S_\alpha = 1.38 \).

3.2.3 Transportation Costs BIC Situation between KMWE and Suppliers

In this section the transportation costs on the BIC are calculated for the transport between KMWE and the selected suppliers and subcontractors. The same structure as Section 3.2.2 is used.

Distance Transport on BIC from KMWE to Suppliers

In this section it is discussed how the distance of transport on BIC is calculated.

The same information as Section 3.2.2 is used for the calculation of the distance between KMWE and a supplier or subcontractor on the BIC. For this calculation two distance are used:

1. The distance from KMWE to central warehouse on the BIC (same as Section 3.2.2).

2. The distance from the central warehouse to a point selected uniformly over the area of the BIC (the location of the supplier/subcontractor).
Figure 3.6: The distance between KMWE and the central warehouse is 1.15 kilometer, the distance between the central warehouse and a uniform distributed point on the BIC is 0.88 kilometer.

The first distance is already calculated in Section 3.2.2. The distance from KMWE to the central warehouse located in the centre of the BIC is 1.15 kilometer.

The distance from the central warehouse to a point selected uniformly over the area of the BIC is calculated by using the L1, the Manhattan Metric$^2$. As said before the BIC will cover 200 hectares this is 2,000,000m$^2$. We take $A = 2,815m$ and $B = 710m$. This results in 881 meter as the average distance from the central warehouse to a point selected uniformly over the area of the BIC according to the Manhattan Metric.

So, the total distance between KMWE and a selected supplier or subcontractor on the BIC, via the central warehouse is approximately 2 kilometer (1.15 + 0.88) (Figure 3.6). The two-way movement (KMWE-supplier/subcontractor-KMWE) is 4 kilometer.

**Transportation Cost AGV from KMWE to Suppliers**

Similar to Section 3.2.2 we estimate some factors for the pay per use policy. The estimations are based on two methods. First we consider the costs based on the current costs, after that the costs based on the AGV system.

**Based on the Current Costs**

The new costs paid for transportation must not exceed the current total transportation costs. This means that the estimated number in this section is an upper limit of the pay per use based on current costs. The company should not pay more than this amount per transport.

To calculate the upper bound per supplier or subcontractor (3.9) is worked out.

$$Z_A \ast (R_\beta \ast F_{x,y}) + Z_B \ast ((\frac{2 \ast D_{x,y}}{K_\beta} + U_\beta) \ast F_{x,y} \ast S_\beta) + Z_C \ast (W_\beta \ast P_{x,y}) \geq P_{x,y} \ast S_\alpha \ast D_\alpha \tag{3.9}$$

In Appendix D the variables are defined. The left part of the equation calculates the transportation costs in the current situation while the right part calculates the transportation costs in the BIC situation.

$S_\alpha$, the fee paid per pallet per kilometer on the BIC, are different for each supplier (Appendix L). This is true because of the fact that the current costs for the transport are different per supplier. The fee $S_\alpha$ is calculated by dividing the total current costs by the number of pallet transported multiplied by the distance travelled on the BIC. Because the total current costs are different for each supplier the $S_\alpha$ is different for each supplier. However, this is not preferable in real life. The BIC management or KMWE should charge a fixed amount per kilometer for each supplier.

On average the upper bound of the fee $S_\alpha$ is €6.16 per pallet per kilometer on the BIC. When we consider only the cost paid per run the upper bound of the fee $S_\alpha$ is €7.50, while the upper bound of the fee paid per hour is €1.91. If we consider the payment per pallet, the upper bound of the fee is much higher, €17.06 (Appendix E).

---

$^2$Given a rectangle with side lengths $A$ and $B$ the average L1 distance from the center of the rectangle to a point selected uniformly over the area of the rectangle is $(A + B)/4$. 

Modeling and Analysis of Supply Chain Centralization at KMWE 23
CHAPTER 3. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON TRANSPORTATION COSTS

Based on Costs AGV system

For the calculation of the costs of an AGV system different assumptions are made. In the future specialized companies will provide KMWE more accurate costs for transport on the BIC. However, given the linear relationship in (3.5) the order in magnitudes of the total costs in the BIC is fixed, if the costs per movement changes (given that the total pallets transported and the distance between KMWE and the suppliers are constant).

In this section we highlight the relationship between the price per movement and the payback time. First we find the relation between the total costs per AGV system and the cost per period. The cost per period time \( C_p \) multiplied by the payback period \( P \) is equal to the cost per AGV system \( C_{tot} \) (3.10).

\[
C_{tot} = P \cdot C_p
\]  

The cost of an AGV system consists of a cost component related to the software and the implementation, and a component that is related with the hardware costs of an AGV system. The total costs of an AGV can be estimated as follows, based on conversations with AGV specialists:

\[
C_{tot} = €125,000 + €50,000 \cdot x
\]  

In which €125,000 is the costs component related to the software and the implementation of the AGV system. The price of one AGV is €50,000, so this is depended on \( x \), the number of AGVs in the system. The cost per period is calculated by using (3.12).

\[
C_p = K_m \cdot N_p
\]  

In which \( K_m \) is the price per movement, and \( N_p \) is the number of movements per period. The number of movements per period \( (N_p) \) is calculated multiplying the maximum number of movement in a period \( (N_{max,p}) \) by the utilization \( (\rho) \) (3.13).

\[
N_p = N_{max,p} \cdot \rho
\]  

As you can see, the cost per period is depended on the price per movement \( (K_m) \), the maximum of movements during a period \( (N_{max,p}) \), and the utilization \( (\rho) \).

Given that 85% of the pallets are transported between the suppliers and subcontractors and KMWE and 15% of the pallets between PC and PS. The average distance that a pallet has to travel is 3.75 kilometer \( (0.85 \cdot 4 + 0.15 \cdot 2.3) \). We assume, based on the speed of a fork-lift-truck, that the average speed of an AGV is 10km/h (“Aalhyster Forklifts,” 2016). Using the average speed we can calculate the number of movements per hour, which is 3 movements \( (\frac{10}{3.75}) \).

The maximum movements during one year \( (N_{max,p}) \) is 26,280 \( (3 \cdot 24 \cdot 365) \). This is based on the fact that an AGV is operational during 24 hours a day, during the entire year. Based on this, we can calculate the utilization. According to the calculation the AGV capacity is 42% \( (\frac{26,280}{24,000} \cdot 100\%) \). If it is possible for the AGV to work 42% of the time, one AGV for the transport between PC and PS and between KMWE and all suppliers and subcontractors for the ASML NL products is suitable. We assume that an utilization of 42% is achievable, and therefore we assume that one AGV for the transport in the scope is enough.

Then, the total cost for the AGV system is €175,000 according to (3.11). By using the utilization \( (\rho) \) of 42%, the maximum movements during a period \( (N_{max,p}) \) of 26,280, and the total movements during a period \( (N_p) \) is 11,012. We found the following relationship between the price per movement \( (K_m) \), and the payback period \( (P) \) (Figure 3.7). The total AGV system costs are divided by the number of payback years. This result is divided by the number of movements to get a price per movement. In Figure 3.7 you can see that the price per movement decreases if the total AGV system costs are divided over multiple years.
CHAPTER 3. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON TRANSPORTATION COSTS

Figure 3.7: The relationship between the price per movement and the payback period. The price per movement creases if the payback period is longer.

Table 3.5: $T_\alpha$ based on the AGV system costs, between KMWE and suppliers and subcontractors.

<table>
<thead>
<tr>
<th>Payback period</th>
<th>5 years</th>
<th>9 years</th>
<th>20 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{x,y}$</td>
<td>9,399</td>
<td>9,399</td>
<td>9,399</td>
</tr>
<tr>
<td>$S_\alpha$</td>
<td>€1.38</td>
<td>€0.77</td>
<td>€0.35</td>
</tr>
<tr>
<td>$D_{alpha}$</td>
<td>4 km</td>
<td>4 km</td>
<td>4 km</td>
</tr>
<tr>
<td>$T_\alpha$</td>
<td>€51,882</td>
<td>€28,949</td>
<td>€13,159</td>
</tr>
</tbody>
</table>

The price per movement is related to the price per kilometer, so a similar graph can be made for the relationship between the price per kilometer and the payback periods. We divide the outcomes of Figure 3.7 by the average distance 3.75 kilometer.

For further calculations we assume that a payback period of 5 years, 9 years or 20 years will be used. The price per kilometer, based on 5 years payback period is €1.38. The prices per kilometer, based on 9 years payback period is €0.77, for 20 years this is €0.35.

The value of $S_\alpha$ will not effect the relative order between the suppliers. An example is if the $S_\alpha$ in (3.5) increases by 50%, the $T_\alpha$ of all suppliers increase by 50%, therefore, the relative relation between the suppliers based on there $T_\alpha$ will not change if $S_\alpha$ changes.

3.3 Comparison Current Situation and BIC Situation

In this section we made the comparison between the transportation costs in the current situation and the BIC situation. First, we only consider KMWE on the BIC, after that we consider the situation where selected suppliers and subcontractors are located on the BIC as well.

3.3.1 Considering KMWE

The total transportation costs in the current situation $T_\beta$ is compared with the total transportation costs in the BIC situation $T_\alpha$ (Appendix E).

The relation between the transportation costs in the current situation between PC and PS and in the BIC situation is dependent on the pay per use method that is used. Moreover if the pay per use method based on the AGV costs is used the relation is dependent on the payback period. If the payback period of 5 years is used, the total transportation costs between PC and PS are higher in the BIC situation. However, if a payback period of 9 or 20 years is used, the total transportation costs in the BIC situation are lower compared to the current situation (Figure 3.8).

If the $S_\alpha$ is based on the current costs, there is no difference between the current costs and the upper bound. The total transportation costs are 55% higher in the BIC situation compared to the
current situation if a payback period of 5 years is used, this is a difference of €4,540\(^3\). However, when the payback period of 9 years is used, the company saves 14% of the total transportation costs between PC and PS, which is a difference of €1,118\(^3\) per year compared to the current situation. If a payback period of 20 years is used the total transportation costs per year between PC and PS are 61% lower in the BIC situation, which is a difference of €5,015\(^3\) compared to the current situation.

### 3.3.2 Considering KMWE and Suppliers

The total transportation costs in the current situation \(T_{β}\) is compared with the total transportation costs in the BIC situation \(T_{α}\) (Appendix E). In Figure 3.9 it is clear that the transportation costs in the current situation are high compared to the BIC situation. The upper bound of the costs method based on the current costs is equal to the transportation costs in the current situation. If a payback period of 5 years is used the BIC costs are €129,705\(^4\) per year, this is a decrease of 57%. Considering a payback period of 9 years the BIC costs are €72,372\(^4\) per year, which is a decrease of 76%, and 20 years €32,898\(^4\) per year, a decrease of 89%.

After analysis of Figure 3.9 and Figure D.3 (Appendix D) it became clear that in general the total transportation costs in the BIC, based on the AGV system are lower than the current transportation costs. However, there are some exceptions, if the transportation costs is based on a payback period of 5 or 9 years. In all cases the transportation costs in the BIC with 20 years payback period will result in a reduction in costs (Figure D.3, Appendix D).

The exceptions have in common that the distance travelled is less than 30 kilometer, and the payment method is pay per hour. This could be the case because the payment method per hour is not appropriate for short distances. Nevertheless, there could be other advantages of moving a company which is located near the KMWE plant. For example advantages because of inventory or forecast sharing or lead time reductions, which results in more savings or earnings.

---

\(^3\)This number is masked, see Appendix E.  
\(^4\)This number is masked, see Appendix E.
CHAPTER 3. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON TRANSPORTATION COSTS

3.4 Transportation Costs Model

In this section we describe a model that is developed to get insight in the effects of the transportation costs if certain suppliers and/or subcontractors of the selected suppliers/subcontractors are present on the BIC.

It is assumed that companies that are currently in the 80% supply lists are willing to move to the new location. Companies that are not in that lists deliver too little supply to KMWE. The companies which deliver little supply are typically the companies in which not much transportation costs is involved. Moreover, moving to the Netherlands for companies abroad seems to be a difficult operation.

In this section the formulas developed in (3.4) and (3.5) are used to develop the mathematical model that determine the best set of suppliers in the BIC, by minimizing the total transportation costs. This model can be used to get insight in the effects of the transportation costs if certain suppliers and/or subcontractors are also present on the BIC. In (3.14) the objective function is added. The restrictions of the model are included in (3.15) and (3.16). Restriction (3.15) makes sure that a supplier or subcontractor is selected for either the current location or the BIC location. Restriction (3.16) makes sure that the number of selected suppliers and subcontractors on the BIC does not exceed the maximum number of companies on the BIC (I).

\[
\begin{align*}
\text{Min} & \sum_{x=1}^{2} \sum_{y=1}^{N} (y_{\alpha} \ast (P_{x,y} \ast S_{\alpha} \ast D_{\alpha}) + y_{\beta} \ast (Z_{A} \ast (R_{\beta} \ast F_{x,y}) + Z_{D} \ast (F_{x,y} \ast S_{\beta} \ast (2 \ast \frac{D_{x,y}}{K_{\beta}} + U_{\beta}) + Z_{C} \ast (T_{\beta} \ast P_{x,y}))) \\
\text{Subject to} & \\
|y_{\alpha} - y_{\beta}| & = 1 \quad (3.15) \\
\sum_{x=1}^{N} y_{\alpha} & \leq I \quad (3.16)
\end{align*}
\]

Figure 3.9: The differences between the current transportation costs and the BIC transportation costs, for the four different scenario’s per supplier/subcontractor.
CHAPTER 3. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON TRANSPORTATION COSTS

This model is developed under the assumption that the transportation capacity is not limited. In the model the current costs of $S_\alpha$ is used, based on either the current costs or the AGV system costs. The $S_\alpha$ based on the AGV costs is calculated for the case were all selected suppliers and subcontractors are on the BIC (Section 3.2.3). Therefore, the $S_\alpha$ will not change if more suppliers or subcontractors are selected to the BIC.

3.4.1 Conclusions Transportation Costs Model

In this section we draw conclusions regarding to the transportation costs model. The minimization function (3.14) is solver by using Excel Solver.

As you can see in Figure 3.10, the transportation costs is decreasing if a higher amount of suppliers or subcontractors are selected for the BIC.

As a conclusion we can state: the higher the number of suppliers selected for the BIC, the lower the total transportation costs. However, there seems to be a certain maximum, for example the transportation costs based on 5 years payback period get stable around 14 selected suppliers or subcontractors. This is a reduction of approximately 50% compared to the current transportation costs (Figure 3.11).

In Appendix K you can find the results of the solutions of the solver. We added the total transportation costs of the selected suppliers and subcontractors, and the names of the suppliers and subcontractors that are selected. This is added for two cases of $S_\alpha$.

Summarizing, the following suppliers or subcontractors are often selected after analysing the results of the solver: S1, S2, S3, S12, S14, S15, and S16.

The companies S2 and S3 are companies that are classified as category 6 companies (Section 3.1.1). The supply of those companies has different characteristics as the other companies. S1, S12, S14, S15, and S16 are classified as category 1 companies (Section 3.1.1).

S2 and S3 are companies that deliver fasteners and tools to KMWE. Which means that the suppliers both deliver the company small, and numerous items. S1, S15 and S16 are subcontractors that do coating of products for KMWE. The company S12 delivers aluminium cast plate to KMWE, the supply is similar as S14.
3.5 Sensitivity Analysis

In the sensitivity analysis we determine how different values of an independent variable will impact a particular variable. We consider the transportation costs in the current situation and in the BIC situation.

3.5.1 Current Situation

For the transportation costs between PC and PS it is possible to derive one generic formula. However for the transport between KMWE and the suppliers and subcontractors this is not possible. This is true because the values of the suppliers all have different values, therefore we only written down the generic effect of the variables on the transportation costs.

