BAS VERHEIJEN

Vendor-Buyer Coordination in Supply Chains

Vendor-Buyer Coordination in Supply Chains

Vendor-Buyer Coordination in Supply Chains

Verkoper-koper coördinatie in supply chains

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de
Erasmus Universiteit Rotterdam
op gezag van de
rector magnificus

Prof.dr. H.G. Schmidt

en volgens besluit van het College voor Promoties.

De openbare verdediging zal plaatsvinden op
vrijdag 21 mei 2010 om 9.30 uur

door

Hubertus Johannes Jacobus Verheijen
geboren te Cuijk

ERASMUS UNIVERSITEIT ROTTERDAM

Promotiecommissie

Promotor:	Prof.dr.ir. J.A.E.E. van Nunen
Overige leden:	Prof.dr. S.L. van de Velde
	Prof.dr.ir. R. Dekker
	Prof.dr. J. Wijngaard
Copromotor:	Dr. R. Kuik

Erasmus Research Institute of Management-ERIM
Rotterdam School of Management (RSM)
Erasmus School of Economics (ESE)
Erasmus University Rotterdam
Internet: http://www.erim.eur.nl

ERIM Electronic Series Portal: http://hdl.handle.net/1765/1

ERIM PhD Series in Management, 194
Reference number ERIM: EPS-2010-194-LIS
ISBN 978-90-5892-234-2

Design: B&T Ontwerp en advies (www.b-en-t.nl)
Cover Art: S. van Drie
Print: Haveka www.haveka.nl

To my parents

Acknowledgments

The emotion that comes with writing this last part of the dissertation is a mix of utmost joy and relief that the finish is near, combined with a sense of regret that this work will now become definite and final, making the addition of any new thoughts or insights or improvements impossible. On top of this, there is the unnerving prospect of the massive amounts of free time that I will soon have at my disposal.

I would like to take this opportunity to acknowledge the people who have helped and supported me and made the process of doing this research a pleasurable journey.

Going back to how this project started, my interest in supply chain research was triggered by my previous job in the high-tech industry in a newly set up billion-dollar facility with dramatically high fixed costs, when, as a result of the burst of the technology bubble in 2001, hardly any production was taking place. The research on Vendor Managed Inventories at RSM suited my interest in researching possibilities to improve the usage of scarce and expensive production resources by improved alignment of demand and supply. I am greatly indebted to Jo and Roelof for trusting my ability to master the skills for conducting academic research in the field of management. Jo, thank you very much for your insights and enthusiasm. I would like to thank you especially for consistently motivating me to work on the dissertation, even during the last few years when finishing this dissertation came second to my job. Roelof, it has always been a pleasure to work with you and witness your truly endless intellectual curiosity. You have introduced me to the world of operations research. I very much appreciate all your support in this project. Apart from our discussions on the world's problems, you were always available to help with good advice and interesting suggestions about the research.

During this research, I had the opportunity to work with Peter Tielemans from Cap Gemini, who shared his insights on the practice of supply chain collaboration.

Together with Henk Jan Meints, also from Cap Gemini, and Yaqin Sheng, who was, at that time, a student working on her Master's project, we surveyed advanced collaboration among Dutch suppliers in the fast-moving consumer goods market, as inspiration for Chapter 2. I have enjoyed many fruitful discussions about supply chain collaboration and synchronization with Piet van der Vlist, resulting in, among others, an article that triggered some further discussion on the benefits of collaboration (van der Vlist et al., 2007).

It was a pleasure to be a member of the department, vg1. I especially enjoyed the interesting conversations we had during lunches. It was nice to see that the 'photo-challenge' became popular in the department. Apart from creating many photo enthusiasts, this has lead to many heated discussions about photos and different camera types. Special thanks go to Niels Lang, our local king of Java, for teaching me the essentials of programming simulations in Java. Umut and João, the discussions we had at the times we went to the cinema, for dinner, or to the 'Mongolian' bar were sometimes weird, often passionately carried out, but always fun. Umut, I am looking forward to celebrating your defense soon. Ting and Hai Liang, Jordan, Muhammad, Elfi, Gabor, Lars, Diederik, Marcel, thanks for making my time in Rotterdam an enjoyable one.

Hans and Niels, I am very happy to have you standing by me at my defense as my paranymphs. I have enjoyed discussing about the research and many other topics with you, as well as our time building kitchens, playing on the Xbox, going for dinners and just being neighbors. You have become good friends.

My friends from Eindhoven University of Technology have been another great source of support. I treasure the fact that our friendship remains strong, even though I have not been around as often as I would have liked to be.

I would also like to thank my colleagues at NXP. Menno, I appreciate your understanding for all of the times when I was grouchy in the morning, after having worked late on the dissertation the night before and your support in enabling me to schedule my 'Ph.D.-holidays'. And Antoine: Yes, it is finished now.

The photo Managing Soap Bubbles on the front cover deserves some explanation. Even though soap bubbles seem simple spherical balls of air, their behavior and trajectory in the real world is difficult to forecast. 'Managing' soap bubbles in the real world with the aim of letting them join forces by traveling collaboratively is even more complex. Still, as with the research of this dissertation, it is great fun to play with soap bubbles, observe their colorful beauty and try to understand their behavior. Pelle and Seger, I hope that you have enjoyed playing with the super soap bubble solution as much as I have enjoyed taking photos of it. Sandra, thank you for designing the cover art at the title page.

Finally, I would like to thank my family. Jacko, Wendy, Dick and Saira, thanks for listening to my stories about this PhD over the past few years. I am looking forward to the extra time I will have to see my nieces Elise, Daniëlle and Sabine. Papa and Mama, thank you for always encouraging my scientific inquiries and curiosity. I really appreciate your support and encouragement at the times when obtaining a PhD seemed to be too much of a challenge.

Martine, it is great that you are there for me. Thank you for your encouragement to finish this dissertation and your patience when I was basically living in the study room. With you, it feels as if the pieces of the puzzle of my life are falling into place. As for the unnerving feeling as to what to do with my time, I am sure that we will find a way together.

Contents

Chapter 1

Introduction

Firms collaborate in order to provide products and services to their customers in a competitive manner. The form of collaboration between firms varies from transaction-based loose collaboration to very tight partnerships. Collaboration can take place in joint research and development projects, risk management, joint marketing efforts and supply chain management, to name a few examples. In this thesis, we focus on collaboration in supply chains. The effects of supply chain collaboration on the performance and competitiveness of the business can be significant. Optimizing the form of collaboration to an ever-changing supply chain environment can be a great advantage to businesses. The central focus of this dissertation is the analysis of the drivers and mechanisms behind advanced collaboration arrangements. This dissertation contributes to improving the knowledge and understanding behind selecting optimal supply chain collaboration arrangements.

This chapter is organized as follows. A generic introduction to supply chain management and supply chain collaboration is presented in Section 1.1. After that, we provide the motivation for our research in Section 1.2. In Section 1.3, we discuss the objectives of the research, the research questions around which the dissertation is organized, and the methodologies used. Finally, we present the outline of the dissertation in Section 1.5.

1.1 General Introduction Supply Chain Management

Various definitions of a supply chain and supply chain management have been suggested in the literature. Based on a combination of a number of these definitions, Lummus and Vokurka (1999) propose a classical definition for a supply chain as: 'all the activities involved in delivering a product from raw material through to the customer including sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, delivery to the customer, and the information systems necessary to monitor all of these activities'. According to their definition, supply chain management 'coordinates and integrates all of these activities into a seamless process'. This definition focuses on physical goods as products. Recently, the scope of supply chain management has become more broadly understood, and services and information as products are included in the scope. This is why we prefer the more generic definition of Cooper et al. (1997), who define supply chain management to be 'the integration of business processes from end user through original suppliers that provides products, services and information that add value for customers'. This makes a supply chain a vertical collaborative management effort with the aim to deliver a product to a customer.

Collaboration with different parties can improve the efficiency of accomplishing tasks, and can even make certain outcomes possible that would have been impossible to realize without collaboration. Firms collaborate both internally and externally. Internal collaboration takes place between colleagues or departments in a firm in order to realize the firm's common goals and objectives. External collaboration takes place with every party a firm transacts externally with, such as suppliers and customers. Businesses are intertwined and tied together via a multitude of collaboration arrangements. A firm that supplies a product to a buyer might have a number of suppliers of its own, each of which can have several suppliers themselves. The focus of this dissertation is the collaboration between different firms in the field of managing the supply chain. Collaboration in supply chains is gaining importance, as illustrated by Lambert and Cooper (2000), who state: 'One of the most significant paradigm shifts of modern business management is that individual businesses no longer compete as solely autonomous entities, but rather as supply chains'. This implies that parties have to collaborate in order to compete as a supply chain.

Strong enablers for creating a supply chain in which multiple firms collaborate are the visibility and accuracy of information that is exchanged and the ease of exercising control over the supply chain. Historically, closely collaborating firms are often located in close proximity to each other to avoid difficulties in information exchange and control. An example of this is the concentration of car-manufacturing industries in 'Motor City' Detroit. Recent developments in information technology allow firms to collaborate using advanced arrangements in which the control-responsibilities and flow of information between firms are arranged more efficiently. Consequently, geographical proximity between firms becomes less important.

Collaboration arrangements between different parties range from collaboration via a spot-market, with minimal interaction, to intimate collaboration, where parties mutually align and make relevant decisions together. We consider collaboration to range from loose collaboration with minimal, and transaction-based interaction, to the tightest form of collaboration where decisions are made by a single decision-making authority for all parties.

1.2 Motivation

The entire spectrum of collaboration —from loose collaboration that is transaction-based to tight collaboration via integrated control— can be observed in practice. Tight collaboration is not necessarily beneficial for every party in every environment. Two opposing forces —one favoring tighter and one favoring looser collaboration— are driven by the effects of and conditions for the collaboration arrangement. The push for tighter collaboration results from, among other reasons, the cost benefits that result from collaboration. A counter-force results from, for example, the costs of the investments required to collaborate closely, as well as the efforts needed to maintain a minimum necessary level of flexibility and decision power or autonomy. For certain effects of collaboration, such as strategic changes for a firm, the impact is not always clear in advance. The impact may depend on the short and long-term benefits that a firm expects to derive from it. However, the form of collaboration can severely affect the performance of the supply chain and the competitiveness of the business. In practice, firms aim to strike a balance between the opposing forces in determining the form of collaboration they use. The 'invisible hand' of Adam Smith implies that the forms of collaboration realized in practice are a reasonable compromise between these collaboration forces.

The landscape of benefits, conditions, and consequences of collaboration is permanently changing. Developments in information technology are an important factor in this changing landscape. Modern information technology mitigates difficulties and inefficiencies in collaboration between members of a supply chain. It reduces the cost of exchanging information, enabling frequent and efficient information exchange. Consequently, control of the supply chain that is virtually independent of geographical location becomes possible. Other factors present in the changing landscape of collaboration are developments such as expanding the physical infrastructure of highways and railroads, the containerization of transported goods, the European single market, satellite navigation, and omnipresent communication possibilities. The underlying economics of the various collaboration forms change as a result of the changing landscape. This calls for a redesign of the division of control, responsibilities, and information exchange between members of a supply chain. Significant gains in supply chain performance can be realized when firms optimize their supply chain partnering to best fit the new environment by striking a new balance between the forces of collaboration. In this research, we aim to study and to understand the mechanisms that define the success of advanced supply chain collaboration arrangements.

1.3 Research Objective and Research Questions

In this thesis, we deal with the fit between supply chain collaboration arrangements and the supply chain environment. In supply chain literature, a vast body of knowledge exists on the benefits of centrally coordinated supply chains (see for instance Clark and Scarf (1960), Eppen and Schrage (1981) and Federgruen and Zipkin (1984a)). A main assumption made when analyzing centrally coordinated supply chains is that a single party has access to all relevant information and has full authority to make decisions affecting the supply chain. One can view a centrally coordinated supply chain as the ultimate form of collaboration. In practice, arrangements between supply chain partners are less collaborative than the ideal of the centrally coordinated version. Nevertheless, substantial benefits derived from advanced collaboration forms have been observed. Advanced collaboration arrangements aim to capture the potential benefits of the centrally coordinated —theoretically optimal— supply chain. These collaboration forms are characterized by frequent and intensive exchange of information and agreement on responsibilities. Resources with finite capacity put constraints on the operational decisions that are practically possible in supply chains. This moderates the potential benefits from economies of scale using coordinated decision making. A growing body of literature is developing on such arrangements.

This dissertation has both practical and an analytical objectives. This dissertation will contribute to

- the exploration of the conditions for and the consequences of advanced collaboration arrangements in practice,
- and the understanding of the mechanisms behind the constraints and consequences of collaboration arrangements in the context of economies of scale with capacitated resources.

This research is organized around four research questions. In order to ensure a link between this research and problems that actually occur in practice, we will start by analyzing reported actual collaboration arrangements.

RQ1: *What are the conditions for and the benefits of collaboration arrangements in practice?*

In answering this question, we explore the practice of supply chain collaboration via reports in the literature. The next step, after identifying associative relations describing supply chain collaboration in practice, is to *understand* the mechanisms behind collaboration. We are particularly interested in benefits resulting from economies of scale for operations that are constrained by finite capacity, such as transport by trucks. This leads to the second research question.

RQ2: *In a supply chain collaboration arrangement, what are the mechanisms that translate the conditions for and the form of such arrangement into benefits? In particular, how does this translation happen in situations where economies of scale and capacitated resources are manifest?*

Much of the potential cost benefits resulting from the coordination of supply chain decisions are realized in optimizing the transportation of goods between firms. The analysis of potential cost savings in the area of transport is complex. The analytical literature often focuses on savings resulting from optimizing the shipping frequency and quantity for the supply chain. Third-party logistics providers can also realize potential savings on transport by optimizing shipment quantities, by offering transport tariffs for shipments that are less-than-a-truckload in size. This leads to the third research question.

RQ3: *How can tariffs for transportation of less-than-a-truckload quantity quantities be modeled to coordinate the usage of trucks efficiently?*

Instead of changing the decision responsibility in advanced collaboration arrangements, coordination between partners can also be realized via the alignment of incentives. We contribute to the body of knowledge on incentive alignment between vendor and buyer by researching the following question.

RQ4: *How can supply chain decisions be coordinated with a simple incentive scheme between vendor and buyer in the case of transport by capacity-constrained trucks?*

1.4 Methodology

Research in the field of Operations Research generally follows the rational knowledge generation approach (Meredith, 1989). Quantitative models are used to explain part of the behavior of real-life operational processes (Bertrand and Fransoo, 2002), under the assumption that these models objectively capture the decision-making problems that managers face. Models to describe reality are necessarily an abstraction of reality. In such idealized models, the aim is to model the smallest set of variables necessary to understand the mechanisms behind the real-life operational processes that are researched. As Bertrand and Fransoo (2002) note, an 'important shortcoming of idealized problems is that the effect of the human factor on the performance of the operational process is largely neglected'. Despite this shortcoming, the generic understanding and knowledge that can be derived from an idealized model may lead to valuable insights into the solution of operational problems.

Bertrand and Fransoo (2002) distinguish between two main types of research: empirical and axiomatic research. Empirical research is usually descriptive rather than normative. Empirical data that is obtained surveys, interviews, or case studies, among other methods, translates into models to describe reality. The relations in the model are associative, via correlations, or causal when the mechanism behind a relation is understood. Axiomatic research is research that is driven by an idealized model. Axiomatic research is generally normative (Meredith, 1989), with the aim to understand and develop operational policies or strategies for new or existing problems. The results of the developed policy can be assessed by comparing it to results known in the literature or to known upper or lower bounds of the problem.

The research in this PhD thesis follows multiple methodologies to mitigate the shortcomings of quantitative model-based research. We use a combination of empirical research and axiomatic normative research, driven by idealized models to answer the four research questions in this thesis. To this end, we start answering the first research question by analyzing empirical research via recent literature on practical observations of supply chain collaboration in the form of surveys, interviews, and case studies. The result is an associative model for collaboration.

The second research question is answered by literature research on axiomatic normative research on idealized quantitative models. Therefore, we review and structure recent analytical literature on advanced collaboration arrangement. This results in a generalized conceptual model for collaboration. Based on the results of the first two research questions, we synthesize an overall model for supply chain collaboration.

The third and fourth research questions that arise as a result of the first two follow an analytical quantitative model-building approach. This is axiomatic normative research, following idealized models of reality. Research question three is answered by modeling the basic interaction between a shipper and a carrier in order to derive transport tariffs. Numerical results to answer the third research question are obtained by Monte-Carlo simulation. In the research to answer the fourth and last research question, we build a quantitative analytical model to derive an optimal policy under given demand and truck capacity. From this, we analyze the effects of incentive schemes on supply chain collaboration.

1.5 Outline

This dissertation consists of six chapters. In Chapter 2, we present an overview of collaboration arrangements between vendor and buyer as they are found in practice. Results from surveys, case studies, and interviews in the literature studying collaboration in practice are used to develop an associative model revealing the conditions for collaboration arrangements and the benefits associated with collaboration. In Chapter 3, we focus on a normative model to study collaboration arrangements between firms. Benefits from coordinated decision making are often seen in realizing economies of scale in operations such as physical transport of goods between two firms. Chapter 4 deals with the pricing of transport services in situations of less-than-truckload transport, by determining the value of empty space in transport. The resulting transport tariffs function to coordinate the usage of the trucks efficiently. A condition for firms to engage in advanced collaboration arrangements is that joining such arrangement has to be economically rational for each firm. In the next chapter, Chapter 5, we research a supply chain collaboration arrangement where coordination is realized via an incentive alignment between a vendor and a buyer. The alignment system enables a vendor to influence the minimum and maximum stock levels within which the vendor controls the buyer's inventory level. The bandwidth-dependent financial incentive that the vendor offers to the buyer is determined via the model. The resulting supply chain coordination and supply costs are analyzed. Finally, in Chapter 6 we summarize the findings, draw conclusions, and point out avenues for future research.

Chapter 2

Drivers for Supply Chain Collaboration in Practice

Campbell Soup's introduction of a novel way to collaborate with its suppliers led to efficiency improvements throughout Campbell Soup's chain (Clark and Hammond, 1997, Cachon and Fisher, 1997). The case of Campbell Soup is but one among many accounts of improvements through supply chain collaboration (see, e.g., Stank and Daugherty (1997), Cottrill (1997), Vergin and Barr (1999), Peck and Juttner (2000), Kuk (2004)). In this chapter, we review collaboration arrangements that exist in practice and investigate the drivers for advanced collaboration arrangements.

In Section 2.1, we review reported forms of collaboration arrangements in practice, based on information collected in interviews, surveys and case study research among firms in the field, published in academic and trade journals. The second part, Section 2.2, discusses drivers for collaboration. Benefits of collaboration are the ultimate driver for collaboration. These benefits might apply to all supply chain parties, or only to a subset of the parties involved. Further, benefits tend to apply to a larger or lesser extent, depending on certain conditions. In this section, we describe the conditions necessary for collaboration, applicable to one or all parties involved in the arrangement. The third part, Section 2.3, presents the resulting associative model with the benefits and conditions as drivers for collaboration in practice. We discuss the validation of the associations in the model. Observations that are based on the model may be subjected to statistical tests. We conclude, in section 2.4, with a discussion of the results and propose directions for the model to be further validated in future research.

2.1 Forms of Collaboration in Practice

In practice, different forms of collaboration arrangements are used to meet supply chain requirements. Each form of collaboration arrangement has its own characteristic elements. To begin with, one is what we call the *conventional* supply chain arrangement between a vendor and a buyer. In a conventional arrangement between buyer and vendor, the buyer is responsible for managing its inventory and determines the quantity and timing of replenishments received from the vendor. The buyer informs the vendor of the requirements via the issued purchase orders. The vendor, upon receiving these orders, manages its operations in such a way that the buyer receives the replenishment within the contracted service agreements. The vendor is responsible for the goods until delivery. This responsibility extends to the vendor's internal operations, the vendor's finished goods inventory, and transportation of the goods to the buyer. The buyer is responsible for managing its own inventory and for on-time triggering the vendor for replenishments via purchase orders.

Towards the end of the twentieth century, awareness arose that this conventional arrangement for the goods and information exchange between a buyer and a vendor did not make adequate use of the newly available information technology. New agreements were proposed to supplement, and at times replace conventional buyer-vendor arrangements. For example, in the mid 90's Efficient Consumer Response (ECR) arose as a program to improve supply chain and marketing performance in the grocery supply chain (see report ECR Europe (1996)). The supply chain management program within ECR was labeled Efficient Replenishment (ER). ER offered a range of ideas and suggestions for supply chain improvement using techniques as Electronic Data Interchange (EDI), and Activity Based Costing. Exchanging data under EDI means that a buyer places electronic orders to a vendor (see Swatman et al. (1994)). Continuous Replenishment Programs (CRP) were then introduced, which went further than information exchange via EDI. Under CRP, instead of replenishments based on orders, a vendor can decide on the timing and sizing of replenishments, based on daily sales data or inventory data that is shared by the retailer as a buyer. Orders from the buyer to the vendor are essentially eliminated (Clark and Hammond, 1997). In essence, CRP is a program that has later become known as Vendor Managed Inventories (VMI).

A VMI arrangement is a supply chain arrangement between a vendor and a buyer in which the vendor is given the authority to manage the inventory of the buyer. This provides the vendor with the latitude to schedule its own production and then decide upon the timing and sizing of replenishments to the buyer as long as agreed customer service levels for the buyer are met (following Claassen et al. (2008)). Even though the vendor manages the buyer's inventory, the buyer remains financially liable for the inventory in a true VMI arrangement. In practice, parties often choose to deviate from this by placing inventory at the buyer under consignment. This is discussed in the sequel of this section.

CRP is a form of a VMI arrangement in which no specific orders from buyer to vendor are needed (Clark and Hammond, 1997). CRP is, however, ill defined. The literature on CRP often refer to exactly the same replenishment arrangement as VMI. In contrast to this, Sabath et al. (2001) make a sharp distinction between VMI and CRP based on the responsibility of the replenishment decision. In their definition of the CRP arrangement, the buyer remains responsible for inventory management and replenishment decisions. Cachon and Fisher (1997) take the position that CRP is a VMI arrangement, where, in addition to shifting the responsibility to the vendor for the timing and sizing of replenishments, two other features are explicitly incorporated. First, EDI linkages are used to electronically transfer data of inventory positions and withdrawals in distribution centers. Second, an Every Day Low Pricing strategy is assumed between producer and retailer. Under an Every Day Low Pricing scheme, no promotions or price-discounts disrupt the supply chain operations. Automated transfer of inventory information via EDI and conditions for stable and predictable demand, undisturbed by price-promotions enable the vendor to manage the retailer's inventory levels efficiently. This dissertation follows the definition of CRP as essentially a VMI arrangement without orders or any sharing of forecasts.

Sometimes the name Supplier Managed Inventory (SMI) is used as another name for VMI (Curtis, 2000, Sabath et al., 2001, Ray and Swanson, 1996, Pohlen and Goldsby, 2003). Sabath et al. indicate that VMI, SMI and Distributor-managed inventory (DMI) (Bjork, 2006) are comparable approaches since the vendor instead of the buyer initiates the replenishments. Pohlen and Goldsby, on the other hand, distinguish between VMI and SMI. They argue that the term VMI is to be used in the relationship between a manufacturer and a retailer whereas SMI is to be used in the transactions between a supplier and manufacturer. The main difference in the two situations is the type of data that is exchanged. In addition to inventory data, actual sales data is shared in a VMI arrangement, while in SMI arrangements the production plans are exchanged. Still, in the case described by Ray and Swanson (1996) as a SMI program between Motorola and 2000 suppliers, the only information that is exchanged is on available inventory, goods receipts and desired minimum and maximum inventory levels. In the cited ECR framework on supply chain arrangement, a distinction is made between a manufacturer trading with retailers and a manufacturer trading with its suppliers.

From a conceptual point of view, a distinction between collaboration arrangements based on the position of a vendor or buyer as a manufacturer, supplier, or retailer, is not necessary. Instead, one may simply consider a supply chain arrangement between a selling party, the vendor, and a buying party, the buyer. The vendor could be a manufacturer with expensive operations and production planning or a simple re-seller whose operations encompass little more than purchasing products and selling and distributing these to its customers. We realize that the specific position or function of a vendor or buyer directly relates to the cost-impact of supply chain collaboration. However, we consider VMI to be defined as a collaboration arrangement between two generic supply chain partners, a vendor and a buyer, where the vendor has the authority to manage the buyer's inventory under mutually agreed-upon conditions. The conditions could be a minimum service level at the buyer (as in Claassen et al. (2008)), or a minimum and maximum within which the inventory has to be kept (as in Fry et al. (2001)).

A vendor might offer to maintain the buyer's stock in consignment. The vendor in that case retains ownership of the goods until these are actually used by the buyer later in the process. Examples of consignment stock arrangements can be found in the automotive industry (Corbett et al., 1999), the high-tech industry (Hung et al., 1995), and industries responsible for medical supplies for hospitals, building materials, spare parts and base chemicals (Cottrill, 1997). Under a conventional arrangement, the buyer pays the vendor at a certain point in time after receiving the goods, as specified in the terms of payment. The title to the goods, and therefore the economic risk, is assumed by the buyer the moment the goods are received and accepted. Economic risk can arise in the form of risk of obsolescence, product deterioration, or demand plunge. Instead, under consignment stock, the transfer of the title to the goods is postponed until the buyer withdraws the goods from its inventories. Only once the buyer withdraws the goods from its stocks does the vendor tender for payment. When the vendor and buyer are in a VMI arrangement and the vendor owns the buyer's inventory (consignment stock), this is called Vendor-Owned Inventory (VOI). Apart from consignment under VMI, it is possible to have consignment stock in a conventional arrangement, which we call a conventional-plus arrangement.

A VOI-arrangement keeps the vendor from placing large amounts of inventory at the buyer's warehouse. Additionally, a vendor under VOI may share part of the cost savings that he gains from implementing VMI by assuming the buyer's inventory holding costs. The actual choice for VMI or VOI depends on customs in the industry and the power situation in the supply chain. Buyers usually favor consignment stocks since no cash reservations are needed for holding inventory and inventory risks for the buyer are limited. Consignment stock arrangements may introduce imbalance between the vendor and buyer. Buyers may feel little incentive to act economically with stock and the vendor might be pushed towards maintaining abundant stocks, of which the financial burden fully falls to the vendor. See Corbett et al. (1999) for a description of a case in which this initially happened.

In some industries, it holds that the vendor has no option but to offer consignment stock arrangements in order to stay in business. In the publishing industry, offering consignment stock in retail outlets may be the only viable distribution strategy as Harrington (1996) indicates. Andel (1996) describes a case where a publisher has taken the challenge and is supplying 2,000 Walmart locations through a consignment program for its Golden Books line. Harrington mentions comparable strategies for seasonal products such as fertilizers and sunscreen. In these examples, the buyer never takes the ownership of the goods sold. Taken to the extreme, the role of the buyer could become confined to assortment and category management, as Peck and Juttner (2000) argue. In other industries, such as in the base chemical industry, the vendor made the first move by proposing a consignment agreement instead of a buyer pushing for consignment stock. The vendor regards the increase in stock that occurs as a result of consignment stock as an investment in service to the buyer instrumental in strengthening buyer loyalty (Vergin and Barr, 1999).

Consignment stock policies, per se, are cash flow constructions that encourage the buyer to optimize his cash flow and minimize his risk of holding inventory. Often, holding the buyer's inventory in consignment is used as a simple method to share the benefits of the vendor with the buyer. Therefore, this dissertation does designate consignment as a separate characteristic that affects the success of VMI. Instead, consignment is part of the overall incentive scheme between vendor and buyer leading to the operational implementation of the VMI collaboration arrangement.

Yet another type of arrangement between vendor and buyer in a supply chain in which the authority for making cost-affecting decisions differs from the conventional arrangement, is Factory Gate Pricing (FGP) (Le Blanc et al., 2006). The distinctive feature of FGP is that the buyer is responsible for triggering replenishments and for collecting the goods from the vendor. The information flow between buyer and vendor is not strictly defined in a FGP-context, so it could be as minimal as only a purchase-order. The buyer, having detailed information on its inventory and sales and responsible for arranging transport, can optimize his inventory level as well as the use of transport resources, possibly by collecting replenishments from multiple vendors in one transportation route. The vendor, on the other hand, has to keep sufficient inventory of finished goods in order to guarantee availability of supply to the buyer. The title to the goods is transferred from vendor to buyer upon accepting the goods, in this case at the factory gate.

Collaborative Planning Forecasting and Replenishment (CPFR) is another collaboration program. It was introduced in the late nineties as an approach to reduce costs and improve service levels in the grocery supply chain, see Stank et al. (1999), Barratt and Oliveira (2001). Although CPFR is positioned as the next step in supply chain integration, no direct link between VMI and CPFR exists. Regarding replenishment decision-making, the major difference between CPFR and VMI is that in CPFR the replenishment is based on a jointly established order forecast and order release pattern. Just as in the conventional arrangement between buyer and vendor, the buyer holds responsibility for triggering replenishments. CPFR should not be regarded as a sibling of VMI but rather as a different approach, focusing on jointly established demand forecasts and order forecasts.

The supply chain arrangements discussed above, conventional, CRP, QR/ECR, VMI, VOI, FGP and CPFR, differ in the division of authority to trigger replenishments. This is visualized in Figure 2.1.

The forms of supply chain collaboration discussed above are listed in Table 2.1. We derive four basic forms of collaboration from this table. First, the conventional form, under which the buyer is responsible for managing the incoming inventory and for triggering replenishments, while the vendor is responsible for the availability of supply. Second, FGP, where the difference with the conventional form is that transport of the goods from vendor to buyer is arranged by the buyer instead of the vendor. FGP will be the preferred choice when the opportunities for improving transport efficiency by the buyer are better than the vendor's opportunities to economize transport. For instance, this is the case when a buyer can collect goods from multiple vendors in close proximity to each other in one transportation route. The third form of collaboration is the group of VMI arrangements (CRP, SMI, DMI and

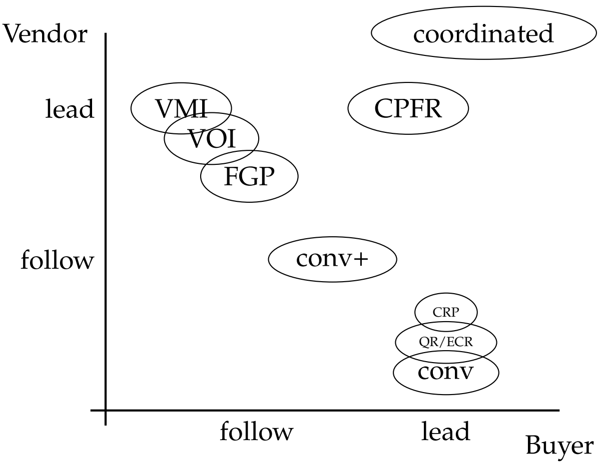


Figure 2.1: Overview of distribution of authority in a dyad between vendor and buyer for different collaboration arrangements.

VMI), in which the vendor assumes the responsibility for managing the buyer's inventory level. The fourth form is CPFR, where vendor and buyer jointly manage the supply chain, including the buyer's inventory level.

Table 2.1: Collaboration arrangements

Collaboration Arrangement	**Replenishment Trigger**	**Responsible Buyer inventory**	**Remark**
Conv	buyer	buyer	order-based communication
ECR	buyer	buyer	intensive communication, EDI
FGP	buyer	buyer	buyer responsible for transport
CRP	vendor/buyer	vendor	EDI and EDLP, no orders
SMI	vendor	vendor	supplier to manufacturer
DMI	vendor	vendor	distributor to retailer
VMI	vendor	vendor	generic vendor to buyer
CPFR	vendor, buyer	vendor, buyer	generic vendor and buyer

The responsibilities for triggering replenishments, organizing transport, and managing inventory levels under a collaboration arrangement are rearranged, under the assumption that the rearranged responsibilities lead to organization of the activities in a more efficient manner. The next section deals with what drives collaboration arrangements: the benefits, as claimed in practice, and the conditions necessary to realize successful collaboration.

2.2 Drivers for Collaboration in Practice

Two types of drivers for collaboration are distinguished: *benefits* that are realized as a result of collaboration and *conditions* that are necessary to realize collaboration. The observation that benefits of collaboration promote the initiation of collaboration is evident. Clearly, when significant benefits are identified in an arrangement, this will raise strong support for that arrangement. Benefits are considered a result ('ex-post') of an arrangement. Conditions, on the other hand, are enablers that may exist 'ex-ante' to an arrangement. The benefits and conditions as drivers for collaboration are further differentiated by the dimension of operational and strategic drivers. Operational benefits may result from effects of collaboration on the efficiency of the processes in the supply chain. Collaboration can lead to efficiency improvements of the vendor's internal processes, the vendor's inventory management, transportation activities, the buyer's inventory management, and the buyer's internal process. The resulting effects of collaboration on the buyer's internal process are usually measured by the buyer's service levels. Benefits of collaboration at a strategic level are positive effects related to the long-term competitive position of a firm in relation to rivals and other firms in the supply network. These latter benefits are categorized as strategic effects of collaboration. Conditions for collaboration in the operational dimension are related to day-to-day activities necessary to collaborate effectively, such as data exchange. Strategic conditions are related to the firm's positioning in the supply chain network and the product's demand and market characteristics.

Peck and Juttner (2000) argue that collaborative arrangements in the form of network organizations can provide a more effective means to satisfy customer needs. The profits realized by collaborating exceed the profits realized by the single firms. Strategists have strongly pushed for system integration. Issues like activity coordination, product movement and information transmission used to be coordinated by the market, but 'failure of markets to control product supply' leads to integrated activities, which span company boundaries. The analysis of the interface between relationships, strategy and supply chain management is far from complete, according to Peck and Juttner (2000).

2.2.1 Operational benefits of Collaboration

Reports from practice show that collaboration pays off. At Guinness, a vendor, the introduction of an arrangement in which the vendor and buyer jointly align on forecasts and production and replenishment planning, stock levels were reduced by 30% in the first year and by 10% in following year, while keeping customer service levels constant (Peck and Juttner, 2000). Benefits are often realized as a result of better forecasting and planning systems for transport and production. Proctor & Gamble Co are reported to have saved over $65 million in 18 months through more efficient logistics, under the heading of 'efficient consumer response', as researched in a case study (Cottrill, 1997). Detailed sales and demand data is exchanged to plan and implement product replenishments and sales strategies. The vendors benefit from more efficient production and logistics, but at the same time bear most of the implementation costs. The ultimate goal, according to this study, is to forge an integrated supply chain, with VMI being one strategy to achieve this. VMI goes beyond automating and reassigning responsibility for replenishments. Instead, supply chains will compete as a close-collaborating supply chain against other integrated supply chains, looking to create economic value across the whole chain and measuring performance using overall chain metrics.

In the Cachon and Fisher (1997) article on the case study at Campbell soup, the vendor assumes the responsibility for managing the buyer's inventory levels via a continuous replenishment program. Information on inventory levels is exchanged between buyer and vendor via EDI. On average, inventory levels decreased by 66%, while maintaining the same or even higher fill rates. This resulted in a reduction of cost of goods sold by 1.2%, which is significant in the grocery industry with its low margins. Interestingly, the authors find no evidence that the savings are related to the vendor managing the buyer's inventory. Instead, they attribute the savings to improvements in information exchange.

Kulp et al. (2004) conclude from a survey of 54 firms in the food and consumer packaged goods industry that sharing information is associated with an increase in manufacturer performance only up to a certain level. Beyond that, collaboration in replenishment planning in the form of a VMI arrangement affects the vendor's margins positively and results in lower stock-outs for the buyer. From a survey in the Taiwanese grocery industry, Tyan and Wee (2003) conclude that implementation of vendor-owned inventory (VMI plus consignment) leads to a service level increase, from 92% to 98%, at the distribution center of the buyer. The holding of inventory is reduced from 26 days to 13 or 16 days. A problem in the VOI arrangement is that the system is manually overruled in case of promotions, new product introductions and when basic data is inaccurate.