We tested the transportation between PC and PS in the current situation, for which we used a certain number for the independent variables (Appendix E). In Figure 3.12 the current numbers are changed according to the percentage of the current numbers (Appendix E). The distance travelled has the least impact on $T_\beta$. Moreover, the function is effected in a negative way by the average speed. The factors with the highest impact are the transportation fee, the (un)loading time, and the frequency. This is summarized in Table 3.6

3.5.2 BIC situation

For the transportation costs between PC and PS it is possible to derive one generic formula. However for the transport between KMWE and the suppliers and subcontractors this is not possible. This is true because the values of the suppliers all have different values, therefore we only written down the generic effect of the variables on the transportation costs. As you can see the change in the transport fee has the major impact on the $T_\alpha$. The distance travelled is effecting the (3.5) the second most. The pallets transported have the least impact on the $T_\alpha$. The number of pallets and the distance travelled have a bigger impact on $T_\alpha$ if $S_\alpha$ is based on the AGV costs. This is summarized in Table 3.7
CHAPTER 3. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON TRANSPORTATION COSTS

Figure 3.12: The effect on $T_\beta$ by changing the values a certain percentage of the original values, considering the current situation and transport between PC and PS.

Table 3.6: The effects of variables on the current transportation costs ((3.2) and (3.9)).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Generic Effect</th>
<th>Formula transport between PC and PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency ($F_{x,y}$)</td>
<td>the higher the frequency of transport, the higher the transport costs</td>
<td>$T_\beta = 9.83 \times F_{x,y}$</td>
</tr>
<tr>
<td>Transportation fee ($S_\beta$)</td>
<td>the higher the fee per hour, the higher the transportation costs</td>
<td>$T_\beta = 132.16 \times S_\beta$</td>
</tr>
<tr>
<td>Distance ($D_{x,y}$)</td>
<td>the higher the distance between the two companies, the higher the transport costs</td>
<td>$T_\beta = 8400 \times (\frac{2+D_{x,y}}{10} + \frac{1}{3}) = 1680 \times D_{x,y} + 2800$</td>
</tr>
<tr>
<td>Average speed ($K_\beta$)</td>
<td>the higher the average speed while driving between the two companies, the lower the transportation costs</td>
<td>$T_\beta = 8400 \times (\frac{3D}{K_\beta} + \frac{1}{4}) = \frac{25200D}{K_\beta} + 2800$</td>
</tr>
<tr>
<td>(Un)loading time ($U_\beta$)</td>
<td>the higher the (un)loading time of the transport, the higher the transportation costs</td>
<td>$T_\beta = 504 + 8400 \times U_\beta$</td>
</tr>
</tbody>
</table>
Table 3.7: The effects of variables on the BIC transportation costs (3.5).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Generic Effect</th>
<th>Formula transport between PC and PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pallets transported ($P_{x,y}$)</td>
<td>the higher the number of pallets transported, the higher the transportation costs</td>
<td>Based on current costs: $T_{a} = 2.047 \times P_{x,y}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Based on AGV system costs: $T_{a} = 3.174 \times P_{x,y}$</td>
</tr>
<tr>
<td>Transportation fee ($S_{a}$)</td>
<td>the higher the fee paid per pallet per kilometer, the higher the transportation costs</td>
<td>$T_{a} = 3709.9 \times S_{a}$</td>
</tr>
<tr>
<td>Distance travelled ($D_{a}$)</td>
<td>the higher the distance between the two companies, the higher the transportation costs</td>
<td>Based on current costs: $T_{a} = 1435.57 \times D_{alpha}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Based on AGV system costs: $T_{a} = 2225.94 \times D_{alpha}$</td>
</tr>
</tbody>
</table>

3.5.3 Transportation Model

In this section the transportation model of Section 3.4 is considered. The effects of changing variables on the selection of the suppliers and the changes in total costs are considered.

The variables that are changed are: fee per run, fee per hour, fee per weight, average speed, (un)loading time, and distance in the BIC. The other variables (frequency of transport, pallets transported and travelling distance in the current situation) are kept fixed. The Excel Solver is runned based on the two methods: $S_{a}$ based on the current costs, and $S_{a}$ based on the AGV system costs. For the latter the Excel solver is runned for a payback period of 5, 9 and 20 years. For this analysis we selected 5 suppliers and subcontractors. We changed the values by 50% of the current value, so an increase of 50% and a decrease of 50%.

We consider the effect on the selection of suppliers or subcontractors on the BIC and the total transportation costs paid in Appendix J. We found that most of the time the selected suppliers and subcontractors are the same as the original situation. However, the total transportation costs varies.

3.6 Conclusions, Recommendations, and Future Research

In the first part of the research the following research question is answered:

What is the effect on transportation costs if the supply chain is centralized on the BIC (in which the empirical research is serving as a benchmark for the analytical research)?

3.6.1 Conclusions

The current situation is compared with the proposed situation on the BIC. In the current situation the transport is done by a van, while in the BIC transport will be executed by AGVs. First, we compared the current situation with the BIC, regarding the transport between PS and PS. After that we considered the transport from suppliers and subcontractors to KMWE.

In the current situation the transportation costs between PC and PS are low (Appendix E). This is due to good agreements and the short distance of transport.

The distance to be travelled will become higher in the BIC, because of the transport to and from the central warehouse. The frequency of transport will increase as well, because of the change in capacity of the transportation mode.
In the BIC situation the transportation costs are determined by using two methods. The two methods are the current costs method and the costs based of the AGV system. The total transportation costs vary depending on the pay per use method used, and the payback period of the AGV system.

When we chose to use the pay per use method based on the current costs, we calculate the upper bound of transport costs, €0.89 per pallet per kilometer. The company should not pay more than this amount, if the restriction is that the transportation costs may not increase.

When we chose to use the pay per use method based on the AGV system costs, the payback period is important. If the payback period of 5 years is used the total transportation costs between PC and PS are 55% higher in the BIC situation compared to the current situation. This is a difference of €4,540\(^5\). However, when the payback period of 9 years is used, the company saves 14% of the total transportation costs between PC and PS, which is a difference of €1,118\(^5\) compared to the current situation. If the payback period of 20 years is used the total transportation costs between PC and PS are 61% lower in the BIC situation, which is €5,015\(^5\) compared to the current situation. We found that when the payback period is higher, the price per pallet per kilometer is lower. This leads to lower total transportation costs, and therefore higher reduction in costs compared to the current situation.

Considering the transportation costs, the changes are relatively small. Therefore, the effect on transportation costs between PC and PS can not be a primary reason to move to the BIC.

Secondly, we considered the transport between suppliers and subcontractors and KMWE. We compared the current situation with the situation where selected suppliers and subcontractors are located on the BIC. The selected suppliers and subcontractors deliver 80% of the products or outside processes.

The current transportation cost between KMWE and its suppliers and subcontractors in 2015 is added to Appendix E. This is calculated by using the three different payment methods: payment per run, payment per hour, and payment per weight.

The situation where suppliers and subcontractors of KMWE are located on the BIC, reduces the total transportation costs. The upper bound of the costs method based on the current costs is equal to the current costs. With a payback period of 5 years the transport costs on BIC are €169,965 per year\(^6\) lower than in the current situation, this is a decrease of 57% compared to the current costs. Considering a payback period of 9 years the difference between BIC costs and the current costs are €227,298 per year\(^6\), which is a decrease of 76%, and 20 years €266,773 per year\(^6\), a decrease of 89%.

If we consider the suppliers and subcontractors on an individual basis, we found that for most suppliers and subcontractors the current transportation costs exceed the BIC transportation costs. However, there are some exceptions if the payback periods of 5 or 9 years are used. Those suppliers or subcontractors have in common that the payment method pay per hour is used, and they are located near KMWE (less than 30 kilometer). This could be a result of the fact that if the pay per hour method is used, the transportation costs are low for a short distance, because we neglect the minimal duration of hiring a 3PL. Nevertheless, there should be other advantages of moving company that is located near the KMWE plant, for example advantages related to inventory, and lead time reductions.

The effect of supply chain centralization on transportation costs is that the total transportation costs will reduce. Here, different factors have to be taken into account: the possible change in transport frequency and the change in costs per movement if another transport mode is used. For the AGV system the payback period is an important parameter for the costs per movement.

In general we can say: the more suppliers and subcontractors are selected for the BIC, the lower total transportation costs will become.

\(^5\)This number is masked, see Appendix E.
\(^6\)This number is masked, see Appendix E.
3.6.2 Recommendations

The recommendations are made regarding to the BIC management and KMWE.

Regarding to the BIC Management

It is recommended to consider the suppliers that are selected for the BIC by the transportation minimization model, the following companies are mentioned: S1, S2, S3, S12, S14, S15, and S16. However, the suppliers or subcontractors have different characteristics, such as their product portfolio.

For example S2 and S3 deliver fasteners and tools, products that are small and inexpensive. Which results in low inventory holding costs. It could be useful to have an inventory hub of S2 and S3 on the BIC. Other BIC companies will probably use similar tools. This means that not only could KMWE use the inventory hub on the BIC, but it is open for all companies on the BIC. S2 and S3 will be responsible for the stock, but it is not needed to move their entire production process to the BIC. The inventory hub on the BIC will decrease the transport frequencies and/or the amount of products per delivering will increase. It might be possible that the sales of the suppliers increase if other BIC companies that used similar products and now switch to products of S2 and S3.

Subcontractors S1, S15, and S16 perform coating of products for KMWE. We recommend to consider a surface treatment specialist (for example one of the three just mentioned) as a co-occupant on the BIC. This is not only useful for KMWE, but also for the other manufacturing companies. We recommend to offer certain treatment processes as a shared facility on the BIC. It might be possible to perform several general processes on the BIC, and more complicated processes at the current location of surface treatment specialists. By performing the process on the BIC the transport frequencies will decrease. It might be possible that the sales of the surface treatment specialists increase if other BIC companies that used similar surface treatment processes and now switch to the process of the surface treatment specialists on the BIC.

Companies S12 and S14 deliver KMWE aluminium cast plate. The intermediate product aluminium is a widely used product in the manufacturing industry. However, the production of aluminium is not classified as a high mix, low volume, high complexity production environment, while the aim of the BIC is to centralized those companies. Therefore, it is recommended to have a BIC-wide contract with an aluminium plate company. The companies on the BIC can do their purchasing process together, to gain economics of scale. This may cause a reduction in purchasing costs. The frequency of transport will then increase, and it is possible that the amount of products per delivering will increase.

Moreover, to be able to make valid conclusions, the costs of the transportation system in the BIC situation has to be improved. Currently, the transportation costs in the BIC situation are based on the current costs, or the costs of an AGV system. Presently, AGV providers are considering the BIC case to develop the business case. During the time of this thesis, the specialists were not finished yet.

Regarding to KMWE

To facilitate the decision process for the BIC case, some recommendations for KMWE are made. Currently, the transportation costs are only tracked company wide, it could be useful to track the transport costs more specific. It might be possible to track the transportation costs per product, supplier, subcontractor, or customer. This will facilitate the analysis of the transportation costs. If the company tracks the transportation costs, it is easier to select a product, supplier, subcontractor, or customer with high transport costs.

Furthermore, KMWE do not track the product sizes and weight. Therefore some assumptions had to be made concerning this subject (the categories). By tracking the sizes and weight a better analysis can be made.
CHAPTER 3. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON TRANSPORTATION COSTS

3.6.3 Future Research

The first step for future research is considering whether the transportation cost model on the BIC is valid. This will be done by AGV specialists in cooperation with the BIC management. Then, it must be considered if an AGV is the appropriate transport mode in the BIC. The BIC management might consider another, less automated, way of transport.

In the mean time, the BIC management should investigate the possibilities of an inventory hub of commonly used items. Here, the question is which companies might be interested in having an inventory hub on the BIC. For example, the companies S2 and S3 could provide an inventory hub of fasteners and tools. Moreover, companies (such as S1, S15 or S16) might be interested to perform treatment processes on the BIC. For other companies, such as S12 and S14, conversations have to be planned in which the possibilities of a BIC-wide contract are considered. This research is dependent on which other companies might be interested in moving to the BIC.
Chapter 4

Effects of Inventory Pooling and Demand Forecasting

In this chapter we analyse the improvements of the BIC situation compared to the current situation concerning the inventory. In this chapter we use the concepts inventory pooling and demand forecast sharing. In this chapter the following research question is answered:

What are the effects when inventory is pooled and demand forecast is shared, due to centralization of the supply chain on the BIC?

The first part of this chapter describes the current situation concerning the inventory practices (Section 4.1). In this section we make a detailed analysis of the inventory practices between PC and PS (Section 4.1.2), in the next section the suppliers and subcontractors are included as well (Section 4.1.3). In Section 4.2 we consider the inventory situation in the BIC situation. There we make a difference between the advantages of inventory pooling (Section 4.2.2) and the demand information sharing (Section 4.2.3). In Section 4.3 we draw the conclusions, make recommendations, and consider the future research directions.

4.1 Empirical Research Inventory

In this section the current situation concerning the inventory is described.

After that we get into more detail, in Section 4.1.2 we focus on the inventory costs and amount of the companies PC and PS. In Section 4.1.3 we consider the inventory situation, in which we take the suppliers/subcontractors in contract as well.

4.1.1 Analysis of Current On hand Inventory

In this section the current situation related to the inventory is described. This is done by considering the inventory in three different ways: the amount of inventory on hand, the value of the items in inventory and the origin of the items (suppliers).

In the current supply chain, all entities hold inventories to protect themselves from uncertainties in demand of the customer and/or lead time of the suppliers in the supply chain. Demand and lead time uncertainty may arise from demand and lead time variability or incomplete knowledge (Tallon, 1993). Currently, each individual makes decisions on the local information. The current situation is visualised in Figure 4.1. In the figure it is illustrated that the information flow is the reverse of the material flow. In each location there is a stocking location, in which items are stored. PC and PS have their own inventory location, even though the stocking locations are both located at Croy in Eindhoven. The suppliers have there own stocking locations, on

Modeling and Analysis of Supply Chain Centralization at KMWE 35
CHAPTER 4. EFFECTS OF INVENTORY POOLING AND DEMAND FORECASTING

Figure 4.1: The current inventory situation, all entities of the supply chain hold their on inventories to protect themselves from uncertainties. The suppliers, KMWE, and ASML NL are responsible for their own inventory. The dashed lines indicate the information flow, while the solid lines indicate the material flow.

different site in the Netherlands and even abroad. ASML NL has a stocking location at its own site.

KMWE operates in a make-to-order environment, the products are manufactured if the customer places an order. Supply associated with those products are ordered when the demand is observed. This means that the supply is used for one specific product (type). On the other hand there are items that are used in different product types. This supply is ordered according to the base stock policy. If the supply reach a minimum point, it is re-ordered. The base stock level differs per item type.

Furthermore it has to be stated that ASML NL’s order policy is subjected to major fluctuations. The OEM places orders in which the delivery time is flexible. This makes the inventory situation of KMWE more complicated.

First, we consider the amount of inventory on hand (Figure M.1a, Appendix M). During every month of 2015 the inventory is analysed. On average there are 12,210 items in inventory for customer ASML NL in PC per month in 2015 (KMWE, 2016). In PS there are on average 209,401 items in inventory in the same year (KMWE, 2016). This means that approximately 6% of the items in inventory during 2015 for ASML NL are stored at PC, while 94% of the items are stored in inventory of PS.

After that, we consider the value of the inventory (Figure M.1b, Appendix M). Every month during 2015 the inventory value is analysed. On average the value of the items in inventory is €2,520,670 in PC per month in 2015 (KMWE, 2016). In PS the value is on average €4,808,508 for the same year (KMWE, 2016). This means that approximately 34% of the inventory value during 2015 for ASML NL is stored at PC, while 66% of the value is stored in PS. Even though PC has less items in inventory, the value of the items is high.