Supply chain integration affects operational performance and the degree of integration influences the cost and efficiency (Bagchi et al., 2005). More than half (57%) of respondents in a explorative survey among 149 European companies confirmed reductions in logistics costs as a result of supply chain integration with partners. Production flexibility improved for 43% of the firms and the inventory turn ratio increased for 57% of the firms after supply chain integration.

The predominant focus in the above studies is on inventory usage and resulting service levels. The focus in the following studies is on the total supply chain costs, including transportation. Supply chain costs in the chemical industry can represent 60% to 80% of the manufacturing costs. A reduction of 10% of supply chain costs through collaboration significantly improves margins (Cottrill, 1997). Over 90% of chemical firms are planning and working on supply chain initiatives for closer partnerships.

As discussed in the previous section, CRP is basically a form of VMI where the vendor continuously manages the buyer's inventory. The name Continuous Replenishment evokes the image of very frequent deliveries with small drop sizes. This is perhaps the reason that also VMI sometimes is associated with an increase in delivery frequency. However, as Kaipia et al. (2002) note, a VMI arrangement itself does not require a greater frequency of deliveries. The effect of VMI on the delivery frequency can go both ways. A routing schedule in which the vendor uses flexibility to replenish multiple buyers on an efficient route in smaller quantities than in the conventional arrangement increases the delivery frequency. The frequency might increase also when buyers provide limited storage capacity for the vendor to place VMI inventory into, then it is sufficient to meet demand only for a limited amount of time. On the other hand, the delivery frequency may decrease when VMI is used to improve the efficiency of transportation to a customer by delivering full trucks, full pallets, or full pallet layers instead of multiple fractional deliveries.

Based on three cases in grocery supply chains, Kaipia et al. (2002) measure the benefits of VMI in time benefits. With many items in assortment, retailers have difficulty managing the ordering process. Under VMI, the vendor assumes authority over and responsibility for the replenishment process, using the availability or stock-out level and inventory turnover-rate as performance measures. The vendor knows information on stock levels much earlier compared to in the conventional case, allowing the vendor time to react. The vendor's safety stock levels can be reduced for a wide range of stock keeping units as a result. The frequency of deliveries does not necessarily increase.

Operational planning of the vendor can be improved compared to just-in-time arrangements. In line with Lee et al. (1997), and Disney and Towill (2003a), Kaipia et al. (2002) conclude that VMI levels peak demand, thus smoothing requirements on the vendor's processes. This leads to cost benefits as it makes a higher average utilization rate possible, allows the vendor to avoid paying overtime to complete fluctuating requirements or avoids last-minute expensive orders for raw materials. VMI leads to the largest benefits for manufacturers with little excess capacity. The reason for this is that the vendor's advantage caused by receiving information earlier disappears when a vendor has sufficient production capacity to produce within the requested lead-time. To illustrate this, imagine an extreme situation where a vendor has infinite production capacity. Any large-sized order from its buyers can be produced instantaneously. In this extreme case, early information on the buyer's needs do not result in efficiency gains in production and therefore has no value.

To sum up, operational benefits resulting from advanced collaboration arrangements such as VMI are realized through efficient use of inventories, efficiency gains in production, and efficiency gains in transportation. An important operational outcome of collaboration is the service level, as this is directly linked to revenues by avoiding lost sales. Service levels at the buyer remain at the same level or even increase. Inventories are used efficiently, effectuated by reduced average inventory levels, especially the inventory at the buyer's facility. The increased visibility and timeliness of information that vendors receive under VMI grants the vendor more time to prepare for demand. As a result, demand fluctuations can be mitigated, improving the supply chain efficiency at production and transportation stages and enabling the vendor to maintain similar or better service levels for the buyer with lower average inventories. Logistics costs for transport are further reduced as a result of additional opportunities for the vendor to plan transport more efficiently than in the conventional supply chain arrangement.

2.2.2 Strategic benefits of Collaboration

VMI not only functions as stepping-stone to a seamlessly integrated supply chain, but is also a powerful tool for strategic advantage for a vendor in three ways. First, VMI positions vendors closer to the buyers, which can be a strategic advantage.

The intensity of the contact and interaction with buyers under VMI increases. Automated information exchange and order handling make it harder for a buyer to change suppliers (Vergin and Barr, 1999) than in a conventional setting. Second, the vendor can use detailed information on the customer sales for improved marketing knowledge. Detailed information on actual inventory levels or even sales data is a prerequisite for VMI. The third strategic advantage of VMI for vendors is that vendors can offer to take inventory problems off the buyer's hands, thus relieving the buyer of the administrative efforts required to schedule and order replenishments (Claassen et al., 2008). In this way, the vendor can forge stronger ties with the buyer.

Establishing a VMI arrangement makes sense only when both the account management strategy of the vendor and sourcing policy of the buyer favor the development of a partnership. Business processes and ICT- infrastructure have to be aligned, so the investments to build and maintain the partnership enlarge the costs of switching to another partner. Implementing a VMI arrangement increases customer contact and customer retention, as reported by chemical companies as BP Amoco, Dow and BASF, all of whom have offered VMI to customers (Challener (2000), see also Corbett et al. (1999). In a small-scale survey of leading Dutch suppliers within the chemical industry, improving customer relations was mentioned as the most important benefit of applying VMI, above efficiency improvements (Hobma (2001)). This is supported by a conclusion based on ten case studies (Vergin and Barr, 1999). They conclude that when a vendor has stock dedicated and consigned to a buyer, a lock-in situation for this buyer to stay with a vendor is created. This results from the increased investment threshold for the buyer to switch suppliers.

Standardized methods and protocols to exchange information and to setup VMI arrangements between vendors and buyers might counter the buyer lock-in effect. Some buying firms set up VMI arrangements with two competing firms, where both firms supply a percentage of the total volume. Apart from reducing the risks of non-supply if one company has delivery issues, having two supplying firms limits the vendor's power over the buyer. On the other hand, a VMI arrangement can be part of the criteria used by the buyer to select suppliers when a main element in the sourcing strategy of the buyer is to establish strong partnerships with preferred suppliers, as it is for ladder manufacturer Green Bull (Lamb, 1997)).

The amount of information exchanged between vendor and buyer in a collaboration arrangement exceeds the amount exchanged in the conventional setting. The vendor has access to more detailed and more precise information, often including actual sales information. Wal-Mart reasoned that the vendors often have the best knowledge of a product's demand rate. Wal-Mart shares point-of-sales data, which is collected at the counter in the supermarket with barcode scanners, with Proctor & Gamble. Proctor & Gamble knows the flow of Pampers best, which is why the vendor in this case, manages the replenishment of Wal-Mart's stock levels under a VMI arrangement (Vergin and Barr, 1999). Such detailed data on customer sales is valuable information to the marketing departments. Lipton actually uses VMI in order to gain access to the point-of-sales data for marketing purposes (Collins, 1997). This detailed information on sales that is transferred from buyer to vendor under a VMI arrangement is the second strategic advantage that stems from VMI.

In summary, there are three strategic advantages of collaboration for a vendor. First, collaboration can improve the vendor's strategic position in the vendor-buyer dyad as a result of close contact with the buyer and increased customer intimacy. This increases the threshold for buyers to switch suppliers and buyers might be 'locked-in' a VMI arrangement with the vendor. Second, the detailed and rich information flow from the buyer to the vendor leads to increased marketing knowledge on actual consumption and purchases of the products produced. Third, a vendor can use the advanced collaboration arrangement to offer to reduce the workload involved in the buyer's administrative process of order management thus reducing overhead.

2.2.3 Operational Conditions for Collaboration

In order to make decisions to assure availability of inventory in a supply chain, inventory management needs to know the state of the inventory at the current point in time, and develop some expectation of future requirements as well as know the capabilities of the supply system. Under VMI, the purchase order is abandoned and replaced by an exchange of data without directly necessitating the scheduling of replenishments. Not surprisingly, one of the main pillars of the vendor-managed inventory arrangement is the content of the information exchanged between the vendor and buyer and the handling of this information. This section deals with the contents and the quality of information exchange between supply chain partners as a condition for supply chain collaboration. The first condition is the information that is exchanged. This refers to the type of information and the content and richness of information that needs to be exchanged for supply chain collaboration. A second condition is the quality of information that is exchanged.

The most fundamental information that a vendor needs for managing the inventory of a buyer is the buyer's inventory level. This basic data has to be transferred accurately and in a timely manner to the vendor. When the buyer updates inventory records periodically (for example every 24 hours), data on actual withdrawals from the buyer's inventory can be used in between inventory data updates to derive an estimate of the current inventory level. Withdrawals can reflect actual sales if the buyer is a retail outlet, or warehouse shipments if the buyer acts as distribution center, or inventory consumption if the buyer is a manufacturer. Compared to sales data, inventory level data is more accurate in that it also accounts for inventory depletion through loss of goods caused by, for example, shrinkage, obsolescence and breakage (Harrington, 1996).

Note that it is by no means trivial to achieve cost savings by more information exchange: Clark and Hammond (1997) report that few firms in the retail industry have actually experienced significant savings from using EDI to improve the information exchange. Sabath et al. (2001) conclude from data gathered through a survey that no major differences in the capability of information systems exist between centrally organized companies versus decentrally organized firms: both are able to manage and control automated replenishment programs. Daugherty et al. (1999) finds a positive relationship between information systems and automated replenishment programs, based on survey data. Although automated replenishment programs are difficult to manage and consume a great deal of resources, they are worth it to a firm because a positive relationship exists between automated replenishment programs and the performance of a firm. The communication protocol between vendor and buyer is important for successful VMI. A standardized platform could be used to establish VMI arrangements (Dong and Xu, 2002).

It is not sufficient to have information sharing alone. The linkages of electronic data exchange (EDI) in the US grocery industry as a means to share information have been investigated by Clark and Hammond (1997). They find that supply chain channel transformation involving EDI in combination with a redesign of the replenishment processes enables performance improvements that are more than an order of magnitude greater than the performance increase achieved with the implementation of EDI alone. Implementation of only EDI without CRP fails to realize significant benefits, while implementing a new replenishment process with EDI leads to 50-100% higher inventory turns for products in a continuous replenishment program (Clark and Hammond, 1997). The same conclusion is reached in the earlier mentioned research by Kulp et al. (2004) that improved information sharing between vendor and buyer without changes in responsibilities in the vendor-buyer dyad leads to improved performance only up to a certain level.

The benefits of a VMI arrangement increase with increasing information precision and information reliability (Kulp, 2002). Information precision reflects the level of detail of information the buyer shares with the vendor. Information reliability relates to the vendor's information linkages (using EDI, content of information shared, quality of information transfer). Kulp analyzes supply chain profits under both conventional and VMI arrangements, depending on the buyer's willingness to share internal (sales and inventory) information and the reliability of data transfer (information precision and information reliability). In the conventional case, the vendor has access to accurate order data from the buyer. However, the buyer's order-size is not optimized for overall supply chain costs. Under VMI, the reliability and precision of information is assumed to be lower, but the vendor is able to optimize replenishments for cost efficiency. Kulp proves analytically that information reliability and precision increases the benefits of VMI. Data from a survey of 53 manufacturer divisions in the consumer packaged food industry corroborates the prediction that vendors are more likely to use VMI when retailers provide accurate and precise data. In partial contrast to the findings of Kulp (2002), the perceived performance improvement from the perspective of a buyer is impacted by the quality of the relationship between buyer and vendor, the quality of the IT-system and the intensity of information sharing, but not by the actual quality of the information shared (Claassen et al., 2008). The buyer-perceived performance impact of VMI in this survey is measured in costs, customer service levels, and supply chain control. All participants of a qualitative preparatory exploration exercise mentioned the importance of trust between vendor and buyer. Only one buyer reported a reduction in administrative costs as a result of VMI.

The logistics system of the buyer may have more than one facility for stocking inventory. For example, the buyer may employ a central distribution center with field warehouses or outlets. Then decisions have to be made on what is meant by 'withdrawal data and the inventory level'. Cohen et al. (2003) label the options for deciding the information content according to information precision. Information precision is a condition related to the success of a VMI arrangement. For example, a buyer with a retail organization that owns a central warehouse from which deliveries to retail outlets are made can choose to share information with a vendor at the warehouse level or data at the outlet level. In the first case, warehouse withdrawals for replenishment of the outlets are communicated to the vendor. The world's largest retailer, Wal-Mart, as one of the early adopters of the VMI concept in the Fast Moving Consumer Goods supply chain, started by communicating warehouse withdrawals to their VMI-partners (Vergin and Barr, 1999). Later, Point-of-Sale (POS) data on outlet sales, outlet inventory, and eventually forecasts were shared. However, only the replenishment of the warehouse stocks remained as the part of the VMI arrangement that is to be upheld by the vendors.

POS-data differ from warehouse data in the level of detail, the definition of the item involved (trading units, such as boxes, crates and cases versus consumer units) and the absence of batching effects due to outlet delivery. Peck and Juttner (2000) argue that in most cases warehouse data is communicated because forecast data at the warehouse level is more accurate than at the outlet level. In addition, practical reasons with regard to data retrieval from information systems favor the communication of warehouse withdrawals. In contrast to a widespread belief, POS-data is not a prerequisite for VMI. However, vendors value POS-data highly because of the market intelligence it comprises. In addition, POS-data can be an enabler for advanced supply chain optimization using cross-docking.

Next to the inventory level, the vendor needs to have some assumption on future withdrawals. To incorporate the buyer's future plans, the vendor can participate actively in the generation of forecasts of future withdrawals. Achabal et al. (2000) describe the development and testing of a VMI decision support system for a retail supply chain that includes the exchange of forecast data. As a result of implementing this VMI system, customer service levels improved dramatically, often coupled with a significant improvement in inventory turnover. Especially in retail supply chains, sales promotions with great temporal impact can have significant impact on sales volumes. In such environments, forecast data including promotional campaigns are to be exchanged between buyer and vendor. Benefits of such joint forecasting are, evidently, not unique to VMI and can be reaped also when some other, more conventional arrangement, is made. In a business-to-business supply chain where the vendor supplies a manufacturer, the expected withdrawals of inventory of raw material from the buyer may be expressed by the production plan instead of by the forecasts of end-customer demand. In these supply chains, the exchange of production plans is common (see for instance Lamb (1997), Corbett et al. (1999), Nolan (1997)).

In summary, operational conditions for successful collaboration are related to the transfer and processing of information to reach operational decisions. The richness of information exchanged, the openness and transparency of information exchange between the partners, including the level of detail of the information, such as forecasts, production plans or POS-data is described within the category 'information richness'. The reliability of information exchange due to the system setup and the communication structure is captured by the category 'information quality'. Both information richness and information quality are positively associated with the success of collaboration. An advanced ICT infrastructure to deal with the information exchange is also positively associated with the success of advanced collaboration. This falls under strategic conditions for collaboration, as we discuss in the next section.

2.2.4 Strategic Conditions for Collaboration

Despite the successes of VMI implementations in practice described above, VMI is not the ultimate solution for a supply chain between a vendor and a buyer (Goffin et al., 2006, de Leeuw and Fransoo, 2009). A grocery chain, Spartan Stores, is an example of a firm that decided to terminate its VMI arrangements. The reasons are problems with inefficient coordination of promotions, inadequate forecasting abilities by the vendors and higher frequency replenishments (Dong et al., 2007). It does not always pay off to optimize by giving the authority for managing inventory and stock levels to another organization. Cooke (1998) describes a number of firms that have abandoned VMI. Only a few studies have focused on factors that influence collaboration (Oh and Rhee, 2008, de Leeuw and Fransoo, 2009). In this section, we distinguish between three strategic conditions for collaboration: the ability of a firm to join advanced collaboration arrangements, the strategic fit between both firms, and the product fit between the market and product characteristics and collaboration arrangement.

One can imagine that factors such as the size of the companies involved, the volume of business to be transacted with VMI arrangements or experience with VMI arrangements mitigate the success of VMI. Vergin and Barr (1999) performed a study on 10 companies in the business of grocery manufacturing with two to seven years of experience with VMI. VMI collaboration arrangements were formed with large volume buyers representing 10 to 40% of business volume. Only one out of the ten vendors —the manufacturers, in this case— claimed a reduction of their own inventories. No statistically significant relevant relationship between the duration of experience with VMI and the number of VMI partners was found. However, a significant positive correlation was found between duration of VMI and the percentage of sales that went through VMI arrangements. Based on anecdotal evidence, Andel (1996) suggests that until VMI volume reaches at least 30%, the volume in VMI is too small to benefit forecasting and production.

Vergin and Barr (1999) further claim that the main benefits of VMI are enjoyed by the buyer. All manufacturers in this research state that the buyers achieved lower inventories and improved their service levels. Next to the lower inventories at the buyers, reductions in stock-outs ranged from 40 to 90%. Still, all manufacturers experienced direct benefits of VMI, such as increased sales or smoother inventory flow. Half of the manufacturing firms view offering VMI as a potential competitive advantage. The main reason to implement VMI was to retain a customer demanding to be delivered in a VMI arrangement. This leads to the second condition for collaboration: the strategic position of both firms.

Relationships between vendors and buyers that are encountered in practice range from one-time transactional relationships to long-term strategic partnerships. Joint product development is a typical example of long-term strategic partnering (see for instance Mentzer and Zacharia. (2000)). Establishing a collaboration arrangement such as VMI requires a shift from a transactional relationship based on purchase orders, goods receipt checking and delivery time monitoring towards a trust-based partnership. In this partnership, inventory control is outsourced and information exchanged is reinforced and integrated with back-office systems. Developing such a relationship consumes time and resources. As Gadde and Snehota (2000) indicate, a cost-benefit analysis should be used to determine the type of vendor-buyer relationship that should be developed. Typically, each firm will end up with a set of relationships differing in the mutual involvement.

The account management strategy and sourcing strategy are typically defined at a tactical or even strategic level in organizations. The decision to start a VMI arrangement heavily depends on the strategies of both potential partners. The benefits of such partnership at a tactical level may exceed the benefits at an operational level. Cox (2001) identifies the need to analyze and to take into account the power-position of a firm in a supply chain or the position a firm aims to have. Instead of assuming that companies strive to enhance the total performance of the supply chain, firms look at the strategic consequences of decisions on their position in a supply chain: How will they control and manage the primary supply chain and where should they position themselves in this chain? A buyer's goal to create a lean and mean supply chain that competes with other supply chains often is impossible to achieve in practice. Integrated supply chain management or full supply chain coordination is only possible when the focal company is either in a position of structural dominance over suppliers or when there is interdependence within an extended network of suppliers, where both sides willingly share power (Cox, 2001).

Companies can be successful if they possess power over something or someone. Suppliers aiming for above-average returns need to close the market to competitors or operate in opaque supply markets. Otherwise, the buyer might force the supplier to accept low margins and pass value on to the buyer. Buyers aiming for best supplier performance tend to push suppliers into such position. To counter this, suppliers strive for market closure through mergers and acquisitions. Collaboration arrangements between a buyer and a vendor may or may not change the strategic position one has in the supply chain. A vendor who is implementing a VMI arrangement with a buyer might be willing to sacrifice financial benefits in the short-term because of long-term improvements in the strategic position with VMI. The vendor has more control over supply and replenishments. VMI might make the buyer more dependent on the vendor. With VMI, the buyer faces higher switching costs when switching to another supplier than when within a conventional supply arrangement.

From sixty interviews among leading-edge firms about partnerships, Lambert et al. (1999) derive a model to guide managers' decisions regarding partnership development and implementation. Three major elements are found: Drivers, Facilitators and Management components. Drivers such as cost benefits or strategic benefits are compelling reasons to partner. Facilitators provide a supportive environment for growth, such as corporate compatibility and mutuality between the firms. Management components include planning, information sharing, joint operating controls, risk- and reward sharing and trust and commitment. Apart from agreements on who decides what (dominance) and what information is shared, additional conditions are a minimum level of trust, compatibility, and infrastructure for joint operating controls. Compatibility of infrastructure is partially covered under the operational conditions for information exchange. The minimum level of trust between vendor and buyer is the third strategic condition for collaboration.

In line with this, looking from the viewpoint of supply chain management, change management, marketing and logistics, Corbett et al. (1999) describe potential pitfalls and practical guidelines for forming and managing supply-chain partnerships based on a case study at a chemical company. The first key component in their framework for successful implementation is trust between both firms. They further note that other important conditions are: agreement on standards, agreement on the benefit-sharing principle and involvement of all relevant functions, especially IT involvement (Corbett et al., 1999).

Trust between the firms setting up a form of collaboration is essential to the success of the effort. Confidential information regarding, among others, production plans and new product introductions is essential to collaboration arrangements (Nolan, 1997). In an overview of cases of supply chain collaboration with a focus on incentive alignment, Narayanan and Raman (2004) distinguish three steps to realize coordination in the supply chain. After companies realize and accept that collaboration and incentive alignment is indeed important, the firms have first to rewrite the contracts. This affects the strategic position of both firms, as the priority in the decision-making changes. Incentives are put in place in order to align the decisions of one firm to the requirements of the other. Second, for this new mode of operation to work, it is important that the firms share all relevant information, including hidden information. This is information that a company prefers to keep private because it is either sensitive or of strategic importance to the firm. Third, a high level of trust needs to exist between both firms so that sharing of such information is possible.

The fourth strategic condition for the success of advanced collaboration arrangements is portfolio matching between the two firms. The type of supply chain arrangement between a vendor and a buyer can be studied from the point of view of the buyer or from the viewpoint of the vendor. Different research approaches are used in the industrial marketing literature and the purchasing literature to study buyer-vendor relationships (see e.g. Olsen and Ellram (1997b)). A popular technique from both the selling and the buying perspective is the portfolio approach (see Olsen and Ellram (1997a)). From the buying perspective, the matrix that Kraljic (1983) developed is the best-known portfolio approach for determining an appropriate supplier relationship. This is represented by a two-by-two matrix with on one axis low and high supply risk and on the other axis the value of the goods involved, low and high. This results in four distinct blocks. It is argued that a strategic partnership only should be developed for purchase items with a high risk of continuity of supply. A cost-efficient supply chain is important especially for routine items of relatively low value (commodity goods). For such items, an operational, cost-saving partnership such as VMI can be established. For the so-called leverage goods with a high purchase value but a low supply risk the sourcing strategy will typically be aimed at reducing direct procurement costs by exploiting competition between different suppliers instead of building long-term partnerships. From a selling perspective a comparable portfolio analysis can be executed favoring accounts that are relatively easy to manage and of strategic importance, to prioritize for building long-term partnerships (Fiocca, 1982). Based on results of a survey on determinants of adapting VMI, (Dong et al., 2007) indicate that the VMI adoption rate is positively associated with competitiveness of the vendor's market, as the competitiveness drives vendors to use efficient collaboration arrangements. Uncertainty in the buyer's operational process is negatively linked to VMI adoption rate. No support was found for the hypothesis —in line with Waller et al. (1999)— that demand uncertainty leads to higher VMI adoption rates.

Fluctuations in the buyer's demand could also fall under the header of portfolio matching. Clark and Hammond (1997) state that VMI is most appropriate for products with stable demand. When the buyer's demand is stable, replenishments can be coordinated and production and replenishments can be planned precisely and efficiently. On the other hand, the potential benefits that might be derived from advanced collaboration arrangements such as VMI are much higher for products with fluctuating buyer's demand. Then, the additional leverage of the buyer, combined with earlier and more precise information under VMI provides opportunities to improve compared to the conventional case. In previous studies, no significant proof is found for the hypothesis that demand uncertainty is associated with higher adoption levels of VMI (Dong et al., 2007).

Previous studies have not been conclusive on the relation between demand uncertainty and supply chain collaboration. van der Vaart and van Donk (2008) claim that uncertainty is a driver for close collaboration, in line with a case study research at Philips (de Kok et al., 2005). Empirical proof however is mixed: Dong et al. (2007) find no significant correlation between demand uncertainty and collaboration. Contrary to this, Holweg et al. (2005) conclude that stable demand is a condition for close collaboration. It might be that a moderating variable needs to be taken into account to understand the correlation between demand fluctuations and collaboration.

To summarize, we distinguish three strategic conditions affecting the success of collaboration. The first condition is a firm's *ability* to deal with advanced collaboration arrangements such as VMI. This is related to the size of a firm, the ICT infrastructure of a firm and the experience a firm has with advanced collaboration arrangements. The second condition for collaboration is the *strategic fit* between both firms. The strategic fit between firms consists of three elements. A.) Strategic argument: a powerful firm in a supply chain network can require the other party to accept a close collaboration arrangement. In that case, the non-dominant firm will make a strategic analysis whether or not to accept the proposed collaboration and continue as close partners. B.) Strategic position improvement: a firm can strive for a close collaboration arrangement in order to alter the strategic position of a firm in the supply network. C.) Trust: trust between both parties is an essential condition for advanced collaboration arrangements such as VMI. We aggregate these three elements under the term strategic fit. The third strategic condition we distinguish is the *product fit* between both firms. This relates to the matching of the type of product and the volatility and risks associated with demand and supply of the product.

2.3 Model for Collaboration in Practice

2.3.1 Associative Model for Collaboration in Practice

In the previous sections, we have identified drivers that are associated with collaboration in the empirical literature. These relations are based on empirical research ranging from surveys to case-studies and interviews. In this section, we categorize and structure the drivers to form an associative model for collaboration in practice. Then, we discuss the statistical support for these relations.

Conditions associated with Collaboration

The conditions for VMI adoption derived in Section 2.2.3 and Section 2.2.4 are grouped and listed in Table 2.3.1.

Two operational conditions are identified. The richness and the quality of information are positively associated with collaboration. Increasing information richness, such as by including production planning data or POS data, provides further inputs for the vendor to use to optimize operations. However, extra information is of value to the vendor only when he is able to act upon the information. Hence, the additional value of extra information decreases when more information is exchanged. Other factors, such as the flexibility a vendor has in production capacity, affect the value of information. The information quality is related to the systems and reliability of information transfer.

Three strategic conditions can be identified: a firm's ability to manage advanced collaboration arrangements, the strategic fit between both firms, and the product fit for the items that are exchanged under VMI. To implement advanced collaboration,

Table 2.2: Conditions that are positively associated with collaboration in practice

Condition	Description	References
info richness	information richness	Corbett et al. (1999)
		Lamb (1997)
		Nolan (1997)
	information precision	Kulp (2002)
	intensity of information sharing	Claassen et al. (2008)
info quality	timely, accurate information	Harrington (1996)
	EDI with VMI	Clark and Hammond (1997)
	standardized messaging	Dong and Xu (2002)
	information reliability	Kulp (2002)
ability	ICT infrastructure advanced	Kaipia et al. (2002)
		Corbett et al. (1999)
		Daugherty et al. (1999)
		Claassen et al. (2008)
	volume VMI experience	Vergin and Barr (1999)
		Andel (1996)
	duration VMI experience	Peck and Juttner (2000)
		Vergin and Barr (1999)
	company size	Vergin and Barr (1999)
strategic fit	trust	Corbett et al. (1999)
		Nolan (1997)
		Lambert et al. (1999)
		Narayanan and Raman (2004)
	prospect of long-term partnering	Fiocca (1982)
	power position favorable	Cox (2001)
	partner characteristics	de Leeuw and Fransoo (2009)
product fit	market conditions	Bensaou (1999)
		Olsen and Ellram (1997a)
	supplier's market competitiveness	Dong et al. (2007)
	market and product characteristics	de Leeuw and Fransoo (2009)
	demand low volume, infrequent	Kaipia et al. (2002)
	demand stable	Holweg et al. (2005)

it is necessary that both firms have the ability to deal with this. This is related to experience with VMI and company size. The strategic fit between both firms is a variable to describe how collaboration fits in the strategic goals of both firms. Factors such as trust, desire to collaborate to improve the strategic position, or consenting to the dominant party's desire to collaborate fall under this condition. The product fit is the third condition for collaboration. The case for collaboration is different for a cheap and easy to procure commodity product compared to a high-value product that is difficult to source. The stability or fluctuation of demand rates also fall under the condition for product fit.

Benefits associated with Collaboration

Companies report benefits that derive from VMI in practice. We structure and summarize the benefits identified in Section 2.2.1 and Section 2.2.2 in Table 2.3.1.

Operational benefits of VMI are efficiency improvements, mainly associated with the increased responsibility of the vendor to plan and optimize the timing and sizing of replenishments. Fluctuating demand can be leveled, resulting in more efficient use of the production capacity. Contrasting views exist in the literature on whether the transport frequency increases or decreases with VMI, but consensus exists on the fact that VMI correlates with increasing efficiency of transport. Inventory levels in the dyad are lower with VMI. Decreasing inventory levels on the side of the buyer, the vendor or both have been reported to result from VMI. The buyer's service level increases with VMI or remains at least at the same level.

Strategic benefits of VMI are an improved strategic position, increased marketing knowledge, or reduced overhead. Collaboration arrangements like VMI might improve the position of a firm in the supply chain network. A vendor can use advanced collaboration arrangements to encourage a tight link between the vendor and the buyer, thus increasing the threshold to change suppliers. Marketing information that is derived from the additional information on actual sales under a collaboration arrangement can be used to improve the performance of the vendor-buyer dyad in the supply chain. A final strategic benefit is that the overall overhead for administration and ordering reduces when the vendor has complete control over inventories in a VMI arrangement.

Table 2.3: Benefits that are positively associated with VMI in practice

Benefit	Description	Reference
production efficiency	reduced demand amplification	Kaipia et al. (2002)
		Lee et al. (1997)
		Disney and Towill (2003a)
	increased production flexibility	Bagchi et al. (2005)
		Tyan and Wee (2003)
transport efficiency	increased transport eff., higher freq	Vergin and Barr (1999)
	increased transport eff., lower freq	Kaipia et al. (2002)
		Cottrill (1997)
	increased transport efficiency	Peck and Juttner (2000)
	increased logistics efficiency	Bagchi et al. (2005)
	increased logistics eff., COGS -1.2%	Cachon and Fisher (1997)
inventory efficiency	reduced inventory vendor and buyer	Kaipia et al. (2002)
	reduced inventory buyer	Vergin and Barr (1999)
	reduced inventory buyer 66%	Cachon and Fisher (1997)
	reduced inventory buyer 30%	Peck and Juttner (2000)
	reduced inventory buyer 26 to 13 wks	Tyan and Wee (2003)
	increased inventory turns	Bagchi et al. (2005)
service level	constant or increased service level	Peck and Juttner (2000)
	increased service level	Vergin and Barr (1999)
	constant service level	Cachon and Fisher (1997)
	increased service level non-VMI cust.	Kaipia et al. (2002)
	increased service level 92% to 98%	Tyan and Wee (2003)
strategic position	increased buyer intimacy	Hobma (2001)
		Challener (2000)
		Corbett et al. (1999)
	strategic fit, close link	Lamb (1997)
	lock-in effect for vendor	Vergin and Barr (1999)
		de Leeuw and Fransoo (2009)
marketing knowledge	improved marketing knowledge	Collins (1997)
		Vergin and Barr (1999)
overhead	reduced administrative effort	Aichlymayr (2000)

Drivers for collaboration

We structure the conditions and benefits that are drivers for advanced collaboration arrangements such as VMI, based based on the results from the literature of empirical research of supply chain collaboration. The research methodologies that are used in the empirical research ranges from surveys to case studies and interviews. The resulting associative model for collaboration in practice is visualized in Figure 2.2. On the left, the conditions that affect the closeness of collaboration are shown: two operational conditions on information richness and information quality, and three strategic conditions on a firm's ability to implement VMI, the strategic fit between firms and the product fit with the collaboration arrangement. The benefits that are associated with collaboration are on the right of Figure2.2. Operational benefits on increased efficiency of production, transport, inventory, and service levels and strategic benefits on the strategic position of a firm in the supply chain network, marketing knowledge and reduction of overhead.

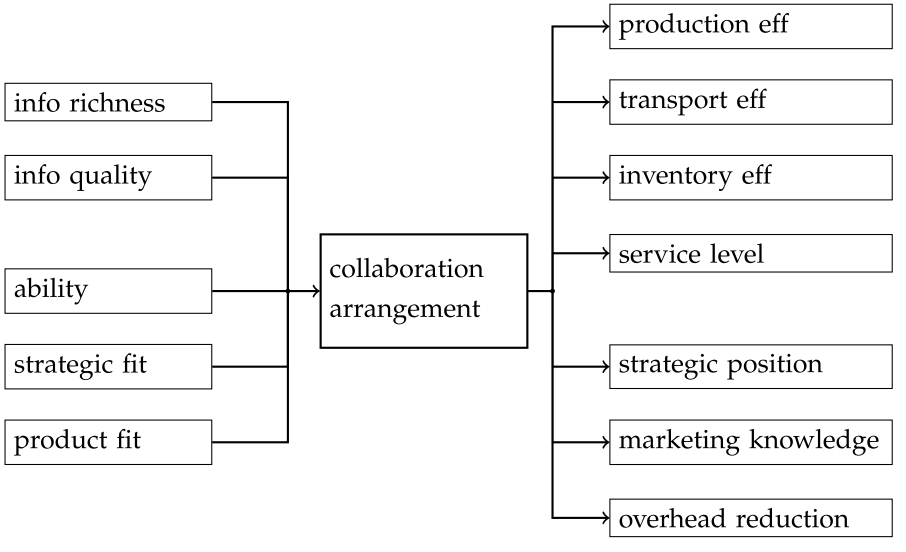


Figure 2.2: Model of conditions and benefits that are associated with collaboration arrangements

2.3.2 Empirical Statistical Support for the Model

The associative relations in the model of Figure 2.2 are based on results from empirical research in the literature. The research methodology behind the relations ranges from surveys to case-studies and interviews. Statistical support for the associative relations in the model of Figure 2.2 can result from survey research. A number of questions can be used to form a construct with which the model-variable is measured. We analyze the constructs that are used in the reviewed literature to measure the variables in the model.

van der Vaart and van Donk (2008) analyzed over 30 surveys on performance impact from supply chain integration. The authors note little consistency in basic definitions and constructs that are used to measure impact and integration. Authors in the literature have failed to build sufficiently upon the research of their predecessors. The overview shows excessive variation in the way supply chain performance is measured, as researchers often develop a new model with new measurement scales. A result of the lack of definitions and scales to measure supply-chain performance and supply chain collaboration is that conclusions from previous research are rarely confirmed by other researchers and progress slows since previous results are not built upon. To measure performance, objective or subjective scales can be used. Objective performance measurements are usually quantitative and comparable and often include financial measures. A problem of when using financial data is that financial benefits resulting from collaboration are difficult to be allocated to a specific collaboration arrangement. Furthermore, non-financial benefits of collaboration cannot be captured in this manner. Therefore, scales used to survey collaboration arrangements are often based on subjective measures of performance (Sodhi and Son, 2009). Perceptual measures are acceptable in large-sample studies, provided that rigorous validity checks are performed (Ketokivi and Schroeder, 2004). The low average response rate found in the overview of survey studies raises doubts that this condition is fulfilled.

The unit of analysis in many studies is the focal firm and its relations to one level upstream or downstream. To study this, the focus ranges from the relationship between the focal firm and the main supply chain partner, between the focal firm and the key supply chain partners or between the focal firm and all supply chain partners. van der Vaart and van Donk (2008) conclude that clear definitions and instructions are necessary to be able to compare results between different studies. A survey (Sodhi and Son, 2009) on paired data of 74 supplier-retailer dyads has a clearly defined focus on both parties in the dyad and describes the methodology used to realize this. Supply chain managers, purchasing managers and merchandisers on the side of the retailer are used to gather contact details of each partnership for key suppliers. Using this data, the suppliers and retailers receive the survey, consisting of a supplier-side and a retailer-side questionnaire.

The focus in the associative model of Figure 2.2 is on the collaboration arrangement and thus involves the vendor and the buyer. For the validation of this model, we propose to build on existing literature by using validated and tested scales and measures where possible. Next, we discuss the constructs that are used in the reviewed literature in relation to the variables in the model in detail. Note that no constructs in the reviewed literature are found to measure the variables for strategic position and marketing knowledge.

Li et al. (2005) develop constructs for the operational conditions for VMI, information sharing and information quality. Information sharing is defined as the extent to which critical and proprietary information is communicated to one's supply chain partner and translates to information richness in our model. Information quality includes aspects such as accuracy, timeliness and credibility of information exchanged. The scales are validated and serve as a parsimonious instrument in further studies of supply chain practices. These scales for information are further validated and used in other survey studies (Claassen et al., 2008). Kulp (2002) measures similar constructs: information precision as measure of information richness and information reliability as measure of information quality. However, information precision is narrowly defined and the focus of information reliability is limited to the use of EDI. Therefore, we prefer the two scales developed by Li et al. (2005).

Information Richness

Reference	Description	Items
Kulp (2002)	info precision	information exchange on % volume store inventory, warehouse inventory, warehouse withdrawals, point-of-sales data
Li et al. (2005), Claassen et al. (2008)	info sharing	information exchange is timely, accurate, complete, adequate, reliable

Information Quality

Reference	Description	Items
Kulp (2002)	info reliability	information link includes EDI, purchase orders, invoice, warehouse inventory, production schedules
Li et al. (2005), Claassen et al. (2008)	info quality	we share proprietary information with partners, partners share proprietary information, inform in advance of changing needs, keeps informed about issues affecting our business, share business knowledge of core processes, we exchange information for business planning, we keep each other informed about events or changes that may affect the other partners

The ability of a firm to deal with VMI is measured through a number of variables. Vergin and Barr (1999) measure the experience a firm has with VMI by asking how long VMI arrangements have existed, how much volume is traded with VMI and how many VMI dyads a firm maintains. The ICT infrastructure can be measured using the scales of Rai et al. (2006).

Ability

Reference	**Description**	**Items**
Claassen et al. (2008)	quality of ICT system	VMI communication compatible with existing IT systems, IT systems compatible with supplier's systems, our information can readily be entered in the supplier's systems, communication system is easy to use, satisfied with our communication system, system is up-to-date
Vergin and Barr (1999)	experience	number of years experience, number of live partners, % volume of business
Rai et al. (2006)	IT infrastructure	Automatic data capture systems , common definitions of key data elements (e.g., customer, order, part number), data consistent in different databases across the supply chain. Supply chain planning applications, supply chain transaction applications, internal applications of our organization, customer relationship applications function real-time.
Kuk (2004)	size	number of staff
Vergin and Barr (1999)	size	revenues, number of staff

The strategic fit between vendor and buyer is determined using the measures for trust and relationship specific assets of Sodhi and Son (2009). Here, the perception of trust in the relationship is measured as well as the primary basis for the relationship's governance structure: trust or the buyer's power position. Relationship-specific assets are assets in ICT or other areas that are specific to setup or that maintain the relationship.

Strategic Fit

Reference	Description	Items
Dong et al. (2007)	supplier buyer cooperation	To what extent do you and this supplier have the following agreements and programs? Supplier involvement in your product/system design, Multi-functional teams with this supplier, Sharing joint cost savings with this supplier

The product fit is measured using the scale defined in a survey to research the conditions for VMI adoption Dong et al. (2007). The authors develop and validate scales to measure the competitiveness of the vendor's and buyer's markets as well as the product uncertainty and operational uncertainty. The maturity of a product, measured via the product-life-cycle scale of Kulp (2002), is another relevant factor to determine product fit.

Product Fit

Reference	Description	Items
Kulp (2002)	lifecycle stage	% products in introduction and growth stage
Dong et al. (2007)	buyer's market competitiveness	On Likert scale of agreement: many firms compete directly with you, your industry has several dominant firms
Dong et al. (2007)	supplier's market competitiveness	On Likert scale of agreement: this supplier has many competitors, there are a few big firms in this supplier's industry
Dong et al. (2007)	product demand uncertainty	On Likert scale of stability for your major product(s): product demand, demand forecast, patterns of market price changes
Dong et al. (2007)	operational uncertainty	On Likert scale of stability: lead times for inbound deliveries, purchase order cycle times, incoming product inspection processes, materials and/or service quality

Ambiguity exists in how to measure the operational performance of VMI. Here, we propose to use the perception of both parties on the changes in costs of production, transport and inventory usage as a result of implementing VMI.

The scale that Dong et al. (2007) introduce for the VMI adoption rate can be used to measure the collaboration adoption rate in the associative model, asking a series of questions about the form of the collaboration arrangement. This avoids problems of different definitions that might occur when a single question is used to rate the percentage of sale with VMI (as in Kulp (2002)).

Collaboration

Reference	Description	Items
Kulp (2002)	percentage VMI sales	percentage VMI sales on Likert scale
Dong et al. (2007)	VMI adoption rate	to what extent do you and this vendor have the following logistics agreements and programs: inventory system managed by the vendor, information sharing with the vendor, timely communication, the same goals?

2.4 Conclusions

Drivers for collaboration in practice are structured and categorized based on reported empirical evidence in literature. Two types of drivers are distinguished: benefits that can be derived from collaboration and conditions that moderate the success of collaboration. The benefits that the vendor or the buyer realize function as a driver of advanced collaboration arrangements. However, collaboration is more or less successful depending on specific conditions. Therefore, conditions that moderate the benefits of collaboration are the second driver. Drivers are further divided into operational and strategic drivers. Operational and strategic benefits can be realized by the vendor-buyer dyad and both operational and strategic conditions moderate the success of collaborating. These conditions and benefits are elaborated upon, resulting in a conceptual associative model for drivers of collaboration.

Operational conditions for supply chain collaboration relate to information transfer, namely information richness and information quality. Strategic conditions include the ability of the firms to implement and manage advanced collaboration arrangements, the strategic position and strategic fit between both firms in relation to the arrangement and the fit of product characteristics such as supply risk with the type of collaboration. Operational benefits include greater efficiency than the conventional case for the vendor in production and transport and more efficient use of inventory. Generally, these effects result in reduced costs. As an outcome, service levels remain constant or increase. Strategic benefits are in terms of the strategic position firms can realize with the arrangement, increased marketing knowledge and reduced administrative work.

Basic agreement on definitions and constructs to be used in survey-based research in supply chain integration is needed in order to improve the consistency and comparability of results and conclusions from survey-based research. This allows researchers to validate and strengthen previous conclusions and to build further on these. We conclude, based on the literature of empirical research, with a structured associative model for drivers of collaboration in supply chains. In order to statistically test and validate the relations in the model, we have provided an overview of the constructs that are used and validated in the literature. This forms a solid basis for future research to the strengthen the support for the relations in the model and for further improvements of the model.

Limitations of the model are that the relations in the model are based on conclusions from research of reports on the benefits and conditions in practice. The consistency of basic definitions and variables to measure in the reviewed literature is limited. Employees in firms knowledgeable or responsible for supply chain management are questioned via methods of survey research, case-study research or interviews. Perceptive rather than absolute measures are gathered. Perceptive measures are difficult to validate and can be unreliable projections of reality (Ketokivi and Schroeder, 2004). Distinguishing the consequences of collaboration arrangements from extrinsic business fluctuations is difficult. Allocation of such benefits to specific collaboration dyads is ambiguous, as benefits often result in transactions with scale economies for multiple buyers.

In future research, this model should be tested and developed further by improving the constructs used to measure the relations between the drivers and collaboration and by further refining the model. A major difficulty in this line of research is that regular market volatility often dominates any effect that is realized by changes in supply chain collaboration. This makes it difficult to draw conclusions on significant correlations. An extreme example of an event that annuls any measurement of collaboration drivers is the economic crisis of 2008–2009, where sales for many firms dropped below 50% of normal levels (Peels et al., 2009). On top of this, conclusions from survey research are based on correlations only, which might lead to inspiration for causal relations. Analytical models help to understand the causes of benefits and the causal conditions for collaboration. We discuss analytical models for collaboration from the literature in the next chapter.

Chapter 3

Analyzing Collaboration in Supply Chains

The associative model for collaboration drivers as developed in Chapter 2 is based on practical and empirical literature on collaboration arrangements in supply chains. The links between conditions for collaboration and the benefits that can be derived from collaboration are based on data provided by practitioners. The links in the model are purely associative. Analytical models provide further insight and understanding of the mechanisms as to how collaboration arrangements lead to benefits.

This chapter analyzes the processes at the boundary between firms in a supply chain by application of formal models. The objective of this chapter is to enhance the understanding of mechanisms of supply chain coordination at the interface between supply chain members. First, reasons behind the existence of boundaries between firms are discussed in Section 3.1. The background of the trend of focusing on the core competencies of a firm and outsourcing activities not belonging to the core is provided. Section 3.2 introduces the control of supply chains and the costs to operate a supply chain. Then, Section 3.3, addresses how issues arising at the interface between firms affect the performance of the supply chain. A central supply chain coordinator authorized to make decisions that affect the total supply chain performance can realize the optimal performance of the supply chain. Organizing a supply chain centrally seems in contrast with the trend of focusing on a firm's core. However, as explained in Section 3.4, firms can remain independent while coordinating supply chain decisions by collaborating with supply chain partners. Conditions necessary to achieve collaboration are discussed. Section 3.5 presents collaboration arrangements to coordinate supply chain decisions. Specific characteristics and properties that define the essence of collaboration arrangements are uncovered, combined with the benefits that result from coordinated decision-making. In Section 3.6 we conclude with a normative model describing the mechanisms, conditions and outcomes of coordinating supply chains through collaboration. After that, we draw conclusions on collaboration and VMI specifically. We discuss differences between findings from collaboration in practice and analytical models for collaboration and highlight interesting gaps in the covered literature.

3.1 Focus on the Strategic Core

Over the last decades, successful companies have focused increasingly on their core business by outsourcing activities that do not belong to this core (Prahalad and Hamel, 1990, Holcomb and Hitt, 2007, Hätönen and Eriksson, 2009). A firm uses assets and resources to make transactions. Some assets are of generic use to the firm. Other assets and resources are invested in for specific transactions. 'Asset specificity' determines the extent to which assets are linked specifically to certain transactions. Transaction-specific assets are non-redeployable physical and human investments that are specialized and unique to a task (Williamson, 1979). Reve (1990) argues that a firm should focus on and maintain these assets within the boundaries of the firm, as internal governance of such assets enables maximum control and organizational incentive alignment. Assets of high specificity, which are necessary to attain the firm's strategic goals, represent the strategic core of a firm.

A firm expands until the point at which the costs it incurs in order to organize an additional transaction within the firm is equal to the costs of carrying out that same transaction on the market or within some other firm, as Coase (1937) states in the seminal paper 'Nature of the firm' : *"I said in 'The Nature of the Firm' (and I have not changed my mind) that the expansion of a firm will halt at the point at which the costs which it has to incur to organize an additional transaction within the firm become equal to the costs of carrying out that same transaction on the market or to the costs of organizing it within some other firm"*. Markets can effectively govern transactions when transactions occur frequently and asset specificity and uncertainty are low. On the other hand, increased asset specificity and uncertainty lead to difficulties using markets and promotes internalization of transactions in the firm. Factors that contribute to difficulties associated with market transactions include cognitive and perceptional limitations of the persons involved (bounded rationality), opportunism of the parties involved, and asymmetrical distribution of information among the parties (information impactedness) (Williamson, 1979, Reve, 1990). Transactional costs increase when specific investments are made to accomplish a transaction. Ambiguity in the definition and performance of a transaction or transactions that occur infrequently result in increased transactional costs as well. The main question around whether to internalize an activity or not is if bringing an extra exchange transaction under the organizing firm's authority is beneficial to this firm. At the margin, the costs of organizing such a transaction inside or outside the firm are the same. A dynamic equilibrium is the result, as businesses constantly experiment in controlling more or fewer transactions internally, thus determining the boundary of the firm (Coase, 1937).

Williamson (2008) systematizes transactions between firms based on the asset specificity. At the lowest level, no specific assets are involved and simple generic transactions take place. Competition on the market ensures governance combined with, in the event of disputes, court awarded damages. Next in Williamson's system are transactions for which some dedicated investments have to be made. Both transacting parties have incentives to promote continuity of the relationship. To safeguard these investments, interfirm contracts are provided to secure bilateral dependencies. Contracts can include penalties, information disclosure and specialized dispute resolution (such as arbitration). Finally, when costly problems in management and realization of transactions continue despite best bilateral efforts, the transaction may be taken out of the market and organized under unified ownership (vertical integration) instead. Because added bureaucratic costs accrue upon taking a transaction out of the market and organizing it internally, internal organization is thought of as the organizational form of last resort: try markets, try hybrids and have recourse to the firm only when all else fails (Williamson, 2008).

Assets or parts of the organization that are not transaction-specific to attaining the firm's goals do not have to be organized within the firm's boundary. These activities might be externalized and outsourced to an external firm. To this external firm however, the activity might be of high specificity and necessary to attain this firm's strategic goals. By organizing the activity through outsourcing, the outsourcing firm might achieve efficiency gains above and beyond what could be realized as part of the firm.

Three phases of outsourcing can be distinguished: 'traditional outsourcing' with a focus on sweating assets harder: 'strategic outsourcing' with the aim to acquire access to capabilities that the firm lacks; and 'transformational outsourcing' as a tool for transforming firms towards flexible organizational forms, whereby the role of tightly integrated hierarchy is supplanted by loosely coupled networks of organizational actors (Hätönen and Eriksson, 2009). Today's view of outsourcing has evolved to a stage where firms achieve operational flexibility, without incurring the costs associated with bureaucracy.

An example of activities that are non-core to many companies are transportation, logistics and warehousing (Hätönen and Eriksson, 2009). Historically, firms organized the logistics around their factories and warehouses internally. Increasingly, these activities are outsourced to third-party logistics providers. Approximately 60% of Fortune 500 companies uses this arrangement to some extent (Lambert et al., 1999). Aside from the inherent scale that such a third-party might realize, the volumes could be used to reduce logistics costs of all participants by engineering innovative transportation solutions such as the coordination of transport volumes for several companies (Sheffi, 1990). A result of the trend for firms to focus and reorganize around core competencies and core products is a breakup of the vertical value chain. Instead of organizing a large part of the vertical value chain within a single company, it is organized among a number of interlinked companies, each interfacing with one or more other companies in the value chain.

Advancements in technology change the nature and associated costs of certain transactions. Advancing technology enable new products to be packed with more capabilities that might provide productivity gains. An example of productivity gains from technology is that economic growth is positively affected by access to communication by mobile phones for large parts of the world's population (Röller and Waverman, 2001). Technology can make distribution logistics more efficient. RFID tags, for example, enable better control, identification and increased efficiency in the logistics chain (Lee and Özer, 2007, de Kok et al., 2008). Further, an improved infrastructure increases the efficiency of transport logistics. This entails not only traditional infrastructure such as roads, railways, ports and sea-ports and the containerization of freight transport, but also the electronic infrastructure. Processes can be prepared and executed faster and more effectively with various sorts of electronic data-exchange. For example, advance freight-notices to authorities can make customs-clearing more efficient. Real-time traffic information to minimize delays due to heavy traffic and blocked roads is another example of reduced transaction costs resulting from technological advances.

Progress in information technology has made exchanging data and information easier, faster and more reliable, and all of this at lower cost than ever before (McAfee and Brynjolfsson, 2008). As a result, the transaction costs for exchanging data have come down dramatically (Garicano and Kaplan, 2001). Coase (1937) argued that the inventions that were gaining acceptance at the first half of the twentieth century, such as the telephone and telegraph, tended to increase the size of the firm by bringing factors of production nearer together. This argument applies equally to recent innovations, specifically to the internet with the ubiquitous information exchange at negligible costs. Impediments due to geographical distance are alleviated by omnipresent information and efficient distribution logistics. The decrease in transaction costs and increased span of control implies growth of the core of a firm. In contrast to this, one can argue that advances in information technology increase the possibilities to outsource transactions because it alleviates the difficulties involved in exchanging information, controlling and managing the other party. Following Williamson's argument that a firm should internalize transactions as a last resort only, we conclude that progress in information systems leads to a maintained focus on core competencies, while at the same time the span of control of a firm widens.

The boundaries between firms, the roles and responsibilities of firms and the number of partners to transact with in a supply chain may change as a result of the focus on core competencies and the increasing possibilities to manage and control this. This can potentially lead to a breakup of the vertical value chain into separate firms, resulting in multiple interfaces between supplying and buying firms for goods or services. Firms have to collaborate in some form in order to control supply chain operations over the boundaries. When the supply chain is controlled by separate firms, this may introduce inefficiencies in supply chain operations. In the next section, we discuss the control of supply chain operations for supply chains controlled by separate firms and for supply chains controlled by a central supply chain manager.

3.2 Operational Control in Supply Chains

In a supply chain, three flows can be distinguished: product flows, information flows and financial flows (Apte and Viswanathan, 2002). The product, as referred to here, may also be a service, such as the product of transportation service. The product flow is in the direction of the end-customer. Information predominantly flows from end-customer upstream the supply chain, in the form of order-information and consumption or production plans. Information on supply delivery issues or new product improvements flows downstream from the vendor to the buyer. The financial flow usually streams in the opposite direction from the product flow.

The costs for the buyer and vendor to sustain to the product flow in the supply chain include the costs for physical goods-flow activities such as order picking, transportation, holding inventory, and management and administration. To determine an operational replenishment policy, such costs can be split into two main parts: unit variable costs, and fixed setup costs (Silver et al., 1998). Unit variable costs are costs incurred proportional to the quantity that is replenished or produced, such as the costs for holding inventory at the buyer or vendor or the unit price paid by the buyer to procure the items. Setup costs or fixed order costs are costs that increase proportionally with the number of orders or setups, such transport costs and fixed production setup costs. Remaining costs, such as the costs of administration and order picking are related to personnel costs and do not directly vary with the number of shipments or number of items that are transacted. So, these latter costs are not relevant in determining operational policy once these resources have been established.

Transport costs can represent a significant proportion of the product costs, contributing up to 50% of the costs (van Norden and van de Velde, 2005). Transport costs often depend greatly on the number of shipments, especially for the case where transport services are purchased on a spot-market. Many models of supply chains assume fixed costs per delivery as a proxy for transport costs. Minimization of only this portion of supply chain costs leads to a minimum number of deliveries. In turn, this leads to orders of maximum order-size. The maximum order-size is constrained by limitations in available storage facilities or limitations in the capacity of the transport means, such as the capacity limitation of trucks. Optimization of transportation costs together with inventory holding costs leads to the economic order quantity. The origin of the familiar square-root formula to calculate the optimal economic order quantity in simple inventory models dates back to 1913, to an article by Harris (1913) (reprinted as Harris (1990)), as found by Erlenkotter (1989). In this calculation, the fixed costs per order are balanced with the holding costs that increase with order quantity. In the most basic form, the economic order quantity derives the optimal quantity to transact under deterministic constant demand and without any capacity constraints on production capacity, transport means or inventory storage space. As long as neither storage capacity nor transport capacity are

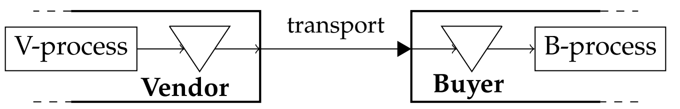


Figure 3.1: Schematic of a vendor-buyer dyad. After the vendor's internal process, the vendor keeps inventory. Transport is organized from the vendor's inventory to replenish the buyer's inventory to serve the buyer's business.

constrained, total transportation costs under optimization are of the same order of magnitude as the as the inventory holding costs.

In any situation where *inventory* is replenished to maintain a desired level of availability, a policy is necessary concerning the *information-basis* and *forecast* on which the need for replenishment is decided. The parties have to agree on the authority for *triggering* the replenishment and on the authorization needed to execute the replenishment. Making an agreement on this point is far from trivial, as the replenishment policy has financial consequences for multiple parties in the supply chain. The supplying firm, the vendor, needs to manage internal operations and inventories in order to ensure reliable delivery to the buyers. Firms in supply chain networks are typically involved in multiple vendor-buyer dyads. The operational efficiency for a vendor or buyer is a result of the outcomes of all relevant dyads.

Consider a dyad of a vendor and a buyer in a supply chain, as depicted in Figure 3.1. The inventory level of incoming goods at the buyer determines the service level downstream from the buyer, or of the end-customer if the buying firm is a retailer. The physical flow of products from vendor to buyer links the finished product inventory level at the supplying firm to the incoming product inventory level of the receiving firm. The physical goods from the supplying firm to the receiving firm drain the vendor's inventory level, while the vendor's inventory level increases with the vendor's internal replenishment or production. The information and financial flows, combined with agreements on who has authority to decide on replenishments, drive the physical goods flow. The inventory levels in both firms, the production rate, transport efficiency and service levels in the receiving firm result to a large extent from the physical goods flows. Therefore, organizing the contents and frequency of information exchange, financial incentives and the authority to trigger replenishments may lead to decisions that are better fit to the combined interest of both firms.

Information about the buyer's incoming product inventory levels and external demand from the buyer is available at the buying firm in the vendor-buyer dyad of Figure 3.1. The authority to trigger replenishments in a conventional arrangement lies with the buyer. Based on the information available to the buyer, the buyer determines the size and timing for replenishment and sends an order to the vendor. The vendor schedules transport from vendor to buyer and goods are moved from the vendor's finished goods inventory to the buyer's incoming product inventory facility. The vendor's inventory is used as a buffer to feed the buyer's demand. Products that are drawn from the vendor's inventory are replenished through internal operations at the vendor. The operational decisions that are made in the dyad to manage the supply chain affect the vendor's process, the vendor's inventory levels, transport and the buyer's inventory level. The replenishment requests from the buyer are considered by the vendor as a given and used to determine the vendor's operational decisions. In this way, the buyer triggers the replenishments and determines the operational decisions in the dyad. Consequently, the buyer affects the dyad's performance to a considerable extent.

3.3 Centrally Controlled Supply Chains

Operational decisions by firms in a supply chain that are based on local optimization by the supply chain partners might lead to results that are inefficient from a supply chain perspective (Whang, 1995). The conventional supply chain arrangement where the buyer determines when and what quantities of goods are required to be delivered is sub-optimal. The buyer drives the operational decisions in the dyad without a guarantee of alignment with the vendor's situation. The vendor complies with the buyer's requests to deliver within an agreed time-frame and optimizes its operations based on these requests. Compliance with the buyer's requests potentially causes the vendor to face inefficiencies in costs, as has been described by Goyal (1976), Monahan (1984), Lee and Rosenblatt (1986). In absence of central supply chain coordination, each of the firms makes decisions independently, based on its own —local— optimization. The information that is available and the financial structure that applies to the firm making the decisions both are the inputs for making this decision. Decision-making also involves identifying opportunities for realizing revenue as well as reducing exposure to risks. Even if both firms aim to optimize for minimal costs, differences in cost functions might result in incompatible solutions: the optimal solution for the buyer might induce higher costs for the vendor.

One stream of research finds the solution to the vendor-buyer coordination problem in centralization of decision-making. Actually, the majority of literature on multi-echelon inventory problems assumes central control (see for instance Clark and Scarf (1960), Eppen and Schrage (1981), Federgruen and Zipkin (1984b), Rosling (1989)). Cachon (1999) remarks that most literature on supply chain inventory management assumes that policies are set by a central decision-maker tasked to optimize total supply chain performance for the part of the supply chain that is in scope. A central supply chain decision-maker is assumed to have access to all relevant information at no cost and furthermore has the means and authority to decide on production and transportation schedules, replenishment quantities and stock levels for both the vendor and buyer. This approach, with an *omnipotent* supply chain coordinator, can achieve a solution that is optimal for the entire supply chain. The objective in the optimization may vary: the decision-maker may optimize for minimum costs, or maximum profits, maximum revenues or maximum market-share.

In practice, however, it might not be desirable or feasible to coordinate a supply chain in a centralized manner (Cachon, 1999). A supply-chain optimal solution may not be optimal for an individual firm, as the total supply chain costs need to be shared in some manner among the firms. A sharing scheme that is perceived to be fair by the involved parties can be difficult to identify. The central decision problem encompasses the decision problems faced by a vendor and buyers. From a supply chain perspective, the optimal solution of a centrally controlled supply chain that is realized by an omnipotent supply chain coordinator dominates the combined optimal solution to the two decentralized problems. Therefore, there is often potential to improve decentrally controlled supply chain systems by coordinating the vendor's and buyers' operational decisions (see among others Lee and Rosenblatt (1986), Monahan (1984), Toptal and Cetinkaya (2008).)

3.4 Collaboration to Coordinate the Supply Chain

The fully decentralized dyad can be inefficient, as we have argued above. Therefore, to survive in an environment of disintegration of the vertical value chain, intensifying competition, shortening of the business-cycle and globalizing scope for sourcing and marketing of products, it is necessary to compete as a value chain with rival value chains (Cox, 2001, Lee, 2004). The organization and location of boundaries between firms are the leading mechanism behind the potential divergence and subsequent inefficiencies of the supply chain. Competing as a value chain requires some form of coordination along that chain. Supply chain management deals with managing the vertical value chain across multiple functions and firms. Rather than optimizing for local performance, a supply chain should be coordinated in such a way that value for end-consumers is created in a manner that is competitive to other vendors of the same product (Lambert et al., 1998, Chen et al., 2001). Coordination of decisions in supply chains can be achieved through a form of collaboration between the supply chain partners.

Coordination of the supply chain is realized through three main factors: coordination on order quantity, coordination on order timing and coordination on matching inventory requirements through information sharing (Li and Wang, 2007). In an overview of models of supply chain contracts (Tsay et al., 1999) remark that despite advances in information technology and a trend to share information, information asymmetry between supply chain partners still abounds in real supply chain relationships. Next to problems in organizing the sharing of information to coordinate inventory requirements, additional problems exist in finding ways to organize for coordination on order quantity and timing. Ways to resolve the latter organizational difficulties are sought in a redistribution of the authority to decide on orders and replenishments. Usually, such redistribution needs to be supplemented by redesigned financial flows and incentives. Otherwise, parties in the chain acting as economically rational parties may be unwilling to accept the redistribution of authority due to implied cost increases.

Even when there are no uncertainties in a dyad concerning demand and supply, and sharing of information updates is of lesser concern, the relationship between the coordination factors of order quantities and timings can be intricate. Indeed, our paper, van der Vlist et al. (2007), discusses this relationship in some detail on the basis of a simple model for a supplier-buyer dyad. Juxtaposition of the discussion in van der Vlist et al. (2007) and Yao et al. (2007b) reveals that alternative decisions on the timing of orders may reverse conclusions on the trend of the change in inventory costs for parties in the dyad when making the transition from a non-VMI to a VMI arrangement. So, the strategy used for timing orders has a substantial impact on the distribution of VMI benefits and costs. The discussion in the papers Yao et al. (2007a), Abdul-Jalbar et al. (2008), Huang and Ye (2010), and Wang et al. (2010), ensuing Yao et al. (2007b) and van der Vlist et al. (2007) provides further evidence that the distribution of costs and benefits towards the supplier and buyer depends not only on the adoption of VMI as such. The discussion shows that it also depends on the way parties exploit the new arrangement by operational decisions, for example through the order timings, allowed within the changed division of authority and responsibility, and information sharing among the parties involved.

3.4.1 Role of Information in Collaboration Arrangements

Collaboration helps to close the gap between the outcome of the decentralized problems and the central problem by providing access to the right information to the decision-makers in the supply chain. With more information than in the conventional supply chain arrangement, a vendor has more insight into the urgency of the buyer's request, thus allowing the vendor to operate more efficiently by prioritizing or de-prioritizing this order in relation to other orders. Dissemination of accurate information is critical for the supply chain to operate effectively (Cachon and Lariviere, 2001). Forrester showed in 1958 the importance of information exchange along a supply chain using system dynamics (Forrester, 1958). In absence of the right information, information distortion and information delay leads to great amplification of demand fluctuations, called the Forrester effect or the bullwhip effect. This leads to costly swings in amounts ordered and elevated levels of inventory. The bullwhip effect is explored further in a paper by Lee et al. (1997), where possible causes of the effect and solutions to avoid the effect are suggested. This research was followed by a large amount of research to study the bullwhip effect and to investigate remedies to reduce it (among others Disney and Towill (2003a,b), Geary et al. (2006), Chen and Samroengraja (2004)). The general consensus of these papers is that demand fluctuations in a supply chain can be mitigated and costs saved when firms in a supply chain exchange information more extensively and more frequently than in the conventional case. A reduction of swings in demand-rates —possibly a result of financial incentives— saves costs. Members of supply chains need to collaborate in order to achieve this. Interestingly, Cachon et al. (2007) investigate the strength of the bullwhip effect in industry-level U.S. data and concludes that the bullwhip effect occurs in wholesale industry, but generally not in retail industries. They conclude that the less seasonal an industry's demand is, the more likely the bullwhip effect will occur.

When a conventional transaction-based relationship exists between the vendor and the buyer, as is the case in Forrester's study, the vendor can base expectations on future requirements on some form of extrapolation of past orders of the buyer. Such purchase orders come from inventory withdrawals at the buyer, but may factor in more considerations, such as convenience of ordering, order batching, or changes in inventory policy, and therefore are only proxies for the downstream consumption. Increasing the accuracy of the forecasts by improving the accuracy of the information that is exchanged leads to costs savings (Kulp, 2002)

Apart from information on the buyer's inventory level, the vendor needs to be able to make some assumptions regarding future withdrawals. Significant savings can be achieved in the case of a diverging supply chain of many buyers and a single vendor under stationary stochastic demand and full information exchange (Cachon and Fisher, 2000). Information about demand on the side of the buyer is most valuable to the vendor when the buyer's inventory approaches a level where a replenishment order is triggered. This is when the retailer tends to submit an order. The authors find that on average, sharing information leads to a 3.4% cost savings in the case of full information transparency, compared to a conventional supply chain in which each buyer reorders based on a reorder point policy.

Information becomes even more powerful in combination with a shift in the authority to trigger replenishments. Not only does the vendor see inventory reductions resulting from improved forecasting, the vendor can also use the acquired authority to determine operational decisions (Lee et al., 2000, Raghunathan and Yeh, 2001) and thus improve supply chain coordination. Waller et al. (1999) investigate the role of information via simulation studies for a conventional and VMI arrangement. Orders in a conventional arrangement are assumed to be infrequent and of large quantity. The increased review frequency under VMI, where the vendor decides when to deliver replenishments, mitigates uncertainties in demand, and enables better resource utilization for the vendor. Waller et al. conclude that buffer stocks for the manufacturer are reduced when capacity is scarce . Under VMI, the vendor's leverage of delivery timing and sizing leads to improved operational matching between production and transport. Service levels go up as non-critical deliveries can be delayed to favor a critical delivery. As a result of this, the benefits that are realized with VMI are positively correlated to the extent of its adoption by the vendor's buyers. As an interesting side effect of having earlier information from VMI customers, Waller et al. note that the delivery service improves also for non-VMI customers. This results from the vendor's increased visibility on near future demand in combination with the vendor's increased flexibility, provided by the VMI arrangements.

Gavirneni et al. (1999) compare the value of information in a partial and full information sharing situation to the conventional arrangement. In the partial sharing arrangement, the vendor knows the demand distribution of the buyer and that the buyer orders according to an (s, S)-policy. In an (s, S)-policy, the buyer orders up to inventory level S whenever the inventory drops to or below s. The vendor knows the development over time of the probability with which the buyer's inventory drops to or below s and a replenishment is due. With full information sharing, the vendor receives the actual inventory level in each period. This information is used to constantly update the development of the probability that a replenishment is due. Gavirneni et al. conclude that information is always beneficial. The value of information increases when the capacity grows significantly above the average demand, as the vendor can decide to save setup costs and produce less frequently. In line with this, when the difference between S and s is large compared to the production capacity, the value of information decreases. This happens because in this case the vendor has to start building inventory in anticipation of a large order. The value of information is also low at the other extreme, when the difference between S and s is small compared to average demand. The reason for this lies in the fact that regular demand triggers replenishments so frequently that additional information becomes worthless.

Lee et al. (2000) analyze the benefits of information sharing for a two-level supply chain between a manufacturer and a buyer. Demand is a simple autocorrelated AR(1) process: the *i.i.d.* (independent and identically-distributed) perturbation in demand fades asymptotically over time. Lee et al. (2000) show that inventory levels decrease with information sharing. The benefits increase for highly correlated demand because current information on demand in that case is a good predictor for future demand, leading to inventory reduction. The value of information increases further with increasing variance of the demand perturbation. Information holds no additional value to the manufacturer in the extreme case of constant demand. Raghunathan and Yeh (2001) build further on this model. Instead of one retailer with autocorrelated demand, a number of retailers are considered of which some share data with the vendors in a VMI arrangement. Demand that occurs at the retailers can be positively cross-correlated within a demand period. An example of where cross-correlation of demand happens is in ice-cream sales: demand will be higher or lower at all retailers in the same period depending on the weather conditions. A result of cross-correlated demand is that the information accuracy rises and production can be planned in relation to transportation in a more efficient manner. The inventories of both the manufacturer and the retailers decreases.

To summarize, exchanging information can lead to a reduction of the bullwhip effect and can make the vendor's forecast on future order sizing and timing more accurate. As a result, inventory is managed more effectively, resulting in lower inventory levels on average while service levels can improve. Improved insight in future demand can lead to reduced setup costs for production or transport, as the vendor knows when a setup can be delayed to instead have a larger —more efficient— volume. It might be that the buyer can adjust the order policy such that the buyer's costs remain largely unaffected, while the total supply chain costs decrease. Assuming that the ex-ante policy for a buyer is buyer-optimal —as the buyer has the authority to decide on replenishments in the conventional arrangement— any change in order-policy for the buyer means that the costs increase for the buyer. A decrease of the total supply chain costs then implies that the vendor's costs decrease. A form of compensation to the buyer might be necessary in order to align the incentives of the buyer with the vendor's incentives. The compensation then makes joining the arrangement rational for the buyer from an economic perspective.

3.4.2 Role of Authority in Collaboration Arrangements

Initiatives to coordinate the supply chain between vendor and buyer range from simple agreements to share information to collaboration arrangements between vendor and buyer that concern not only the flow and content of exchanged information but also the division of responsibilities for deciding on replenishment policies and triggering of replenishments.

When the authority to trigger replenishments and drive operational decisions in a dyad lies with the buyer, operational decisions from the vendor are not necessarily synchronized with the requirements of the buyer. As a result, the costs for transport, production and the costs for maintaining inventory can be reduced by coordinating operational decisions. It is evident that decisions can be optimized for the entire supply chain by using centralized control. The gap in supply chain performance between a conventionally controlled supply chain and a centrally controlled supply chain can be partially closed by redistributing the decision authority between supply chain partners. In practice, such a change from an existing —conventional— supply chain arrangement to a collaboration arrangement where the decision authority is differently distributed between both parties requires that this change is individually rational for both parties from an economic perspective.

3.4.3 Individual Rationality of Collaboration Arrangements

Even though overall supply chain effects of collaboration arrangements are positive, it is far from trivial to get both parties to collaborate through participating in such an initiative. Changing the content and frequency of information exchange, combined with a change in decision authority for operational decisions in a supply chain has effects on the costs and risks for the firms involved. In order to join, the supply chain initiative has to be economically rational for each individual firm.