Finally, a consideration is made of the origin of the items in inventory, the suppliers of the products. A distribution is made by considering the on hand inventory and the value of the products per supplier. If we consider the suppliers of the inventory of PC we found that there are 38 unique suppliers of the items in inventory for specific customer ASML NL. The amount on hand items per supplier ranges from 1 to 3026 items. The total value of the items per supplier ranges from approximately €1 to €9500 in PC. In PC 80% of the items are delivered by 7 suppliers, 80%

\(^1\) Value is masked, see Appendix N
4.1.2 Inventory in Current Situation PC and PS

In this section we describe the inventory practices of PC and PS. We describe the item types and the amount of items.

There are items both available in the inventory in PC and PS. After analysis of the monthly inventory records of 2015, it is found that there are on average 498 items types in inventory of PC. The same analysis is done for the inventory of PS, we found that there are on average 2,218 items types in stock per month during 2015 (KMWE, 2016j). On average there are 140 similar item types in inventory of PC and PS. In other words the shared item inventory portfolio of PC and PS consists of 140 items. This is approximately 5% of the total unique items in inventory in 2015 (Figure 4.2).

As a next step in the analysis we considered how much items are associated with the item types. When we consider the list of equal item types between the two KMWE companies, the conclusion can be drawn that there are 11,038 items in inventory per month that are both part of inventory PC as PS. This can be divided in on average 5,665 items in PC inventory (which is 46.3% of the items in inventory for customer ASML) (Figure M.4a, Appendix M) and on average 5,373 items in PS’ inventory (which is 2.6% of items in inventory for customer ASML) (Figure M.4b, Appendix M). It has to be stated that PS produces a higher amount of products for customer ASML NL (209,401 products) than PC (12,210 products).

The item types that are identified as shared item inventory portfolio are potential item types to reduce their order up to level. As stated before, if the risk is shared in the BIC, is it possible to reduce the inventory on hand which will result in a lower average inventory (Chapter 2). This question is answered in Section 4.2.2.
Figure 4.3: The current inventory situation, with suppliers S2, S3, and S33. Each entity has its own inventory holding point. The dashed lines indicate the information flow, while the solid lines indicate the material flow.

4.1.3 Inventory in Current Situation KMWE and Suppliers

In this section we describe the current inventory practices of KMWE and its suppliers/subcontractors. All the products have their own primary supplier, this is the most preferable supplier for that specific product. The supplier could be preferable because of the price, quality and/or reliability. Currently, it is possible for the KMWE companies to have different primary suppliers for one specific product. For example it is possible that PC orders product A at supplier X and PS orders same product A at supplier Y.

In Section 4.1.1 an analysis is made of major suppliers in inventory. There are several suppliers that are both in the 80% amount and value list of PC and PS. The lists are added in the Appendix P. There are three origins of the supply that are outstanding and are present in two or more lists. Those suppliers are: S2, S3, and S33. S40 is present on two lists as well, but is not associated with a large amount of items that are always available for production. Therefore, this supplier is not added to the list of major origin of the inventory.

Similar to Section 4.1.2 an analysis is made of the unique items in inventory, the amount of items, and the value of the items in inventory. In Figure 4.3 the illustration is made of the situation considered. The products are ordered at PC and PS in an isolated manner. The inventory is kept in inventory of PC and PS. The suppliers have their own inventory, and the customer has its own inventory as well.

In Figure M.5 (Appendix M) the inventory item portfolio of PC and PS for the three suppliers is illustrated. The items are specific for customer ASML NL, analysed for each month of 2015. There are on average 30 unique items per month of supplier S2 in inventory (KMWE, 2016j). While S3 is responsible for on average 428 unique items per month in inventory (KMWE, 2016j). PC and PS have on average 50 unique items per month in inventory with origin S33 (KMWE, 2016j). So, S3’s item portfolio in inventory of KMWE is large compared to the item portfolio of S2 and S3.

In Figure M.6 (Appendix M) the analysis is done for the amount of items in inventory. This figure illustrates the amount of items that are inventory of PC and PS for the three suppliers during each month of 2015 for specific customer ASML NL. There are on average 8,576 items in inventory per month from supplier S2 (KMWE, 2016j). S3 is responsible for on average 58,037 items per month in inventory (KMWE, 2016j). PC and PS have on average 9,388 items in inventory with origin S33 (KMWE, 2016j). So, the amount of items from supplier S3 in inventory of KMWE are high compared to the amount of items from S2 and S33.

In Figure M.7 (Appendix M) the analysis is done for the value of items in inventory. This
CHAPTER 4. EFFECTS OF INVENTORY POOLING AND DEMAND FORECASTING

...figure illustrates the value of items that are in inventory of PC and PS for the three suppliers during each month of 2015 for specific customer ASML NL. The value of the items in inventory from supplier S2 are per month on average €18,215² (KMWE, 2016j). S3 is responsible for on average a value of €89,993² per month in inventory (KMWE, 2016j). PC and PS have on average a value of €7,130² in inventory with origin S33 (KMWE, 2016j). So, the value of the items in inventory from S3 are high compared to the value of the items in inventory of suppliers S2 and S33.

4.2 Analytical Research Inventory

First we introduce the main idea behind the inventory practices in the BIC situation (Section 4.2.1). After that we describe the effects of inventory pooling, which is possible on the BIC (Section 4.2.2). In Section 4.2.3 the effects of demand forecast sharing are considered.

4.2.1 Description BIC Situation Inventory

In this section we describe the BIC situation concerning the inventory.

In the BIC situation, the inventory will be consolidated into fewer centralized locations and information can be shared more easily with other individuals on the BIC through face-to-face meetings and a shared information system. This situation is visualised in Figure 4.4. The dashed lines indicate the information flow, while the solid lines indicate the material flow. As you can see in the Figure 4.4, there are still stocking locations at the suppliers that stay at their current location. Furthermore, ASML NL has its own inventory stocking location.

As you can see in Figure 4.4 inventory is held on one physical central location on the BIC. Furthermore, information is not only shared with one unit upstream, but with the other companies on the BIC. This implies that there must be a BIC wide information sharing system.

4.2.2 Inventory Pooling BIC Situation PC and PS

In this section we discuss the improvement potential of risk pooling between PC and PS on the BIC. First we consider one item, after that the entire shared item portfolio is considered. We investigate the difference between an isolated order decision and a consolidated order decision.

Risk pooling in the area of inventory is applicable if members of the supply chain network hold the same items in inventory. For the items available in inventory, and not ordered specific for the customer, inventory pooling is applicable. It is stated in Chapter 2 that when stock is aggregated, the uncertainty will reduce. This will result in lower safety stock levels, which will cause lower average inventory. So, if some items in inventory of two entities of our supply chain network are equal, risk pooling could be a potential for the reduction of goods in inventory. As stated in Section 4.1.2 PC and PS had a shared item portfolio during 2015, therefore inventory pooling is investigated for the two companies.

Currently, KMWE makes individual ordering decisions, it is considered in this section whether it could be profitable to change this policy in the BIC situation. The two situations are visualized in the Figure 4.5a and Figure 4.5b. In this section we assume no seasonality, which aligns well with the ordering behavior of ASML NL.

Considering One Item

A random item is chosen from the shared item portfolio of PC and PS. The item with item number 07130035 is every month in 2015 available in the inventory of both PC and PS. Every month the KMWE companies use this item for production of ASML NL products. For this item a base stock policy is used. In Table 4.1 the number of items used for production during 2015 are added. The required items for the production of ASML NL ($R_t$) during period $t$ are calculated by using (4.1).
CHAPTER 4. EFFECTS OF INVENTORY POOLING AND DEMAND FORECASTING

Figure 4.4: Illustration of the new inventory situation. The PC, PS and selected suppliers and subcontractors are present on the BIC. The central warehouse is used by all the entities on the BIC. There are suppliers and subcontractors that stay at their current location.

Figure 4.5: Figure 4.5a illustrates the isolated ordering method, while Figure 4.5b illustrates the consolidated ordering method.
Table 4.1: Gross requirements plan for productions ASML products using item 07130035 (KMWE, 2016j and KMWE, 2016e).

<table>
<thead>
<tr>
<th>Month</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>3</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>PS</td>
<td>140</td>
<td>140</td>
<td>148</td>
<td>174</td>
<td>240</td>
<td>282</td>
<td>112</td>
<td>120</td>
<td>213</td>
<td>178</td>
<td>235</td>
</tr>
</tbody>
</table>

Table 4.2: Required items for production at PC, $E(R_{x,t})$, $Var(R_{x,t})$ and (rounded) target inventory level $y_{x,t}$.

<table>
<thead>
<tr>
<th>Month</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{1,t}$</td>
<td>3</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>$E(R_{1,t})$</td>
<td>1.5</td>
<td>2</td>
<td>3.5</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>$Var(R_{1,t})$</td>
<td>2.25</td>
<td>4</td>
<td>0.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.25</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$y_{1,t}$</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

In which $I_t$ is the inventory position of period $t$, $I_{t+1}$ is the inventory position of period $t + 1$, and $p_t$ are the products purchased during period $t$ at the suppliers. The required item for the products, $R_t$, is calculated by using the items demanded and the Bill of Material (BOM).

$$I_{t+1} = I_t + p_t - R_t$$

As stated before, the base stock policy is used for the ordering policy of general items in the two companies. The goal of this ordering policy is to bring the actual inventory towards the desired inventory, the target inventory (Johnson Lynwood A. Douglas C. Montgomery, 1974). The target inventory is calculated by using the following formula.

$$y_{x,t} = E(R_{x,t}) + z \times \sqrt{Var(R_{x,t})}$$

In which $N$ is the number of recent observations used as a forecast for the next period $t$. Because of the change of the required items needed for production the $E(R_{x,t})$ and $Var(D_{x,t})$ change over time.

By using the simple 2-period moving average $MA(2)$ we can calculate $E(R_{1,t})$, $E(R_{2,t})$, $Var(R_{1,t})$ and $Var(R_{2,t})$. This is a simplified version of the real ordering policy at KMWE. The results of this calculation are added to Table 4.2 and 4.3.
Table 4.3: Required items for production at PS, \( E(R_{2,t}) \), \( Var(R_{2,t}) \) and (rounded) target inventory level \( y_{2,t} \).

<table>
<thead>
<tr>
<th>Month</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_{2,t} )</td>
<td>140</td>
<td>140</td>
<td>148</td>
<td>174</td>
<td>240</td>
<td>282</td>
<td>112</td>
<td>120</td>
<td>213</td>
<td>178</td>
<td>235</td>
</tr>
<tr>
<td>( E(R_{2,t}) )</td>
<td>140</td>
<td>144</td>
<td>161</td>
<td>207</td>
<td>261</td>
<td>261</td>
<td>197</td>
<td>116</td>
<td>166.5</td>
<td>195.5</td>
<td></td>
</tr>
<tr>
<td>( Var(R_{2,t}) )</td>
<td>0</td>
<td>16</td>
<td>169</td>
<td>1089</td>
<td>441</td>
<td>7225</td>
<td>16</td>
<td>2162.25</td>
<td>306.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( y_{2,t} )</td>
<td>140</td>
<td>153</td>
<td>191</td>
<td>284</td>
<td>310</td>
<td>395</td>
<td>125</td>
<td>275</td>
<td>236</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4: Target inventory level \( y_{x,t} \) in isolated and aggregated manner.

<table>
<thead>
<tr>
<th>Month</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \hat{y}_{1,2,t} )</td>
<td>145</td>
<td>160</td>
<td>196</td>
<td>287</td>
<td>313</td>
<td>398</td>
<td>130</td>
<td>279</td>
<td>238</td>
</tr>
<tr>
<td>( \tilde{y}_{1,2,t} )</td>
<td>145</td>
<td>156</td>
<td>195</td>
<td>287</td>
<td>312</td>
<td>398</td>
<td>127</td>
<td>276</td>
<td>238</td>
</tr>
</tbody>
</table>

Because we want to compare the target inventory of the two different ordering methods, the overall target inventory has to be calculated. The overall target inventory level in the isolated manner \( \hat{y}_{1,2,t} \) is calculated by the summation the target inventory of both companies, (4.5).

\[
\hat{y}_{1,2,t} = y_{1,t} + y_{2,t} = E(R_{1,t}) + E(R_{2,t}) + z \left( \sqrt{Var(R_{1,t})} + \sqrt{Var(R_{2,t})} \right) \tag{4.5}
\]

While in the aggregate manner \( \tilde{y}_{1,2,t} \) the inventory level is calculated by using (4.6). Here, the assumption is made that the demand of items required for production are statistically independent.

\[
\tilde{y}_{1,2,t} = E(R_{1,t}) + E(R_{2,t}) + z \sqrt{Var(R_{1,t}) + Var(R_{2,t})} \tag{4.6}
\]

The results of the calculations are added to Table 4.4.

As you can see in Table 4.4 the total \( \hat{y}_{1,2,t} \) per period is on average 238 items while \( \tilde{y}_{1,2,t} \) is on average 237 items per period. This is an insignificant difference, therefore we want to calculate the potential savings of the entire shared item portfolio of PC and PS. While there are 140 item types that are used in PC and PS (11,038 items) the potential savings due to aggregate ordering could be significant. The entire shared item portfolio is considered in the next section.

The reasoning behind the possible savings is explained in Chapter 2, the idea behind the reduction of target inventory level is based on risk reduction due to inventory sharing. The reduction in inventory will result in savings of inventory cost. Even though, the major part of the items that are ordered according to base stock policy have low inventory holding cost, the total potential saving of the entire shared item portfolio could considerable, and will be considered in the next section.

Considering the Entire Inventory of PC and PS

In this section the entire inventory of PC and PS is considered, to evaluate the inventory reduction if risk pooling is applied for not only one item (as in previous section), but for the entire shared item portfolio.

As said in Section 4.1.2 there are on average 140 similar item types in inventory, these are on average 11,038 items per month. In the last section one of those item types is considered, a conclusion is drawn that there is no significant difference between the isolated ordering method and the aggregated ordering method for one specific product. Therefore the entire shared item portfolio is considered. In this section SQL is used to perform the calculations. The SQL queries to perform the calculations are added in Appendix Q.

The items that are considered, are items both in inventory of PC and PS, for end customer ASML NL in 2015. The analysis is performed on the data of 2015 only, this means there there
were 11 months available to perform the analysis. Because we use a MA(2) it means we have 9 periods to consider, similar as Table 4.2 and Table 4.3.

After doing the analysis on the entire inventory it can be stated that the target inventory is on average 13,633 items per month if the companies perform their order policy in an isolated manner. While if the stock is aggregated this results in an average of 12,736 items as target inventory level. Which is a difference of 897 items in the target inventory, for each period. This is a reduction of approximately 7% of the target inventory level. In Figure 4.6 you can see that the order-up-to level of the isolated manner is higher than the order-up-to level in the aggregated manner.

After the consideration of the total inventory items, the inventory value is considered. The value of the items in inventory is a major indicator for the company’s financial position and profitability. After the analysis is it found that on average the value of the selected items is €554,330 if the companies perform their order policy in an isolated manner. While if the stock is aggregated this results in an average of €500,533. This is a difference of €53,797, approximately a reduction of 10% of the total inventory value. In Figure 4.7 you can see that the total inventory value of the isolated manner is higher than the total inventory value of the aggregated manner.

Summarizing, if we consider the shared inventory portfolio of PC and PS, it became clear that there is a potential for reduction of the amount of items in inventory and the inventory value. By sharing the inventory, the total amount of items in inventory can be reduce by 7%. Moreover, the value of the items in inventory will reduce by 10% of the total inventory value.
CHAPTER 4. EFFECTS OF INVENTORY POOLING AND DEMAND FORECASTING

4.2.3 Bullwhip Effect BIC Situation KMWE and Suppliers

In this section we discuss the improvements of demand forecasting sharing. In this section we consider whether demand information forecasting could have an effect on the inventory for ordering at the three suppliers identified in Section 4.1.3. First, we consider one product per supplier as an illustrative example (Section 4.2.3), after that we consider multiple product of the supplier portfolio (Section 4.2.3).

As illustrated in Section 4.1.1 both KMWE and their suppliers hold inventory to protect themselves for uncertainties in the delivery of supply and demand of customers in the supply chain. KMWE holds inventory to protect itself for uncertainties in the demand of ASML NL and for delivery uncertainties of the supply. The suppliers of KMWE do the same, they hold inventory to protect themselves for uncertainties in the demand of KMWE, caused by variance of the demand of ASML NL. The effect associated with this is the bullwhip effect. As mentioned in Chapter 2 the bullwhip effect suggests that the variability of orders increases as we move more upstream in the supply chain. In this case, the variability of orders increases from KMWE to its suppliers.

In Figure 4.8 the supply chain considered is visualized. As we know, ASML NL orders products at PC and PS. To meet the demand of ASML NL \( D_t \), KMWE needs supply. The required items for demand are ordered at suppliers (in this case S2, S3, and S33).

In the Bill of Material (BOM) KMWE adds all the supply needed for the manufacturing of a specific demanded item. The amount of demanded products times the BOM leads to required items for satisfying the demand during a specific time period \( R_{x,t} \), with \( x \in \{A_n, B_n, C_n\} \). \( A_n, B_n, C_n \) stand for products made at supplier S2, S3, S33 respectively, \( A \in \{A_1, A_2, ..., A_N\} \) etc. with \( N \) are the total products ordered at the supplier S2. KMWE holds inventory, with an item specific order up-to-level per time period \( y_{x,t} \). The order quantity placed at a specific supplier is indicated by \( q_{x,t} \).

We use data available in the company to calculate the bullwhip effect. In this section the work orders (wo) and purchase orders (po) are considered. The purchase orders are identified as \( q \), the orders that KMWE places at their suppliers. The work orders are internal orders to satisfy a certain demand. The work orders are identifies as \( R \).

By following the procedure of Frank Chen et al. (2000) the bullwhip effect is quantified by using (4.7).

\[
\frac{\text{Var}(q)}{\text{Var}(R)} \tag{4.7}
\]

In which \( \text{Var}(q) \) refers to variance of the purchase orders. \( \text{Var}(R) \) indicates the variance of the work orders.
CHAPTER 4. EFFECTS OF INVENTORY POOLING AND DEMAND FORECASTING

Figure 4.9: The bullwhip effect is observed by the ordering policy of three products at three suppliers considered. The blue lines indicate the purchase orders, while the orange line indicate the work orders.

Table 4.5: The bullwhip effect according to calculation of Frank Chen, Drezner, Ryan, and Simchi-levi (2000), for the 12 months in 2015. \( \frac{\text{Var}(q)}{\text{Var}(R)} > 1 \) this means that the variance of the items purchased at the suppliers is higher than the variance of the items demanded.

<table>
<thead>
<tr>
<th>Supplier name</th>
<th>Item number</th>
<th>( \frac{\text{Var}(q)}{\text{Var}(R)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2</td>
<td>4022 439 8781/1</td>
<td>( \frac{27430.96}{5111.85} = 8.11 )</td>
</tr>
<tr>
<td>S3</td>
<td>4022 439 8021/5</td>
<td>( \frac{1188.66}{30.965} = 5.37 )</td>
</tr>
<tr>
<td>S33</td>
<td>4022 439 8780/2</td>
<td>( \frac{1941857.03}{30.363.74} = 6.32 )</td>
</tr>
</tbody>
</table>

Considering One Item per Supplier

First we select one item per supplier, to calculate the bullwhip effect, following the procedure of Frank Chen et al. (2000). This is an illustrative example.

In Figure 4.9 the work orders and purchase orders are analysed during 12 months in 2015. As you can see the variance of the purchase orders is higher than the variance of the work orders. This is equal to the phenomenon described in Chapter 2. In Table 4.5 the bullwhip effect is calculated by using the formula of Frank Chen et al. (2000) (4.7).

When \( \frac{\text{Var}(q)}{\text{Var}(R)} = 1 \) this means that the variance of the items purchased at the suppliers is equal to the variance of the items demanded, on other words the bullwhip effect does not exist. When \( \frac{\text{Var}(q)}{\text{Var}(R)} > 1 \) this means that the variance of the items purchased at the suppliers is higher than the variance of the items demanded. When this is the case, the bullwhip effect is observable. So, we can conclude that the variance of the specific items purchased at supplier S3, S3, and S33 is higher than the variance of that supply needed for production of ASML NL, the bullwhip effect is observed.

As stated in Chapter 2 one of the major solutions for the bullwhip effect is information sharing.

When information is shared, upstream supply chain members (retailers) allow downstream entities to manage their orders based on the echelon inventory level rather than the order quantity placed by its immediate customer (Fangruo Chen, 1998), which will reduce the amplification component of the bullwhip effect. When entities of a supply chain are located in the same location, this could potentially increase the information sharing through face-to-face meetings (Weterings and Ponds, 2009). However, according to research the bullwhip effect remains observable when information on inventory levels is shared. According to several research done on this subject, the inventory information sharing helps to reduce the bullwhip effect, but it will not completely eliminate the phenomenon (Croson and Donohue, 2006, Fangruo Chen, 1998).

Consider Multiple Items per Supplier

In Section 4.2.3 we considered one item per supplier (in this case S2, S3, and S33). In this section we describe the procedure of considering multiple items per supplier. In this section we considered
Table 4.6: The lead time is divided into three parts (transport, inventory holding, and production), this is based on the analysis done in Chapter 5.

<table>
<thead>
<tr>
<th></th>
<th>Supplier (Assumption)</th>
<th>KMWE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport time</td>
<td>25%</td>
<td>18%</td>
</tr>
<tr>
<td>Inventory holding time</td>
<td>25%</td>
<td>37%</td>
</tr>
<tr>
<td>Production time</td>
<td>50%</td>
<td>45%</td>
</tr>
</tbody>
</table>

17 unique items from supplier S2, 292 unique items from S3, and 19 unique items from S33. This are the unique items of which the data is complete.

In this section SQL is used to perform the calculations. The SQL queries are added to Appendix Q.

We calculated the bullwhip effect according to calculation of Frank Chen et al. (2000). We found that the bullwhip effect of S2 is on average 24.93 (Figure M.8a, Appendix M). The bullwhip effect of S3 is on average 86.80 (Figure M.8b, Appendix M). The bullwhip effect of S33 is on average 39.26 (Figure M.8c, Appendix M). These numbers of high, this is the result of the fact that the items are bought in bulk orders. The suppliers produce small products, with small inventory holding cost.

Possible Reduction Bullwhip Effect

It is stated that information sharing is one of the major solutions for the bullwhip effect. However, according to research of Croson and Donohue (2006) and Frank Chen et al. (2000) information sharing helps to reduce the bullwhip effect, but it will not completely eliminate the phenomenon. In this section we consider what the possible reduction of the bullwhip could be if information is shared in the BIC. By using the formula Frank Chen et al. (2000) the lower bound of the bullwhip effect is calculated:

\[
\frac{\text{Var}(q_{k})}{\text{Var}(D)} \geq 1 + \left( \frac{2}{p} \sum_{i=1}^{k} L_i \right) + \frac{2(\sum_{i=1}^{k} L_i)^2}{p^2}(1 - \rho^p),
\]

(4.8)

in which \(L_k\) is the lead time between stage \(k\) and \(k + 1\), \(p\) is the number of periods observed and \(\rho\) is the correlation parameter (\(|\rho| < 1\)).

To calculate the lower bound of the bullwhip effect, we first analyse the lead time of the current situation. We derive the lead time of the BIC situation from the lead time of the current situation. In Chapter 5 a more detailed description of the lead time is given.

The lead time of the current situation is analysed first. The lead time of the supply chain consists of the lead time between ASML NL and KMWE (KMWE, 2016h), and the lead time between KMWE and its suppliers (KMWE, 2016g). The average lead times of the current situation are added to Table 4.7.

In the current situation the lead time is based on three steps in the process: transport, inventory holding, and production. In general, we can say that the lead time for products of ASML NL is for 18% caused by the transport. 45% by the production, and 37% of the time is caused by inventory holding (Table 4.6).

The lead time of the suppliers consist of the same components: transport, inventory holding, and production. We assume that 25% of the lead time is caused by transport, 50% by the production, and 25% by inventory holding (Table 4.6).

When the suppliers are located at the BIC and the inventory is shared in the central warehouse, the supplier lead time will reduce by 25%. This is caused by the reduction of the transportation time. The lead time to the customer will reduce by 16% of the supplier is located on the BIC. This is caused by the reduction of the transportation time and inventory holding time (Table 4.7). In Chapter 5 a more detailed description and calculation is given.

The lower bound of the bullwhip effect is calculated for suppliers S2, S3, and S33 by using (4.8) we assumed that \(\rho = 0\) (Table 4.8).
We performed a sensitivity analysis on the assumptions made. The first assumption is made about the distribution of the lead time at the suppliers, this has no impact on the lower bound of the bullwhip effect, because the supplier lead was available (KMWE, 2016h and KMWE, 2016g). Moreover, we made an assumption for \( \rho \). If \( \rho = 1 \) then all lower bounds are 1. When \( \rho = 0.5 \) or \( \rho = -0.5 \) the lower bound are the same as \( \rho = 0 \). When we use a lower bound of 1, the percentage reduction of the bullwhip effect is the same (99%). So, a change in the assumption in \( \rho \) has not impact on the percentage reduction of the bullwhip effect, based on (4.7) and (4.8).

When we compare the results of the average bullwhip effect and the lower bound it can be stated that there is enough room to reduce the bullwhip effect. As said before, inventory and demand information sharing is one of the major solutions for the improvements.

If we assume that the variance of the work orders stay the same for the current situation and the BIC situation the variance of the purchase orders could reduce. Summarizing, KMWE has a potential to better match the purchase orders with the work orders, this is possible by sharing demand information on the BIC. It is clear that the bullwhip effect will reduce if the variability of the purchase orders decrease.

### 4.3 Conclusions, Recommendations, and Future Research

In the second part of the research the following research question is answered:

**What are the effects when inventory is pooled and demand forecast is shared, due to centralization of a supply chain on the BIC?**

#### 4.3.1 Conclusions

We divided the conclusion part into two sections: the first section considers the effect of inventory pooling between PC and PS. The second part considers the effect of demand forecast sharing between KMWE and its suppliers.

**Inventory Pooling**

Inventory pooling on the BIC is defined as the consideration of inventory in an aggregated manner. In inventory pooling the variabilities in demand and lead time are shared. PC and PS could share the variabilities and reduce their aggregated inventory level. By only considering the items of PC
CHAPTER 4. EFFECTS OF INVENTORY POOLING AND DEMAND FORECASTING

and PS in inventory for ASML NL a reduction of 7% in inventory amount is possible. This will reduce the inventory value by 10%. The inventory amount is on average 13,633 items per month if the companies perform their order policy in an isolated manner. When the companies perform their order policy in an aggregated manner, this will change to on average 12,736 items per month in inventory. On average the value of the selected items is €554,330 if the companies perform their order policy in an isolated manner, while if the order policy is performed in an aggregated manner the values of the selected items is €500,533.

Summarizing, inventory pooling is easier if a supply chain is centralized, because of the shared physical inventory location and information system. An effect of inventory pooling is a reduction of amount of items in inventory, and therefore the inventory value.

Demand Forecast Sharing

Currently, there is a mismatch between the purchase orders at the suppliers and work orders for ASML NL in KMWE. The bullwhip effect is observed in the ordering behaviour of the company at three suppliers. This means that the variance of the purchase orders at suppliers is higher than the variance of the work orders for ASML NL in KMWE. Demand information could be shared to reduce this effect.

However, there is a lower bound of the bullwhip effect. The lower bound is based on the lead time of the supply chain. We found that there is a potential for reducing the bullwhip by on average 99% for the three suppliers considered.

The effect of demand forecast sharing, which is easier if a supply chain is centralized due to face-to-face meetings and a shared information system, is a better match between the purchased orders and the demanded orders. In other words the bullwhip effect will reduce as demand information is shared. However, it has to be stated that there is a lower bound, the lower bound is based on the lead time of the supply chain.

4.3.2 Recommendations

We divided the recommendations part into two sections: the first section considers the effect of inventory pooling between PC and PS. The second part considers the effect of demand forecast sharing between KMWE and its suppliers.

Inventory Pooling

We recommend KMWE to change the purchasing and safety stock level determination from the isolated manner, to an aggregated manner for the items that are ordered according to the base-stock policy. This will reduce the amount of items in inventory, and the value of the items in inventory, due to the sharing of risks. This will bring a change in business process and responsibilities. It is assumed that the change from the current location to the BIC will result in other business processes, tasks, and responsibilities, wherefore the relocation is a good moment to change.

A first step in the uniting of the processes could be the standardization of the primary suppliers. Currently, PC and PS have their own primary suppliers, by standardizing the primary suppliers the products purchased will increase. This could lead to advantages, caused by the economics of scale. Furthermore, the inventory of those items can be shared, which leads to a lower safety stock, resulting in less inventory holding costs.

Demand Forecast Sharing

As a first step in demand forecast information sharing, PS could provide PC more detailed information.

If information is shared with more downstream suppliers, a better match between supply orders and customer demand is possible. However, a good information sharing system is needed within the BIC. If there is no good information sharing system, companies are located at the same location, but will not exploit the potential competitive advantages.

48 Modeling and Analysis of Supply Chain Centralization at KMWE
4.3.3 Future Research

We divided the future research part into two sections: the first section considers the effect of inventory pooling between PC and PS. The second part considers the effect of demand forecast sharing between KMWE and its suppliers.

Inventory Pooling

When other BIC companies are identified, it is possible to do further research on inventory pooling. Other companies might have the same (or similar) items in inventory, it might be possible to share those items. This is dependent on what kind of companies will be located on the BIC. Here, a complicated issue to be solved is the priority issue. What if two companies both need an item, but there is only one item available?

Demand Forecast Information Sharing

A good information sharing system is needed to share demand forecast with entities on the BIC. In the future, it must be investigated whether it is possible to arrange a BIC-wide information system. Here, it must be taken into account that the companies on the BIC are still individual companies, this means that privacy issues must be considered.
Chapter 5

Effect of Supply Chain Centralization on Lead Time

In this chapter we analyse the lead time of the current situation, and propose the lead time of the situation where KMWE and suppliers and/or subcontractors are located at the BIC. In this chapter the following research question is answered:

What is the effect on lead time of the supply chain if it is centralized on the BIC?

In the first section the empirical research of the lead time is described. First we describe the current situation concerning the lead time. Then, we focus on the broad overview of the current situation, after that we consider the situation in more detail. Furthermore, we consider the current lead time by making a MCT map of the average lead time for products of ASML NL in the specific supply chain.

In Section 5.2 we describe the results of the analytical research of the lead time. First the proposed lead time is described in the BIC situation. Similar to the first section we first describe the BIC situation concerning the lead time, after which we dive into a more detailed analysis. Furthermore, we consider the proposed lead time by making a Manufacturing Critical-path Time (MCT) map of the average lead time for products of ASML NL in the specific supply chain.

In Section 5.3 the first and second section are compared.

In Section 5.4 we draw our conclusions, make recommendations, and guide the future research directions.

5.1 Empirical Research Lead Time

In this section the current situation concerning the lead time is described. In this section we first consider the lead time in a broad manner, after which we dive into more detail. Finally, the current situation is described by a MCT map.