In Section 2.2.4, we discussed that a dominant firm in a supply chain has a position different than other supply chain partners in that the other firms largely depend on the dominant firm's business. When such a dominant party sees benefits in a new distribution of responsibilities under a new supply chain arrangement, the dominant firm may make the new supply chain arrangement individually rational for a partnering firm by threatening to sever business with this firm if it does not accept the new arrangement. Another method to realize cooperation with shifted authority is to establish some mechanism to make the arrangement individually rational for all partners involved, by sharing the benefits between the vendor and buyer. An economic motive to cooperate exists as long as both parties are better (or at very least, not worse) off within the coordination arrangement compared with the conventional arrangement. The sharing of the cost savings can be done by means of quantity discounts, rebates, refunds, fixed-payment contracts between the parties or any combination of these. In an overview of supply chain coordination with contracts, Cachon (2003) study the set of transfer payments to align the objectives of each firm with the supply chain goal. Single period —news-vendor type models— and multi-period models are reviewed. They conclude that failure of coordination is common as incentive conflicts arise in a wide range of operational situations. Managing supply chain coordination can lead to Pareto improvements, a 'win-win' situation. In many situations, multiple types of contracts exist that can achieve coordination.

Incentive alignment arrangements involve a flow of financial compensation to change how certain decisions affect the costs to parties (Narayanan and Raman, 2004). The challenge is to (re-)design incentives such that the supply chain partners are induced to behave in ways that maximize supply chain profits. Compared to a conventional supply chain arrangement, where the buyer authorizes replenishments, an incentive program setup by a vendor can induce the buyer to change its order policy. Such arrangement might result in equal or better performance for both parties. An example of this in a bilateral monopoly are two-part contracts, under which the vendor sells products at marginal costs and charges a fixed side-payment to coordinate the supply channel. Simple wholesale pricing contracts would face the problem of double marginalization, meaning that the vendor's margin increases the costs for the buyer such that with the buyer's margin taken into account, the overall profitability of the chain is below the optimal level.

Coordination with incentive schemes in a situation where information is provided in an asymmetrical way has been compared to incentive schemes with full information transparency (Corbett and de Groote, 2000). The setup costs of the vendor in a conventional EOQ-type setting are assumed to be greater than the setup costs of the buyer. The order size is determined by the buyer. Since the vendor benefits from economies of scale by shipping larger order quantities, he offers the buyer quantity discounts in order to entice the buyer into increasing its order quantity. Two cases are considered: quantity discounts under full information sharing, where the vendor knows the buyer's costs drivers, and quantity discounts under asymmetric information sharing, where the vendor does not know the buyer's cost drivers, specifically the inventory holding costs. In the latter case, the vendor offers a menu of contracts to the buyer to choose from. Depending on the buyer's holding costs, the vendor needs to offer a smaller or larger discount to entice the buyer to accept deliveries of a larger order size. It turns out that in the case of full information, the vendor can make the buyer pay the maximum price. The overall supply chain result is that of a fully coordinated supply chain. The vendor has to offer more to the buyer when the buyer holds private information. Nevertheless, Corbett and de Groote conclude that the total supply chain costs are still lower than when no coordination takes place.

Two-part contracts are proposed to coordinate the supply chain. Two-part contracts avoid the double marginalization problem (Lerner, 1934). Under a two-part contract, the vendor sells products to the buyer at marginal costs, but charges an additional fixed side payment to coordinate the supply chain. Corbett et al. (2004) conclude that two-part contracts under information asymmetry between vendor and buyer with linear side payments can coordinate the channel. Further, the value of information increases with two-part contracts, while at the same time the value of two-part contracts increases under full-information.

The optimal supply chain policy for replenishing a two-level supply chain has been studied by many. Cachon and Zipkin (1999) conclude that it is possible to achieve a supply-chain optimal, coordinated decision, but only when vendor and buyer are willing to share the cost benefits through some cost re-alignment scheme. Tsay and Agrawal (2000) studied a supply chain system under deterministic demand, where two retailers were replenished by one vendor. In this case, the retailers compete on price and service level. In the article, the authors study and characterize a scheme for wholesale pricing to coordinate such supply chain system.

The performance gap that exists between a centrally controlled supply chain and a decentrally controlled—conventional— supply chain can be mitigated by collaboration arrangements to coordinate operational decision-making in supply chains with. Mutual agreement on two factors constitute a collaboration arrangement: mutual agreement on information exchange and distribution of decision authority. Resulting collaboration arrangements are discussed in the next section.

3.5 Collaboration Arrangements

Collaboration arrangements such as VMI, VOI, FGP, CPFR, ECR have been introduced in Chapter 2 as potential improvements over the conventional (conv) arrangement. Figure 3.2 on the following page categorizes different collaboration forms based on the level of information sharing for both vendor and buyer. The buyer in the conventional arrangement shares nothing but sales orders, while the vendor also keeps his stock and production information private. In the case of Efficient Consumer Response programs or Quick Response programs a much higher density of information flows from buyer to vendor and vice versa. A buyer in VMI or VOI arrangements needs to share information to enable the vendor to manage its inventory. The vendor might share information on production plans. In FGP, the vendor shares when replenishments are ready to collect and buyers share when a pickup is scheduled. Under collaborative planning and forecasting (CPFR), vendor and buyer are very open in information sharing. The ultimate in information sharing is full coordination in the central solution. In this case, the omnipotent supply chain coordinator has access to all information from both vendor and buyer. A shift in authority between vendor and buyer changes the attitude towards information privacy or information sharing for these collaboration arrangements compared to the conventional setting.

Figure 3.3 illustrates the four main supply chain arrangements we distinguish between. For each form of collaboration, the vendor is shown on the left side of the figure. Products are transported from the vendor to the buyer positioned on the right side of the figure. The flow of goods considered here starts with

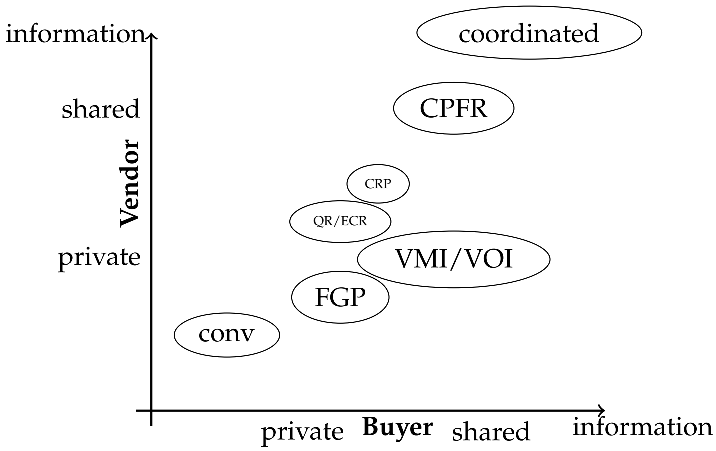


Figure 3.2: Schematic of information sharing on the vendor-buyer interface. Information to buyer or vendor is private or shared depending on the collaboration arrangement.

the process of the vendor making the products available. This can range from procurement when the vendor is a distributor, to a manufacturing process when the vendor is a manufacturer. The vendor can keep an inventory facility to store the finished products. Next, products are transported to the buyer's incoming inventory facility. From there, the goods flow to the buyer's process. The process of the buyer might be a manufacturing operation when the buyer is a manufacturer or the sales operation to customers when the buyer is a retailer. The dashed lines in the graph indicate the reach of responsibility for the vendor and buyer, in line with the responsibilities discussed in Section 2.1 and listed in Table 2.1.

3.5.1 Collaboration Analyzed

When the buyer decides if and how much to order, the routine information exchange between vendor and buyer is transaction based: the buyer notifies the vendor that he needs a number of products. This information exchange occurs only when the buyer decides to order goods and the information is limited as far as actual and planned consumption by the buyer is concerned. The vendor does not know the stock level of his buyer and hence, does not know the urgency of the delivery. Under a VMI arrangement, the vendor receives frequent updates about the inventory level at the buyer. Since he now knows the inventory-level at the buyer,

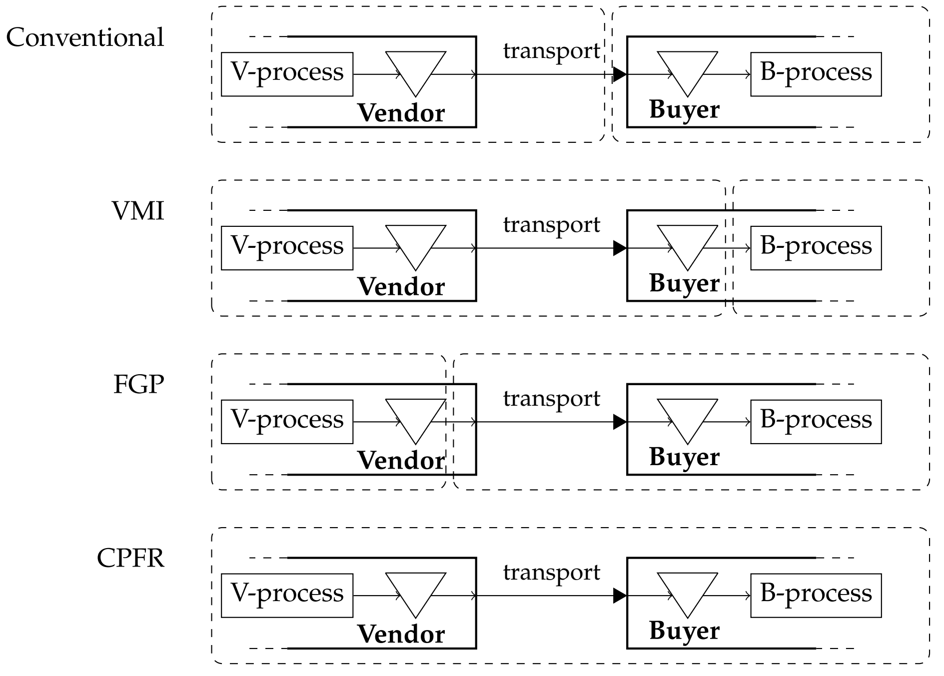


Figure 3.3: Overview of different vendor-buyer collaboration forms: Conventional, FGP, VMI and CPFR

the vendor can determine the timing and quantity of goods to ship, and manage the buyer's inventory, while at the same time aiming to organize transport and his own inventory efficiently.

In a true VMI setting, the vendor is given the freedom to plan his own production and decide upon the replenishment schedule as long as the agreed customer service levels are met (Claassen et al., 2008). VMI is often implemented with minimum and maximum limits set on the inventory levels of the buyer in order to protect minimum availability for the buyer (Disney and Towill, 2003a). The tighter the limits, the less leeway for vendors to optimize (Kaipia et al., 2002, Fry et al., 2001).

Fry et al. (2001) find that many of the benefits proclaimed to be results of VMI are in fact only the result of sharing information. They reach this conclusion from analysis of a VMI arrangement with minimum (z) and maximum (Z) inventory levels. The vendor pays the buyer when the inventory level of the buyer attains values below z or above Z. In this way, the (z,Z) boundaries function as a mechanism to transfer payments between vendor and buyer and may be used to make the VMI arrangement economically rational for the buyer. The side-payments resulting from the (z,Z) boundaries align the incentives for the buyer and vendor, leading to some form of supply chain coordination. In the study of Fry et al., the focus is production in optimally sized production batches, while maintaining inventory at the buyer.

In general, the central idea is that total channel costs for VMI-consignment in a supply chain channel between a buyer and vendor decrease over both the short and long term, but such a decrease may fall short of the centrally coordinated supply chain (Dong and Xu, 2002). In the Dong and Xu study, VMI-consignment arrangement is compared to a base case in which the buyer dominates and determines the order quantities and a proposed transfer price according to local profit maximization. The benefits of VMI increase with increasing difference between the vendor's and the buyer's setup costs for a transaction —and thus their preferred order-sizes. Evidently, implementation of VMI with consignment is always beneficial to the buyer as the inventory holding costs are absorbed by the vendor. However, when the transaction setup costs for the buyer and vendor are of the same magnitude, it is possible that implementation of VMI-consignment leads to a decrease of the vendor's profits in the short term. In the long-term, however, reduction in overall supply chain channel costs results in an competitive edge, leading to increasing sales volumes, so the vendor's profits could increase. A special assumption in the Dong and Xu study is that the production costs increase convexly in quantity. Note that other efficiency gains attributed to VMI —such as improved coordination and forecasting, leading to reduced safety stocks and 'more degrees of freedom' for vendor to manufacture or deliver— have not been taken into account in this study.

Bernstein et al. (2006) introduce a concept called echelon operational autonomy (EOA). EOA states that the costs incurred by a vendor for a given vector of sales volumes depend only on operational decisions controlled by the vendor. Under general cost and demand functions, this condition suffices to make perfect supply chain coordination feasible. VMI is shown to create EOA, meaning that the vendor in a VMI arrangement can realize supply chain coordination.

Cheung and Lee (2002) derive upper and lower bounds for the costs in a supply chain consisting of multiple retailers in close proximity of each other. In their study, the vendor dominates the dyads and decides when and how much to replenish. The buyers share information on their inventory levels with the vendor. Two policies are compared to a conventional re-order policy. The first policy uses inventory information to optimize the use of economies of scale in transport. A second policy focuses on rebalancing the inventory levels of the buyers during delivery of replenishments. The costs of the conventional reorder policy are higher than the costs of transport optimization. The lowest cost solution rebalances inventory levels during replenishments.

Many studies start from a basic model introduced by Goyal (1976). The Goyal model considers deterministic constant demand, linearly increasing holding and fixed replenishment costs. Modeling capacity limitations involving the transport source or the production capacity are both interesting extensions to the basic model. Toptal and Cetinkaya (2008) model these extensions by including stepwise increasing transportation costs. As a result, the identification of benefits of collaborating becomes less intuitive. As an example, it is not always beneficial to a vendor to increase the ordering batch size when this means costs increase by one step (Toptal and Cetinkaya, 2008).

Çetinkaya and Lee (2000) analyze the cost savings that are achieved when a vendor gains the flexibility to consolidate transport for replenishments in case of a VMI arrangement. Here, a vendor serves a group of retailers that generate a succession of random demands. The retailers are located in close proximity of each other. The costs of transport are a fixed charge per replenishment. In a base case, the vendor meets demand as it occurs and sends equal-sized shipments to each retailer of the economically optimal size. When the vendor and retailers decide to cooperate in a VMI arrangement, the vendor uses the flexibility in timing and sizing of the shipments to consolidate shipments until a certain quantity has accumulated or until a certain time has passed. In the latter strategy, consolidation until a certain length of time has elapsed is referred to as time-based policy. The optimal replenishment quantity and dispatch frequency are computed approximately.

Axsäter (2001) continues on the model of Çetinkaya and Lee (2000) and provides an exact optimization as well as a new heuristic. A problem in the analysis is that the cost of transport is modeled as a fixed amount per truck. Consequently, the analysis gives an upper value of the potential cost savings. The reason for this is that when the calculated cost savings are large -meaning that the efficient order quantity differs significantly from the truck's capacity- it is very likely that the shipper contracts a carrier who offers Less Than a Truckload Tariffs (LTL-tariffs) instead of hiring full trucks. In case of LTL-transport, the carrier's business lies in achieving efficient use of the transport capacity by sourcing for additional freight. As LTL-tariffs for the shipper reflect part of these cost savings, the savings in transport costs, according to Çetinkaya and Lee (2000), are an upper-bound.

A joint replenishment problem for a retailer facing stochastic demand is studied by Cachon and Fisher (2000). Transport occurs in trucks of finite capacity. The costs of transport are modeled as a fixed amount per truck. Three policies are compared: a continuous review policy, a periodic review policy and an adjusted periodic review policy where only full trucks are shipped. A lower bound for the costs of the latter policy is derived by decomposing the problem to one where each item is shipped in its own truck.

Piplani and Viswanathan (2003) study a system where a number of buyers collaborate in Vendor-Owned Inventory-arrangements, while others remain a conventional arrangement with the vendor. When it is efficient, the vendor optimizes transport and production by combining replenishments for a conventional customer with VOI-customers. Therefore, the review period for VOI-customers is a multiple of the review period for conventional customers. Assuming that only reasonable review periods (such as days, weeks) are feasible, cost minimization is achieved by full enumeration over 730 possible review periods (1 day to 2 yrs). The findings are that the total supply chain costs never increase with VOI and that the costs decrease is greater when the holding costs of the VOI-customers are lower. Further, the savings increase when the share of VOI-demand increases. When the ratio of setup costs for production to VOI delivery costs is low, supply chain costs are reduced. The impact on the vendor's costs suggest that there is an optimum ratio between production and VOI replenishment costs, but it remains unclear why. For many other parameter settings, the vendor's costs increase with VOI.

Bertazzi and Speranza (2005) look at a problem where a producer distributes one item to a set of retailers, facing deterministic demand. A fleet of vehicles (limited capacity) is used for transport. Both production and distribution are optimized. The production costs consist of setup costs plus variable costs plus holding costs. The distribution costs are a fixed fee for every truck that is needed over the time horizon plus costs of the distance traveled by a truck for each time period. Retailers face holding costs. The inventory at retailers must be kept between lower and upper limits. The problem to minimize total costs under constraints is shown to be NP-hard. Two VMI policies are studied: and order-up-to level policy, where each retailer receives products up to the order-up-to level in each period and a fill-fill-dump policy. Under the latter policy, all but the last retailer is replenished up to the inventory capacity they have made available. The last retailer receives the minimum of remaining space in truck and up-to-level quantity. The fill-fill dump policy turns out to outperform the order-up-to policy due to a reduction of distribution costs.

To summarize, analytical models show that vendor-buyer dyads can realize significant benefits under well-formed collaboration arrangements. A limitation in the analytical models is that reality must be simplified in order to make it tractable. A specific example of this is that the cost function for transport in models where capacity limitations for transport are taken into account is usually a simple fixed amount per truck-ride, independent of the actual load in the truck. In practice, a vendor who regularly ships loads that are less than a truckload will make use of a third-party logistics provider offering discounted LTL-tariffs, possibly based on the total annual volume. In this way, the third-party logistics provider realizes part of the potential benefits that can be derived from a VMI arrangement between buyer and vendor and passes some of these savings on to the vendor. Consequently, the projected potential benefits of VMI from such analytical models overestimate the cost savings. In Chapter 4, we will deal with transport tariffs in detail.

3.6 Conclusions

3.6.1 Normative Model for Collaboration

The conclusion emerging from the previous sections is that agreement on the division of information exchange and on decision authority for operational decisions constitutes a collaboration arrangement. The generic condition for economic rationality for each individual firm for changing a collaboration arrangement warrants that a new arrangement is more efficient for the supply chain. Individual rationality for the supply chain partners is realized via incentive schemes in which part of the benefits realized from the new arrangement are transferred between the partners or as a result of dependence on a dominant supply chain partner enforcing the new collaboration arrangement.

Coordination of decisions can occur by an ‘entrepreneur’ when activities are internalized, or via a price mechanism as a coordinating instrument in markets (Coase, 1937). The trend of a firm to focus on core activities leads to an increased need for coordination via the market. Coordination via pricing mechanisms in the market as referred to by Coase, is generalized to coordination in the form of a collaboration arrangement, where joining this arrangement is individually rational to each firm concerned from an economic standpoint. Benefits of collaboration re-

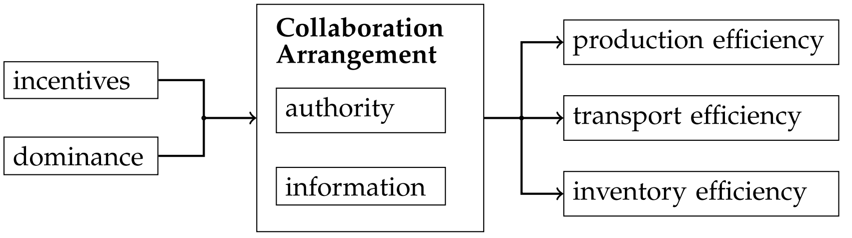


Figure 3.4: Normative Model of collaboration. Incentives and the position of dominance may make an arrangement individually rational, fulfilling this condition for collaboration. Agreement on authority and information exchange constitute collaboration, leading to operational benefits in production, transport or inventory management.

sult from coordination of operational decisions between firms in the supply chain. Part of the performance gap between a conventional arrangement and a centrally controlled supply chain can be closed. Benefits are realized in the domains of inventory holding costs, or setup costs such as transport and production.

Figure 3.4 summarizes the findings in a normative model. It depicts, in a conceptual way, the factors that affect the type of arrangement between a vendor and buyer and the effects of such arrangements. The type of collaboration arrangement between a vendor and a buyer is a result of agreements on the content and frequency of information sharing as well as agreement on authority in the dyad. The latter refers to the priority and influence each party has on the operational decisions that are the outcome of the arrangement.

We hasten to add that the model depicted in Figure 3.4 is generally insufficient for detailed quantitative analysis and predictions. As we have argued on different occasions, see e.g. the discussion at Page 52, the benefits and costs of a collaboration arrangement, specifying the division of authority and sharing of information, are much impacted by the way the arrangement is subsequently exploited by the parties involved. Exploitation of the possibilities that arise from collaboration involved optimization. So, the outcomes of a transition to an advanced collaboration arrangement depends also on the effects, capabilities and strategies that the parties put into the optimization of operations under the new arrangement. A further convolution, not shown in Figure 3.4 arises from the distinction of different authority modes, as discussed in the next section.

3.6.2 Conclusion on Authority Modes

The outcome of the processes across the interface in a dyad is a set of operational decisions determining the replenishment timing and quantities of the buyer's inventory facility as well as the timing and quantities of the vendor's internal replenishment process. In this thesis, economic rationality is assumed to lead decision making. Three modes of authority are distinguished that achieve operational decisions. The first mode is the case where the vendor and buyer act as one. The complete information of the vendor and buyer is centrally available to determine the optimal policy for the combined vendor-buyer. The second mode is the conventional case with the buyer dominating the dyad by triggering replenishment decisions. The vendor subsequently uses this trigger and the information available to optimize his operations. The third mode of authority is the vendor-dominated case. In this case, the vendor uses all information available to optimize his operations, resulting in a schedule of when and what to ship to the buyer. The supply chain costs for the vendor, buyer or the entire dyad is thus a result of the authority mode and the information that is available to the decisions makers. Obviously, the total costs of the vendor and buyer in the central solution are always less than or equal to the costs of the vendor or buyer-dominated solution.

We denote operational decisions by σ_C for the central case, σ_B for the buyer's operational decisions and σ_V for the vendor's operational decisions. The information available to buyer or vendor are denoted by $\imath_B$, $\imath_V$ respectively. The outcome of the three forms of authority on operational decisions depends in different sequential dependence of decisions and information. We assume that the making of operational decisions between vendor and buyer unfolds as a Stackelberg game (Stackelberg, 1952). The three modes are shown analytically in Eq.(3.1).

$$\sigma \leftarrow \begin{cases} \sigma_C(\imath_B, \imath_V) & \text{central} \\ \{\sigma_V(\imath_V, \sigma_B(\imath_B)), \sigma_B(\imath_B)\} & \text{buyer dominant} \\ \{\sigma_V(\imath_V), \sigma_B(\imath_B, \sigma_V(\imath_V))\} & \text{vendor dominant} \end{cases} \tag{3.1}$$

The operational decisions in the first, centrally operated mode are based on information from buyer and vendor. In the second, —buyer-dominated— mode, σ_B is based on the buyer's information. The vendor uses σ_B as input: σ_V is based on the vendor's information and σ_B. In the third —vendor-dominated— mode, the vendor decides based on information available to the vendor, so σ_V is based on the vendor's information only. The buyer subsequently determines σ_B based on the vendor's decisions, σ_V combined with the buyer's information.

Note that the solution obtained in the three approaches in (3.1) vary. In fact, upon studying an assembler-(multiple) suppliers supply chain the paper Wang and Gerchak (2003) conclude that structurally different solutions obtain in a central case, an assembler-dominant case and a supplier dominant when deciding on capacity investments, compare Cachon (2004) and Lariviere and Porteus (2001). Moreover the different approaches put different requirements on the way information is shared: in the two Stackelberg approaches the leader needs to be able to predict how the follower responds to its actions and for that it needs the follower's cost structure. It is not possible to identify one single approach as being the best in explaining all of empiricism.

3.6.3 Conclusion on VMI

There are three main factors as to why VMI arrangements can be more efficient than conventional vendor-buyer arrangements. First, more information is available to the decision-maker, enabling better solutions and efficiency gains. Second, the party with the authority to decide is the same party bearing the costs. Third, the asymmetry of information between vendor and multiple buyers can be exploited by the vendor to increase the transport efficiency by consolidating shipments. All three factors are explained below.

Improved coordination of the supply chain under VMI is possible because the vendor has more information available. Instead of only having order data, the vendor under VMI has frequent access to knowledge of actual inventory levels of his buyer. This presents the vendor with the possibility to schedule orders with flexibility in timing and quantity: he can decide to send smaller or larger shipments or he can send a shipment slightly earlier or later to accumulate orders in time and to consolidate across destinations in order to increase the efficiency of transportation.

A second factor for potential coordination improvement under VMI comes from a single party driving the supply chain performance and bearing the costs. Under the conventional arrangement where the vendor assumes the cost of transportation while the buyer decides when, and how much to order, the buyer's timing and sizing of orders may not induce efficient transportation. By assigning the authority *as well as the costs* for ordering, shipping and inventory control to the vendor, this party can align decisions with costs implications and achieve a better solution. With the addition of a target inventory levels at the buyer, to reflect service level requirements, the system may succeed in coordination of the supply chain.

The third factor is asymmetry of information. This factor can be made clear by first explaining the concept of symmetry of information. Under VMI, more information is exchanged between vendor and buyer. Theoretically, once the buyer and vendor share information and responsibilities, it becomes irrelevant who makes the decisions, as the decision is based on the same inputs anyway. When a vendor has multiple buyers, the vendor-buyer relationship is non-symmetric. Then symmetry of information for each vendor-buyer link is impossible: the information that the vendor shares with buyer A must remain separate from the information that is shared between the vendor and buyer B. Therefore, each buyer can only posses a limited amount of information, but on the other hand, *all the information* is available to the vendor. This places the vendor in a central position. In particular, this opens up opportunity to consolidate freight for several geographically near buyers in a single shipment, thus increasing the efficiency of transportation.

In general, the party with most decision authority in the dyad is best off in terms of costs. In a VMI arrangement, the vendor dominates the dyad. In order to entice the buyer into accepting this change in authority the buyer must be guaranteed not to be worse off. In practice therefore, the buyer sets the boundary conditions for the vendor within which the VMI arrangement must be managed. Alternatively, the buyer forces the vendor to manage the buyer's stock point under consignment, VOI, so that costs disappear for the buyer.

To overcome the problem of a buyer setting VMI-boundary conditions such that the vendor cannot realize the maximum benefits, we study in Chapter 5 an arrangement where the vendor creates contracts with the buyer aiming to influence the buyer's boundary conditions for a VMI arrangement.

As discussed above, a generic issue in the papers where the difference between operational performance of a conventional dyad and a dyad under a collaboration arrangement is compared is the calculation of the costs of transport. In the literature, the cost of transport are often taken as a fixed fee per truck-ride, independent of the volume to be transported. Any arrangement in which the vendor can improve control of shipment size and timing will therefore be (very) favorable to the vendor. In practice however, a market for less-than-truckload (LTL) transport exists. The business of the LTL-carrier is to combine transport needs in the market. As a result, attractive LTL transport rates can be offered. In Chapter 4 we present a model to derive transport tariffs for LTL-transport in an environment of several shippers with transport needs.

3.6.4 Practice versus Theory

Analytical models make assumptions on reality. An underlying assumption in theoretical models on information sharing is often that the quality of information is perfect and that information becomes available simultaneously to both vendor and the buyer. Supply chain partners in the dyad are thought to act economically rationally. This implies that in theory a firm cooperates fully on any alternative collaboration arrangement as long as they are not worse off cost-wise. Rarely taken into account are considerations of strategic nature or market dominance of a firm. A firm that is dominant in a supply chain might force the other party into a collaboration arrangement by simply using its dominance. Near-term decisions on how to collaborate in the supply chain will play a role on the strategic position of a firm in the long term. Supply chains are typically assumed to compete, but in reality competing supply chains join forces at times —for instance via standardization bodies (e.g., CD, DVD standards, EDI, RFID).

Analytical models often focus on operations and neglect such considerations even though these considerations play an important role in practice and have a significant influence on the results or outcome of a collaboration arrangement. The reason lies in the complexity involved in modeling such considerations and the difficulty in determining reasonable parametric values to use in the models. Including practically-relevant considerations may make a model appear contrived. For example, how does one model the economically irrational behavior of a firm? Further, the introduction of additional complexity makes an optimization model analytically intractable so that simulation must be used to get results. A problem in this is the parametric value one assumes for such practical considerations such as, e.g., imperfect information quality. When information in a model is assumed to be delayed and not 100% perfectly transferred, the question arises as to how imperfect it should be. The uncertainty on the parameters with which to model the additional considerations often greatly affects the outcome of the model and raises questions on the results.

When considering a supply chain with repeat business the accuracy and reliability of the transfers of information updates that are shared as part of a collaboration arrangement, becomes vital. Information sharing places requirements on information transfers that go beyond the issuing of orders. Such requirements are rarely modeled as part of a theoretical optimization-based collaboration study. In theoretical models, information transfers are normally modeled to be 100% correct and accurate, see Chen (2003). Rare papers that do have discussion of these issues of information transfer are Chen and Samroengraja (2004) and Anand and Mendelson (1997). In practice, on the other hand, it is not easy to guarantee accurate and reliable data transfers. The infrastructure of each firm has to be at a minimum level and matched with the other party. This goes beyond the information technology infrastructure alone. Systems obviously need to be able to communicate to share information, but also mutual agreements on standards, on standard ways of ordering, measurement, data management and data maintenance are essential for successful ongoing data transfer.

Further, strategic considerations are important to determine the type and success of collaboration models. The reason for a firm to join a collaboration arrangement ranges from being forced by the other party to individual economic rationally based on financial or strategic benefits. The long-term view of how to develop one's position in the supply chain and network of buyers and vendors plays an important role. Such considerations are hard to convincingly quantify. It must be realized that neglect of such factors make the theoretical models an optimistic abstraction of practice.

A specific example of these difficulties is observed in models where the benefits of the introduction of Radio Frequency Identification (RFID)-tags instead of barcodes are analyzed. Basic RFID-tags hold data that is comparable to data in a barcode (a multi-digit number), but the reading speed, reading distance and read-accuracy by far surpasses that of barcodes. However, to quantify benefits, assumptions must be made on the costs of not being able to read so many tags at certain distance. In a study to derive the benefits of RFID, a parameter to model the shelf replenishment responsiveness is introduced (Gaukler et al., 2007). This parameter depends on miscategorization, theft from the shelf, and other errors in the execution of shelf replenishment. The parameter is set to 100% responsiveness when RFID is used and estimated to be 90% for a non-RFID case. Logically, the benefits that are expected to be derived from introducing RFID depend on these values. Similarly, de Kok et al. (2008) analyze the break-even point for implementing RFID tags in theft-sensitive products.

In the next chapter, we go into a more detailed analysis of the benefits that can be realized by coordinated decision-making in supply chain collaboration arrangements. To enhance the understanding of the role of transport costs in determining the benefits from coordination on transport, we study transport tariffs for the situation of LTL-transport.

Chapter 4

A Model for Transport Tariffs for Single Orders on a Single Link

The potential cost benefits from coordinated supply chain decision making often result from optimization of operations by exploiting economies of scale. In practice however, resources of finite capacity moderate the benefits from scale economies. Transport of goods between firms is a main source of potential cost savings from supply chain coordination, but the limited capacity of trucks makes the analysis of such cost savings complex. The analytical literature often focuses on savings resulting from optimizing the shipping frequency and quantity for the supply chain. Third-party logistics providers can also realize potential savings on transport by optimizing shipment quantities, by offering transport tariffs for shipments that are less-than-a-truckload in size. To understand this further, we study in this chapter our third research question: How can tariffs for transportation of less-than-a-truckload quantities be modeled to coordinate the efficient usage of trucks?

Transport tariffs are used to determine a size-dependent rate that is charged for the service of transporting goods from one to another location. The efficiency of transportation may be improved by coordination of supply chain decisions. The main mechanism to make transportation more economical is aggregation of goods, resulting in fewer economically sized shipments. Third-party logistics providers may offer transport tariffs for shipments of size less-than-a-truckload, in which part of the cost-savings that are realized by economizing transportation are passed on to the shippers. In this chapter, we develop models to determine transport tariffs. We consider tariffs that are based on cost-allocation and tariffs that are based on profit-maximization. [1]

This chapter is organized as follows. After introducing the problem in Section 4.1, we present a review of literature addressing transport costs on a single link in Section 4.3. Subsequently, in Section 4.4, we present the methodology by which tariffs are derived. Two approaches for deriving tariffs are discussed: cost-based and profit-based. In Section 4.5, the first method allocates costs according to the cost impact of an order. The second logic, in Section 4.6 derives tariffs based on profit maximization by the carrier. The influence of the arrival pattern and distribution of demand is studied using simulation. Finally, we present our conclusions with respect to the research performed in Section 4.7.

4.1 Transport between Firms in a Dyad

The costs and efficiency of physical distribution of goods between two firms in a supply chain is a focal point in establishing advanced collaboration arrangements between a buyer and a vendor. Transport tariffs specify as a function of order-size the rate that is charged for the service of transporting the goods. The shape of transport tariffs as a function of order-size affects both shipping decisions and the efficiency and fill-rate of the means of transport.

In this chapter, we develop models to determine transport tariffs. The focus is on a transport service by trucks on a single link for orders of size less than a truckload (LTL). Shippers issue transport orders to a carrier who charges a tariff for providing the transport service. Since multiple orders can be combined in one truck-ride, the carrier can charge each order a tariff that is lower than that of a full truckload. The problem now becomes setting rates for orders to promote maximum economic benefit, like lowest transportation costs or maximum carrier's profit. The rate for an order will depend on many factors, notably on the order's size measured by volume or weight. A schedule that states the rate as a function of order characteristics, in particular size, will be referred to as a tariff. How the tariff looks like depends on several factors such as the underlying economics of the transportation activity, the demand and market for transportation services and the operating policy employed by the carrier. The complex interplay between these

[1] This chapter has been transformed in a paper, submitted for publication (Kuik and Verheijen, 2010)

factors makes it hard to identify a tariff that realizes maximum economic benefit.

The problem is compounded, as transportation is often only one of the activities in a supply chain that also includes production, inventory storage and warehousing activities. When such supply chains are analyzed for the effects of different shipping strategies, for example, Just-In-Time (JIT) and delivery or replenishment under vendor managed inventory (VMI) control, one needs an understanding of how such strategies affect transportation. Therefore, one needs to understand how these strategies affect and are affected by transport tariffs.

The motivation for this research stems from the fact that many advanced collaboration arrangements such as JIT and VMI lead to increased flexibility in timing and sizing of transport orders. The flexibility enhances opportunities to consolidate orders and to increase transport efficiency. As a result, advanced collaboration arrangements can lead to savings on logistics costs. The cost savings might be passed on to the shipper in the form of a reduced tariff for the transport service. However, in order to assess the shipper's potential cost savings from an advanced collaboration arrangement, it is essential to understand how transport tariffs are affected by the transport cost structure. Therefore, we develop a model to derive an analytical tariff for LTL transportation services. Note that the rate brings an expense for the shipper and revenue for the carrier, and these do not necessarily equate to the costs incurred by the carrier. This study is limited to that of transportation services on a single transportation lane offered by a single common carrier to multiple shippers. Both private and common carriage is examined. In the case of common carriage, a semi-proportional cost allocation rule results in transport tariffs that display properties such as economies of scale and sub-additivity. In the case of private carriage, the frequency of order arrivals determines the extent to which the carrier's efficiency-gains are passed on to the shippers. Simulation is used for numerical evaluation.

4.2 Transport Tariffs

An essential function of businesses is utility maximization by coordinating the usage of scarce resources. Often, these resources have limited capacity, which might be shared among multiple users, making this the problem of coordinating the usage of shared capacitated resources. An example of such a problem is transportation of goods by trucks. Multiple orders of sizes that are less than a truckload (LTL) may be combined to share the finite capacity of a truck. A similar problem is that of ships or airplanes in which orders for multiple customers can be combined. The main difference with trucks is the granularity of the orders: in container ships, the smallest increment is an extra container, while in LTL trucking, the smallest increment is a fraction of what fits in a truck, such as a pallet-layer.