5.1.1 Broad Overview Current Situation Lead Time

As described in Section 3.1.1 the products in the supply chain flow from different suppliers to PC. Then, the supply is used in the production, in which sometimes an outside process is performed by a subcontractor. After that the products are delivered to PS, where the production process is continued. When the products are finished, they are shipped to the customer ASML NL. To perform the tasks at the different stages time is needed. In this section we analyse the time to perform the steps in the supply chain.

Figure 5.1 illustrates the flow of products through the supply chain. In the figure the different processes are indicated (inventory, production, shipment). The average lead time is considered for
Fig. 5.1: The current situation concerning the lead time in the supply chain. The products flow from a supplier to ASML NL is indicated. The entire process takes 14 weeks (KMWE, 2016g and KMWE, 2016h).

each stage of the process.

In general, a supplier of KMWE has a lead time of four weeks (KMWE, 2016g). It is assumed that the lead time is divided in two weeks production, one week is reserved for the transport, the rest of the time (one week) are the products stored in inventory. The latter is a time buffer.

In the second step of the supply chain are the products shipped to PC. In general the processes in PC for ASML NL takes 6.5 weeks per product (KMWE, 2016h). The lead time is divided into two weeks of inventory holding, four weeks of productions, and half a week is reserved for transport.

Often, 1.393 times during 2015 (KMWE, 2016c), products have to undergo a process that is not performed in the company, therefore a subcontractor is hired to perform a certain process. In general, this takes two weeks for the products of end customer ASML NL (this is included in the total production time at PC) (KMWE, 2016g). It is assumed that the lead time of the subcontractor is divided into one week that is reserved for transport, and one week production.

When a product is finished in PC, the product is shipped to PS, there the production process takes less time than the process in PC. On average, products produced for ASML NL are 3.5 weeks in the company (KMWE, 2016h). The lead time is divided into 1.5 weeks of inventory holding, one week of production, and one week is reserved for transport.

Then, the product is shipped to the customer, ASML NL. So, in general we can say that the entire described process takes 14 weeks (Fig. 5.1).

### 5.1.2 Lead Time of Supply Chain in Current Situation

The lead time of a typical product produced in KMWE for ASML NL is considered in more detail. In Figure R.1 (Appendix R) the lead time consideration is visualized. Similar as Figure 5.1 we
CHAPTER 5. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON LEAD TIME

Table 5.1: The supplier lead time per entity of the supply chain (KMWE, 2016g and KMWE, 2016h).

<table>
<thead>
<tr>
<th>Entity</th>
<th>Supplier lead time</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>4 weeks</td>
</tr>
<tr>
<td>PS</td>
<td>4 + 6.5 = 10.5 weeks</td>
</tr>
<tr>
<td>ASML NL</td>
<td>4 + 6.5 + 3.5 = 14 weeks</td>
</tr>
</tbody>
</table>

start with the supplier process. In general this takes four weeks (KMWE, 2016g), the processes involved are inventory storage, production, and shipment. Then, in general it takes PC 6.5 weeks to produce a product for end customer ASML NL (KMWE, 2016h). The production process consists in general of seven steps: two times processing on a work center, two times a quality test, two times material handling, and an outside process (KMWE, 2016c). The outside process is done by a subcontractor. On average this outside process takes two weeks (KMWE, 2016g). After the process in PC, the product is processed in PS. The production process takes on average one week, the process consists in general of assembling activities and packaging activities (KMWE, 2016c).

PC buys components at their supplier, so their supplier lead time is on average four weeks. PS buys components at their supplier, PC, so their supplier lead time is on average 10.5 weeks. End customer ASML NL buys the products at PS, their supplier lead time is on average 14 weeks (Table 5.1).

5.1.3 MCT Map Current Situation Lead Time

In partnership with industry, and based on the QRM principles (Chapter 2) the MCT map is developed by Suri (1998) to measure the lead time in companies. The Manufacturing Critical-path Time (MCT) is defined as the measure of the true manufacturing lead time. The MCT map visualize the amount of calendar time between the creation of a customer order, through the critical-path until the first, single piece of that order is delivered to the customer. The MCT is used to define the company’s lead time, and specifies the total system wide waste. Within the MCT map the grey spaces illustrate the total working time (touch time), the white space is the remaining time, where nothing is happened to the order (other elapsed time) (Suri, 2014).

In Figure 5.2 the MCT map for the general production process is made. In general, the total calendar time elapsed between the creation of a customer order until the first delivering is 14 weeks.

The processes of PC consist of inventory storing, production, and shipment. The production is in general four weeks, and consists of subprocesses (KMWE, 2016c). The three major subprocesses, based on the frequencies (Table 5.2), are “outside process”, “quality control”, and “material handling”. The other subprocesses are included in another process, which we call “work center”. The four subprocesses are added to the MCT map. For each of the processes the average of the actual run time (touch time) and average of the fixed lead time (other elapsed time) is analysed (Table 5.3). In the actual run time we added the machine setup time and the run time.

The processes of PS consist of inventory storing, production, and shipment. The production is in general one week, and consists of subprocesses (KMWE, 2016c). The two major subprocesses, based on the frequencies (Table 5.4) are “assembly” and “material handling”. The other subprocesses are included in another process, which we call “general process”. The three subprocesses are added to the MCT map. For each of the processes the average of the actual run time (touch time) and average of the fixed lead time (other elapsed time) is analysed (Table 5.5). In the actual run time we added the machine setup time and the run time.

The information provided in Table 5.3 and Table 5.5 is used to create the MCT map (Figure 5.2). For the suppliers and subcontractors there is no information about the actual run time (touch time), therefore it is assumed that the suppliers and subcontractors always have touch time during the production phase.
CHAPTER 5. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON LEAD TIME

Table 5.2: The subprocesses in the production of PC, with their frequency of occurring during 2015 (KMWE, 2016c).

<table>
<thead>
<tr>
<th>Function (subprocess)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly (ASS)</td>
<td>11</td>
</tr>
<tr>
<td>Account Team (AT)</td>
<td>483</td>
</tr>
<tr>
<td>Work Bench (BW)</td>
<td>2,211</td>
</tr>
<tr>
<td>CNC Milling (CNC Mill)</td>
<td>1,061</td>
</tr>
<tr>
<td>CNC Turning (CNC Turn)</td>
<td>200</td>
</tr>
<tr>
<td>Common (Common)</td>
<td>23</td>
</tr>
<tr>
<td>Engineering (ENG)</td>
<td>13</td>
</tr>
<tr>
<td>Material Handling (MH)</td>
<td>4,289</td>
</tr>
<tr>
<td>Outside Process (OP)</td>
<td>1,393</td>
</tr>
<tr>
<td>Programming (Prog)</td>
<td>444</td>
</tr>
<tr>
<td>Quality Control (QC)</td>
<td>2,174</td>
</tr>
<tr>
<td>Sawing (Saw)</td>
<td>253</td>
</tr>
<tr>
<td>Vibration Finish (VibFin)</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 5.3: The actual run time and fixed lead time per subprocess in PC (KMWE, 2016c). The average fixed lead time is the average of the planned lead time of the subprocess.

<table>
<thead>
<tr>
<th>Function (subprocess)</th>
<th>Average actual run time</th>
<th>Average fixed lead time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work Center (WC)</td>
<td>9 hours</td>
<td>2.2 days</td>
</tr>
<tr>
<td>Outside Process (OP)</td>
<td>-</td>
<td>10.5 days</td>
</tr>
<tr>
<td>Quality Control (QC)</td>
<td>0.5 hours</td>
<td>3.8 days</td>
</tr>
<tr>
<td>Material Handling (MH)</td>
<td>0.3 hours</td>
<td>2.6 days</td>
</tr>
</tbody>
</table>

Table 5.4: The subprocesses in the production of PS, with their frequency of occurring during 2015 (KMWE, 2016c).

<table>
<thead>
<tr>
<th>Function (subprocess)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly (ASS)</td>
<td>1,006</td>
</tr>
<tr>
<td>Conversion Milling (Conv Mill)</td>
<td>16</td>
</tr>
<tr>
<td>Finishing (FINI)</td>
<td>141</td>
</tr>
<tr>
<td>Junior Project (JR-Proj)</td>
<td>2</td>
</tr>
<tr>
<td>Material Handling (MH)</td>
<td>1,067</td>
</tr>
<tr>
<td>Outside process (OP)</td>
<td>152</td>
</tr>
<tr>
<td>Preparation (Prep)</td>
<td>304</td>
</tr>
<tr>
<td>Projects (Proj)</td>
<td>1</td>
</tr>
<tr>
<td>Prototyping (Proto)</td>
<td>3</td>
</tr>
<tr>
<td>Quality (Q)</td>
<td>1</td>
</tr>
<tr>
<td>Senior Project (SR-Proj)</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5.5: The actual run time and fixed lead time per subprocess in PS (KMWE, 2016c). The average fixed lead time is the average of the planned lead time for the subprocess.

<table>
<thead>
<tr>
<th>Function (subprocess)</th>
<th>Average actual run time</th>
<th>Average fixed lead time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly (ASS)</td>
<td>4.8 hour</td>
<td>1.4 days</td>
</tr>
<tr>
<td>Material Handling (MH)</td>
<td>0.25 hours</td>
<td>1 day</td>
</tr>
<tr>
<td>General Process</td>
<td>0.5 hours</td>
<td>3.9 days</td>
</tr>
</tbody>
</table>

54  Modeling and Analysis of Supply Chain Centralization at KMWE
Table 5.6: Summary of the ratio between the touch time and no touch time in the supply chain.

<table>
<thead>
<tr>
<th>Function</th>
<th>Location</th>
<th>Touch Time</th>
<th>No touch Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory</td>
<td>Supplier</td>
<td>0.5 week</td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>Supplier</td>
<td>2 weeks</td>
<td>0.5 week</td>
</tr>
<tr>
<td>Production</td>
<td>Supplier</td>
<td>1 week</td>
<td></td>
</tr>
<tr>
<td>Inventory</td>
<td>PC</td>
<td>9 hours</td>
<td>8 hours and 36 minutes</td>
</tr>
<tr>
<td>Production - Work Center</td>
<td>PC</td>
<td>30 minutes</td>
<td>29 hours and 54 minutes</td>
</tr>
<tr>
<td>Production - Material Handling</td>
<td>PC</td>
<td>20 minutes</td>
<td>20 hours and 30 minutes</td>
</tr>
<tr>
<td>Shipment</td>
<td>Subcontractor</td>
<td>1 week</td>
<td>0.5 week</td>
</tr>
<tr>
<td>Production</td>
<td>Subcontractor</td>
<td>1 week</td>
<td>0.5 week</td>
</tr>
<tr>
<td>Shipment</td>
<td>PS</td>
<td>1 week</td>
<td></td>
</tr>
<tr>
<td>Production - General Process</td>
<td>PS</td>
<td>30 minutes</td>
<td>30 hours and 42 minutes</td>
</tr>
<tr>
<td>Production - Assembling</td>
<td>PS</td>
<td>4 hours and 48 minutes</td>
<td>6 hours and 24 minutes</td>
</tr>
<tr>
<td>Production - Material Handling</td>
<td>PS</td>
<td>15 minutes</td>
<td>7 hours and 45 minutes</td>
</tr>
<tr>
<td>Inventory</td>
<td>PS</td>
<td>15 minutes</td>
<td>0.5 weeks</td>
</tr>
<tr>
<td>Shipment</td>
<td>PS</td>
<td>1 week</td>
<td></td>
</tr>
</tbody>
</table>

Starting with the suppliers, the process consists of inventory holding, production and shipment. It is assumed that the process consists of two times inventory holding of 0.5 weeks. This is defined as no touch time. The production takes two weeks, and is classified as touch time. One week is reserved for shipments, this is classified as no touch time.

When a product is shipped to PC the products are first stored in inventory, on average one week. This time is defined as no touch time. Then the real production process starts. The production process begins with production at the work center, on average there are nine touch hours, and eight hours and 36 minutes no touch time. Then we consider the quality control, in which on average 30 minutes are touch time, and on average 29 hours and 54 minutes are no touch time. The material handling consists of 20 minutes touch time, on average and 20 hours and 30 minutes no touch time.

Then a product is shipped to a subcontractor, the entire process is two weeks. It is assumed that the process consists of two times 0.5 week reserved for shipment. Shipment time is defined as no touch time. It is assumed that the production process takes one week, this is classified as touch time.

The next steps are again undertaken in PC, the steps are described before. After that, the items are shipped to PS. Shipment is defined as no touch time, the shipment time is 0.5 week.

In PS the products are first stored in inventory for on average 1 week, this is defined as no touch time. Then the production process starts with the general process. The touch time in the general process is 30 minutes, and the no touch time is on average 30 hours and 42 minutes. Then, the product is assembled, this process is divided into four hours and 48 minutes touch time, and on average six hours and 24 minutes no touch time. Then the product is assembled, this process is divided into 15 minutes touch time, and on average seven hours and 45 minutes no touch time. Then the products are stored in inventory again for 0.5 week, this is defined as no touch time. The last process is the shipment, the shipment is defined as no touch time. The total time reserved for shipment is one week (KMWE, 2016g and KMWE, 2016h).

In Table 5.6 the above mentioned is summarized. In total 70% of the lead time is no touch time. If we consider the lead time of PC 91% of the time is no touch time, for PS is this 96%.
Figure 5.2: The MCT map of the current situation, the grey spaces indicate the actual touch time. The white spaces indicate the other elapsed time. The production time at the suppliers and subcontractors is assumed to be completely touch time.
5.2 Analytical Research Lead Time

This section consists of the description of the BIC situation concerning the lead time. In this section we first consider the lead time in a broad manner, after which we dive into more detail. Finally, we present the MCT map of the BIC situation.

5.2.1 Broad Overview BIC Situation Lead Time

In the BIC situation KMWE moves to the BIC, and it is possible for other suppliers and subcontractors move to that location as well. This will effect the distance between the company and the suppliers and subcontractors (Section 3.2) and the physical inventory location (Section 4.2). Furthermore, information sharing might change the inventory policy and practices.

Figure 5.3 illustrates the flow of products through the supply chain. In the figure the different processes are indicated, similar as Figure 5.1. The average lead time in the BIC situation is derived from the lead times in the current situation. As you can see, the lead time of suppliers and subcontractors on the BIC is lower than the lead time of the suppliers and subcontractors who stay in the current situation. The lead time for the suppliers that stay at their current location is on average four weeks, while the lead time for the suppliers in the new situation is on average two weeks plus inventory time.

The same is true for the subcontractors: the subcontractors that stay in the current location have on average a lead time of two weeks, while the lead time of the subcontractors on the BIC is only one week. This is caused by the fact that the shipment time is reduced, from half a week or one week to 0.5 hour, and the inventory time is assumed to reduce in the new situation as well, by using the Little’s Law\(^1\). Depending on the number of suppliers and subcontractors that are moving to the BIC, we can calculate the lead time of the entire process. In Section 5.3 we made the comparison between the current lead time and the BIC lead time.

5.2.2 Lead Time of Supply Chain in BIC Situation

Similar as before, the average lead time of product produced in KMWE for ASML NL is considered. In Figure R.2 (Appendix R) the lead time consideration is visualized. As you can see, the lead time is dependent on whether the suppliers and subcontractors are located on the BIC or stay at their current location.

First, we considered the supplier lead time of PC. If the supply is produced off the campus it takes four weeks. The lead time will reduce in the BIC situation, because transportation time will reduce from one week to 0.5 hours. The inventory time of the supplier will not effected by the change of the location, if we assume that the ordering of the raw material still takes the same time. The reduce in transportation time will cause in a reduction of the supplier lead time of PC from four weeks to three weeks.

Secondly, we considered the inventory time in inventory of PC. We used Little’s Law to calculate the effect of a change in arrivals on the inventory holding time. If the supply lead time is reduced, in other words the one over the arrival rate ($\lambda$), this will reduce the inventory time ($W$) when the average inventory ($L$) is kept constant. If the average inventory is fixed, the service level will be the same as before. So, if the supplier lead time of PC reduce from four weeks to three weeks, the inventory time could be reduced by $\frac{3}{4}$ times.

Thirdly, we considered the lead time of the subcontractors. The location of the subcontractors will effect the lead time of PC. In the situation where the subcontractors are located on the BIC the transportation time is 0.5 hours, while in the current situation two times half a week is reserved for the transport. So, this results in a reduction of the subcontractor lead time of one week.

Then, we considered the lead time of PC itself. The process of PC consists of 2 weeks inventory, 4 weeks production and 0.5 week shipment in the current situation. First, the inventory time is

\(^1\)The long-term average number of customers in a stable system $L$ is equal to the long-term average effective arrival rate, $\lambda$, multiplied by the average time a customer spends in the system, $W$. The Little's Law is expressed algebraically by: $L = \lambda W$ (Little, 1961).
CHAPTER 5. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON LEAD TIME

Figure 5.3: The BIC situation concerning the lead time in the supply chain. The products flow from a supplier to ASML NL, some suppliers/subcontractors are located at the BIC. The inventory time is depended on the lead time.
CHAPTER 5. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON LEAD TIME

Table 5.7: The lead time of PC, for three different situations. Depending on the location the lead time is changed.

<table>
<thead>
<tr>
<th></th>
<th>Current Situation</th>
<th>BIC Situation Both off BIC</th>
<th>BIC Situation Suppliers on Subcontractors off BIC</th>
<th>BIC Situation Suppliers off Subcontractors on the BIC</th>
<th>BIC Situation Both on BIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory</td>
<td>2 weeks</td>
<td>2 weeks</td>
<td>$2 \times \frac{3}{4} = 1.5$ week</td>
<td>2 weeks</td>
<td>$2 \times \frac{3}{4} = 1.5$ week</td>
</tr>
<tr>
<td>Production</td>
<td>4 weeks</td>
<td>4 weeks</td>
<td>4 weeks</td>
<td>3 weeks</td>
<td>3 weeks</td>
</tr>
<tr>
<td>Shipment</td>
<td>0.5 week</td>
<td>0.5 hour</td>
<td>0.5 hour</td>
<td>0.5 hours</td>
<td>0.5 hours</td>
</tr>
<tr>
<td>Total</td>
<td>6.5 weeks</td>
<td>6 weeks</td>
<td>5.5 weeks</td>
<td>5 weeks</td>
<td>4.5 weeks</td>
</tr>
</tbody>
</table>

Table 5.8: The lead time of the suppliers and the PC lead time. Depending on the location the lead time is changed.

<table>
<thead>
<tr>
<th>Supplier location</th>
<th>Subcontractor location</th>
<th>Total lead time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier not on BIC</td>
<td>Subcontractor not on BIC</td>
<td>4 + 6 weeks = 10 weeks</td>
</tr>
<tr>
<td>Supplier on BIC</td>
<td>Subcontractor not on BIC</td>
<td>3 + 5.5 weeks = 8.5 weeks</td>
</tr>
<tr>
<td>Supplier not on BIC</td>
<td>Subcontractor on BIC</td>
<td>4 + 5 weeks = 9 weeks</td>
</tr>
<tr>
<td>Supplier on BIC</td>
<td>Subcontractor on BIC</td>
<td>3 + 4.5 weeks = 7.5 weeks</td>
</tr>
</tbody>
</table>

reduced due to the reduction in supplier lead time (described in the second step). The inventory time will become $2 \times \frac{3}{4} = 1.5$ week. Secondly, the production time is four weeks, in which two weeks of subcontractor process is included. As explained in the third step the subcontractor lead time could reduce to one week if the subcontractor is located on the BIC. Moreover, the shipment time between PC and PS will reduce from 0.5 week to 0.5 hour. In the current situation the lead time of PC is 6.5 weeks. In the BIC situation, if all suppliers and subcontractors are located at their current location, the lead time is 6 week. When the suppliers are located on the BIC and the subcontractors stay at their current location, the lead time will be 5.5 weeks. When the suppliers are located at their current location and the subcontractors are located on the BIC the lead time will be 5 weeks. When both the suppliers as the subcontractors are located on the BIC the lead time will be 4.5 weeks (Table 5.7).

The supplier lead time of PS consists of the supplier lead time and the lead time of PC. In Table 5.8 the two values are added. The supplier lead time is dependent on the location of the supplier. If the suppliers and subcontractors are located off the BIC the supplier lead time of PS will be 10 weeks. If the suppliers are located on the BIC and the subcontractors are located at their current location the supplier lead time will be 8.5 weeks. If the suppliers are located at their current located and the subcontractors on the BIC the lead time will be 9 weeks. If the suppliers and the subcontractors are located on the BIC the lead time will be 7.5 weeks.

In PS the process consists of 1.5 weeks inventory, one week production, and one week shipment in the current situation. The inventory time will change in the BIC situation. In the situation where all the suppliers and subcontractors stay at their current location the inventory time will reduce to 1.4 weeks. When the suppliers are on the BIC, and the subcontractors are located on their current location the inventory time will be 1.2 weeks. When the suppliers stay at their current location and the subcontractors are located on the BIC the inventory time will be 1.3 weeks. When the suppliers and subcontractors are located on the BIC the inventory time will be 1.1 week (Table 5.9). The reduction of the inventory time is again based on Little’s Law. The production time is one week in the current situation, and this is the same in the BIC situation. The shipment time (to ASML NL) is one week in the current situation, and this is the same in
CHAPTER 5. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON LEAD TIME

Table 5.9: The lead time of PS, for five different situations.

<table>
<thead>
<tr>
<th></th>
<th>Current Situation</th>
<th>BIC Situation both off BIC</th>
<th>BIC Situation supplier on BIC subcontractor off BIC</th>
<th>BIC Situation supplier off BIC subcontractor on BIC</th>
<th>BIC Situation both on BIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory</td>
<td>1.5 weeks</td>
<td>1.5 * 1.2/10.5 = 1.4 weeks</td>
<td>1.5 * 1.2/10.5 = 1.2 week</td>
<td>1.5 * 1.2/10.5 = 1.3 week</td>
<td>1.5 * 1.2/10.5 = 1.1 week</td>
</tr>
<tr>
<td>Production</td>
<td>1 week</td>
<td>1 week</td>
<td>1 week</td>
<td>1 week</td>
<td>1 week</td>
</tr>
<tr>
<td>Shipment</td>
<td>1 week</td>
<td>1 week</td>
<td>1 week</td>
<td>1 week</td>
<td>1 week</td>
</tr>
<tr>
<td>Total</td>
<td>3.5 weeks</td>
<td>3.4 weeks</td>
<td>3.2 weeks</td>
<td>3.3 weeks</td>
<td>3.1 weeks</td>
</tr>
</tbody>
</table>

Table 5.10: The total lead time of the supply chain per entity.

<table>
<thead>
<tr>
<th>Entity</th>
<th>Supplier location</th>
<th>Subcontractor location</th>
<th>Total supplier lead time</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>Off BIC</td>
<td>N/A</td>
<td>4 weeks</td>
</tr>
<tr>
<td>PC</td>
<td>On BIC</td>
<td>N/A</td>
<td>3 weeks</td>
</tr>
<tr>
<td>PS</td>
<td>Off BIC</td>
<td>Off BIC</td>
<td>4 + 6 = 10 weeks</td>
</tr>
<tr>
<td>PS</td>
<td>On BIC</td>
<td>Off BIC</td>
<td>3 + 5.5 = 8.5 weeks</td>
</tr>
<tr>
<td>PS</td>
<td>Off BIC</td>
<td>On BIC</td>
<td>4 + 5 = 9 weeks</td>
</tr>
<tr>
<td>PS</td>
<td>On BIC</td>
<td>On BIC</td>
<td>3 + 4.5 = 7.5 weeks</td>
</tr>
<tr>
<td>ASML NL</td>
<td>Off BIC</td>
<td>Off BIC</td>
<td>4 + 6 + 3.4 = 13.4 weeks</td>
</tr>
<tr>
<td>ASML NL</td>
<td>On BIC</td>
<td>Off BIC</td>
<td>3 + 5.5 + 3.2 = 11.7 weeks</td>
</tr>
<tr>
<td>ASML NL</td>
<td>Off BIC</td>
<td>On BIC</td>
<td>4 + 5 + 3.3 = 12.3 weeks</td>
</tr>
<tr>
<td>ASML NL</td>
<td>On BIC</td>
<td>On BIC</td>
<td>3 + 4.5 + 3.1 = 10.6 weeks</td>
</tr>
</tbody>
</table>

The BIC situation. Moreover, we add 0.5 hour for the transport from PS to the central warehouse. The total lead time for each entity is given in Table 5.10. The total lead time is dependent on the location of the suppliers and subcontractors. In Figure R.2 (Appendix R) the flows are visualized.

5.2.3 MCT Map BIC Situation Lead Time

In the BIC situation the percentage touch time will change due to the decrease in inventory time and transport time. The inventory time and the transport time are defined as no touch time. Depending on the location of the suppliers and subcontractors the percentage of touch time will increase (Table 5.11). In the current situation the no touch time of the total process is 70%, while in the BIC situation the no touch time is 69%, 65%, 63% or 58%.

By using the values the MCT map of the BIC situation is created (Figure 5.4).
Figure 5.4: The MCT map of the BIC situation, the grey spaces indicate the actual touch time. The white spaces indicate the other elapsed time. The production time at the suppliers and subcontractors is assumed to be completely touch time.
### 5.3 Comparison Current Situation and BIC Situation

In this section the comparison between the current lead time and the proposed lead time in the BIC is made (Table R.1, Appendix R).

When we compare the current lead time with the lead time on the BIC, the differences are caused by the fact that transportation times will reduce. Furthermore, inventory time could be reduced because of the changes in supplier lead time.

Figure 5.5 shows the differences in the supplier lead time. First, we consider the supplier lead time of PC. In the current situation the supplier lead time is four weeks. Depending on the location of the supplier, in the BIC situation the lead time could be four weeks or three weeks. After that we consider the supplier lead time of PS, this is dependent on the supplier and subcontractor location. The supplier lead time in the current situation is 10.5 weeks. In the BIC situation the supplier lead time could reduce to 10, 9, 8.5, or 7.5 weeks.

We considered the supplier lead time of ASML NL as well, this is dependent on the supplier and subcontractor location as well. The supplier lead time in the current situation is 14 weeks. In the BIC situation the supplier lead time could reduce to 13 weeks and 2 days, 12 weeks and 2 days, 11 weeks and 4 days, and 10 weeks and 3 days.

As a conclusion we can say that the total lead time of ASML NL products, in the considered supply chain, changes from 14 weeks to:

- 13 weeks and 2 days if only KMWE is located on BIC. This is a reduction of 4% compared to the current situation.
- 12 weeks and 2 days if KMWE and subcontractors are located on BIC. This is a reduction of 12% compared to the current situation.
- 11 weeks and 4 days if KMWE and suppliers are located on BIC. This is a reduction of 16% compared to the current situation.
- 10 weeks and 3 days if KMWE, suppliers, and subcontractors are located on BIC. This is a reduction of 24% compared to the current situation.

---

**Table 5.11: The total touch time and no touch time for the BIC situation, in hours.**

<table>
<thead>
<tr>
<th></th>
<th>Total touch time</th>
<th>Total no touch time</th>
<th>Percentage touch time</th>
<th>Percentage no touch time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total (two off BIC)</td>
<td>145.21</td>
<td>459.85</td>
<td>31%</td>
<td>69%</td>
</tr>
<tr>
<td>Total (suppliers on BIC, subcontractors off BIC)</td>
<td>145.21</td>
<td>392.35</td>
<td>37%</td>
<td>63%</td>
</tr>
<tr>
<td>Total (suppliers off BIC, subcontractors on BIC)</td>
<td>145.21</td>
<td>416.85</td>
<td>35%</td>
<td>65%</td>
</tr>
<tr>
<td>Total (two on BIC)</td>
<td>145.21</td>
<td>349.35</td>
<td>42%</td>
<td>58%</td>
</tr>
<tr>
<td>PC (two off BIC)</td>
<td>19.66</td>
<td>198.5</td>
<td>10%</td>
<td>90%</td>
</tr>
<tr>
<td>PC (suppliers on BIC, subcontractors off BIC)</td>
<td>19.66</td>
<td>178.5</td>
<td>11%</td>
<td>89%</td>
</tr>
<tr>
<td>PC (suppliers off BIC, subcontractors on BIC)</td>
<td>19.66</td>
<td>198.5</td>
<td>10%</td>
<td>90%</td>
</tr>
<tr>
<td>PC (two on BIC)</td>
<td>19.66</td>
<td>178.5</td>
<td>11%</td>
<td>89%</td>
</tr>
<tr>
<td>PS(two off BIC)</td>
<td>5.55</td>
<td>141.85</td>
<td>4%</td>
<td>96%</td>
</tr>
<tr>
<td>PS (suppliers on BIC, subcontractors off BIC)</td>
<td>5.55</td>
<td>133.35</td>
<td>4%</td>
<td>96%</td>
</tr>
<tr>
<td>PS (suppliers off BIC, subcontractors on BIC)</td>
<td>5.55</td>
<td>137.35</td>
<td>4%</td>
<td>96%</td>
</tr>
<tr>
<td>PS (two on BIC)</td>
<td>5.55</td>
<td>129.35</td>
<td>4%</td>
<td>96%</td>
</tr>
</tbody>
</table>
CHAPTER 5. EFFECT OF SUPPLY CHAIN CENTRALIZATION ON LEAD TIME

5.4 Conclusions, Recommendations, and Future Research

In the last part of the research the following research question is answered:

What is the effect on the lead time of the supply chain if it is centralized on the BIC?

5.4.1 Conclusions

The total lead time of the ASML NL products, in the considered supply chain, will reduce. The reduction of the lead time is dependent on whether the suppliers and subcontractors are located on the BIC or stay at their current location. The lead time reduction is based on the fact that transport time will reduce. Furthermore, because of the reduction of lead time at the suppliers and subcontractors the arrival time will increase. An increased arrival time will lead to a reduction in inventory time, while maintaining the same service level.

The current lead time is on average 14 weeks, this could be reduced by 24% if KMWE, all the suppliers and subcontractors are located on the BIC. The lead time could be reduced by 16% if KMWE, and the suppliers are located on the BIC. The lead time could be reduce by 12% if KMWE, and the subcontractors are located on the BIC. The lead time could be reduced by 4% if only KMWE is located on the BIC.

By doing the analysis of the touch time and other time elapsed it became clear that there is room for improvement regarding to the ratio between the touch time and the elapsed time. Currently, the no touch time for ASML NL products produced in PC is on average 91% and in PS 96%. Especially in the subprocesses material handling and quantity control use a long lead time, while the actual touch time is low. Furthermore, the items stay relatively long inventory.

The effect of centralization of a supply chain is the reduction of total lead time. Depending on which supplier or subcontractors are located on the BIC, KMWE can reduce their lead time.

Figure 5.5: The comparison between the supplier lead times, for PC, PS and ASML NL. The lead time is depended on whether the suppliers/subcontractors are located in the current location or the BIC.
5.4.2 Recommendations

After the analysis it became clear that there is a potential for reducing the lead time in the supply chain. When a company is interested in moving to the BIC, the BIC management can calculate the potential reductions in the lead time compared to the current situation.

We recommend KMWE to reconsider the process flow in the company. According to the research it might be possible to reduce the lead time by increasing the ratio touch time and elapsed time.

5.4.3 Future Research

When it will become clear which other companies will be located on the BIC, a more comprehensive research is needed. The lead time of that specific company in the supply chain of KMWE has to be investigated into more detail. Here, the question is if it is possible to reduce the lead time because of the reduction in transportation time, sharing the same inventory, and information sharing.