Two functions can be identified in the transportation business: the function of a carrier and the function of a shipper. Carriers provide the transport service to shippers. When both functions are combined under a single authority who makes decision to release orders and dispatch trucks, the problem of coordination of truck usage reduces to a problem to minimize the total costs subject to a set of capacity and service constraints. However, when two or even more parties are involved, such as one or more carriers and one or more shippers, the problem is one of aligning the objectives and expectations of different parties.

A tariff is usually stated as a rate table. For purpose of analysis, an analytical expression of rates as a function of order attributes has more potential for interpreting results as such analytical expressions involve far fewer parameters than entries in a tariff table. In case precision is important, such as when analyzing a practical case for the purpose of consulting, an analytical expression for rates that applies to the whole range of potential transportation orders may be too coarse. In these cases a collection of functions may be used on different intervals limited by break points that reflect the discrete nature of a tariff table. Such approach has been used in e.g. Li et al. (2004) , Fleischmann (1993), and Tersine and Barman (1991). Still, even with rates specified per interval, an expression is needed for providing the rate on each of the intervals.

We consider transport for LTL-orders for which shippers and carriers deal on a transactional basis and where commitment does not extend beyond a single order. Demand for transport services originates from shippers who issue orders to a carrier to transport a specified amount of goods. The carrier assumes the responsibility for the organization of transport and bears the costs. As compensation for transporting the orders, the carrier charges the shipper a fee for each order, based on the transport tariff. These tariffs serve to coordinate the usage of the trucks. Thus, the problem becomes how to impute, in the form of tariffs, the costs and risks associated with transportation activities to orders issued by the shippers.

Two types of carriage can be distinguished: private and common carriage. A vendor who owns a fleet of trucks combines the function of shipper and carrier. This is often called 'private carriage' (Hall and Racer, 1995). Determination of the total costs and profits does not require that costs be imputed to orders. However, tariffs can still be used for internal allocation of transport costs to orders. These can function to optimize transport efficiency and thus minimize the total costs of transport for the transport service. The opposite of private carriage is 'common carriage'. In this case, the shipper and carrier are independent entities. The carrier assumes the costs and risks related to dispatching the trucks. In return, the carrier can determine tariffs in such a way that his profits are maximized.

The costs incurred by trucks, which are dispatched on a specific route, are largely independent of the set of orders that is carried by those trucks. This means that the carrier's costs on a specific route are expected to increase as a staircase-function with the number of trucks dispatched. Therefore, in order to minimize costs in relation to the service offered, the carrier aims to maximize the utilization rate of the trucks.

In a non-deterministic setting, the carrier faces uncertainty in the time and size of order arrivals, especially with independent shippers. When service standards guarantee delivery of an order within a certain time period, the carrier might be forced to dispatch partially filled trucks. This brings up the question of what tariffs a carrier should charge for orders of a specific size in order to fulfill to requirements: charge a tariff low enough to entice the shipper to use the transport service and to charge a tariff high enough to recover at least the costs of the transport-operation.

When tariffs are imputed such that the carrier recovers his costs, some properties of the tariff function are expected. We denote by $T(q)$ the tariff charged to an order of size q, where q is the fraction that an order claims on the truck's capacity Q_F. In order for tariffs to recover the carrier's costs, assumed to be c_F per truck dispatched, $T(q)$ needs to satisfy $T(q) \geq c_F\, q$ for at least some order-size q. We assume that $c_F = 1$ in the remainder of this chapter. A tariff meeting the above inequality is one where each shipper pays for the costs the truck that is used for the order, $T_+(q) = \lceil q \rceil$ (where $\lceil x \rceil$ equals x rounded up to the next integer). An order of size q is thus charged the costs for dispatching the number of trucks that fits the order. Even when no consolidation takes place, the carrier recovers the costs by charging such tariff. However, the carrier saves costs by consolidating multiple orders in a truck, enabling him to charge a tariff lower than $T_+(q)$. Competitive pressure from the market is a driving force to confer part of the cost savings from consolidation on to the shippers.

Two contrasting scenarios for the market conditions for a carrier exist. In a scenario in which orders arrive relatively infrequently, the probability that multiple orders can be combined is small. In the extreme, the costs of the transport activity becomes independent of the order-size and approaches the function $T_+(q)$. On the other hand, in a scenario where orders arrive frequently, a carrier has ample opportunity to create efficient shipment quantities by combining multiple orders in one truck. The cost-impact of an order of size q approaches a linear function in order-size, when a carrier is so efficient that he realizes near 100% utilization. This enables the carrier to charge tariffs approaching a tariff that is proportional to the order-size, $T(q) \approx q$. A tariff that covers the carrier's costs but that is lower than $T(q) = q$ can only be charged if orders of such order-size are cross-subsidized by orders of a different size. Opportunities to consolidate are contingent on the transport service that is offered by the carrier and by the distribution of arrivals and size of orders to transport.

The aim of this chapter is to find a tariff function $T(q)$ for orders of size q for a carrier. This tariff function is based on a demand pattern of order arrivals at the carrier according to a stochastic process and the cost structure of the carrier.

4.3 Review of Transport Cost Literature on a Single Link

The main decisions of importance with respect to consolidation for increasing transport efficiency are when and how to dispatch orders (Jackson, 1981). The tradeoff between dispatching large and efficient shipments and dispatching frequently to curb inventory holding costs has led to studies in which both types of costs are considered together. In these studies, the functions of the carrier and shipper are assumed to be combined, so that order-decisions and the related costs are in a single hand. The decision strategy is a policy that aims to minimize total costs by adjusting timing and sizing of shipments. Economies of scale in transportation then lead to a lot-sizing problem to decide on the size of the orders.

In general, the costs involved with transportation depend not only on the quantity that is transported, but also on the distance that is traveled. To sketch the context of the transport problem on a single link between two points, it is also possible to combine multiple orders on a delivery route. This 'milk run'-type of consolidation leads to vehicle routing problems. The complexity implied by the vehicle routing problem is the reason why much research has focused on simplification of the full model by limiting the transportation strategy to direct deliveries. In this chapter, we focus on understanding the relationship between order-consolidation and transport tariffs instead of on the routing problem. Therefore, the problem concentrated on consolidation by accumulating orders over time for transport over a single origin-destination link.

For deterministic demand, the lot-sizing problem is often approached analytically by using EOQ-type studies. Hall (1987) presents strategies for consolidation in inventory, vehicles or terminals. Inventory consolidation is defined as the process where items remain in inventory in order to enable consolidation of orders at dispatch. Blumenfeld et al. (1985) study this by grouping several products together according to their demand rates in a virtual aggregated product. The economically optimal quantity is calculated for this aggregated product in order to determine the lot-size. The consolidation policy is quantity-based: once a certain amount has accumulated, transport is organized.

Speranza and Ukovich (1994) consider a system where the costs of dispatching trucks is proportional to the number of trucks that is used. Trucks are scheduled to be dispatched according to a frequency schedule, which is an example of a time-based consolidation policy. Clearly, a time-based policy is preferred over a quantity-based policy when the shipper requires a reliable transportation lead-time or a guaranteed service level. Only in the case of deterministic demand —as in the above-mentioned examples— there is a simple relation between quantity-based and time-based policies.

Çetinkaya et al. (2006) present results from optimal dispatch strategies for consolidation over time and quantity within the context of private carriage with stochastic demand (see also Çetinkaya and Lee (2000) and Axsäter (2001)). Both the optimal quantity to accumulate before dispatch as well as the optimal dispatch frequency is derived.

Higginson and Bookbinder (1994) use simulation to study the effect of randomness in order arrivals on consolidation decisions. Freight-rate discounts are used to determine the costs of transport. The costs of time-based, quantity-based and time-quantity-based policies are compared with each other for several order arrival processes. Bookbinder and Higginson (2002) build on this by employing probabilistic modeling to choose the maximum holding time and optimal dispatch quantity. Optimal time and quantity-policies are derived by Çetinkaya and Bookbinder (2003) for specific order arrival processes. Both private and common carriage is considered, where in the case of common carriage, freight-rate discounts are used to determine tariffs.

Firms that ship goods regularly on a fixed origin-destination link often have long-term transport contracts with a carrier. van Norden and van de Velde (2005) analyze the problem of determining transport lot-sizes to meet demand, while minimizing the total costs of transportation, inventory-holding costs and ordering costs. The firm faces a fixed freight-rate to transport up-to a certain amount of goods. If the quantity of goods that the shipper plans to transport exceeds the contracted amount, the shipper has to purchase transport capacity at the spot market at a higher rate. In this chapter, we do not focus on transport contracts for fixed quantities, but instead we investigate transport tariffs in the spot-market for LTL-orders.

A number of studies consider the problem of optimizing the total inventory holding and transportation costs from the perspective of an independent shipper. The shipper pays a tariff for each transport order, which he perceives as costs. Accumulation of orders leads to more efficient transport, but at the costs of increased inventory holding costs and decreased service level. To study a shipper's optimal decision strategy, a relation that describes the shipper's transport costs as a function of the order-size is required. Such a tariff function can be constructed from empirical data or it can be based on theoretical assumptions.

Transport tariffs are often difficult to uncover in practice. Published tariffs of a carrier often serve only as a starting point for negotiating the price of transportation services. Langley Jr. (1980) analyzed the effects of several theoretical functional forms for transport tariffs on the lot-sizing problem. Tersine and Barman (1991) consider the lot-sizing problem with consolidation opportunities, using detailed actual tariffs. Fleischmann (1993) uses actual German freight-rates to study the design of transport networks with economies of scale in transport. Swenseth and Godfrey (2002) used actual freight-rates to find a fit for the transport costs function. These fitted tariff functions are used to derive the expected costs in order to determine the optimal mode of shipment: full-truckload or Less-than-Truckload.

Smith et al. (2007) develop and test a statistical model of revenue from expedited freight services by regressing revenue on weight and distance related variables. The empirical data on which the regression has been developed were taken from actual shipment data of a major North-American carrier. The proposed model for monthly revenue on a shipping lane (Model 1 in (Smith et al., 2007)) is

$$\text{revenue (\$)} = \beta_0 + \beta_1\,(\text{total shipments}) + \beta_2\,(\text{total weight})$$
$$+\,\beta_3\,(\text{total weight squared}) + \beta_4\,(\text{total ton-miles})$$
$$+\,\beta_5\,(\text{square of total ton-miles}) + \beta_6\,(\text{lane distance} \times \text{total ton-miles}) \quad (4.1)$$

with expectation, statistically accepted, that β_1, β_2, and β_4 are positive and β_3, β_5, and β_6 are negative based on the observation that there are discounts for shipping large volumes. The model was found to explain 89% of variance in revenue.
Note that abstracting from distance (miles) related variables reduces the revenue model to one that is quadratic in weight shipped. The model of Smith et al. (2007) shows how from weight-distance variables are used to predict aggregate revenue, summed over shipments, for a particular shipping lane.

Swenseth and Godfrey (1996) analyzed *actual transport tariffs* from all over the USA on 40 alternative routes for LTL and TL-transport. Specific functional forms for transport tariffs were fit to this data. The best fit was found for a rate that increases quadratically in order-size. In this case, the rate per unit freight ($T(q)/q = t(q)$ decreases proportionally in order-size and is given by

$$t(q) = a - bq, \quad (4.2)$$

where $a = c_F - Q_F b$, in which c_F is the costs for a truckload and QF is the size of a truckload. Constant b is the decrease in rate per unit as the order-size increases. Swenseth and Godfrey label this tariff function $T(q) = q(a - bq)$, the proportional tariff function. A good fit with actual tariffs was found for rates per unit that decrease inversely with the order-size: $t(q) = c/q + d$. It is called the adjusted inverse function due to the inverse proportionally decreasing rate plus an offset. Tariffs in this case are a linear function of order-size with an offset for size zero, $T(q) = c + dq$ with c, d constants. Both functions are illustrated in Figure 4.1.

Arcelus and Rowcroft (1991) analyzed actual freight-rates for small orders on routes in Canada and fitted these to a power tariff function, $T(q) = aq^b$, with a, b suitable constants. Typically, they find b in the order 0.4. Fitting to the same power tariff function, Tyworth and Zeng (1998) found a good fit for $b = 0.67$ for some representative freight-rate data published by major trucking company in 1995. The power function was also argued by Cheung et al. (2001) as making the best fit to a tariff based on order-size. Cheung et al. concluded that the best fit was found for a value $b = 0.5$, based on a case study of DHL in Hong Kong, where staff were consulted to find the perceived impacts on the amounts of resources required

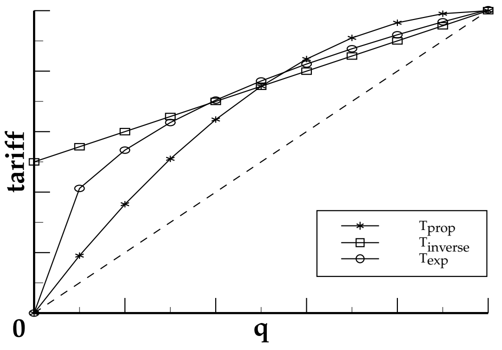


Figure 4.1: Proportional, adjusted inverse and exponential tariff function

for different shipment-weights. Figure 4.1 illustrates the proportional, the adjusted inverse and the power tariff functions.

A number of intuitively expected properties are common to the three tariff functions. First, transport rates increase monotonically with increasing order-size, which prevents shippers from over-declaring orders. Second, transport rates per unit decrease monotonically as function of order-size, as expected due to economies of scale. Further, the transport cost functions are expected to be sub-additive, so that it is never economical for a shipper to split an order into multiple orders of smaller size. Note that sub-additivity implies that the rate per unit decreases as a function of order-size. To summarize, the tariff $T(q)$ that specifies the rate a shipper pays to a carrier for transporting an order of size q should satisfy the following properties:

1. Monotonicity of rates: $q' > q \Rightarrow T(q') \geq T(q)$. This property states that the rate can be assumed to increase in the size of the order.

2. Monotonicity of rate per unit: $q' > q \Rightarrow t(q') \leq t(q)$. This property states that the rate per unit can be assumed to decrease in the size of the order, as expected by economies of scale.

3. Subadditivity: $T(q+q') \leq T(q) + T(q')$. This property states that for a shipper it does not make sense to declare an order of size $q+q'$ as two separate orders, one of size q and one of size q'. In terms tariff per unit, subadditivity states that $t(q+q') \leq \frac{q}{q+q'}t(q) + \frac{q'}{q+q'}t(q')$, implying that the second property of decreasing rates per unit is satisfied.

Figure 4.1 illustrates that tariffs for orders of small order-size for both the proportional and the exponential tariff function are relatively high. This property is expected in real tariffs, since an order of small order-size necessitates the use of a truck, but the probability to use the remaining space in a truck with another order is less than one. For orders above half the truck size, the proportional and exponential tariff increase in a similar fashion, with tariffs below the tariff of the inverse proportional function. The inverse proportional tariff displays a property that is expected for orders which are close to the size of a truckload. In this case, the probability that the remaining space in the truck can be used to transport another order decreases rapidly to zero. As a result, a tariff that is close to the tariff for full-truck is expected to be rated for orders with order-size close to the truck's capacity. In conclusion, the exponential and proportional tariffs are expected to describe tariffs well in markets where few small orders dominate, while the inverse proportional might be better suited in markets of many orders, both small and larger.

The literature above shows that many researchers have ascertained the shape and properties of transport tariffs based on actual tariffs in the market. However, few researchers seem to have addressed the question from a theoretical perspective as to what determines the structure and shape of the tariff function. The topic of allocating the costs of transport to specific customers is gaining interest. The authors of a working paper, Özener et al. (2010), argue that assessing the cost-to-serve of customers is of value when setting prices, targeting prospective customers, prioritizing deliveries, or revisiting routing/quantity decisions. The authors propose several cost allocation methods to determine the cost-to-serve for customers and show empirically that our proposed methods perform significantly better than the proportional allocation schemes typically used in practice as these schemes ignore the synergies among customers.

We distinguish tariffs in the case of private carriage and tariffs in the case of common carriage. In the case of private carriage, we assume that there is a supply chain coordinator who lacks the ability to fully control transport decisions, but who has the capacity to determine transport tariffs. In Section 4.5, we discuss how these tariffs are a result of allocating the shared costs for transport to individual orders. In the case of common carriage, where carrier and shipper are independent, we assume that the carrier sets the tariffs such that his expected profits are maximized. This is discussed in Section 4.6. The generic framework for the carrier's operations of transporting and consolidating orders is described first.

4.4 Model Framework and Assumptions

4.4.1 Introduction

We consider a carrier who does business with a shipper on a transactional basis. The carrier transports LTL-orders from the shipper, for which the shipper pays a tariff to the carrier. The carrier determines and publishes the tariffs for performing transport services. The transport tariffs depend on the demand pattern for transport orders and on the cost structure and organization of transport by the carrier. The cost-impact of an order depends on the other orders with which the order can be combined. Shippers however, have no information on the status of order-arrivals at the carrier. We further assume that the demand pattern for transport and the carrier's cost structure do not depend on time.

4.4.2 Transportation Service

The transportation service considered is that of transportation on a single lane from location A to location B. Service standards are assumed to guarantee delivery of an order within a certain time after submission of the order. We assume that the service guarantee is implemented through a timetable of dispatches published by the carrier: each transportation order is promised to be carried out at the first timetable's dispatch time subsequent to the time of submission of the order. Such a transportation policy is referred to by Bookbinder and Higginson (2002) as a "time policy" or "scheduled shipping policy", in contrast with a "quantity policy" which states that shipping occurs when the volume of orders accumulated exceeds a certain threshold. Note that under a time policy a carrier may have to dispatch lowly filled trucks to comply with the published schedule of dispatches.

To reflect the carrier's uncertainty regarding transport orders, transport orders are assumed to arrive according to a stochastic process at the carrier. At a dispatch time, all orders that have accumulated are shipped: the system renews at each dispatch event. Without loss of generality, we take the time interval between two dispatch events to be 1 time unit. The problem that we consider is illustrated in Figure 4.2. In between two dispatch epochs, orders accumulate into an order-pool where they accumulate at the collection point of a carrier **A**. At a dispatch epoch on a regular time schedule, the carrier initiates transport of all orders that have accumulated in the order-pool. The orders are packed into the necessary number of trucks and transported to the destination at point **B**. The carrier charges a rate

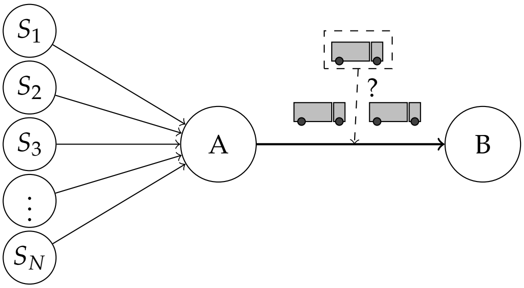


Figure 4.2: Illustration of the problem that is considered: orders from shippers accumulate at the carrier in **A**. The carrier consolidates the orders that are available in trucks and transports these to the destination **B** according to a regular time schedule.

to shippers as compensation for the carrier's risks.

The activity of collecting orders and consolidating these to dispatch trucks is the business of the carrier. Trucks are packed efficiently, such that the smallest number of trucks is used. There are sufficient trucks available to transport the entire order-pool. All trucks are identical. The capacity is measured in units of order-size. Therefore, the optimal packing of orders in trucks becomes a one-dimensional bin-packing problem.

4.4.3 Cost structure Carrier

The costs that the carrier incurs for organizing transport is comprised of fixed costs and costs related to the distance traveled and the load transported. The fixed costs are costs for among others depreciation, salaries, administration and information technology. These cannot be altered by the carrier's operational decisions. Therefore, we focus on the costs that are relevant to the carrier's dispatch decisions. Such costs are related to the trip, such as mileage, costs of fuel, wages, and wear and tear of trucks. These costs depend only to a small extent on the actual load inside a truck. Neglecting the effect of actual load and given that only transport on a single link between origin and destination is considered, the costs of each truck that is dispatched is a constant. For every dispatch, the resulting number of trucks that is deployed for the dispatch determines the costs of the carrier. As a result, the carrier's costs becomes a step-wise increasing function, dependent on the number of trucks deployed.

The number of trucks that is needed at a dispatch epoch depends on all orders in the order-pool, since orders may or may not fit in a truck, depending on the complete set of orders. This implies that the carrier's costs are a function of the orders in the order-pool. These costs cannot be expressed as a linear combination of costs per order. Our interest lies in the tariff that the carrier charges as a function of order-size.

4.4.4 Determination of Tariffs

Tariffs are levied to coordinate the use of transport means. Tariffs reflect the cost-impact of an order on the carrier. Therefore, to distinguish between orders of different size that put larger or smaller claims on the transport capacity, the rate this is charged is a function of order-size. The tariff-function depends on the cost structure of the carrier, the organization of transport by the carrier and the order arrival pattern or market for transport orders. Further, in determining tariffs, the carrier can decide if the tariffs are merely reflecting the cost-impact, or if the tariffs are such that the carrier's profits are maximal. To facilitate comparing tariffs, all tariffs are expressed in units of the carrier's costs per truck-ride.

In the case of private carriage, tariffs can be used to optimize cost performance. In such a setting, the carrier's transport costs are allocated to individual orders. We consider the expected additional costs of an extra order, the Shapley value of orders and allocation by proportion of order-size to the order-pool.

In the case of common carriage, the carrier aims for profit maximization. Shippers can decide to offer transport orders to the carrier or find an alternate carrier. We assume that shippers are able to hire a full truck at a tariff equal to the carrier's costs per truck-ride. This puts an upper bound on the tariff that a carrier can charge. We determine the resulting tariffs for such a carrier.

Numerous shippers issue orders for transportation service. To model demand risk, the number and size of the arriving orders in a dispatch period is taken stochastic. Orders are assumed to arrive according to a compound Poisson process with rate λ and Gamma distributed order-size. The $\Gamma(\alpha, \beta)$ distribution is skewed to small orders by choosing a small α. Comparison to data from medium sized package industry as well as to other real world data demonstrate that such an order-arrival process and order-size distribution represents LTL-orders well (see Higginson and Bookbinder (1994) and Bookbinder and Higginson (2002)).

The detailed models to determine tariffs proved too difficult to analyze analytically. Therefore, we resort to simulation by computer. The simulation proceeds as follows. Realizations of the order pool are generated in accordance with the specified probabilities. For each realization, a principle is applied to derive at the cost impact of each order, in order arrive at a cost allocation or implied profit. Averages are computed to arrive at the resulting tariff. In the case of profit maximization, this is done after carrying out a maximization. Details of the simulation process are discussed in Appendix A.

For the order arrivals, we consider $3 \times 2 = 6$ scenarios consisting of three levels for the arrival intensity and two choices for the order size distribution as specified in Table 4.1. We use two Gamma distributed order-size distributions in the simulation experiments: a distribution with predominantly small orders, ($\Gamma(2, 1.2)$ with average order-size 2.4) and one with medium-sized orders ($\Gamma(2, 5)$, average order-size 10). Both distributions are realistic to model LTL-transport for a truck of capacity $Q_F = 20$. The order-arrival rates is varied between $\lambda = 1, \lambda = 2$, and $\lambda = 10$. As mentioned before, the order-size q is the fraction of the truck's capacity that is used (so $q \in [1/Q_F, 2/Q_F, \cdots, 1]$) and the tariff is normalized to the tariff of a full truck. For details on the simulation study and the derivation of the transport tariffs, see Appendix A.

Table 4.1: Scenarios for order arrivals. Under each scenario the truck's capacity is $Q_F = 20$. Scenarios with $\Gamma(2, 1, 2)$ are 'small' order size scenarios and those with $\Gamma(2, 5)$ are 'medium' order size scenarios.

arrival intensity per dispatch period	size distribution $\Gamma(\alpha, \beta)$	average order size $\alpha\,\beta$	average pool size $\lambda\,\alpha\,\beta$
1	$\Gamma(2, 1.2)$	2.4	2.4
1	$\Gamma(2, 5)$	10	10
2	$\Gamma(2, 1.2)$	2.4	4.8
2	$\Gamma(2, 5)$	10	20
10	$\Gamma(2, 1.2)$	2.4	24
10	$\Gamma(2, 5)$	10	100

The following two sections give the descriptions of the models and simulations with additional, formal details supplied in Appendices A.1 and A.2.

4.5 Tariffs by Cost Allocation

In this section, we determine transport tariffs by allocating the total costs of transport to each order. The shipper and the carrier cooperate in a system with a supply chain coordinator who knows the carrier's cost structure and the demand patterns for transport orders. This knowledge is used to derive the expected transport costs and to set transport tariffs. The tariffs are determined by allocating the expected costs to individual orders: the transportation costs are thus internalized by the shipper function. The tariffs induce shippers to issue orders such that the usage of the transport resources is economical.

The most common and logical method to allocate transport costs to orders is based on the size of an order. The size of an order may be expressed in terms of weight, volume, or a combination of both. However, the transport costs of a carrier depend on the combination of all orders with their specific order-size that arrive in the order pool. We can illustrate this by assessing the additional costs of an order that just arrives at the carrier. No extra costs are incurred when the order-size is such that it fits into the available space of one of the trucks that are anyway planned for transporting the order-pool at dispatch-time. Alternatively, if the size of the arrived order does not fit into the remaining space, it may be that the order necessitates the use of an extra truck to transport all orders. In that case, the additional costs equal the costs of a complete truck-ride. The result of the dependence of the costs to transport an order on the entire order pool is that the carrier's transport costs are not simply separable in order-size. This makes determining transport tariffs complex. If transportation costs would have been separable in order-sizes, the cost increment for adding an order to the pool would be independent of the existing pool and in that case, costs may be allocated to an order based on its share in the pool. When costs are not separable in order-size –as is the case in this problem–, no straightforward logic exists for allocating transport costs to order-size. Additional rules or principles are needed to arrive at an allocation of the carrier's costs to individual orders in order to derive a tariff.

4.5.1 Principles of Cost Allocation

Allocation of costs can be based on various grounds: by volume, weight, number of items, timing of arrival etc. The purpose of cost allocation can be optimization of resource utilization or some acceptable or 'fair' distribution of cost. Therefore, any type of cost allocation is essentially ambiguous. The problem of allocating shared costs under cooperation is addressed in game-theory. Billera and Heath (1982) describe the general problem of allocating shared costs. The problem that we have here is a cooperative game for which the costs of transporting the order-pool need to be allocated to individual orders. A number of requirements for the allocation procedure, which are stated in game-theory, are applicable to our situation. We restate some requirements here in relation to the transport case. First, the carrier has to recover the costs for transportation. Therefore, the allocation should be such that the sum of the tariffs charged to each order adds up to the total costs at least. Second, published tariffs should be symmetrical, meaning that the tariff for an order is independent of the sequence in which orders arrive.

We analyze three mechanisms of allocating costs: marginal allocation, Shapley value and semi proportional allocation. Based on a simulation study, we show the resulting tariffs for these allocation mechanisms.

A number of requirements for the allocation principle, also frequently stated in game theory, are applicable to our situation. First, the carrier has to recover the costs for transportation, therefore, the allocation should be such that the sum of the rates charged to orders at least add up to the total costs on average. Second, published tariffs should be symmetrical, meaning that the rate for an order is independent of the state of the order pool at the time of submission of the order. Only the order's size, not its timing, may be input to the rate applied. Below three precise allocation principles will be considered in more detail, the marginal costs, the Shapley value, and the semi-proportional principle. In each case computations are founded on considerations of the costs impact of adding an order to an existing order pool. For a realization of the order pool $\mathcal{O} = (q_1, \cdots, q_{|\mathcal{O}|})$ we compute the separate impact of the k-th order being of size q as

$$\tau_k(\mathcal{O}, q) = \begin{cases} Ntruck((q_1, \ldots, q_{k-1}, q_k)) - Ntruck((q_1, \ldots, q_{k-1})) & \text{if } q = q_k \\ 0 & \text{if } q \neq q_k \end{cases} . \quad (4.3)$$

Note that the allocation τ is efficient in that $Ntruck(\mathcal{O}) = \sum_{k=1}^{|\mathcal{O}|} \tau_k(\mathcal{O}, q_k)$.

We add to the requirement of cost recovery to the properties that were found from literature in Section 4.3. Then, transport tariff functions for LTL-orders are expected to satisfy:

1. transport rates increase monotonically with increasing order-size
2. transport rates per unit decrease monotonically as function of order-size
3. transport rates are *sub-additive*

4. transport rates *sum up* to at least the carrier's costs.

These properties are assessed for each cost-allocation mechanism.

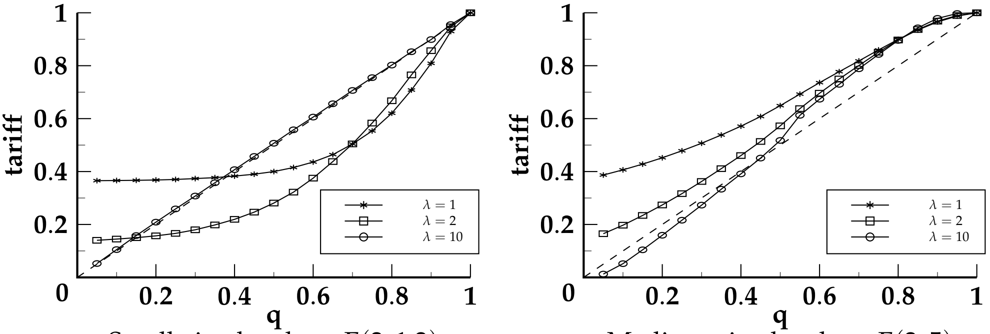
4.5.2 Expected Marginal Transport Costs

Marginal cost allocation might be used when the aim is to consider and optimize for the total system. The transport tariff in the case of marginal costs is determined at dispatch time by the additional costs for transporting an extra order of size q on top of the costs for transporting the orders that had already accumulated in the order-pool. When the additional order fits into a partially filled truck that was already scheduled for other orders, then no additional costs apply. Otherwise, the costs of the required extra truck is charged to the order.

Figure 4.3 shows the tariffs derived from marginal transport cost analysis for different order-arrival rates as a result of a simulation study. The arrival-rate is varied between 0.1 and 10, but plotted here are only the tariffs for arrival rates $\lambda = 1$, $\lambda = 2$ and $\lambda = 10$ order arrivals per time unit. The graph on the left of the figure shows results for orders drawn from the small-order distribution, while the orders in the right graph are drawn from the medium-size order-distribution.

The graphs show that the arrival rate strongly affects the tariff that is charged for orders of small order-size. When the arrival rate $\lambda = 10$, the tariff for small orders is almost zero, while in the case of a small arrival rate, the tariff for small orders is greater than zero. The reason for this is that when other trucks are dispatched, the probability that such small order can be combined is high, resulting in marginal costs close to zero. On the other hand, when the order-pool is empty, any additional order causes the need to deploy a truck to transport it. Therefore, the expected marginal tariff for the smallest order equals the costs of a truck-ride, weighted by the probability that no orders arrive. We discuss tariffs for the smallest order in more detail later in Section 4.7.2.

The slope of the tariff function differs for different order arrival rates. The tariff for a small arrival rate is relatively insensitive to the size of an order for small orders. The functional form of such tariff shows some similarity to the carrier's step-function of costs. For a high arrival rate however, the tariff depends strongly on the order-size. This is due to the increased opportunities to consolidate orders when many orders arrive, with the average utilization rate rising as a result. This causes the marginal costs for an extra order to approach a function that is increasing linearly in order-size.



Small-sized orders: $\Gamma(2, 1.2)$

Medium-sized orders: $\Gamma(2, 5)$

Figure 4.3: Expected marginal transport rates as function of order-size for different order arrival rates.

The difference between the graph with small order distribution and medium-sized orders is most prominent for $\lambda = 1$ and $\lambda = 2$. In the left graph, the distribution of the order-size is narrow with small average order-size. With one expected arrival per dispatch period, the size of the order-pool that is transported has average size 2.4. Therefore, the probability that one additional order can be combined in the same truck at no extra costs is high. As a result, the tariff function for low order-arrival rates in the left graph increases relatively slowly as long as the order-size is small. Tariffs start to increase sharply only for large orders, when the size of the combined orders exceeds the truck's capacity. In the right graph, the distribution of order-sizes is wider with bigger average size than in the case on the left. This reduces the probability that an additional order can be combined for free into any deployed truck. As a result, the tariffs are higher and the dependence of the tariff on the size of the additional order is stronger.

For arrival rate $\lambda = 10$, the difference between the functional shape in the left and right graph is not as distinct. The reason is that when many orders arrive in between two dispatch epochs, the distribution of order-size of the accumulated order-pool widens. This diminishes the effect of the order-size of an individual order, which explains the similarity in the shape of the tariff function between between the small and the medium order-size.

A problem with marginal cost pricing is that orders are cross-subsidized. In this case, the marginal costs of an order of certain size are less than the fraction such order claims of the truck capacity. Another problem is that when all orders are

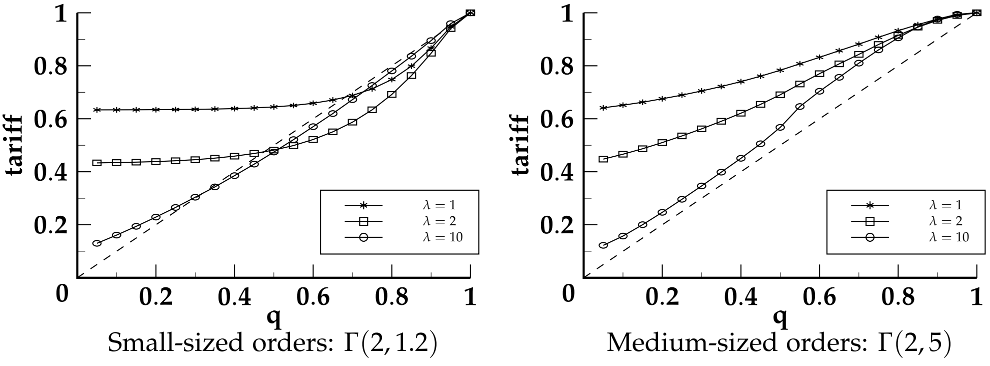


Figure 4.4: Expected Shapley transport rates as a function of order-size for different arrival rates.

charged at their marginal costs, the sum of these tariffs is not necessarily sufficient to recover the transport costs of the carrier. Further, tariffs based on this are not necessarily sub-additive. A commonly used alternative to marginal cost-pricing is allocation based on the Shapley value. Tariffs based on the Shapley value do sum up to the total of the carrier's transport costs. Costing based on the Shapley value is discussed in the next section.

4.5.3 Expected Shapley Value for Transport Costs

The Shapley value is a concept that originates from game theory. The Shapley value is one way to determine the gains that can be associated with each player in coalitional game. Consider all coalitions a player could form and calculate the gains the player would get in each coalition. The Shapley value is determined as the average of the gains of all possible permutations of coalitions possible (Peters, 1992, page 194). In the context of transport tariffs, the Shapley value is calculated as the weighted marginal costs for each order that is part of the order-pool over all possible order arrival sequences.

Tariffs that are derived based on the Shapley value are displayed in Figure 4.4. The functional form of the Shapley tariffs is similar to that of the marginal tariffs, especially for the graph with medium orders. This is because orders of widely varying size are shipped which reduces the averaging effect of the Shapley value compared to marginal tariffs. For small orders, with a narrow order-size distribution, the functional shape of the Shapley tariffs appears less extreme compared to the marginal tariffs. Even though tariffs for some order-sizes are still cross-subsidized by other orders, the Shapley tariffs dampen this effect. Comparison of the tariff for the marginal and Shapley allocation at $q = 0.8$ and $\lambda = 1$ shows that the tariff function in case of Shapley tariffs deviates less from the strictly proportional tariff ($T(q) = q$) compared to the marginal cost pricing of Figure 4.3.

However, Shapley tariffs are not necessarily sub-additive, meaning that under this tariff, it might be economical for shippers to split a large order into multiple orders of smaller size. An example of an allocation method that results in sub-additive tariffs is when costs are allocated according to a semi-proportional allocation rule.

4.5.4 Semi-proportional Transport Cost Allocation

In the case of semi-proportional allocation, each order is charged a fraction of the carrier's transport costs, proportional to the ratio of its order-size to the size of the order-pool, but never exceeding the costs of a full truck. Orders of large order-size have the highest risk that their proportional share would exceed the costs of a full truck. Therefore, to ensure that the carrier recovers the costs, we proceed as follows. First, orders in the order-pool are sorted from large to small order-size. After that, a fraction of the costs is allocated to the largest order. This fraction is the minimum of the proportion of the size of the order to the size of the order-pool and the costs of one truck. Subsequently, a proportional share of the remaining costs over the remaining order-pool is allocated to the next largest order. This is repeated until the total costs are recovered.

Tariffs that are based on the semi proportional cost allocation method for different order-arrival rates are shown in Figure 4.5. In case of small distributed order-size and low arrival-rate, the occurrence of large order-size in the order-pool becomes very rare. As a result, the standard deviation between replications increases, explaining why the graph is not smooth in this region. It is expected that the cost function in this region turns out to continue smoothly if the simulation would continue until sufficient of such occurrences are generated.

The slope of the tariff function for large orders approaches zero, meaning that large orders of size near the truck's capacity are charged the costs of a truck's dispatch, as observed in practice. This is caused by the low probability for the carrier of making economic use of the remaining space in a truck for such large orders.

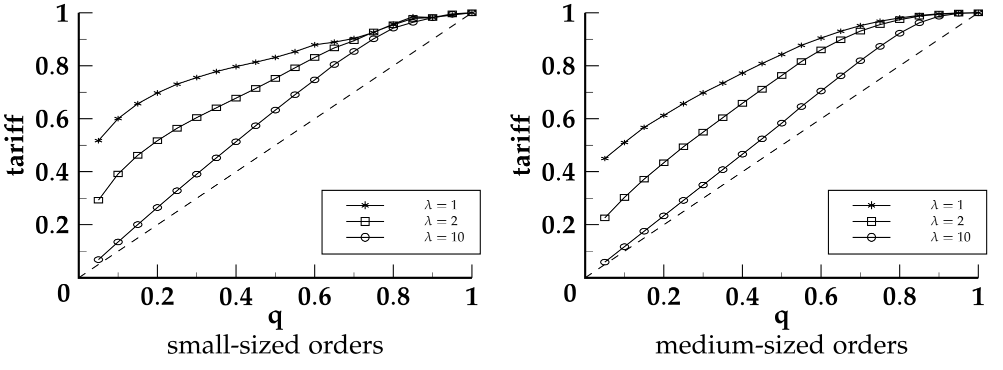


Figure 4.5: Expected semi-proportional transport rates as function of order-size for different order arrival rates

Table 4.2: Overview of expected properties for different cost-allocation transport tariff functions.

Tariff Property	marginal	Shapley	semi-proportional
Monotonically increasing rate	+	+	+
Recover total costs	-	+	+
Sub-additivity	-	-	+
Monotonically decreasing rate per unit	-	-	+

Table 4.2 summarizes for the assessed cost-allocation methods the expected properties. The marginal cost-allocation only satisfies the requirement that the tariff is non-decreasing. The tariff based on Shapley values also satisfies the requirement that orders of one size are not cross subsidizing other orders. Further, the sum of Shapley rates add up to the total transport costs. Finally, the semi-proportional cost-allocation satisfies the requirement of sub-additivity on top of the other requirements. The semi-proportional cost-allocation method functions as an acceptable method to determine transport tariffs based on cost-allocation.

4.6 Tariffs by Profit Maximization

4.6.1 Profit Maximization Tariffs: Theoretical Model

In the situation of common carriage, where carrier and shipper are independent businesses, we consider a carrier who aims to maximize profits from transport services. The carrier determines the tariff $T(q)$ for shipping orders of size q. The shipper has a choice to offer orders to the carrier or not, based on the tariff. The shipper can organize transport differently if he decides that the tariff is too high: he can go to another carrier or organize the transport himself. The fraction of orders that shippers submit to the carrier, $f(q)$, is a function of the order-size and tariff.

The a priori probability that an available order has size equal to q is $\phi(q)$. Therefore, since the order-arrival rate is λ, orders of size q emerge with rate $\lambda_q = \lambda\phi(q)$. The rate of orders *that a shipper submits to the carrier* is $\lambda_q f(q)$.

The fraction of orders that is submitted to a carrier depends on the transport tariff. For a tariff $T(q) \geq 1$, the shipper submits no orders as it becomes more economical to hire a truck from another source. When the carrier's utilization rate is 100%, the cost per order is q. It is not possible to achieve lower costs per order without cross-subsidizing orders. Therefore, when a carrier charges a tariff $T(q) \leq q$, shippers decide to submit all the orders that they have to such carrier. We assume that the submitted fraction on $T(q) = [q, 1]$ decreases exponentially with constant α to model the sensitivity of the tariffs on the market. The factor α in the exponent represents the shipper's utility. For a shipper who can afford to be price-sensitive —possibly due to strong competitive forces between carriers— the constant α is greater than one. In that case, tariffs are expected to approach $T(q) = q$. On the other hand, in a market that is dominated by carriers, so $\alpha \leq 1$ shippers might have little choice but to accept the tariff that the carrier sets.

In summary, given that an arrived order has size q, the proportion of orders that are submitted, $f(q)$, is modeled as:

$$f(q) = \begin{cases} 1 & \text{if} \quad T(q) \leq q \\ \left(\frac{1-T(q)}{1-q}\right)^{\alpha} & \text{if} \quad q < T(q) \leq 1 \\ 0 & \text{if} \quad T(q) > 1. \end{cases} \tag{4.4}$$

The expected size of the order-pool, Q_{tot}, that has arrived between two dispatch events (inter-dispatch time is 1 time unit) is

$$Q_{tot} = \sum_q f(q)\lambda_q\, q.$$

The expected revenues $R(\lambda, T(q))$ for the carrier are calculated by summing the revenues for orders of size q

$$R(\lambda, T(q)) = \sum_q T(q) f(q) \lambda_q. \tag{4.5}$$

With $C(\lambda, T(q))$ the expected costs, the carrier's expected profit can be calculated. Maximization of the expected profit Π^* results in the following problem

$$\Pi^* = \max_{T(q)} \Pi(\lambda, T(q)) = \max_{T(q)} (R(\lambda, T(q)) - C(\lambda, T(q)))$$

The carrier's costs depend on the order arrival rates as well as tariffs. In general, the costs are not separable in order-size, as the submission rate of orders of certain size affects the efficiency with which other orders are packed and shipped.

However, assume for the moment that the carrier's cost function can be approximated by a function linear in total quantity shipped, with proportionality constant c. In this case, there are no economies of scale in order quantity and therefore the expected costs and profits are separable in q:

$$\Pi(\lambda, T(q)) = \sum_q \left(T(q) f(q) \lambda_q - cq f(q) \lambda_q \right). \tag{4.6}$$

Maximization of the expected profit leads to a maximization problem for each $q \in [1/Q_F, 2/Q_F, \cdots, 1]$. When this is solved, the optimal tariffs $T^*(q)$ are

$$T^*(q) = \min \left(\max \left(\frac{1 + \alpha c q}{1 + \alpha}, q \right), 1 \right) \tag{4.7}$$

Figure 4.6 shows the optimal tariffs for some values of c and linear price-sensitivity for the shipper, $\alpha = 1$. When the stepwise increasing function of costs in number of trucks is approximated by the linearly increasing costs function, the constant c needs to be $c \geq 1$. The special case of $c = 1$ occurs when all trucks are filled to their capacity, which in general does not occur, due to the uncertainty in order arrivals. The resulting tariffs for this linear approximation of the carrier's cost function are strictly increasing in order-size and piecewise concave. The rate (p/q) decreases monotonically. When the shipper's response to the price changes (α), the tariff at $q = 0$ changes ($T(0) = 1/(1 + \alpha)$): when the shipper is sensitive to the price (α large), the carrier is forced to set tariffs near to $T(q) = q$. When the shipper is not price-sensitive (α small), the carrier can charge higher tariffs for orders of small size.

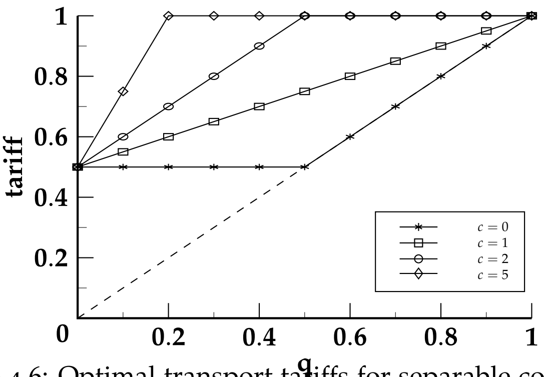


Figure 4.6: Optimal transport tariffs for separable costs and $\alpha = 1$.

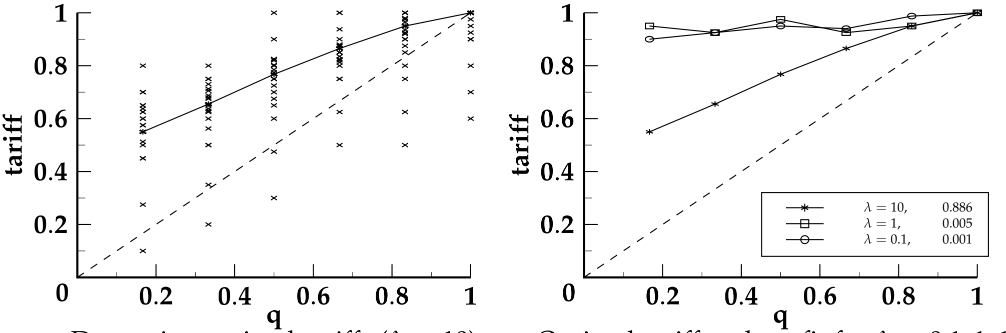
4.6.2 Simulation results, Common carriage

The tariffs in the case of common carriage, with a carrier optimizing for maximum profits are derived by simulation. Due to the computational issues, the truck-size is limited to $Q_F = 6$, but as before, the order-size is normalized in the results. The other settings remain unchanged. Figure 4.7 on the left shows the tariff functions for the case of $\lambda = 10$ arrivals per time unit and the small order-size distribution. The crosses in the graph show all rates that were tried in order to determine the maximal expected profits. The standard deviation between replications is below 1%.

Figure 4.7 on the right shows the optimal tariffs for varying order arrival rates. The occurrence of order-arrivals for $\lambda = 1$ becomes so rare that the standard deviation between replications increases to up to 10%. The exact shape of these tariff functions therefore is uncertain, but the general trend that these tariffs approach the carrier's step function of costs is clear. The expected profit per dispatch is listed in Table 4.3

Table 4.3: The expected profit per dispatch for several order arrival rates.

λ	$\Pi(\lambda)$
0.1	0.001
1	0.005
10	0.886



Determine optimal tariffs ($\lambda = 10$) Optimal tariff and profit for $\lambda = 0.1, 1, 10$

Figure 4.7: Derivation of optimal tariffs in the case of common carriage. Crosses indicate trial rates.

4.7 Discussion on Transport Tariffs

Efficiency gains in the fields of managing inventories, logistics between companies and production planning are typically found as a result of cooperation. For both the vendor and the buyer, enhanced cooperation impacts the management of inventories as well as the organization of transporting goods from vendor to buyer. When a vendor and buyer decide to cooperate, the information flow improves and the leverage for making decisions in which constraints and circumstances of both parties are taken into account increases. This creates opportunities in making processes such as transport more efficient. In order to assess the potential of opportunities and alternatives to organize transportation more efficiently, it is essential to have a method for estimating the impact of this on the costs and service for transport. In this chapter, we study consolidation of multiple orders in a truck on a single link. Orders are of of size Less-Than-a-Truck-Loads (LTL). We derive transport tariffs for such orders for the situation of both private as well as common carriage. We show that tariffs with practically required and expected properties can be derived based on a relatively simple model.

4.7.1 Tariff Comparison

In the case of private carriage, transport tariffs are the result of allocating the carrier's costs of transport to orders. We have considered three allocation mechanisms: marginal, Shapley and semi-proportional allocation of costs. The plots in Figure 4.8

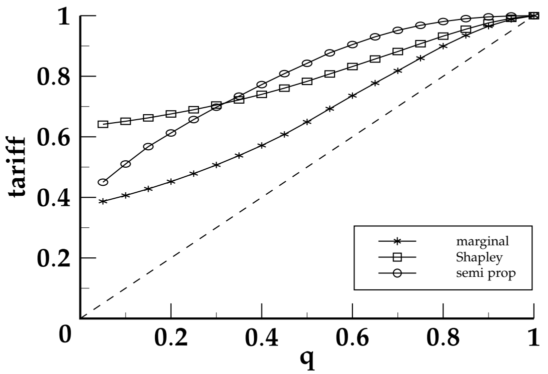


Figure 4.8: Comparison of tariffs for private carriage, based on three cost allocation mechanisms. $\lambda = 1$ Arrival per time-unit.

show a comparison for these three tariff functions. The marginal tariffs are lower than the Shapley tariffs for all order-sizes. This is because in the case of marginal tariffs, only the marginal costs of the last order are considered, while for the Shapley tariffs the average of many marginal costs is used. In the case of proportional tariffs, costs are allocated according to a different principle. Therefore, the functional shape differs and these tariffs are lower compared to Shapley tariffs for low order-size, but more expensive when the order-size is greater.

The semi proportional tariff fulfils best the requirements for allocating shared costs that we discussed in section 4.5.1. Indeed, the total costs of transport are recovered using these tariffs. Further, the tariffs are symmetrical in the order-arrival sequence. Tariffs that are based on the semi-proportional allocation are strictly increasing in order-size. Further, the numerically derived tariffs are concave, meaning that the tariffs reflect economies of scale in order-size. Furthermore, the tariff function is sub-additive which means that it is not efficient to split an order into multiple smaller orders.

4.7.2 Tariffs for Small Orders

All tariffs show a strong dependence on the order arrival rate when the order-sizes of orders is small. In Figure 4.9, the minimum tariffs for infinitesimally small order-size are plotted in detail. A carrier can ship an order of the smallest size at zero costs when there is already a commitment to dispatch a truck. Only when no other

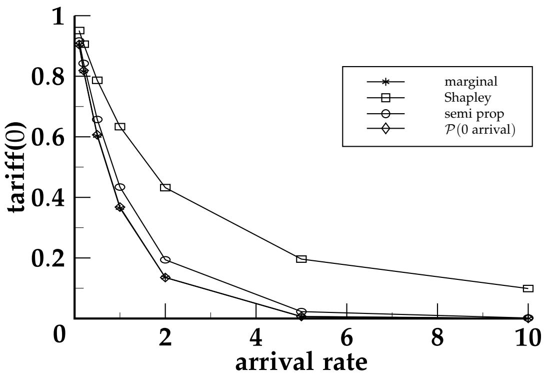


Figure 4.9: Comparison of tariffs for different cost allocation methods for the smallest order size. This is derived by extrapolation of the derived tariff functions to approach 0.

orders arrived during a dispatch period does a small order trigger the need to deploy a truck. Therefore, the theoretical marginal tariff for such order is the costs of a truck, weighted by the probability that no orders arrive. Indeed, for the marginal costs allocation tariff, the tariff equals this value. This tariff serves as a lower bound for small-order tariffs. In the case of the Shapley tariff, where the tariff is based on the expected marginal costs for an order averaged over all order-sequences, the carrier's costs for deploying a truck is shared between the orders. As a consequence, the tariff function is always higher compared to marginal tariffs. In the case of the proportionally allocated costs, the tariff for small orders is in between the marginal and Shapley tariff. The reason is that the proportional allocation function allocates a smaller fraction of the costs to small orders, compared to Shapley tariffs.

4.7.3 Cooperation

The focus of many arrangements for cooperation between a vendor and a buyer is to improve the organization of logistics operations between them. Take for example the case of Vendor Managed Inventories, in which case the vendor manages a buyer's inventory. Because of this, rather than shipping when the buyer sends a purchase order, the vendor decides when and how much to ship to the buyer, in an efficient manner as discussed in the literature of Chapter 3. Many studies (Çetinkaya and Lee (2000), Cachon (2001a), Disney et al. (2003)) assume that the shipper's costs for transport depend stepwise on the number of trucks that is deployed. When a shipper requests transport for an order of size less than a truckload, the tariff often is less than that of a truckload. This is why we argue that the tariff that a shipper is charged depends on the quantity that is shipped. As a consequence, the actual savings on transportation costs that a vendor can achieve by implementing VMI are less than what is commonly argued in literature.

By implementing VMI, the biggest transportation cost savings from consolidation can be achieved by a vendor who is currently using private carriage. When common carriage is used, part of the efficiency gains that VMI enable are already achieved by consolidating multiple orders from the market.

Chapter 5

Incentive Alignment and Inventory Capacity

In general, a problem in shifting decision authority under advanced supply-chain collaboration arrangements is that the decisions that one party makes, may affect the other party's costs. As defined in Section 2.1, a buyer in a true VMI arrangement faces holding costs for inventory that is placed at the buyer, under authority of the vendor. In order to maintain some form of control over these costs, the buyer tends to enforce financial compensation for costs incurred by him or control over boundary conditions within which the vendor manages operations. An example of this is a buyer who determines minimum and maximum inventory levels for the buyer's inventory that is managed by the vendor under VMI.

In this chapter, we investigate a VMI arrangement in which the vendor assumes responsibility for the buyer's inventory management. The buyer retains some control over supply-chain decisions by determining the inventory storage-capacity that is available to the vendor, by setting minimum and maximum inventory levels. This is often used to protect product availability (see Fry et al. (2001), Kaipia et al. (2002), Disney and Towill (2003a), Claassen et al. (2008)). The minimum and maximum levels determine a bandwidth within which the vendor maintains the inventory level. The level of trust between the buyer and the vendor affects the difference between the minimum and maximum inventory levels. Parties aiming for repeat business can be expected to refrain from gaming by strategically timing demand or shipments (Claassen et al., 2008).

The vendor uses trucks of limited capacity for the transportation of products to the buyer. The vendor offers incentives for the buyer to influence the buyer's decisions. We characterize how such incentives from vendor to buyer contingent on the bandwidth of allowable inventory can function to coordinate supply-chain decisions. The effects of the inventory bandwidth on the vendor's and buyer's operational decisions and costs are investigated in order to assess the value of this bandwidth to the supply chain. We consider two scenarios: an altruistic vendor, aiming to coordinate decisions for optimal supply-chain performance, and a selfish vendor, aiming to minimize the vendor's costs only.

This chapter is organized as follows. In the next section, we discuss the literature on mechanisms to distribute the benefits of cooperation among supply chain partners.

This chapter is organized as follows. We present a general introduction in incentive alignment in supply chains in Section 5.1. Section 5.2 gives an overview of the literature on incentive alignment in supply chains. This discussion is built on general principles regarding supply chain coordination. These principles function as a guide to understand the effects of our proposed coordination mechanism based on inventory bandwidth at the buyer. Section 5.3 deals with modeling a VMI setting in which the buyer determines the maximum inventory level while the vendor determines the delivery of goods to the buyer. We develop an exact iterative algorithm to determine the vendor's optimal replenishment policy for the dyad under consideration, given the inventory bandwidth. We investigate how incentive alignment can coordinate supply chain decisions in Section 5.4. Numerical examples are used to gain insight in the resulting coordination of the supply chain under an altruistic and a selfish vendor. Based on this analysis, we draw conclusions about the coordination of the supply chain under different VMI constraints in Section 5.5.

5.1 Incentive Alignment in Supply Chains

The conceptual model of Chapter 3 shows how advanced collaboration arrangements can lead to various cost savings. The primary mechanisms behind cost savings with collaboration arrangements such as VMI is that the party in the supply chain who bears the cost consequences of a particular operational policy is the party who decides, sets and executes this operational policy. This contrasts the conventional supply-chain arrangement in which the buyer has the lead in making operational decisions by deciding on when and how much is ordered at each time-period, while the vendor fulfils these requests by delivering the ordered goods within agreed standards of service. To meet such standards, the vendor can make provisions by establishing flexibility in production, transportation, and/or storage of finished goods. These provisions come at a cost. In this way, the buyer's pattern of ordering decisions imposes costs on the vendor. In order to have a sustainable partnership between buyer and vendor, these costs are —implicitly or explicitly— factored into the price that is charged by the vendor. Often, these costs are part of the agreed upon price per unit paid by the buyers.

Even though the price per unit may involve discounts offered on annual volumes, it rarely incorporates details of the buyer's order pattern. Buyers only receive indirect and partial feedback on the cost impact of their ordering strategy. As a consequence, the buyers' ordering decisions do not fully factor in the vendor's costs. Such a vendor-buyer setting does not lead to perfect supply chain coordination, i.e. coordination that achieves the lowest-cost solution for the vendor-buyer supply chain dyad. An operating arrangement in which responsibilities are rearranged to match cost implications more closely opens up the opportunity to improve the coordination of supply chain operations and to close the gap to perfect supply chain coordination.

The type of coordination sought should be such that unwanted 'gaming' effects are discouraged. Gaming effects can adversely affect the total costs in a supply chain when a member of the supply chain reduces his private expenses by imposing more than the expense reduction as extra costs to the rest of the supply chain. Coordination mechanisms close the gap between operational decisions that are made in a conventional supply-chain arrangement and operational decisions made in a perfectly coordinated, centrally controlled, supply chain. Perfect supply chain coordination for supply chain partners leads to a set of operational decisions for which total supply chain costs are minimal. The benefits that arise as a result of the coordinating contract may be shared among the supply chain partners.

As discussed in Chapter 2, the bargaining power of one firm in relation to other firms significantly impacts agreements on supply chain arrangements between two parties, and with that the deviation from a conventional supply-chain arrangement. Other elements that influence the operating arrangement are considerations of a strategic nature. Another aspect to take into account regarding supply chain collaboration is the effort involved in administrating the arrangement. Despite the importance of each of these considerations, economic feasibility of the operating arrangement is expected to be prominent. In this line, the focus of this chapter lies on economic benefits that accrue from the new operating arrangement for the buyer and the vendor. As stated earlier, supply chain partners are assumed to behave economically rational.

Economic rationality on a supply chain perspective demands that the supply chain as a whole benefits of changing to a new collaboration arrangement. The cost savings that one party realizes due to economizing transport or production must exceed any additional costs inflicted on other parties in the supply chain. Individual economic rationality takes into account that each party in the supply chain is assumed an independent decision-making unit. Therefore, the supply chain savings need to be shared among all parties in such a way that no individual party is worse off after the new arrangement is implemented.

In the case of a VMI arrangement, the vendor makes the operational decisions regarding replenishment at the buyer's location. As the leader in the arrangement, the vendor has the opportunity to achieve efficiency gains by coordinating production, transportation and stocking activities. To entice the buyer to hand over the authority of replenishments to the vendor, the buyer will demand guarantees about his costs and benefits that result from the new arrangement. Indeed, consider the following example. Exploiting the latitude given to him under a VMI arrangement, the vendor may increase the efficiency of transportation by accumulating replenishment loads over time until a full truck can be dispatched. In this way, the transport costs per unit will decrease. The average inventory level for the buyer however, increases. The decrease in transportation cost benefits the vendor, but at the expense of added costs for holding inventory for the buyer. Therefore, provisions have to be made in order to share the benefits among the supply chain partners in a manner that is satisfactory to both parties.

In any VMI arrangement where the buyer and vendors are independent parties, attention has to be paid to distribute the benefits of VMI in such a way that the arrangement is acceptable to each supply chain partner. As mentioned above, one form of acceptance that is often encountered in practice is acceptance through dominance. A dominant party can force certain supply chain decisions and still demand the lion's share of the savings. However, we consider supply chains in which no party is dominant. A mechanism may be needed to have accrued benefits flow from one party to others. Different classes of such mechanisms exist. The simplest sharing principle consists of a fixed monetary transfer that is agreed upon ex-ante, under conditions for agreed upon behavior. A problem with such a sharing principle is that it is based on the anticipated behavior of the parties. The transfer is independent of the actual operational decisions that are made, and -ex post- it might be beneficial to deviate from the agreed upon behavior.

On the other extreme, one can consider a transfer mechanism by which supply chain savings are distributed in some fixed proportion among the partners. Such a transfer mechanism modifies the local costs experienced by each supply chain partner with each operational decision. It is possible that each party shares in the supply chain savings in such a way, that each partner has an incentive to act in the best interest of the supply chain as a whole. The transfer mechanism then functions to coordinate supply-chain decisions by allocating costs among the supply chain partners. A carefully designed transfer mechanism may close the gap to a centrally coordinated supply-chain.

Evidently, in a supply chain in which all parties are consolidated into one corporation, perfect supply chain coordination can be achieved. In practice however, corporations have limited size and scope. Supply chain coordination is sought for chains of companies who retain the authority and responsibility for their own business. A hybrid form between a fully centralized and completely decentralized supply chain can be created by allowing relatively simple transfer mechanisms between the parties. The challenge is to develop an agreement of money transfers that is contingent on operational decisions, but leaves the principal responsibility for the business to the individual supply chain partners. The aim of the transfer scheme is to incite the supply chain partners to make operational decisions, which decrease total supply chain cost.

5.2 Literature on Coordination Mechanisms in Supply Chains

The issue of coordinating operational decisions in supply chains is classically studied from a strategic and an operational point of view. Strategic decisions could involve material handling systems or data exchange technology. In this chapter, the focus is on operational models.

The main factors that are of importance in the optimization of a supply chain are the costs of holding inventory for the buyer, the costs of holding inventory for the vendor, the costs involved in transporting the products from the vendor to the buyer and the costs involved with producing or handling the products at the vendor's site. The focus in most optimization models is a subset of these factors. Operational models can be divided into three categories according to the focus of the optimization, as in Thomas and Griffin (1996). We will discuss these three categories next.

The first category of models for coordination focuses on optimization of the production and setup costs for the vendor and the order-costs for the buyer. A jointly optimal lot-size for shipments between vendor and buyer is determined (see e.g. Monahan (1984)). A second category of coordinating operational models focuses on coordination of transportation and production activities (see for instance Blumenfeld et al. (1985), Bertazzi et al. (2005) and van der Vlist and Broekmeulen (2006)). Both activities, vehicle routing and dispatching and scheduling production, pose problems that are hard to solve. Few models address both problems simultaneously. In practice, inventory buffers are often used to decouple these problems. In the third category of models for supply chain coordination, the focus of the optimization is on multi-echelon inventory distribution. The inventory at every echelon and the costs of distribution is taken into account when determining operational decisions that minimize cost. Common in all models of coordinating mechanisms is that the operational decisions taken result in replenishment timing and quantities that differ in a coordinated setting from an uncoordinated setting, leading to supply chain cost savings. As mentioned before, the savings that are realized by coordination must be divided among the supply chain partners. There is no a-priori limitation as to how the benefits of coordination are distributed between the supply chain partners.

Failure of coordination in supply chains is common. Conflicts in the incentive schemes can lead to adverse effects for the supply chain. Managing these incentive conflicts can lead to better coordination and to Pareto improvements for the supply chain. A Pareto improvement for the supply chain holds that the change is an improvement for at least one party, while no other party is worse off. Multiple types of contracts can be used to achieve coordination. In general, since the interactions between parties are complicated, the way a coordination mechanism functions or how an incentive scheme works out is not trivial. Decisions made by one party might depend on decisions made previously by other parties and can influences subsequent decisions for all parties. To complicate matters further, there is *common knowledge* between the parties: each party knows what the other party optimizes for, and each party knows that the other party knows this, ad infinitum. The party that is taking the first decisions tries to maximize the utility of these decisions by anticipating all subsequent decisions that are made by the supply chain parties.

In order to gain some understanding of coordination mechanisms, the problem is structured into two classes: single period newsvendor problems and multi-period problems as in Cachon (2003). The single period newsvendor problem can be used to illustrate several coordinating contracts. In the newsvendor problem, a buyer is allowed to place an order once at the beginning of a sales season. The buyer faces stochastic demand from end-consumers. Under uncertainty of the end-demand volume, the newsvendor buyer determines the order-size. If demand turns out to be less than the quantity that he ordered, the buyer has costs due to excess stock at the end of the season (overage): the buyer could have saved money had he ordered less products. Alternatively, when demand exceeds the order-quantity, the buyer could have sold more items and faces opportunity costs for the lost sales (underage).

The issue of determining the right order-size affects not only the buyer: when the buyer orders too little and an out-of-stock situation occurs, the vendor suffers also. The vendor loses income due to missed margin on these lost sales. This means that a buyer does not experience the full impact of a lost sale. An essential feature of all coordinating contracts is that it lets the buyer receive a bigger proportion of the costs that are involved in taking a decision that is not optimal to the supply chain. In this way, the buyer is enticed into ordering more than the amount that he would have ordered in absence of such a contract.

An example of a coordinating contract for the newsvendor setting is the buy-back or markdown contract. The vendor reduces the risk of overage for the buyer by offering to buy back at a certain price the stock that is not sold (Pasternack (1985)). In this way, the buyer's full order quantity is partially protected against not selling. The costs per item due to overage decreases and the newsvendor buyer orders more. Another, closely related agreement is the revenue sharing contract. In this case, the buyer pays the vendor a wholesale price per unit plus a percentage of the revenues the buyer generates. In the videocassette rental industry, such contracts are commonly used (Cachon and Lariviere (2005)). Other coordinating contracts are a quantity flexibility contract, under which the vendor fully protects a proportion of the order against underselling. A buyer can receive an extra amount of products for which payment is due only when the product is actually sold. In the case of a sales-rebate contract, the vendor provides an incentive for each item that is sold above a certain threshold (Taylor (2006)).

Any of the contracts described above could be used to achieve coordination of the newsvendor chain. Other coordinating contracts, where the benefits can be divided differently among the supply chain partners could achieve similar results.

There is no distinct coordinating contract that stands out as the best. However, the administrative and monitoring effort involved in managing a contract in comparison to the cost benefits the contract offers may tip the balance in favor of a particular mechanism. This could be one explanation why the simple but Pareto inferior wholesale price contracting still abounds in practice. Wholesale pricing mechanisms are Pareto inferior to other contracts in general, since such contracts fail to realize a set of operational decisions that are optimal for the supply chain. Therefore, there is some coordination mechanism leading to Pareto improvements for the supply chain. Total supply chain costs are reduced and no party in the chain is worse off with this mechanism.

Until now, we have discussed single period newsvendor models. In the single period newsvendor problem, the order-size is determined once at the beginning of a sales period. Excess inventory that remains at the end of the period is disposed of. An extension of this problem considers multiple periods and allows inventory to be carried over to the next period. Holding costs are charged to account for inventory that is carried over from one period to the next. When an out-of-stock event occurs, not all goods that are demanded can be supplied. Unsatisfied demand is assumed back-ordered and a penalty is charged for each back-ordered unit per unit of time. Instead of determining the one-time order quantity, the problem is now to determine the optimal quantity to order each time-period. Coordinating contracts in case of a multi-period problem are comparable to the newsvendor problem, in that the vendor can persuade the buyer to increase replenishment order and inventory levels by subsidizing the buyer's inventory holding cost. For various supply chain settings, including a supply chain consisting of one vendor and one buyer, Leng and Zhu (2009) study how side payments or transfer payments can be used to coordinate the supply chain. A side payment to coordinate the supply chain must have a constant transfer term and a transfer function.

When only the buyer's inventory is considered for which holding and back-order costs apply, and transport costs and transport capacity are neglected, the optimal policy is a base-stock policy, see Clark and Scarf (1960). This means that each time-period, the inventory is brought back to an order-up-to level. The optimal operational policy changes when, for example, the costs for transport or some setup costs for starting a production batch are taken into account. Such costs do not increase linearly with the quantity of products that are transported or produced and thus give rise to economies of scale effects. Because of this, it is efficient for replenishments taking place in bigger quantities and at a lower frequency compared to situations where no economies of scale apply.

Bichescu and Fry (2009a) analyze the profits in a periodic-review supply chain model where the vendor determines shipment frequency and the buyer determines shipment quantities. Full information symmetry is assumed. The central solution is compared to a simultaneous decentralized decision and a decision in which the vendor hold greater channel power and acts as a Stackelberg leader. In the latter case, the vendor determines the shipment frequencies after which the buyer sets the order quantity. Channel profits in this case can be very close to the centralized scenario, but at the costs of lower customer level.

When the costs for the buyer is a function of the inventory at the buyer's only, the optimal policy for a buyer is to order each period up to the reorder level. The vendor cannot take advantage of economies of scale in transport or production. In contrast, a VMI arrangement between the vendor and buyers can function to coordinate the supply chain. One instance of such VMI arrangement is when a vendor determines the reorder level for the buyer and pays back-order penalty costs to the buyer in case of backlogging at the buyer (Cachon, 2001b). The buyer's cost function consists of inventory related costs and the balance of the transfer payments. To avoid that the vendor places the entire inventory at the buyer's firm, a constraint to the optimization is that no buyer is worse off after VMI than before VMI implementation.

Bichescu and Fry (2009b) study a VMI arrangement in which the buyer determines the service level or reorder point, while the vendor determines the shipment quantity. They conclude that the savings that are realized by a supply chain under such an arrangement depend significantly on the relative division of channel power between both parties. The lowest system costs are achieved when the vendor is a powerful agent who is leading the Stackelberg game.

As long as each firm is accepting to share a fixed pre-defined fraction of the benefits that are gained with the VMI arrangement, a VMI arrangement can lead to perfect supply chain coordination. The exact supply chain cost parameters are assumed known among the supply chain partners. Such an arrangement is difficult to maintain, especially if one considers dynamics in the costs and periodic renegotiations of the contracts. In that case, it is not clear how costs or cost-savings change over time and how this will or should affect the fixed transfer payments over time. Therefore, other coordination schemes are worth considering.

A specific implementation of a VMI arrangement in which the buyer determines minimum and maximum inventory levels is a so-called (z, Z)-VMI contract

(Fry et al., 2001). The study of Fry et al. (2001) discusses three actual cases of VMI-implementations in which the buyer defines the minimum (z) and maximum (Z) inventory levels at the buyer's location. Whenever the inventory undershoots the lower or overshoots the upper inventory level, the vendor pays the buyer a penalty per unit of inventory that is not within the (z,Z)-limits. In the model, only costs for holding inventory and for backlogs or expediting production are considered. No costs are taken into account for production or delivery of products. The transfer payment that occurs as a result of these penalties functions to coordinate the supply chain. The study shows that (z,Z)-contracts function significantly better than traditional arrangements under most circumstances, as long as the values for z and Z are chosen correctly.

Up to now, non-divergent networks have been discussed. Divergent networks, consisting of a vendor and multiple buyers are an extension of this. Buyers in such a network might be relatively independent of each other, as in the case where the buyers are geographically separated. When this is the case, the divergence of the network affects the vendor only. Alternatively, the buyers might be in close proximity to each other in an economic sense. By this, we mean that end-customers of a buyer are able to choose to purchase the items at a cheaper shop. In that case, the buyer-firms can compete with each other by setting the retail price. When the price for the end-customer determines the demand volume, the total demand volume for the vendor is a function of all buyers' retail prices. The divergence of the network affects all parties. Such a divergent supply chain can be coordinated by a simple wholesale pricing scheme under some conditions that are discussed next (Bernstein et al. (2006)).