Furthermore, it has to be investigated if it is possible to reduce the elapsed time in the production process. There could be some reasons why the touch time is low compared to the elapsed time.
Chapter 6

Effects of Centralization in a Supply Chain

We modeled and analyzed the effects of supply chain centralization at KMWE on BIC, for customer ASML NL. The research question of this project is:

What are the effects on the transportation costs, inventory, and lead time if companies of the supply chain are centralized?

After consideration of the literature it is decided to consider three subjects: transportation, inventory, and lead time.

In this section we conclude the research, we make recommendations, and opportunities for future research are given.

6.1 Conclusions

First, centralization causes a reduction of the transportation costs which is dependent on the changes in transportation modes, structures, and frequencies (Holweg, 2008). In the case of KMWE and BIC the transportation costs will change depending on the costs of the transportation system on the BIC, the pay per use method that will used (based on current costs or AGV system costs), and the payback period of the transportation system.

This research points out that the transportation costs between PC and PS will decrease in most cases. Moreover, there will be savings in transportation costs if suppliers or subcontractors of KMWE are located on the BIC.

However, it has to be clear that the BIC is not developed to reduce costs. The major aims of the development are cooperation and innovation to obtain competitive advantages and deal better with the changing market environment.

Even though companies focus more and more on logistics costs, a cost saving of a few thousands euro per year is negligible by considering the opportunities of lead time savings in today’s “Time-Based-Competition” (Hummingbird, 1995 and Stalk, 1988).

Secondly, inventory pooling and information sharing in a centralized situation is easier as a in a de-centralized situation. Information input of orders from a downstream supply chain member could be a misleading parameter for production and inventory decisions of the upstream supply chain members. A seamless and effective supply chain is the result of synchronized information flows and systems (Childerhouse and Towill, 2003 and Voisin, 1996). Competitive advantage could be raised by sharing up-to-date logistics information (Ang, 1999). One possible way to coordinate the product’s physical flow and the information flow is proximity. The fact that the companies could easily arrange face-to-face meetings will increase the exchange of knowledge (Weterings and
CHAPTER 6. EFFECTS OF CENTRALIZATION IN A SUPPLY CHAIN

Ponds, 2009), which makes more intense relationships (Venables, 2004) and increases innovations (Oerlemans and Meeus, 2015 and Gertler, 2003).

Inventory pooling is possible if companies has the same items in inventory. Moreover, one physical inventory location and shared information system will facilitate the inventory pooling. If PC and PS change their purchasing and safety stock level determination for supply ordered according to the base-stock policy from the isolated manner, to an aggregated manner this will reduce the inventory amount by 7% and the inventory value by 10%.

By sharing the information with upstream supply chain members the variance of the purchase orders at the suppliers could shift more to the variance of the work orders for ASML NL in KMWE. In other words the bullwhip effects could reduce. We found that there is a potential for reducing the bullwhip by on average 99% for the three suppliers considered. By decreasing the bullwhip effect less inventory must be held to maintain the same service level.

A decrease in inventory level is always desirable. It could be possible that the inventory spaces in the warehouse on the BIC are limited or KMWE has to pay a high inventory holding price. If this is the case, the aim is to reduce the inventory as much as possible. Moreover, by increasing the information sharing the BIC companies could strive for Just-In-Time (JIT) management. JIT management is an other goal of the BIC.

Last but not least, the lead time is considered, the lead time is defined in most industries as a competitive advantage (Hummingbird, 1995 and Stalk, 1988). The change in lead time could have the greatest impact on the benefits of centralization of KMWE and its supply chain.

The reduction of the lead time is based on the reduction in transportation time and the reduction of inventory time. The reduction of the lead time is dependent on the location of the suppliers and the subcontractors. The current lead time is on average 14 weeks, this could be reduced by 24% if KMWE, all the suppliers and subcontractors are located on the BIC. The lead time could be reduced by 16% if KMWE and the suppliers are located on the BIC. The lead time could be reduced by 12% if KMWE and the subcontractors are located on the BIC. The lead time could be reduced by 4% if only KMWE is located on the BIC.

The lead time reduction is based on the reduction of transportation time and the reduction of inventory holding time.

The value of the lead time reduction is dependent on the customers. Customers might be willing to pay an extra amount if the lead time is reduced. Another scenario is that customers are willing to pay extra for emergency orders. Moreover if back order costs are high, the reduction of lead time is of major importance.

Finally, the effects for KMWE on the BIC are not only expressible in monetary value, other factors are of major importance as well. For example synergy, economics of scale, relationship management, and work satisfaction. These factors are hard to quantify.

It is up to individual companies which of the factors have the most value for them. Depending on this, the decision can be made to relocate to the BIC.

6.2 Recommendations

First we have recommendations for the BIC management, after that the recommendations for KMWE are considered.

Regarding BIC management

Several suppliers are identified as important potential partners for the BIC. S2 and S3 are suppliers that deliver fasteners and tools, it could be useful to have an inventory hub of S2 or S3 on the BIC. Presumably, the products of S2 and S3 are not only used by KMWE, but also by other BIC companies. Moreover subcontractors S1, S15, or S16 could be considered as a surface treatment
specialist. This could be a processes that is offered as a shared facility on the BIC. Presumably, the processes of S1, S15, or S16 are not only used by KMWE, but also by other manufacturing companies located on the BIC. Finally, it is recommended to discuss the possibilities of a BIC-wide contract with suppliers such as S12 and S14. Their products are assumed to be widely used in the manufacturing industries, and it might be possible to gain economics of scale if the entire BIC orders in an aggregated manner.

A good information system on the BIC is essential to obtain competitive advantages. It is recommended to investigate the possibilities for a BIC-wide system.

Finally, if a supplier is interested in moving to the BIC the BIC management could calculate the lead time reduction for a specific supply chain and company. With the focus on the reduction of the transportation time and inventory time.

**Regarding KMWE**

First, we would like to recommend KMWE to track their transportation costs more specific, this to facilitate the analysis and decision process for the BIC case. Other important parameters are the product sizes and weights.

Secondly, we recommend KMWE to change the purchasing and safety stock level determination from the isolated manner, to an aggregated manner for the items that are ordered according to the base-stock policy. Moreover, as a first step KMWE could standardize the primary supplier selection. Both changes will lead to a decrease in inventory amount. Besides, demand forecast information could be shared. The sharing of information between PC and PS is a first step.

Moreover, we recommend to reconsider the process flow in the company. It might be possible to reduce the lead time by increasing the ratio of touch time and elapsed time.

**6.3 Future Research**

First we consider the future research subjects for the BIC management, after that the future research subjects for KMWE are considered.

**Regarding BIC management**

Starting with the transportation system. It is recommended to do further research on the costs of the transportation system in the BIC situation. This could be done by involving AGV specialists. After that is it is possible to conclude whether or not the use of AGVs in the BIC is appropriated.

Moreover, the willingness to move or operate at the BIC of the mentioned suppliers and subcontractors have to considered. When other companies are interested, it is possible to do further research on inventory pooling.

The information sharing system is needed to share information among BIC members. In the future, it must be investigated whether it is possible to arrange a BIC-wide information system. Here, it must be taken into account that the companies on the BIC are still individual companies, this means that privacy issues must be considered.

On top of that, if inventory is pooled on the BIC, the BIC management has to solve issues relating to priority between the different individual companies.

**Regarding KMWE**

KMWE could investigate if it is possible to reduce the elapsed time in the production process. There could be some reasons why the touch time is low compared to the elapsed time.
Bibliography

BIC. (2016). De nieuwe locatie voor de Hightec maakindustrie Brainport Industries Campus.
KMWE. (2016k). Powerpoint Organogram KMWE.
Aalhyster Forklifts. (2016). Retrieved from http://www.aalhysterforklifts.com.au/index.php/about/blog-post/forklift%7B%5C_%7Dspeed%7B%5C_%7Dlimits%7B%5C_%7Dand%7B%5C_%7D braking%7B%5C_%7Din%7B%5C_%7Dthe%7B%5C_%7Dwarehouse


Appendix A

Turnover Distribution

This appendix is used for Chapter 1. This appendix is confidential.
Appendix B

Suppliers KMWE

Suppliers specific for ASML Netherlands during 2015, specified for PC and PS are added in this appendix. The appendix is confidential.
Appendix C

80% supply and outside processes

In this appendix we listed the suppliers that delivered 80% of the material and the subcontractors that performed 80% of the processes. This is specified for PC and PS during 2015. This appendix is confidential.
Appendix D

Transportation Graphs & Tables

In this appendix we added graphs and tables used in Chapter 3. This appendix is public.

Table D.1: The capacity and percentages used per transportation mode.

<table>
<thead>
<tr>
<th>Transportation mode</th>
<th>Capacity (in number of Europallets) (Logistics, 2016)</th>
<th>Percentage (un)loading PC (KMWE, 2016m)</th>
<th>Percentage (un)loading PS (KMWE, 2016m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car van</td>
<td>1</td>
<td>13%</td>
<td>8%</td>
</tr>
<tr>
<td>Van</td>
<td>5</td>
<td>52%</td>
<td>68%</td>
</tr>
<tr>
<td>Tail-lift truck</td>
<td>17</td>
<td>20%</td>
<td>21%</td>
</tr>
<tr>
<td>Curtain side truck</td>
<td>34</td>
<td>15%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Figure D.1: The total amount of products transported from PC to PS, specific for customer ASML NL in 2015 (KMWE, 2016e).
Figure D.2: The number of incoming shipments per day at PC (Figure D.2a) and PS (Figure D.2b) (KMWE, 2016e).

Table D.2: Indices used in Chapter 3.

<table>
<thead>
<tr>
<th>Indices</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>Member of KMWE Group, $x \in {PC, PS}$</td>
</tr>
<tr>
<td>$y$</td>
<td>Supplier or subcontractor of KMWE Group, $y \in {1, \ldots, N}$</td>
</tr>
<tr>
<td>$N$</td>
<td>Total number of suppliers and subcontractors</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Index for $x$ and $y$ on BIC</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Index for $x$ on BIC and $y$ not on BIC</td>
</tr>
<tr>
<td>$A$</td>
<td>Index used to indicate that transport is paid per run</td>
</tr>
<tr>
<td>$B$</td>
<td>Index used to indicate that transport is paid per hour</td>
</tr>
<tr>
<td>$C$</td>
<td>Index used to indicate that transport is paid per weight.</td>
</tr>
</tbody>
</table>
### Table D.3: Fixed variables used in Chapter 3.

<table>
<thead>
<tr>
<th>Fixed Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_\alpha$</td>
<td>The shipment fee per package per km on BIC.</td>
</tr>
<tr>
<td>$R_\beta$</td>
<td>The fixed fee paid per run in current situation</td>
</tr>
<tr>
<td>$S_\beta$</td>
<td>The fixed fee paid per hour in current situation</td>
</tr>
<tr>
<td>$W_\beta$</td>
<td>The fixed fee paid per pallet in current situation</td>
</tr>
<tr>
<td>$D_\alpha$</td>
<td>The distance of transport on BIC.</td>
</tr>
<tr>
<td>$K_\beta$</td>
<td>The average speed (in km/h) in the current situation</td>
</tr>
<tr>
<td>$U_\beta$</td>
<td>The (un)loading time per vehicle</td>
</tr>
<tr>
<td>$I$</td>
<td>The maximum number of companies in the BIC.</td>
</tr>
</tbody>
</table>

### Table D.4: Input parameters used in Chapter 3.

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{x,y}$</td>
<td>The total number of pallets transported between node $x$ and $y$.</td>
</tr>
<tr>
<td>$F_{x,y}$</td>
<td>The shipment frequency between node $x$ and $y$.</td>
</tr>
<tr>
<td>$D_{x,y}$</td>
<td>The distance of transport between node $x$ and $y$.</td>
</tr>
<tr>
<td>$Z$</td>
<td>The payment contract. $Z_A \in {A}$, $Z_B \in {B}$, and $Z_C \in {C}$</td>
</tr>
</tbody>
</table>

### Table D.5: Decision variables used in Chapter 3.

<table>
<thead>
<tr>
<th>Decision variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_\alpha$</td>
<td>$Y_\alpha = \begin{cases} 1, &amp; \text{if } {x,y} \in \alpha; \ 0 &amp; \text{else.} \end{cases}$</td>
</tr>
<tr>
<td>$Y_\beta$</td>
<td>$Y_\beta = \begin{cases} 1, &amp; \text{if } {x,y} \in \beta; \ 0 &amp; \text{else.} \end{cases}$</td>
</tr>
</tbody>
</table>

### Table D.6: Output parameters used in Chapter 3.

<table>
<thead>
<tr>
<th>Output parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_\alpha$</td>
<td>The total transportation costs in the BIC situation, per supplier/subcontractor</td>
</tr>
<tr>
<td>$T_\beta$</td>
<td>The total transportation costs in the current situation, per supplier/subcontractor</td>
</tr>
</tbody>
</table>
Figure D.3: Percentage difference between the current transportation costs and the BIC transportation costs per supplier (considered for the three pay back periods). A negative number indicates a decrease in costs if BIC transportation cost is used.
Appendix E

Transport Confidential

In this appendix we added the confidential parts of Chapter 3. This part is confidential.
Appendix F

Background Calculations
Transportation

In this section we describe how we derived the number of shipments between PC and PS. This appendix is public. Unfortunately this data was not available at the company. If we assume that the scheduled date is the same as the shipment date, the products produced for ASML NL in PC and PS are transported during 213 days (KMWE, 2016e). During a transport day 45 products are shipped, on average, from PC to PS ($\frac{213}{4.679} = 45$). If we assume that there fit on average 45 products in the van, we can calculate the total shipments during 2015.

When we analyse the data about the number of products transported per shipment day, we found that during 68% of the shipment days there is one transport between PC and PS. During those 144 days the total number of transported items are below 45 items.

18% of the shipment days there were two transports between PC and PS. The number of shipments per shipment day are reducing from 8% to 0.5% for 3 to 7 shipments per shipment day. The distribution of the number of transports per shipment day is given in Figure F.1.

The total shipments made during 2015 from PC to PS are calculated by (F.1). Here, the total number of shipments per shipment day ($d$) are multiplied by the number of times that this shipment per shipment day exists ($F_d$). So, for example there are 144 times ($F_1$) a transport day during 2015 where one shipment ($d$) is performed.

Total shipments = $\sum_{d=1}^{7} d \cdot F_d = 1 \cdot 144 + 2 \cdot 38 + 3 \cdot 18 + 4 \cdot 6 + 5 \cdot 1 + 6 \cdot 1 + 7 \cdot 1 = 336$ (F.1)

As you can see the total shipments between PC and PS specific for customer ASML NL are 336 times during 2015.

Figure F.1: The distribution of number of shipments per shipment day for products transported in 2015 from PC to PS.
Appendix G

Background Information: Automated Guided Vehicle

In this appendix we added more information about the Automated Guided Vehicle. This appendix is public. An Automated Guided Vehicle (AGV) is a mobile robot that navigates independently using magnets, lasers, vision or geo-guidance. The vehicles are used in industrial environment to transport materials and products in a factory or warehouse. The last decades the use of AGVs is growing in popularity, especially as companies struggle with a shortage of skilled labour, high labour costs, and 24/7 operational requirements (Richards, 2014). The benefits of a AGV compared to traditional forklift trucks are listed below (Richards, 2014):

- An AGV system requires a minimal amount of human interactions. Therefore, the use of an AGV system could save a significant amount of labour costs.
- By using an AGV system, it is possible to work continuous, 24/7 (disregarding the downtime for repair).
- The use of AGVs is preferable in environments that are dangerous or have sensitive conditions (for example in clean rooms).
- By using the robots, human error is minimized.