In order to clarify the decisions and responsibilities of each supply chain partner, let σ_B denote the complete set of operational decisions that the buyer makes. In a standard supply chain arrangement between a buyer and a vendor, the operational decisions of a buyer can consist, for example, of decisions on the reorder and an order-up-to levels (as in Silver et al. (1998)). The complete set of operational decisions the vendor makes is denoted by σ_V. The vendor's operational decisions may comprise scheduling production and transportation as well as ordering raw material and managing the vendor's inventories. The operational decisions of all partners taken together determine the costs for the firms in the chain and the supply chain as a whole. Decisions of one party can have an effect on the costs of another partner in the supply chain.

The concept of *Echelon operational autonomy* (EOA) , introduced by Bernstein et al. (2006), is discussed briefly in Chapter 3. EOA specifies that operational decisions of the buyers (σ_B) impact the buyers' costs only, while decisions of the vendor may impact the costs of the entire echelon. EOA may or may not hold under different supply chain models. When EOA applies, the vendor can choose a set of operational decisions such that the supply chain costs for the echelon are minimized.

The model that Bernstein et al. use for their study concerns a divergent supply chain consisting of a vendor and multiple buyers facing Cournot competition. The conditions under which a vendor can achieve perfect supply chain coordination using a simple constant wholesale discounting scheme are:

1. Echelon Operational Authority.

2. Profit functions for buyers are quasi-concave in quantity sold.

3. The second derivative of the profit function for each buyer i is greater than the sum of partial derivatives of i to the rest of buyers ($-\frac{\partial^2 \pi_i}{(\partial q_i)^2} > \sum_{j \neq i} \left| \frac{\partial^2 \pi_i}{\partial q_i \partial q_j} \right|$, for $i = 1, \ldots, N$, with π_i the profit function and q_i the annual demand).

The first condition ensures that the vendor's decisions can steer supply chain-wide cost. The second condition implies that a Nash equilibrium exists for the prices and thus demand each buyer realizes, while the third condition ensures the uniqueness of the equilibrium. Taken together, when these conditions are fulfilled, the vendor is able to select wholesale discounts such that the selected annual sales volume by the buyers form a unique Nash equilibrium in which total supply chain costs are minimized (Bernstein et al., 2006).

The EOA condition is not satisfied in a traditional supply chain setting. In this setting, the buyer decides on the order-quantity for replenishments. This has a direct impact on the vendor's costs in terms of scheduling the replenishments, buyer's inventory, production and the vendor's inventories. Under VMI arrangements however, the vendor has the autonomy to determine operational decisions that can impact echelon cost. When the buyer's decisions are such that these do not affect the vendor's costs or any other buyers' cost, the EOA condition is fulfilled.

In the case of the (z,Z)-contract of Fry et al. (2001), there is no echelon operational autonomy. The buyer can set z and Z and by doing this, he affects the costs of the vendor. Perfect supply chain coordination under a (z, Z)-contract therefore is not guaranteed. As argued in the paper, the resulting policy might even be *worse* than the traditional case.

In the subsequent section, we describe a model of a supply chain that consists of a vendor and —in general— multiple buyers. An incentive scheme that is based on the level of the maximum inventory storage capacity that is available to a vendor for a storing a specific product at the buyer's inventory is investigated and characterized. We study how such coordinating contract can coordinate a supply chain. The focus of our model is on coordinating the inventory level of a buyer and the distribution from the vendor to the buyers. Unlike many models in literature where the transport means have infinite capacity, replenishments are modeled with trucks which have a limited capacity for transporting products from a vendor to the buyer. We extend the work of Jin and Muriel (2009) who studied direct shipments from a single warehouse to multiple buyers. In their model, transport is performed by trucks of limited capacity, but no capacity constraints on the inventory levels are taken into account.

The combination of transport by capacitated transport-means and limited capacity for storing inventory has not been studied before. The cost savings that are realized by the vendor through accumulation of replenishments over time to organize transport more economically can be shared with the buyers. We propose a transfer payment as a discount on the wholesale price per item. The transfer is a function of the inventory bandwidth at the buyer's location that is available to the vendor to use.

5.3 Modeling Coordination by Inventory Capacity

Our goal is to characterize the effects of offering transfer payments based on the maximum inventory level that the buyer makes available at his location to a vendor. In order to study the effects of paying a transfer fee that is based on the maximum inventory capacity, the dependence of the operational decisions of the buyer and vendor on the inventory capacity needs to be investigated. We confine ourselves to a two-echelon supply chain, consisting of a vendor and a number of buyers. We assume that the buyers face constant demand d per period of time, in order to maintain tractability of the model. The buyers are responsible for and bear the costs of holding inventory at their location, while the vendor is responsible for organizing transport to ship products to the buyer. Replenishments from vendor to the buyers are performed by trucks that have a limited capacity Q. We assume that the vendor has sufficient inventory for replenishments. The transportation lead-time is negligible and considered zero. The capacity for storing products in the inventory facility of a buyer is limited.

As in the previous section, let σ_B denote the complete set of operational decisions that the buyers make. We add a subscript $i = 1, \ldots, N$ to indicate the operational decisions σ_{B_i} of buyer i. The vendor's decisions are denoted by σ_V. The buyers select the optimal policy by minimization of the local cost. The local costs for buyer i, C_{B_i}, may depend on all the buyers' decisions as well as the vendor's operational decisions: $C_{B_i}(.) = C_{B_i}(\sigma_V, \sigma_{B_i})$. Given the operational decisions of the vendor, the buyer optimizes for minimal local cost, so

$$\sigma^*_{B_i}(\sigma_V) = \underset{\sigma_{B_i}}{\operatorname{argmin}}\, C_{B_i}(\sigma_V, \sigma_{B_i}) \ .$$

The buyers' decisions impact the costs of the vendor. With σ_B indicating the set of operational decisions for all buyers ($\sigma_B = \{\sigma_{B_1}, \ldots, \sigma_{B_N}\}$), the vendor's costs are a function of the buyers' optimal set, σ^*_B, and the vendor's decisions σ_V , so $C_V(.) = C_V(\sigma_V(.), \sigma^*_B)$. The vendor's optimal operational decisions are the result of local cost minimization. Since the vendor in our setting reacts to the buyer's optimal operational policies, the optimal policy for the vendor is

$$\sigma^*_V(\sigma^*_B) = \underset{\sigma_V}{\operatorname{argmin}}\, C_V(\sigma_V, \sigma^*_B).$$

The base-case of our model is a conventional supply chain setting in which the buyer issues replenishment orders, which are satisfied by the vendor according to an agreed-upon service level. In this case, the optimal replenishment policy for the buyer is a base-stock policy.

Supply chain optimality is achieved by finding operational decisions ($\{\sigma_V, \sigma_B\}$) that minimize the total supply chain costs. Total supply chain costs are the sum of the vendor's and the buyer's local cost, $C = C_V + C_{B_1} + \cdots + C_{B_N}$. Any transfer mechanism in which the coordination costs and benefits are redistributed among the supply chain partners cancel out in the cost function for the total supply chain.

As explained previously, any transfer mechanism that is based on the total supply chain costs can lead to supply chain optimal solutions. In such situation, some omnipotent supply chain coordinator can design a transfer mechanism that replaces the autonomy of each supply chain partner by the scheme of transfers. Costs and benefits are transferred in such a way that supply chain optimal decisions become optimal for each partner. Therefore, the result of such mechanism is evident: the operational decisions of each supply chain partner are exactly the supply chain optimal decisions. The situation is as if a central decision-maker has all responsibility at the cost of the individual responsibility of the supply chain partners. We do not seek such solution. Instead, we are seeking a transfer scheme in which the supply chain partners remain responsible for their own business, but the transfer scheme still functions to coordinate the supply chain.

In the analysis so far, decisions of a buyer might affect the costs of other buyers because of routing effects. In the remainder of this section, we limit the problem to trucks that travel on direct links between the vendor and each buyer. This way, the costs at the vendor separates and the problem decouples into a series of problems for buyer-vendor dyads. Decoupling of the buyers allows us to focus the analysis of the vendor's and the buyer's operational policies on the relations and interactions between one vendor and one buyer. Therefore, we use subindex B instead of subindex B_i. The system is illustrated in Figure 5.1. There is a single vendor (V) and a one buyer (B). The vendor sends items by trucks with capacity Q to the buyer. The buyer has space for $(s + \Delta)$ units inventory. The value s indicates the inventory level that triggers replenishments. Demand d is considered constant.

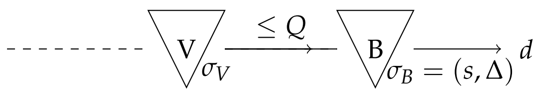


Figure 5.1: One vendor (V) and a single buyer (B). The vendor sends items by trucks of capacity Q to the buyer. The buyer determines the re-order level s and capacity to store $(s + \Delta)$ units of inventory. Demand d is considered constant.

The problem becomes more tractable when the system is decoupled into multiple vendor-buyer dyads: the vendor's operational decisions are a direct result of the operational decisions the buyer takes. Since the buyer optimizes to minimize his local cost, the decisions σ_B^* might differ from supply chain optimal decisions. As a result, the vendor's decisions deviate from the supply chain optimal decisions as well. Therefore, total supply chain costs can be reduced using a mechanism to allow better-coordinated decisions.

Consider a VMI arrangement. The buyer transfers the authority to decide on the operational replenishment decisions to the vendor. The buyer retains the authority to take tactical decisions on the re-order level s and the capacity that is available to the vendor for placing inventory $s + \Delta$. The values z and Z as used by Fry *et al.*'s (z, Z)-policy (Fry et al. (2001)) are lower and upper critical values for inventory beyond which penalty payments are made that function as transfer mechanism to coordinate the chain. In contrast to this, the buyer's inventory capacity $(s + \Delta)$ is a hard constraint in our model, as is the constraint that the buyer's inventory before demand may never undershoot $s + 1$. The vendor offers the buyer a transfer payment that is contingent on the inventory bandwidth Δ.

The cost function for the buyer is a function of the tactical decisions on (s, Δ) and the vendor's operational decisions σ_V. The buyer can still take operational decisions regarding the marketing and pricing of the product, but the effects of these decisions are considered constant for this model. Therefore, we consider that the set of operational decisions for the buyer is empty ($\sigma_B = \emptyset$). The vendor takes the operational decisions of scheduling trucks to replenish the buyer. These decisions are constrained by the minimum and maximum inventory levels that are permitted. To manage this, only the bandwidth of the allowable inventory level is relevant for the vendor. The buyer's re-order level s does not affect the vendor and functions only to guarantee a minimum service level for the buyer. The vendor's cost function $C_V(\sigma_V, \Delta)$ thus depends on his own operational policy as well as the inventory bandwidth. Under this VMI arrangement, the costs of the vendor do not depend on operational decisions of the buyer. Therefore, the decisions of the vendor impact the costs of himself and the subsequent echelon of the buyer, while the buyer's decisions affect only himself. Therefore, the condition for echelon operational autonomy is fulfilled.

Common knowledge, or complete information transparency between buyer and vendor is assumed: both parties know each other's cost function and the basis of their optimization. This way, the buyer deduces the operational decisions that the vendor takes as a function of the values he selects for s and Δ. The vendor knows that the buyer uses this information to minimize his cost. The vendor uses this to design the transfer scheme as compensation for the inventory bandwidth in such a way that his costs are minimal. The sequence of steps and responsibilities is as follows:

1. vendor determines transfer function $\mathcal{T}(\Delta)$
2. buyer determines inventory parameters s and Δ
3. vendor decides optimal operating policy σ_V, based on minimization of $C_V(\sigma_V, \Delta, \mathcal{T}(\Delta))$
4. buyer determines optimal operating policy σ_B, based on minimization of $C_B(\sigma_B, \sigma_V, \Delta, \mathcal{T}(\Delta))$

The first two decisions are of a tactical nature, while the last decisions concern the operational policies.

Since the decision-making behavior of other parties is known, each party can make decisions while taking subsequent decisions of the other party into account. To analyze the decision process, the steps are considered in opposite direction. The operational decisions for a buyer σ_B^* are determined only after the transfer function $\mathcal{T}(\Delta)$, the value Δ that the buyer selected at a tactical level and the vendor's policy σ_V that matches these choices are known. Knowing σ_B^*'s dependency on $\mathcal{T}(\Delta)$ and Δ , the vendor determines his optimal policy σ_V^*. The buyer determines the optimal value for the inventory bandwidth Δ to minimize his cost, knowing how the operational policies depend on Δ. The vendor knows the resulting flow of decisions for a given transfer scheme that is a function of Δ and a parameter β, $\mathcal{T}_\beta(\Delta)$. Therefore, this scheme can be designed in such a way that his costs are minimized. The equations are as follows:

$$\sigma_B^*(\sigma_V,\Delta,\beta)) = \operatorname*{argmin}_{\sigma_B} C_B(\sigma_B,\sigma_V,\Delta,\mathcal{T}_\beta(\Delta)) \tag{5.1}$$

$$\sigma_V^*(\Delta,\beta) = \operatorname*{argmin}_{\sigma_V} C_V(\sigma_V,\Delta,\mathcal{T}_\beta(\Delta)) \tag{5.2}$$

$$\Delta^*(\beta) = \operatorname*{argmin}_{\Delta} C_B\left(\sigma_B^*\left[\sigma_V^*(\Delta,\beta),\Delta,\mathcal{T}_\beta(\Delta)\right], \sigma_V^*(\Delta,\mathcal{T}_\beta(\Delta)),\ \Delta,\ \mathcal{T}_\beta(\Delta)\right) \tag{5.3}$$

$$\beta^* = \operatorname*{argmin}_{\beta} C_V\left(\sigma_V^*\left[\Delta^*(\beta),\beta\right],\ \Delta^*(\beta),\ \mathcal{T}_\beta(\Delta^*(\beta))\right)$$

To summarize, the model's assumptions so far are listed in Table 5.3. We consider that events occur in discrete time. The sequence of events in a period is such that first inventory is replenished and second demand is met. At the beginning of a period t, the inventory is I_t, the level after a replenishment r_t is I_t^+, the level after demand equals the inventory level at the beginning of the next period before demand, I_{t+1}. So

$$I_t^+ = I_t + r_t \quad \text{and} \quad I_{t+1} = I_t^+ - d\ .$$

The following set of constraints determine the feasibility of a policy:

$$s < I_t^+ \leq s + \Delta, \qquad \forall t \tag{5.4a}$$

$$s + 1 \geq d\ . \tag{5.4b}$$

Inventory capacity constraint (5.4a) limits the maximum inventory after replenishment and ensures that the buyer's inventory is always brought to a level above s.

Table 5.1: The assumptions of the model.

General	
• two-echelon system consisting of a vendor and a buyer	
• complete information transparency between vendor and buyer	
Buyer	**Vendor**
• pays inventory holding costs at rate h per unit per unit of time	• pays transport costs ν per truck dispatch
• has limited space $(s+\Delta)$ for inventory	• transports with trucks of capacity Q
• meets constant demand d	• has delivery lead-time zero
	• has sufficient items to replenish buyer
	• maintains inventory between s and $s+\Delta$

Constraint (5.4b) ensures that end-of-period inventory is non-negative, i.e. demand can be met by inventory.

A replenishment of r_t units may be delivered through multiple trucks each accommodating a maximum of Q products. The truck shipments that make up a replenishment will be referred to as deliveries. So a replenishment $r = \sum_{j=1}^{k} r_j$ can consist of k deliveries of sizes $(r_j)_{j=1,\cdots,k}$ all occurring at a particular time. Of course, we have $r_j \leq Q$ for each j. There is no limit on the number of trucks deployed at any one time. However, we will assume that the minimum number of trucks is used for each replenishment.

Note that $\Delta = 1$ implies by (5.4a) that $I_t^+ = s+1$ for all t. Then $I_{t+1} = I_t^+ - d = s+1-d$ and $r_{t+1} = I_{t+1}^+ - I_{t+1} = d$. So $\Delta = 1$ represents a base-stock policy where there is no room to vary the replenishment size: every period the per period demand is replenished. For $\Delta > 1$, the inventory level after replenishment is not fixed by Constraint 5.4 and the vendor has some latitude in deciding on the strategy. The vendor can use this flexibility to schedule replenishments more efficiently as long as the replenishment policy ensures that the buyer's inventory level after replenishment is maintained between $s+1$ and $s+\Delta$ by (5.4a). A replenishment is required in period t whenever the inventory $I_t \leq s$. The size of a replenishment is bounded by the capacity constraints of the inventory. Call the inventory level I_t the state of the system. Since demand is discrete and deterministic, the state assumes values in the range of $s-d$ to $s+\Delta-d$. The number of states assumed is thus bounded by $s+\Delta-d-(s-d) = \Delta$.

Next, we study the optimal policy for a vendor for given truck size Q, inventory bandwidth Δ, and per period demand d.

5.3.1 Vendor Optimal Policy: Formal Model Formulation

In this section we are concerned with determining vendor optimal delivery policies. Among these policies, the policy that implies the lowest costs for the buyer is selected.

A policy is optimal for the vendor if it achieves the smallest average number of deliveries per unit of time among all policies. We are interested in long-run costs per period. So, the smallest possible average number of deliveries per period has to be achieved over a long, in principle infinitely long, time horizon. This means that, possibly after a transient phase, we can assume the system to be in any of the states in which the system orders. These ordering states are $\{s+1-d,\ldots,s\}$. In particular, we may take the system to start with the first period having the lowest possible beginning of period inventory, $s+1-d$. Given the vendor's delivery policy that sets the frequency of delivery, this initiation of the timing of replenishment is optimal for the buyer. The minimum inventory $s+1-d$ is a sunk inventory, existing in every period. We may and will take $s+1-d=0$ without loss of generality, so

$$s = d - 1\ . \tag{5.5}$$

To find a vendor optimal policy we first set up a formal representation for the problem in a model. To state the formal model we introduce notation to specify that the upper bound on inventory is respected. For an integer x define $\phi_{d,Q}(x) \equiv Q + (x \bmod d)$ and for a counting number n

$$\phi^{(n)}_{d,Q}(x) = \phi_{d,Q}\left(\phi^{(n-1)}_{d,Q}(x)\right) \qquad \text{with } \phi^{(0)}_{d,Q}(x) \equiv x,$$

so

$$\phi^{(n)}_{d,Q}(x) = Q + (\phi^{(n-1)}_{d,Q}(x) \mod d)\ .$$

For a pair of counting numbers k and T, consider the following conditions, where the value r_1 is an integer. The operators $\lfloor x \rfloor$ and $\lceil x \rceil$ indicate the *floor* respectively the *ceiling* of x, meaning that x is rounded down respectively up to the nearest integer.

$$(k-1)Q + r_1 = Td \tag{5.6a}$$

$$T = \lfloor kQ/d \rfloor \text{ and } k = \lceil Td/Q \rceil \tag{5.6b}$$

then

$$Q - d < r_1 \leq Q \tag{5.6c}$$

We will see below that the numbers k and T are the number of deliveries and the total number of time-periods respectively in an inventory cycle. A more intuitive understanding of the model is presented in Section 5.3.2. Here follows the formal development.

Note that (5.6c) follows from (5.6a) and (5.6b), as (5.6b) implies that $T > kQ/d - 1$ and $k \geq Td/Q$. Moreover, for $Q - d < r_1 \leq Q$ the value of r_1 is uniquely determined from $(k-1)Q + r_1 = Td$ for given values of (Q, d) and (k, T). So the equations (5.6) determine r_1, if such value exists, uniquely.

We are interested in particular pairs of integers denoted as Ω.

$$\Omega(Q, \Delta, d) = \{(k, T) \in \mathbb{N}^2 | 0 < \min(k, T), \text{ and } (k, T) \text{ satisfies (5.6)},$$
$$\text{with } \phi_{d,Q}^{(n)}(r_1) \leq s + \Delta \quad \text{for } n = 0, \ldots, k-1\} \; .$$

Theorem 1 (Formal Model)**.** *Consider a problem with truck capacity Q, with inventory bandwidth Δ and per period demand d. The minimum number of trucks per period, e^*, is given as*

$$e^* = \lfloor d/Q \rfloor + \begin{cases} \min\{k/T | (k,T) \in \Omega(Q, \Delta', d')\} & \text{if } d \bmod Q \neq 0 \\ 0 & \text{if } d \bmod Q = 0 \end{cases} \tag{5.7}$$

where $\Delta' = \Delta - \lfloor d/Q \rfloor Q$ and $d' = d \bmod Q$.

Note that for $d < Q$ we have $\lfloor d/Q \rfloor = 0$ and $d \bmod Q = d$ so that

$$e^* = \min\{k/T | (k, T) \in \Omega(Q, \Delta, d)\} \; .$$

Also note that by (5.6b), $Td/Q \leq \lceil Td/Q \rceil = k$ so that $k/T \geq d/Q$ and therefore $e^* \geq d/Q$. There is another, less evident, lower bound on e^* that involves the maximum inventory that can be carried.

Lemma 1. *For any $(k, T) \in \Omega(Q, \Delta, d)$, we have $k/T \geq 1/(\lfloor (\Delta - 1)/d \rfloor + 1)$.*

Proof. From the definition of ϕ and since $x \mod d = x - \lfloor x/d \rfloor d$, we have for any integer x that $Q = \phi_{d,Q}^{(n)}(x) - \phi_{d,Q}^{(n-1)}(x) + \lfloor \phi_{d,Q}^{(n-1)}(x)/d \rfloor d$. We take the sum of this expression for $n = 1$ to $n = k-1$:

$$\begin{aligned}(k-1)Q = {} & \phi_{d,Q}^{(k-1)}(x) - \phi_{d,Q}^{(k-2)}(x) + \lfloor \phi_{d,Q}^{(k-2)}(x)/d \rfloor d + \phi_{d,Q}^{(k-2)}(x) - \phi_{d,Q}^{(k-3)}(x) \\ & + \lfloor \phi_{d,Q}^{(k-3)}(x)/d \rfloor d + \cdots + \phi_{d,Q}^{(1)}(x) - \phi_{d,Q}^{(0)}(x) + \lfloor \phi_{d,Q}^{(0)}(x)/d \rfloor d \\ = {} & \phi_{d,Q}^{(k-1)}(x) - \phi_{d,Q}^{(0)}(x) + \sum_{n=0}^{k-2} \lfloor \phi_{d,Q}^{(n)}(x)/d \rfloor d \,.\end{aligned}$$

Now $\phi_{d,Q}^{(0)}(x) = x$ and $\phi_{d,Q}^{(k-1)}(r_1) \mod d = 0$, as $(k-1)Q + r_1$ is a multiple Td of d. So,

$$(k-1)Q + r_1 = \sum_{n=0}^{k-1} \lfloor \phi_{d,Q}^{(n)}(x)/d \rfloor d \,.$$

Consequently,

$$\begin{aligned}T = {} & \frac{(k-1)Q + r_1}{d} = \sum_{n=0}^{k-1} \lfloor \phi_{d,Q}^{(n)}(x)/d \rfloor \\ \le {} & \sum_{n=0}^{k-1} \lfloor (s+\Delta)/d \rfloor = k \lfloor (s+\Delta)/d \rfloor \,.\end{aligned}$$

It follows that $k/T \ge \frac{1}{\lfloor (s+\Delta)/d \rfloor} = \frac{1}{\lfloor (\Delta-1)/d \rfloor + 1}$, using (5.5) to arrive at the latter expression. ■

The next subsection addresses the proof of the theorem. In the course of the proof we will identify efficient replenishment cycles of certain length T with k deliveries.

5.3.2 Vendor Optimal Policy: Formal Model Analysis

In our search for an optimal policy a first observation is that we can reduce the problem to the case where $d < Q$ by the following reflection.

Observation 1. *Delivery of a full truckload is maximally efficient for the vendor. Therefore, when per period demand exceeds the capacity of a truck, it is optimal to dispatch a number of full trucks per period, $\lfloor d/Q \rfloor$, until a remainder of demand is left that is less than a truckload Q.*

So we only need to prove Theorem 1 for the case $d < Q$. In the following we therefore assume that $d < Q$.

The maximum inventory allowed, $s + \Delta$, may limit the amount of product that can be delivered in a period. In determining the possible quantities delivered three cases can be distinguished according to whether full truck deliveries are never, sometimes, or always feasible.

1. *Full truck deliveries are never feasible*. Since delivery occurs at inventory levels $\{s+1-d, \ldots, s\}$ an upper bound on the amount delivered is $s + \Delta - (s+1-d) = \Delta - 1 + d$. So full truck deliveries are never feasible if
$$Q > \Delta - 1 + d \; . \tag{5.8a}$$
2. *Full truck deliveries are sometimes feasible*. When $s + 1 - d + Q \leq s + \Delta$ a full truck delivery is feasible when starting inventory is $s + 1 - d$ whereas such delivery is infeasible if starting inventory is s and $s + Q > s + \Delta$. So full truck deliveries are possible depending on circumstance when
$$\Delta < Q \leq \Delta - 1 + d \; . \tag{5.8b}$$
3. *Full truck deliveries are always feasible*. When $s + Q \leq s + \Delta$ full truck delivery is always feasible, independent of a period's starting inventory. So if
$$Q \leq \Delta \tag{5.8c}$$
feasibility of full truck delivery is guaranteed.

Third Case. The third case, expressed by condition (5.8c), is easiest to analyze. A truckload fits in the inventory bandwidth ($Q \leq \Delta$), so at any time when a delivery is made -this is called a replenishment epoch- a full truck can be delivered. As the vendor wishes to minimize the number of truck dispatches, only truckloads are delivered. This results in the following schedule of dispatches, starting in Period 1 with beginning of period inventory $s + 1 - d = 0$. Dispatch $m(n)$ trucks in period n where $m(n) = M(n) - M(n-1)$ with

$$M(n) \equiv \min\{m | mQ \geq nd\} \; . \tag{5.9}$$

The value $M(n)$ is the minimum number of full truck deliveries required during periods 1 through n to keep inventory after replenishment above s in each of the

periods. This schedule is optimal for the vendor, and among all policies optimal for the vendor it is optimal for the buyer.
We need to verify that Theorem 1 applies. To this end write $x = \lfloor d/Q \rfloor$ and let $d' = d \bmod Q$. Also, let (k, T) be a pair of integers such that $kQ = Td'$. A 'minimal' solution would be $(k, T) = (d/g, Q/g)$ where g is the greatest common divisor (gcd) of Q and d. In any case, for any such pair

$$x + k/T = x + d'/Q = (xQ + d')/Q = d/Q \; .$$

Put $r_1 = d'$. The value r_1 is the size of the first delivery. It is easily verified that $(k, T) \in \Omega(Q, \Delta, d')$. So by (5.7), $e^* = d/Q$ and Theorem 1 applies.

First Case. The first case, condition (5.8a), demands a little analysis. The maximum inventory allowed, $s + \Delta$ can cover demand for at most $\lfloor (s + \Delta)/d \rfloor = \lfloor (\Delta - 1)/d \rfloor + 1$ periods. The number of periods between two replenishment epochs is therefore bounded by $\lfloor (\Delta - 1)/d \rfloor + 1$. Therefore, the average number of trucks dispatched per period can under no policy be less than $\frac{1}{\lfloor (\Delta-1)/d \rfloor + 1}$.

Now consider the following policy. Starting with zero inventory at the beginning of period 1 deliver an amount $(\lfloor (\Delta - 1)/d \rfloor + 1)\, d < Q$ and repeat delivering such quantity every $\lfloor (\Delta - 1)/d \rfloor + 1$ periods. Clearly the average number of trucks dispatched per period is $\frac{1}{\lfloor (\Delta-1)/d \rfloor + 1}$ and this policy therefore is optimal.
We need to verify that Theorem 1 applies in this case also. First note that $Q > \Delta - 1 + d \geq d$ and so $e^* = \min\{k/T | (k, T) \in \Omega(Q, \Delta, d)\}$. Therefore, by Lemma 1 $e^* \geq \frac{1}{\lfloor (\Delta-1)/d + 1 \rfloor}$. Now consider $(k, T) = (1, \lfloor (\Delta - 1)/d + 1 \rfloor)$ with $r_1 = \lfloor (\Delta - 1)/d + 1 \rfloor d \leq Q$. Then $(k, T) \in \Omega(Q, \Delta, d)$ with $k/T = \frac{1}{\lfloor (\Delta-1)/d + 1 \rfloor}$. So Theorem 1 applies.

Second Case. Having completed the analysis of the first and third case, the second, most involved case remains to be analyzed. The analysis of this second case consumes the major part of the remainder of this and the next section. In this case, at certain replenishment epochs full truck-deliveries fit in the inventory while at other replenishment epochs only less-than-a-truckload shipments might fit.

The first and third case only had one binding constraint: the inventory capacity and the truck's capacity respectively. In this second case, potentially for some replenishment epochs the truck's capacity is binding , while the inventory capacity is a binding constraint for other epochs. Yet it may happen that at an epoch in fact neither of the two constraints is binding. An example of this happening is shown in the following example. In this example, we take $d = 4$, $Q = 7$, $s = 3$, and $\Delta = 6$.

The inventory capacity is $s + \Delta = 9$. An optimal replenishment policy is shown in Table 5.2. The pattern of replenishment repeats from period 6 onwards. In periods 1 to 5 there are three deliveries, two full truck deliveries and one delivery of size less than a full truck. Note that for the first delivery neither the truck's capacity of $Q = 7$ units nor the maximum inventory level $s + \Delta = 9$ is binding.

Table 5.2: A simple example of a minimum-length cycle.

period	I	r_i	I^+	d	$I^+ - d$
1	0	6	6	4	2
2	2	7	9	4	5
3	5	–	5	4	1
4	1	7	8	4	4
5	4	–	4	4	0
6	0	6	6	4	2

A sequence of replenishment-state pairs (r_t, I_t) is a deterministic policy. As the state space is finite, the parameters are stationary and the horizon is infinite, an optimal policy exists among the stationary deterministic policies. We only consider deterministic stationary policies. This means that for policies considered, $I_t = I'_t$ implies that $r_t = r'_t$. As the state space is finite, a stationary policy (r_t, I_t) cycles with a cycle length T bounded by the size of the state space, so $T \leq \Delta$.

The vendor's costs increase per truck that is dispatched. Therefore, the vendor tries to ship replenishment quantities that are as close as possible to full trucks. To create opportunity for shipping large quantities, a replenishment is delayed until the latest moment possible, until the buyer's inventory level $I \leq s$. The buyer's inventory ranges between $I = \{s - d + 1 = 0, 1, 2, \cdots, s, s + 1, \cdots, s + \Delta\}$.

An *inventory cycle* is a sequence of states $(I_\tau)_{\tau = t_1, \ldots, t_2}$ such that $I_{t_1} = I_{t_2+1} = i$. A cycle is a minimum-length inventory cycle if in addition to $I_{t_1} = I_{t_2+1} = i$, it holds that $I_\tau \neq i$, for $\tau = t_1 + 1, \ldots, t_2$. So a minimum-length cycle is a cycle that does not contain sub-cycles. As $I_{t_1} = I_{t_2+1} = i$, a cycle repeats.

In a period with replenishment the state must be in $\{s - d + 1 = 0, \ldots, s = d - 1\}$. There are only d of such states. Therefore, the number of replenishment epochs that occurs in a minimum-length cycle is bounded by d.

For a cycle $(I_t)_t$ replenishment quantities are determined from $r_t = I_{t+1} + d - I_t$. We assume that a minimum number of trucks is deployed to deliver each of these delivery quantities. We call such a cycle where we implicitly assume an efficient use of trucks a *replenishment cycle*.

We consider cycles starting with zero inventory at the beginning of period 1. Then during a minimum-length cycle the states at other periods in the cycle are positive. The next lemma expresses the intuitive result that a vendor optimal cycle with sub-cycles has vendor optimal sub-cycles only.

Lemma 2. *Suppose that a cycle contains sub-cycles. If the cycle is vendor optimal then any two sub-cycles are vendor optimal as well.*

Proof. Let the cycle have k deliveries and length T. Consider two sub-cycles that cover the full cycle. Let the two sub-cycles have numbers of deliveries and cycle lengths given as k' and T', and k'' and T''. Then

$$\frac{k}{T} = \frac{k' + k''}{T' + T''} = \beta\frac{k'}{T'} + (1 - \beta)\frac{k''}{T''}$$

where $\beta = \frac{T'}{T'+T''}$. It follows that $\frac{k}{T} \leq \min\left\{\frac{k'}{T'}, \frac{k''}{T''}\right\}$ only if $\frac{k'}{T'} = \frac{k}{T} = \frac{k''}{T''}$. ■

Given a policy for the vendor we try to find a timing of deliveries such that inventory is kept as low as possible. The following lemma shows how this is achieved. In the following we will order deliveries according to their time. If multiple deliveries occur at the same time then the less-than-truckload deliveries go before the full-truckload deliveries.

Lemma 3. *For each minimum-length replenishment cycle $(I_t)_t$ there exists a replenishment cycle $(I'_t)_t$ with the same length such that*

1. *the number of deliveries in $(I_t)_t$ is not more than in $(I'_t)_t$,*
2. *each delivery after the very first delivery in cycle $(I'_t)_t$ is a full-truck delivery,*
3. *the inventory costs for the buyer under $(I'_t)_t$ is not more than under $(I_t)_t$.*

Proof. If cycle $(I_t)_t$ consists of a single replenishment, the lemma's statement is evident. So, assume now that the cycle $(I_t)_t$ has $k \geq 2$ replenishment epochs. If all but the first delivery are full truck deliveries, nothing remains to be proven. Also if all but the first replenishment consists of truckload deliveries once again the Lemma is evident. So consider a case where a less-than-truckload delivery ℓ occurs in an period after period 1. Let $t_\ell > 1$ be the time that the delivery r_ℓ occurs. We can assume that ℓ is the first delivery in the period t_ℓ. We have $0 < I_{t_\ell} \leq s = d - 1$. Now, consider shipping x units more in period t_ℓ sharing the truck together with delivery ℓ and at the same time reducing the amount shipped with deliveries preceding delivery ℓ by x. We can do so without hitting a stock-out by an amount equal to I_{t_ℓ}. We need to consider truck capacity also in order to succeed in shipping x with delivery ℓ in the same truck. Considering both inventory and truck capacity, the maximum shift, x, such that the replenishment cycle remains feasible is

$$x = \max\{y | y \leq I_{t_\ell} \text{ and } r_{t_\ell} + y \leq Q\} . \tag{5.10}$$

So $x = \min(I_{t_\ell}, Q - r_{t_\ell})$. Now $I_{t_\ell} > 0$ because Lemma 2 ensures that in a minimum length optimal replenishment cycle the inventory equals zero only once, at the start of the cycle, and so $I_{t_\ell} > 0$ and thus $x > 0$. Continue in this manner with scheduling out product shipment until such is no longer possible. This means that ultimately (5.10) does not apply: there is no non-full truck delivery after the first delivery. Note that the shifting does not increase the number of deliveries. Furthermore, as shifting postpones delivery the holding costs for the buyer will be reduced under the shifting. The result is a replenishment cycle satisfying the three claims of the lemma. ∎

Note. The result in Lemma 3 can also be found in Jin and Muriel (2009), where the result is proved by a contradiction argument.

We will call a replenishment cycle satisfying condition 2 of Lemma 3 a just-in-time (jit) replenishment cycle. Lemma 3 shows that among the jit replenishment cycles there is a cycle that has the least number of deliveries per period among *all* cycles. So a jit cycle that achieves the least number of deliveries per period among all jit replenishment cycles does so too among among *all* replenishment cycles. To summarize, Lemma 2 states that among the optimal cycles there is one of minimal length and Lemma 3 states that among the minimal length cycles there is one cycle that is a jit replenishment cycle. We can thus focus on pairs of numbers k and T with the interpretation that k deliveries are made in a replenishment cycle of T periods. Of these deliveries, at least $k-1$ are truckload deliveries.

Consider a jit replenishment cycle of length T and with k deliveries. Clearly

$$(k-1)Q + r_1 = Td$$

where $0 < r_1 \leq Q$ is the size of the first delivery. So we have condition (5.6a).