In conversations with specialists in the field and BIC, it became clear that the AGVs will have a capacity of one pallet.
Appendix H

Information about the 80% of supply Suppliers/Subcontractors

This appendix is used for Chapter 3. This appendix is confidential.
Appendix I

Total transport costs per payment method

The calculations are used in Chapter 3. This appendix is confidential.
Appendix J

Effect selection and transport costs

This appendix is used for Chapter 3. This appendix is confidential.
Appendix K

Solver Analysis

Consists of the total transportation costs and the names of the suppliers and subcontractors that are selected. This information is used for Chapter 3. This information is confidential.
Appendix L

Table $S_\alpha$

This information is used for Chapter 3. This information is confidential.
Appendix M

Inventory Graphs & Tables

In this appendix we added some graphs and tables used in Chapter 4. This appendix is public.
Figure M.1: The inventory amount (Figure M.1a) and inventory value (Figure M.1b) in items during the year 2015, for customer ASML NL in PC and PS. The figure shows that the value of inventory for ASML NL in PC is lower than in PS, during 2015 (KMWE, 2016j).

Figure M.2: The inventory amount (Figure M.2a) and inventory value (Figure M.2b) of inventory on hand at PC for customer ASML NL during 2015 (KMWE, 2016j).
Figure M.3: The inventory amount (Figure M.3a) and inventory value (Figure M.3b) of inventory on hand at PS for customer ASML NL during 2015 (KMWE, 2016).

Figure M.4: The number of items in inventory of PC, and the number of items that are in the shared inventory of PC and PS, for customer ASML NL during 2015 (Figure M.4a). The number of items in inventory of PS, and the number of items that are in the shared inventory of PC and PS, for customer ASML NL during 2015 (Figure M.4b) (KMWE, 2016).
Figure M.5: The unique items in inventory of PC and PS, during 2015 for three suppliers. The figure illustrates that the number of unique items in inventory of PC and PS are highest for supplier S3 (KMWE, 2016j).

Figure M.6: The amount of items in inventory of PC and PS, during 2015 for three suppliers. The figure illustrates that the number of items in inventory of PC and PS are highest for supplier S3 (KMWE, 2016j).
Figure M.7: The value items in inventory of PC and PS, during 2015 for three suppliers. The figure illustrates that the value of items in inventory of PC and PS are highest for supplier S3 (KMWE, 2016j).
Figure M.8: The bullwhip effect is observed by the ordering policy of multiple products at three suppliers considered.
Appendix N

Inventory Confidential

In this appendix we added the confidential part of Chapter 4. This appendix is confidential.
Appendix O

Background Inventory

In this appendix we added more information about the theory used in Chapter 4. This appendix is public.

Researchers found that upstream supply chain members gain most from information sharing (Croson and Donohue, 2006). However, if information is fully shared, it is stated that the decision makers continue to exhibit the bias. In the experiments done by the researcher it appears that downstream entities of the supply chain do not use inventory information to their full advantage. It is stated that the information sharing has a different impact, depended on the place of the supply chain. The results suggest that inventory information may be more useful as one moves further away from end user demand. In Figure O.2a the researchers visualized the amplification component of the bullwhip effect, if inventory information is not shared. In Figure O.2b it indicates the variance of the orders, but here the inventory information is shared. In this figure you can see that sharing of inventory information may be more useful as one moves further away from end user demand.

Frank Chen et al. (2000) states that there is a lower bound of the bullwhip effect. According to them, the lower bound on the variance of the orders placed by each stage of the supply chain relative to the variance of customer demand is given by (O.1).

\[
\frac{Var(q^k)}{Var(D)} \geq 1 + \left( \frac{2 \sum_{i=1}^{k} L_i}{p} + \frac{2(\sum_{i=1}^{k} L_i)^2}{p^2} \right)(1 - \rho^p) \tag{O.1}
\]

In which \( L_k \) is the lead time between stage \( k \) and \( k + 1 \), \( p \) is the number of periods observed and \( \rho \) is the correlation parameter (\(|\rho| < 1\)).

Sucky (2009) investigates the effect of risk pooling on the bullwhip effect. As you can see in Figure O.3 the bullwhip effect will reduce if risk is pooled.
Figure O.1: Illustration of the bullwhip effect, variability of the orders is high compared to the variability of the sales (Lee, Padmanabhan, and Whang, 2004).

Figure O.2: The variance of orders is lower if inventory information is shared (Figure O.2b) compared to the situation where inventory information is not shared (Figure O.2a) (Croson and Donohue, 2006).
Figure O.3: In Figure O.3a bullwhip effect without considering risk pooling, between the two retailers. The figure shows that the wholesaler’s orders vary more than the retailers’ periodical demand. In Figure O.3b the bullwhip effect with considering risk pooling, the variance is reduced significantly (Sucky, 2009).
Appendix P

80% Suppliers Amount and Value Inventory

The lists of suppliers that are responsible for 80% of the amount and value of the items in inventory. This appendix is confidential.
Appendix Q

SQL queries

Q.1 Entire Inventory

In this section the SQL queries are included used for the analysis made in Section 4.2.2 of Chapter 4. This appendix is public.

1. Create the equal list per month, per item. This list consists of all the items that are in inventory at KMWE Precision Components and KMWE Precision Systems analysed per month, the shared item portfolio.

   ```sql
   SELECT b1.Item, b1.Month FROM 'Blad1' as b1
   INNER JOIN 'Blad1' as b2
   ON (b1.Item = b2.Item AND b1.month = b2.month
       AND b1.Ccn = 1000 AND b2.Ccn = 3000)
   GROUP BY Item, Month
   ```

2. Create an extra column in shared item portfolio, that adds all the inventory on hand inventories if ccn, month and item are equal.

   ```sql
   INSERT INTO work.sum.matching
   SELECT work.*, SUM('OH Qty') AS OH Qty
   FROM work
   WHERE Item IN (SELECT b1.Item
                   FROM 'work' AS b1
                   INNER JOIN 'work' AS b2
                   ON ( b1.Item = b2.Item
                        AND b1.month = b2.month
                        AND b1.Ccn = b2.Ccn)
                   )
   GROUP BY Ccn, Item, month
   ```

3. Update the date (day-month-year) to month.

   ```sql
   UPDATE Purchase
   SET Month=(SELECT SUBSTRING(
                  'Closed Date',
                  LOCATE(’-’, 'Closed Date')+1,
                  LOCATE(’-’, 'Closed Date', LOCATE(’-’, 'Closed Date')+1) -
                  LOCATE(’-’, 'Closed Date') -1
               )
   FROM Purchase)
   ```
APPENDIX Q. SQL QUERIES

4. Create a new table with the total products used in a certain month, per item, per ccn.

```
CREATE TABLE 'used.per.month'
SELECT Ccn, Item, period, Sum(use)
FROM (  
    SELECT m1.Ccn, m1.Item, m1.Month +1 as period, 'Oh Qty' as 'use'
    FROM 'work.sum.matching' as m1
    UNION ALL
    SELECT m2.Ccn, m2.Item, m2.Month as period, -'Oh Qty' as 'use'
    FROM 'work.sum.matching' as m2
    UNION ALL
    (SELECT Ccn, 'Po.Item' AS Item, Month as period, SUM('Rec Qty') as 'use'
     FROM Purchase
     Group by Ccn, 'Po.Item', Month)
) AS used
GROUP BY Ccn, Item, period
```

5. Create new columns for the values of products used one/two time steps before.

```
INSERT INTO 'used.per.month' (Ccn, Item, Period, 'used-1')
SELECT t.Ccn, t.Item, t.Period +1, t.'Sum(diff)' AS 'used-1'
FROM used AS t ON DUPLICATE
KEY UPDATE 'used-1' = t.'Sum(diff)'

INSERT INTO 'used.per.month' (Ccn, Item, Period, 'used-2')
SELECT t.Ccn, t.Item, t.Period +2, t.'Sum(diff)' AS 'used-2'
FROM used AS t ON DUPLICATE
KEY UPDATE 'used-2' = t.'Sum(diff)'
```

6. Calculate $E$, $Var$ and $y$ for each ccn, item, month

```
SELECT Ccn, Item, Period, 0.5*('used-1' + 'used-2') AS E,
0.5*(Pow('used-1' - (0.5*('used-1' + 'used-2'))),2) +
(Pow((('used-2' - (0.5*('used-1' + 'used-2'))),2))) AS VAR,
0.5*('used-1' + 'used-2') +
2.33*(SQRT(0.5*(Pow('used-1' - (0.5*('used-1' + 'used-2'))),2)
+Pow(('used-2' - (0.5*('used-1' + 'used-2'))),2))) AS y
FROM 'used.per.month'
WHERE period < 12 AND period > 2
```

7. Calculate $\bar{y}$ for each item and month.

```
SELECT a1.Item, a1.Ccn, a1.period, a1.y, SUM(a1.y+a2.y)
FROM 'E.VAR.y' as a1
INNER JOIN 'E.VAR.y' as a2 ON
(a1.Item = a2.Item
AND a1.Ccn=1000 AND a2.Ccn=3000 AND a1.period=a2.period)
GROUP BY Ccn, Item, Period
```
8. Calculate $\tilde{y}$ for each item and month.

\[
\text{SELECT p1.Ccn, p1.Item, p1.Period, p1.E, p1.VAR,}
\]

Q.2 Entire Items

Used for the calculation done in Section 4.2.3 of Chapter 4. This appendix is public.

1. Selected item specific supplier out of history list.

\[
\text{SELECT b1.Item, b1.Type, b1.Quantity, b1.Month}
\text{FROM 'history' as b1}
\text{INNER JOIN 'unique_items_supplier' as b2}
\text{ON (b1.Item = b2.Item)}
\]

2. Insert result into new table.

\[
\text{CREATE TABLE 'supplier_unique'}
\text{SELECT b1.Item, b1.Type, b1.Quantity, b1.Month}
\text{FROM 'history' as b1}
\text{INNER JOIN 'unique_items_supplier' as b2}
\text{ON (b1.Item = b2.Item)}
\]

3. Add the work orders, if work order are part of the same item and same month. Add the purchase orders, if purchase order are part of the same item and same month.

\[
\text{CREATE TABLE 'sum_quantity_supplier'}
\text{SELECT Item, type, SUM(Quantity), Month}
\text{FROM 'supplier_unique'}
\text{GROUP BY Item, Type, Month}
\]

4. Make a primary key on item, type, and month.

5. Make sure that there is a quantity during every month, do for every month:

\[
\text{INSERT IGNORE INTO 'sum_quantity_supplier'(Month, Item, type)}
\text{SELECT 1 AS Month, Item, type}
\text{FROM 'sum_quantity_supplier'}
\]

6. Change all NULL to actual number 0.

\[
\text{CREATE TABLE 'sum_quantity_supplier_new'}
\text{SELECT IFNULL('SUM(Quantity)', 0), 'Item', 'type', 'Month'}
\text{FROM 'sum_quantity_supplier'}
\]

7. Calculate the variance of work orders and purchase orders, and create an excel document for further analysis.

\[
\text{CREATE TABLE 'variance_supplier'}
\text{SELECT VARIANCE('IFNULL(''SUM(Quantity)'', 0)'), Item, type}
\text{FROM 'sum_quantity_supplier_new'}
\text{GROUP BY Item, type}
\]
Appendix R

Lead Time Graphs & Tables

In this appendix we added some graphs and tables used in Chapter 5. This appendix is public.
Figure R.1: Typical lead time of product produced at KMWE for ASML NL, in the current situation. The lead time of the entire process is 14 weeks (KMWE, 2016g and KMWE, 2016h).
Figure R.2: Typical lead time of a product produced at KMWE for ASML NL, in the BIC situation. This is based on empirical research.
Table R.1: The comparison between the lead time in the current situation and in the BIC situation.

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Current Situation</th>
<th>BIC Situation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inventory</td>
<td>Suppliers on BIC</td>
</tr>
<tr>
<td></td>
<td>0.5 week</td>
<td>Inventory</td>
</tr>
<tr>
<td></td>
<td>Production</td>
<td>Production</td>
</tr>
<tr>
<td></td>
<td>2 weeks</td>
<td>2 weeks</td>
</tr>
<tr>
<td></td>
<td>Inventory</td>
<td>Suppliers on BIC</td>
</tr>
<tr>
<td></td>
<td>0.5 week</td>
<td>Inventory</td>
</tr>
<tr>
<td></td>
<td>Shipment</td>
<td>Shipment</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>0.5 hour</td>
</tr>
<tr>
<td></td>
<td>Suppliers on BIC</td>
<td>Inventory</td>
</tr>
<tr>
<td></td>
<td>Production</td>
<td>Production</td>
</tr>
<tr>
<td></td>
<td>2 weeks</td>
<td>0.5 week</td>
</tr>
<tr>
<td></td>
<td>Production</td>
<td>Production</td>
</tr>
<tr>
<td></td>
<td>4 weeks</td>
<td>4 weeks</td>
</tr>
<tr>
<td></td>
<td>Inventory</td>
<td>Suppliers on BIC</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>Inventory</td>
</tr>
<tr>
<td></td>
<td>Shipment</td>
<td>Shipment</td>
</tr>
<tr>
<td></td>
<td>0.5 week</td>
<td>0.5 hour</td>
</tr>
<tr>
<td></td>
<td>Suppliers on BIC</td>
<td>Subcontractors off BIC</td>
</tr>
<tr>
<td></td>
<td>Production</td>
<td>Production</td>
</tr>
<tr>
<td></td>
<td>3 weeks</td>
<td>3 weeks</td>
</tr>
<tr>
<td></td>
<td>Inventory</td>
<td>Subcontractors off BIC</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>Inventory</td>
</tr>
<tr>
<td></td>
<td>Shipment</td>
<td>Shipment</td>
</tr>
<tr>
<td></td>
<td>0.5 hour</td>
<td>0.5 hour</td>
</tr>
<tr>
<td></td>
<td>Suppliers on BIC</td>
<td>Subcontractors off BIC</td>
</tr>
<tr>
<td></td>
<td>Production</td>
<td>Production</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>1 week</td>
</tr>
<tr>
<td></td>
<td>Inventory</td>
<td>Subcontractors on BIC</td>
</tr>
<tr>
<td></td>
<td>0.5 week</td>
<td>Inventory</td>
</tr>
<tr>
<td></td>
<td>Shipment</td>
<td>Shipment</td>
</tr>
<tr>
<td></td>
<td>0.5 hour</td>
<td>0.5 hour</td>
</tr>
<tr>
<td></td>
<td>Suppliers on BIC</td>
<td>Subcontractors on BIC</td>
</tr>
<tr>
<td></td>
<td>Production</td>
<td>Production</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>1 week</td>
</tr>
<tr>
<td></td>
<td>Inventory</td>
<td>Subcontractors on BIC</td>
</tr>
<tr>
<td></td>
<td>0.5 week</td>
<td>Inventory</td>
</tr>
<tr>
<td></td>
<td>Shipment</td>
<td>Shipment</td>
</tr>
<tr>
<td></td>
<td>0.5 hour</td>
<td>0.5 hour</td>
</tr>
<tr>
<td></td>
<td>Suppliers on BIC</td>
<td>Subcontractors on BIC</td>
</tr>
<tr>
<td></td>
<td>Production</td>
<td>Production</td>
</tr>
<tr>
<td></td>
<td>1 week</td>
<td>1 week</td>
</tr>
<tr>
<td></td>
<td>Inventory</td>
<td>Subcontractors off BIC</td>
</tr>
<tr>
<td></td>
<td>0.5 week</td>
<td>Inventory</td>
</tr>
<tr>
<td></td>
<td>Shipment</td>
<td>Shipment</td>
</tr>
<tr>
<td></td>
<td>0.5 hour</td>
<td>0.5 hour</td>
</tr>
</tbody>
</table>