Lemma 4. *Let $(I_\tau)_{\tau=1,\ldots,T}$ be a vendor-optimal jit replenishment cycle of length T with k deliveries. If $Q \leq \Delta - 1 + d$, then (k, T) satisfies* (5.6b), *i.e.*

$$T = \lfloor kQ/d \rfloor \text{ and } k = \lceil Td/Q \rceil .$$

Proof. Let $t_1, \dots, t_k$ be the periods with delivery. The amount that is shipped during a cycle of T periods equals the demand during the cycle, so $r_{t_1} + r_{t_2} + \cdots r_{t_k} = r_{t_1} + (k-1)Q = Td$, based on Lemma 3. Condition $Q \le \Delta - 1 + d$ allows that at least one delivery in the cycle is a full truck. We know that $I_{T+1} = 0$ and using $I_{t-1} = I_t + d - r_{t-1}$ with

$$r_t = \begin{cases} 0 & \text{if } t \notin \{t_1, \dots, t_k\} \\ Q & \text{if } t \in \{t_2, \dots, t_k\} \end{cases}$$

we can deduce the inventory level throughout the jit replenishment cycle. Also $I_1 = 0$ and $r_1 = r_{t_1}$ is determined from

$$r_1 = I_2 - I_1 + d = I_2 + d > 0 \,. \tag{5.11}$$

Suppose, ad absurdum, that the first truck would fit one more period's demand d: $r_1 + d \le Q$. Since the starting inventory is zero in period 1 we have $I_1^+ = r_1 + d \le Q \le \Delta - 1 + d = s + \Delta$. So, shipping one more period's demand in the first truck would result in a feasible cycle employing the same number of trucks but with a cycle length that is one period longer. This is not possible by the assumption of the lemma that the cycle is a vendor-optimal jit cycle, with minimum deliveries per period. So $r_1 = Q - b$ with $0 \le b < d < Q$. But then from $b + kQ = Td$ it follows that $T = \lfloor kQ/d \rfloor$ and $k = \lceil Td/Q \rceil$. ■

Define the nonnegative integers a and ρ as

$$a = \lfloor Q/d \rfloor \quad \text{and} \quad \rho = Q - \lfloor Q/d \rfloor d \,.$$

Note that $Q = ad + \rho$.

Lemma 5. *Consider a vendor optimal jit replenishment cycle with k deliveries and cycle length T*

1. *If $k/T = 1/a$ then $k = 1$ and each delivery has size ad.*
2. *If $k = 1$ then $1/T = 1/a$ and each delivery has size ad .*

Proof. We begin with the proof of 1. If $\rho = 0$ then the policy that dispatches always full trucks $Q = ad$ is clearly optimal. This policy is also clearly the unique policy that is optimal. For this policy $k = 1$.

Next consider cases where $\rho > 0$. Then $d/(ad + 1) < 1/a = k/T$ implies that a policy that always ships $ad + 1$ units is infeasible, as it would otherwise improve on the value k/T for the optimal cycle. So $s + ad + 1 = d - 1 + ad + 1 = (a+1)d > s + \Delta$, or $(a+1)d - 1 \geq s + \Delta$. An upper bound on the time periods between two deliveries is $\lfloor (s+\Delta)/d \rfloor$ and so a fortiori $((a+1)d-1)/d = a+1-1/d$ is an upper bound on the time between two deliveries. So the maximum integer time between two deliveries in any policy is a. As an optimal policy achieves $1/a$ deliveries per period, the time between any two deliveries must always be a periods exactly. In particular $r_1 \geq ad$. The only policy that achieves $r_1 + (k-1)Q = kad$ is the one with $r_1 = ad$ and $k = 1$.

Next consider the lemma's second claim. Note that $r_1 = Td$ together with $r_1 = Q - b$ and $0 \leq b < d < Q$ implies $T = a$. ∎

Corollary 1. *For the size, r_1, of the first delivery of a vendor optimal jit replenishment cycle with length T and k deliveries, the following holds.*

$$r_1 = Q - (kQ - \lfloor kQ/d \rfloor d) \ , \tag{5.12}$$

and

$$r_1 = ad + \rho' \quad \textit{where } a \equiv \lfloor Q/d \rfloor \textit{ and } 0 \leq \rho' < d \ . \tag{5.13}$$

Proof. Expression (5.12) is evident from Lemma 4. Furthermore, from $r_1 = Q - b$ with $0 \leq b < d < Q$ it follows that $r_1 = \alpha d + \rho'$ with α equal to a or $a - 1$. We are going to show that $\alpha = a - 1$ can be excluded.
We distinguish two cases.

1. First suppose that $k = 1$, then evidently $r_1 = ad$ is the only option consistent with the cycle's optimality.

2. Suppose now $k \geq 2$ and suppose, ad absurdum, that $r_1 = (a-1)d + \rho'$ with $0 \leq \rho' < d$. Then $x = ad - r_1 = d - \rho' > 0$. Now consider changing the cycle by shipping x units extra in the first delivery and shipping x less with the second delivery, while at the same time delaying the second delivery by one time-period. (It may happen that a second delivery now coincides with a third delivery but this is not relevant for the subsequent argument.) The resulting cycle no longer is a jit cycle but it is feasible, and even vendor optimal. The new cycle breaks up in two cycles, the first sub-cycle consisting of a periods after which the state returns to zero. The sub-cycle has one delivery of ad covering a periods of demand. This sub-cycle is vendor optimal by Lemma 2. So $k/T = 1/a$. But then $k = 1$ by Lemma 5 and we have arrived at a contradiction. Hence $\alpha = a$.

■

Note that Corollary 1 implies that

$$Q - d < \lfloor Q/d \rfloor d \leq r_1 \leq Q, \tag{5.14}$$

in line with (5.6c) under the assumed conditions $Q > d$ (from page 123) and $Q \leq \Delta - 1 + d$ (Case 2 on page 123).

Consider a period where inventory is x after the replenishment opportunity, but before demand has been met. The inventory immediately after the first subsequent full truck delivery is $\phi_{d,Q}(x) = Q + (x \bmod d)$. Immediately after n subsequent consecutive full truck deliveries the inventory is $\phi^{(n)}_{d,Q}(x) = \phi_{d,Q}\left(\phi^{(n-1)}_{d,Q}(x)\right)$. So for a jit cycle with k deliveries starting with a first delivery of r_1 units feasibility for the maximum inventory capacity is equivalent to

$$\phi^{(n)}_{d,Q}(r_1) \leq s + \Delta \quad \text{for } n = 0, \ldots, k-1\,. \tag{5.15}$$

as $k-1$ consecutive full truck deliveries are part of the feasible cycle. So for feasible jit replenishment cycles Expressions (5.6) and (5.15) hold.

The converse is also true. Let $(k, T) \in \Omega(Q, \Delta, d)$. As $d < Q$, we have $\lfloor Q/d \rfloor \geq 1$ so $r_1 \geq \lfloor Q/d \rfloor d \geq d$ implies that r_1 brings inventory above $s = d - 1$. So a fortiori any of the other full-truck deliveries will bring the inventory above $s = d - 1$. Therefore, (k, T) represents a feasible (jit) cycle.

5.3.3 Vendor Optimal Policy: Formal Model Solution

A straightforward method for calculating an optimal policy is based on the following lemma.

Lemma 6. *Within the set of jit replenishment cycles, the transport effort, measured as the number of trucks used per period, decreases with an increasing number of deliveries of a full truck used in a cycle.*

Proof. Consider a jit replenishment cycle of k deliveries and cycle length T and another cycle of $k-1$ deliveries. The latter cycle can cover demand for $T - \ell$ periods with $\ell \geq 1$, since it replenishes one truckload $Q > d$ less. The transport effort, measured as the fraction of periods with deliveries, of the second cycle is therefore

$$\frac{k-1}{T-\ell} = \frac{k}{T}\frac{k-1}{k}\frac{T}{T-\ell} = \frac{k}{T}\frac{kT-k}{kT-k\ell} \geq \frac{k}{T}. \tag{5.16}$$

■

By definition, at least $k-1$ trucks carry full truck shipments in a jit cycle with k deliveries in total. Abstracting from the inventory levels, we denote a cycle with k deliveries and length T simply as a (k, T) cycle. Note that by a (k, T) cycle we mean in fact the equivalence class of all jit inventory cycles with k trucks used in T periods. As argued on page 125, there are maximal d replenishments in a minimum replenishment cycle. This results from the fact that the state of the system just before a replenishment is between $s-d$ and $s-1$ and every state is only visited once. Therefore, $k \leq d$.

Lemma 6 shows that the following algorithm computes an optimal policy.

1. Start considering a replenishment cycle with $k = d$ deliveries.
2. Considering a jit replenishment cycle with k deliveries, compute the first replenishment r_1 from (5.12). Next check its feasibility under allowing only full truck deliveries after period 1.
3. If the cycle turns out infeasible, then put $k \leftarrow k-1$ and return to the second step, else the current cycle is optimal.

The number of calculations required for checking feasibility of a cycle with k deliveries is bounded by $\lfloor kQ/d \rfloor$. So an upper bound on the number of calculations required for the algorithm to stop is

$$\sum_{k=1}^{d} \lfloor kQ/d \rfloor \leq \sum_{k=1}^{d} kQ/d = \frac{d(d+1)Q}{2d} = (d+1)Q/2 \,.$$

Below we are presenting an algorithm that has a smaller upper bound on the number of calculations required.

Lemma 7 (Immediate Solvability)**.** *Write $Q = ad + \rho$ and $\Delta + d - 1 = bd + \sigma$ with $0 \leq \rho, \sigma < d$.*

There is an optimal cycle with a single delivery of size $r = xd$ where x is some counting number.	$\iff Q = ad$ *or* $a \geq b$

When either of the two cases holds then $x = \min(a, b)$.

Proof. Assume an optimal cycle consisting of a single delivery of size $r = xd$. Consider the policy that ships $\min(a, b)d$ products every $\min(a, b)$ periods. From optimality of the cycle with xd as delivery size we have $x \geq \min(a, b)$.

Assume, ad absurdum, that $\rho > 0$ and $a < b$. Then $x = a$. Consider the policy that ships deliveries of $ad + 1 \leq Q$ units each time a delivery is required. Since $d - 1 + ad + 1 = (a+1)d \leq bd \leq \Delta + d - 1$ this policy is feasible and strictly improves the policy that ships xd each time. Thus we have arrived at a contradiction and we conclude that either $Q = ad$ or $a \geq b$ or both.

Now assume that $Q = ad$. Consider an optimal minimum-length jit replenishment cycle with k deliveries and length T. Then $(k-1)Q + r_1 = Td$ and so $r_1 = (T - (k-1)a)d$. But the first replenishment being a multiple of d means that $k = 1$. That is, the policy that ships a multiple of d is optimal.

Now assume that $a \geq b$. For any policy the time between deliveries is bounded by b. The policy that ships bd units each delivery is feasible and the number of truck dispatches per time is $1/b$. This policy is therefore optimal. ∎

When $Q = ad$ or $a \geq b$ Lemma 7 shows that it is optimal to ship $\min(a, b)d$ every $\min(a, b)$ periods. If neither $Q = ad$ nor $a \geq b$ the situation is more involved. The structure of a replenishment cycle hinges on the values for the remainders $\rho' = r_1 - ad$ and $\rho = Q - ad$ where $a = \lfloor Q/d \rfloor$. To analyze the situation in more detail we consider 'filtering out' full period demands to reduce the structure of the problem to a simpler one. This reduction is carried out in two steps. The first step eliminates periods that need not be considered in optimizing cycles. The second step then alters demand per period to match the reduced set of periods. The two steps taken in tandem will lead us to our main result.

We begin with the introduction of the step that eliminates periods from consideration. The elimination uses that both Q and r_1 cover a periods of demand in full, see Lemma 5. The periods can be viewed as 'sunk', not making part of the optimization. There are k deliveries making a total of ka periods in a cycle that need not be considered. So the plan is to view

- only the remainder of the capacity of a truck after deduction of ad covering a 'sunk' periods at each delivery,
- only the relevant part of the inventory capacity, $\Delta - da$, after deduction of ad which is included in each delivery,
- only the remaining periods that need to be covered, $T - ka$, i.e., after deducting ka periods that have been covered by the k deliveries.

The following formalizes this idea.

Consider a cycle $(k, T) \in \Omega(Q, \Delta, d)$. Then

$$\begin{aligned}\phi_{d,Q-ad}(r_1 - ad) &= Q - ad + ((r_1 - ad) \bmod d) \\ &= Q - ad + (r_1 \bmod d) \\ &= \phi_{d,Q}(r_1) - ad\ .\end{aligned}$$

More generally, $\phi^{(n)}_{d,Q-ad}(r_1 - ad) = \phi^{(n)}_{d,Q}(r_1) - ad$. Therefore, by Eq. (5.15)

$$\phi^{(n)}_{d,Q-ad}(r_1 - ad) \leq s + \Delta - ad \qquad \text{for } n = 0, \ldots, k-1\ .$$

It is easy to see that $(k, T - ka)$ satisfies (5.6a) under $(Q - ad, \Delta - ad, d)$, as

$$(k-1)(Q - ad) + r_1 - ad = (T - ka)d\ . \tag{5.17}$$

Furthermore $0 \leq r_1 - ad \leq Q - ad$, so (5.17) implies

$$k = \left\lceil \frac{(T - ka)d}{Q - ad} \right\rceil$$

provided $r_1 - ad > 0$. Hence

$$T - ad = \lfloor k(Q - ad)/d \rfloor \quad \text{and} \quad (Q - ad) - d < 0 < r_1 - ad \leq Q - ad\ .$$

We obtain immediately the first implication stated in the following lemma.

Lemma 8. *Consider parameters (Q, Δ, d) with $a = \lfloor Q/d \rfloor > 0$. Then*

1. *If $r_1 - ad > 0$ then $(k, T) \in \Omega(Q, \Delta, d) \Rightarrow (k, T - ka) \in \Omega(Q - ad, \Delta - ad, d)$.*
2. *Conversely, $(k', T') \in \Omega(Q - ad, \Delta - ad, d) \Rightarrow (k, T) = (k', T' + k'a) \in \Omega(Q, \Delta, d)$ and $r_1 > ad$.*

Proof. Case 1 has been shown in the text leading to the lemma.
Consider now Case 2. Let r_1' be the value that makes (5.6) true under $(Q - ad, \Delta - ad, d)$ for (k', T'). Consider the value r_1 with $r_1' = r_1 - ad$. Note that $\phi^{(n)}_{d,Q-\alpha d}(r_1 - \alpha d) = \phi^{(n)}_{d,Q}(r_1) - \alpha d$ for any integer α, negative or positive. So

$$\phi^{(n)}_{d,Q-\alpha d}(r_1 - \alpha d) \leq \Delta - ad \Rightarrow \phi^{(n)}_{d,Q}(r_1) \leq \Delta$$

ensuring that the inventory capacity is never overshot. Now from $(k', T') \in \Omega(Q - ad, \Delta - ad, d)$ we obtain by (5.6) that

$$\begin{aligned}&(k'-1)(Q - ad) + r_1' - ad = T'd && \Rightarrow (k'-1)Q + r_1 = (T' + ka)d \\ &T' = \lfloor k(Q - ad)/d \rfloor && \Rightarrow T' + ka = \lfloor kQ/d \rfloor \\ &(Q - ad) - d < \lfloor (Q - ad)/d \rfloor d && \\ &\qquad \leq (r_1 - ad) \leq Q - ad && \Rightarrow Q - d < \lfloor Q/d \rfloor d \leq r_1 \leq Q\end{aligned}$$

and also

$$k' = \left\lceil \frac{(T-ka)d}{Q-ad} \right\rceil \Rightarrow (k-1)(Q-ad) + (r_1 - ad) = (T-ka)d$$

and

$$0 < r_1 - ad \leq Q - ad$$

so that $(k-1)Q + r_1 = Td$ and $ad < r_1 \leq Q$ which implies that $k = \lceil Td/Q \rceil$. So $(k, T) \in \Omega(Q, \Delta, d)$. ■

Corollary 2. *Consider parameters (Q, Δ, d) with $a = \lfloor Q/d \rfloor > 0$. If $(k', T') \in \Omega(Q - ad, \Delta - ad, d)$ then (k, T) is a feasible jit replenishment cycle*

Lemma 1 shows that the transformations retain feasibility. The following lemma asserts that optimality is retained as well.

Lemma 9. *Consider parameters (Q, Δ, d) with $a = \lfloor Q/d \rfloor > \lfloor (\Delta + d - 1)/d \rfloor$ and $Q > ad \geq d$. If (k, T) is an optimal minimum-length jit replenishment cycle then*

$$\frac{k}{T-ak} = \min_{(k',T')} \left\{ \frac{k'}{T'} | (k', T') \in \Omega(Q - ad, \Delta - ad, d) \right\} .$$

Proof. Let $(\hat{k}, \hat{T}) \in \Omega(Q - ad, \Delta - ad, d)$. By Lemma 8, $(\hat{k}, \hat{T} + \hat{k}a)$ represents a feasible cycle and so $\frac{\hat{k}}{\hat{T}+\hat{k}a} \geq \frac{k}{T}$. Then, as $x \mapsto x/(1-ax)$ is monotonic,

$$\frac{\hat{k}}{\hat{T}'} = \frac{\frac{\hat{k}}{\hat{T}'+\hat{k}a}}{1 - a\frac{\hat{k}}{\hat{T}'+\hat{k}a}} \geq \frac{k/T}{1-ak/T} = \frac{k}{T-ak} .$$

Lemma 8 states that $(k, T - ka) \in \Omega(Q - ad, \Delta - ad, d)$ completing the proof of the lemma. ■

Observation 2. *Consider the cycle (k', T') feasible under $(Q', \Delta', d) = (Q - ad, \Delta - ad, d)$. Clearly $Q' < d$ so considering (Q', Δ', d) as a vendor problem with trucks of size Q' means that these trucks cannot fit a period's demand d, as mentioned before in Observation 1. But then we will schedule full truck deliveries of size Q' until the remainder of demand that has to be fulfilled is less than Q'. So consider*

$$\mu = \lfloor (d-1)/Q' \rfloor \text{ and } d' = d - \mu Q' = \begin{cases} d \bmod Q' \\ Q' & \text{if } d \bmod Q' = 0 \end{cases}$$

Then evidently (k', T') is feasible and optimal under $(Q', \Delta', d) = (Q - ad, \Delta - ad, d)$ if and only if $(k' - \mu T', T')$ feasible and optimal under (Q', Δ', d').

Solution Algorithm

The optimal replenishment schedule for a vendor, within the constraints determined by an instance of (Q, Δ, d) is determined with the following algorithm.

Algorithm Truck

1. *Initialization*. Consider the instance (Q, Δ, d) and set $n = 1$.

2. *Branch*. If $Q \leq \Delta$ then Step 3 else go to Step 4.

3. *Always Full*. Set $g = \gcd(Q, d)$, $\alpha_n = Q/g$ and $(k_n, T_n) = (d/g, \alpha_n)$ and go to Step 8.

4. *Subbranch*. If $\lfloor Q/d \rfloor \geq \lfloor (\Delta - 1 + d)/d \rfloor$ then go to Step 6 else go to Step 5.

5. *Reduction*. Put $\alpha_n = \lfloor Q/d \rfloor$ and $\mu_n = \lfloor (d-1)/(Q - \alpha_n d) \rfloor$, and

$$(Q, d) \leftarrow (Q - \alpha_n d, d - \mu_n (Q - \alpha_n d)) \tag{5.18a}$$

$$\Delta \leftarrow \Delta - \alpha_n d \tag{5.18b}$$

   Set $n \leftarrow n + 1$. Go to Step 4.

6. *Immediate Solvability*. Set $\alpha_n = \min\left(\lfloor Q/d \rfloor, \lfloor (\Delta + d - 1)/d \rfloor\right)$ as well as $(k_n, T_n) = (1, \alpha_n)$ and go to Step 7.

7. *Result*. For $m = n - 1, \ldots, 1$ do

$$(k_m, T_m) = (k_{m+1} + \mu_m T_{m+1}, T_{m+1} + (k_{m+1} + \mu_m T_{m+1})\alpha_m) \; . \tag{5.19}$$

   Go to Step 8.

8. *Output*. Set $(k, T) = (k_1, T_1)$.

The algorithm has a flow diagram depicted in Figure 5.2.

Note that transformation (5.19) can be written as

$$\begin{pmatrix} k_m \\ T_m \end{pmatrix} = \begin{pmatrix} 1 & \mu_m \\ \alpha_m & 1 + \mu_m \alpha_m \end{pmatrix} \begin{pmatrix} k_{m+1} \\ T_{m+1} \end{pmatrix}$$

where

$$\begin{pmatrix} 1 & \mu_m \\ \alpha_m & 1 + \mu_m \alpha_m \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ 1 & \alpha_m \end{pmatrix} \begin{pmatrix} 0 & 1 \\ 1 & \mu_m \end{pmatrix} \; .$$

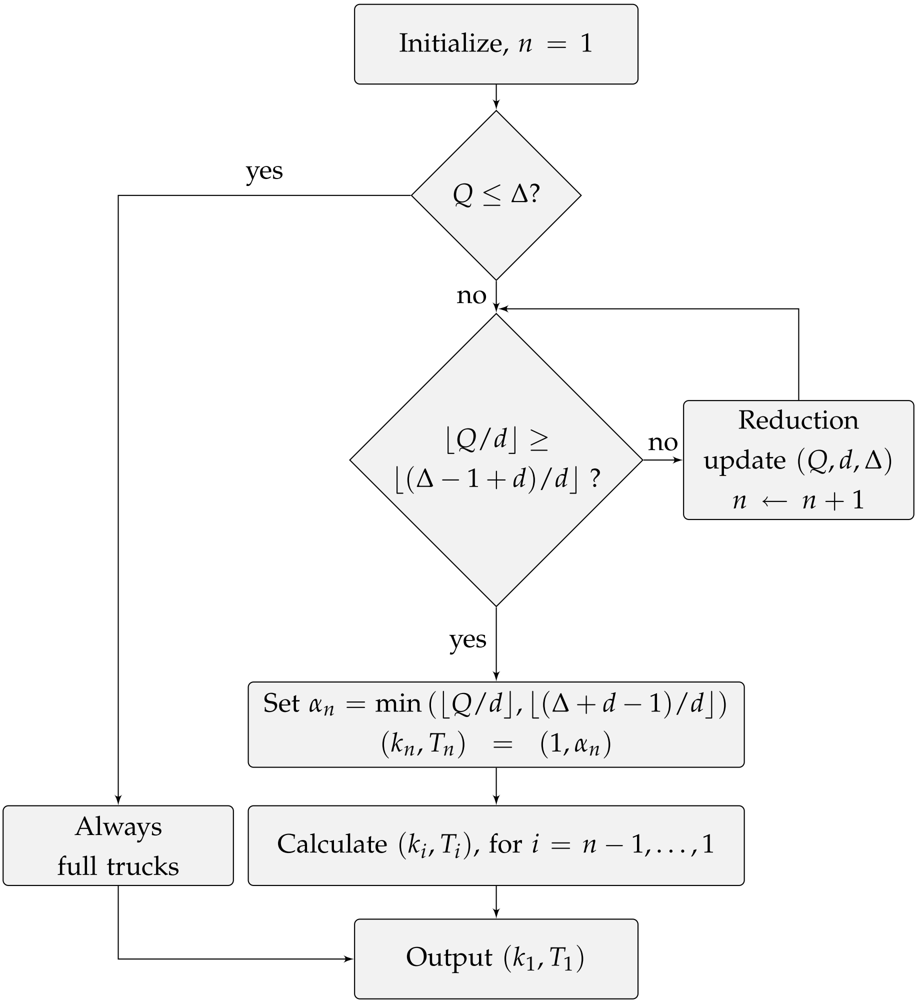


Figure 5.2: Algorithm Truck: flow diagram.

As

$$\begin{pmatrix} k_n \\ T_n \end{pmatrix} = \begin{pmatrix} 1 \\ \alpha_n \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ 1 & \alpha_n \end{pmatrix} \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

we have for $\Delta < Q$ that

$$\begin{pmatrix} k_1 \\ T_1 \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ 1 & \alpha_1 \end{pmatrix} \begin{pmatrix} 0 & 1 \\ 1 & \mu_1 \end{pmatrix} \cdots \begin{pmatrix} 0 & 1 \\ 1 & \alpha_{n-1} \end{pmatrix} \begin{pmatrix} 0 & 1 \\ 1 & \mu_{n-1} \end{pmatrix} \begin{pmatrix} 0 & 1 \\ 1 & \alpha_n \end{pmatrix} \begin{pmatrix} 0 \\ 1 \end{pmatrix} .$$

This latter representation of the calculation (5.19) in Step 7 makes it possible to introduce a variant of Algorithm Truck that eliminates Step 7 altogether. The details of this variant are in the following algorithm.

Algorithm Truck Variant

1. *Initialization*. Consider the instance (Q, Δ, d).

2. *Branch*. If $Q \leq \Delta$ then Step 3 else go to Step 4.

3. *Always Full*. Set $g = \gcd(Q, d)$, $M := \begin{pmatrix} 0 & d/g \\ 1 & Q/g \end{pmatrix}$ and go to Step 7.

4. *Subbranch*. If $\lfloor Q/d \rfloor \geq \lfloor (\Delta - 1 + d)/d \rfloor$ then go to Step 6 else go to Step 5.

5. *Reduction*. Put $\alpha = \lfloor Q/d \rfloor$ and $\mu = \lfloor (d-1)/(Q - \alpha_n d) \rfloor$, and

$$(Q, d) \leftarrow (Q - \alpha d, d - \mu(Q - \alpha d)) \tag{5.20a}$$

$$\Delta \leftarrow \Delta - \alpha d \tag{5.20b}$$

   Set $M \leftarrow M \times \begin{pmatrix} 0 & \mu \\ \alpha & 1 + \alpha\mu \end{pmatrix}$. Return to Step 4.

6. *Immediate Solvability*. Set $\alpha = \min\left(\lfloor Q/d \rfloor, \lfloor (\Delta + d - 1)/d \rfloor\right)$, update $M \leftarrow M \times \begin{pmatrix} 0 & 1 \\ 1 & \alpha \end{pmatrix}$ and proceed to Step 7.

7. *Output*. Set $\begin{pmatrix} k \\ T \end{pmatrix} = M \times \begin{pmatrix} 0 \\ 1 \end{pmatrix}$.

For integers (x, y) consider the transformation $\mathrm{E}(x, y) = (y, x \bmod y)$ and note that

$$(d, Q') = (d, Q \bmod d) = \mathrm{E}(Q, d)\ .$$

If (k', T') is a feasible optimal cycle under $(Q', \Delta', d - \mu Q')$, then $(k, T) = (k' - \mu T', T')$ is a feasible optimal cycle under (Q', Δ', d), with $\mu = \lfloor d/Q' \rfloor$. Note that

$$(Q', d') = (Q', d \bmod Q') = \mathrm{E}(d, Q')\ .$$

Also note that the transformation (5.18a) can be presented as

$$(Q, d) \leftarrow (Q \bmod d, d \bmod (Q \bmod d)) = \mathrm{E}^2(Q, d)\ .$$

Euclidean Algorithm

1. *Initialize*. Consider a pair of integers (x, y) with $x > y$. Go to Step 2.
2. *Iterate*. If $y \neq 0$ then $(x, y) \leftarrow \mathrm{E}(x, y)$ and repeat Step 2 else go to Step 3.
3. Output x.

The output of the Euclidean Algorithm is the greatest common divisor of x and y, $\gcd(x, y)$. The number of times Step 2 needs to be applied before arriving at the output is bounded by $(\log y)/(\log \theta) + 1$ where $\theta = (1 + \sqrt{5})/2$, see (Buchmann, 2000, Theorem 1.8.6).

Proposition 1. Algorithm Truck *terminates. An upper bound on the number of calculations before termination is*

$$B = O((\log d)/(\log \theta) + 1) = O(\log d) \ .$$

where the 'big O 'notation $O(x)$ denotes a generic function with the property that $O(x) \leq C|x|$ for some constant $C > 0$ and all x large.

Proof. We distinguish two types of runs of the algorithm according to whether Step 3 is called.
Assume that Step 3 is visited: $\Delta \geq Q$. We then need to calculate $\gcd(Q, d)$. This can be done through the Euclidean Algorithm which needs no more than B iterations.
Assume that Step 3 is not visited: $\Delta < Q$. Each Step in the algorithm is called once with the exception of Step 5. Each of the visits to this step implements two iterations of the Euclidean Algorithm, E^2. So the number of times Step 5 is called is bounded by $B/2$. ■

Note that for $\Delta < Q$ Algorithm Truck can be viewed as the Euclidean Algorithm on (Q, d) supplemented with the stop criterion

$$Q > \Delta - 1 + d \quad \text{or} \quad \alpha d = Q$$

of Step 4. In each Step 5 demand d is decreased by at least one and it could mean that the final problem is considered for $d = 1$ before meeting the stop criterion $Q > \Delta - 1 + d$ or $\alpha d = Q$.

Theorem 2. *The output of* Algorithm Truck (k_1, T_1) *determines a vendor optimal jit replenishment cycle for problem instance* (Q, Δ, d).

Proof. When $Q \leq \Delta$ then the vendor optimal replenishment cycle is immediately clear: deliveries of full trucks can always be made. By no means, it is possible to have less trucks per time-period than when all trucks are full (Case 3 in Section 3 and Theorem 1). When $Q > \Delta$, the inventory bandwidth Δ is constraining at least for some replenishment epochs. The problem instance is iteratively reduced by transformations guaranteed allowed by Lemma 8.1. until a representation of the problem is reached for which the vendor optimal cycle is known by Lemma 7. In that case the optimal cycle consists of a single replenishment per cycle of size equal to xd with $x = \min(\lfloor Q/d \rfloor, \lfloor (\Delta + d - 1)/d \rfloor$. Note that condition $Q \mod d = 0$ in the algorithm is contained by inequality $\lfloor Q/d \rfloor \geq \lfloor (\Delta - 1 + d)/d \rfloor$. Since $Q > \Delta$ the following holds $\lfloor (\Delta + d - 1)/d \rfloor \leq \lfloor (Q + d - 1)/d \rfloor$. The right-hand side of this equation equals Q/d for Q mod $d = 0$, so that equality holds for the original condition.

By Lemma 8.2 this optimal replenishment cycle for the reduced problem can be transformed to a vendor optimal jit replenishment cycle for the original problem, as in Step 7 of Algorithm Truck. The feasible optimal cycle for a reduced problem (k_m, T_m) (Q_m, Δ_m, d_m) is transformed into a feasible cycle $(k_m + \mu_{m-1}T_m, T_m)$ for (Q_m, Δ_m, d_{m-1}) by Observation 2, using $\mu_{m-1} = \lfloor (d_{m-1} - 1)/Q_m \rfloor$. Subsequently, this cycle is transformed to a feasible optimal cycle for problem $(Q_{m-1}, \Delta_{m-1}, d_{m-1})$ by Lemma 8.2, to $(k_m, T_m) = (k_{m+1} + \mu_m T_{m+1}, T_{m+1} + (k_{m+1} + \mu_m T_{m+1})\alpha_m)$. Lemma 3 and Corollary 1 determine the sequence of the deliveries and the size of the first replenishment. ∎

5.3.4 Numerical Examples

Using the Algorithm Truck, we can determine the vendor's optimal policy and costs for given (Q, d, Δ). In order to study the effects on the supply chain, the total supply chain costs (C_{SC}) are considered. The total costs for the supply chain are the sum of the vendor's and the buyer's costs. The vendor's costs are the costs for deploying the trucks according to an inventory cycle (k, T) at costs ν per truck. Consequently, inventory is held at the buyer's for which the buyer incurs inventory holding costs per item per period of time. So

$$C_{SC}(k, T) = C_V(k, T) + C_B(k, T) = \nu k/T + h\bar{I}(k, T) \ .$$

In this, $(k, T) = \text{argmin}_{(k,T)} C_V$ using Algorithm Truck. The average inventory at the buyer's location is indicated by $\bar{I}(k, T)$.

Lemma 10. *The average inventory in a vendor optimal jit-cycle satisfies*

$$\bar{I} = \left\lfloor \frac{\Delta - 1}{d} \right\rfloor \frac{d}{2} \qquad \textit{for } \Delta \leq Q - d \tag{5.21a}$$

$$\bar{I} > \left\lfloor \frac{\Delta - 1 + d}{d} \right\rfloor \frac{d}{2} \qquad \textit{for } \Delta > Q - d\,. \tag{5.21b}$$

Proof. First consider $\Delta \leq Q - d$, then full trucks are never delivered and $k = 1$ and $T = \lfloor (\Delta - 1)/d \rfloor + 1$. The inventory is $d[(T-1) + (T-2) + \cdots + 2 + 1]$. So $\bar{I} = dT(T-1)/2T = d(T-1)/2$. Consequently,

$$\bar{I} = \left\lfloor \frac{\Delta - 1}{d} \right\rfloor \frac{d}{2}, \quad \text{for } \Delta \leq Q - d\,.$$

For $\Delta > Q - d$, the delivery schedule of the first case is still feasible, with $k = 1$ and $T = \lfloor (\Delta - 1)/d \rfloor + 1$. So, no delivery is of size smaller than Td. However, the extra flexibility due to the inventory capacity allows cycles with $k \geq 1$. For $k > 1$, inventory has to cover at least one period's demand, so the inventory at some point must be at least Td. For the average inventory in this case, the following holds

$$\begin{aligned} \bar{I} &> \frac{dT(T-1)/2 + Td}{T+1} \\ &= \frac{T(T+1)}{T+1} d/2 \\ &= Td/2\,, \end{aligned}$$

or $\bar{I} > \lfloor (\Delta - 1 + d)/d \rfloor d/2$. ■

Conjecture 1. *The average inventory for the buyer in a vendor optimal cycle does not decrease when the maximum inventory level that is reached in the cycle increases.*

Lemma 10 makes this conjecture true for $\Delta < Q - d$. For $\Delta \geq Q - d$, the lower bound of the average inventory is indeed non-decreasing in Δ. We assume that this non-decreasing behavior also holds for the average inventory. The assumption that the average inventory in a cycle increases with the maximum inventory level is tested and confirmed in the numerical experiments. It is also conceptually logical: the transport effort decreases with increasing Δ (see Lemma 6), as transport can become more efficient, when more stock are allowed to be stored at the buyer. A formal proof however, remains for future research.

Theorem 3. *Assuming that Conjecture 1 holds, then the optimal solution for the supply chain can be enforced by the setting the inventory capacity.*

Proof. Assume that, under a binding constraint for Δ, the (k, T) cycle is supply chain optimal, but another cycle $(k', T') \neq (k, T)$ is cheaper for the vendor under the same capacity constraint. According to Lemma 6, the vendor's transport effort and thus transport costs decrease when the cycle length increases. Therefore, $T' > T$. The supply chain optimal cycle and the vendor's optimal cycle are the same during the final T periods of the cycle. The vendor's optimal cycle however adds $T' - T$ periods in front of this. Since Δ is binding, the maximum inventory level in cycle (k, T) is Δ. Every inventory level is reached only once in an inventory cycle. Therefore, the maximum inventory level reached prior to the last T periods must be less than Δ. Therefore, according to Conjecture 1 $\overline{I}(k', T') < \overline{I}(k, T)$. Then, a cycle (k', T') results in lower costs for the vendor as well as the buyer, contradicting the assumption that (k, T) is supply chain optimal. ■

For different sets (Q, d, Δ), Algorithm Truck is used to derive the vendor optimal jit-cycle and to calculate the implied C_V, C_B, and C_{SC}. In Figure 5.3, the costs are plotted for $d = 16$ units per period as a function of the inventory capacity. The combinatorial nature of the problem makes it interesting to use a prime number for the trucks' capacity. The capacity of the truck is set to $Q = 31$ in the graph on the left, and $Q = 50$ in the graph on the right. We take for the costs for transport $\nu = 50$ per truck and holding costs $h = 1$ per unit per time.

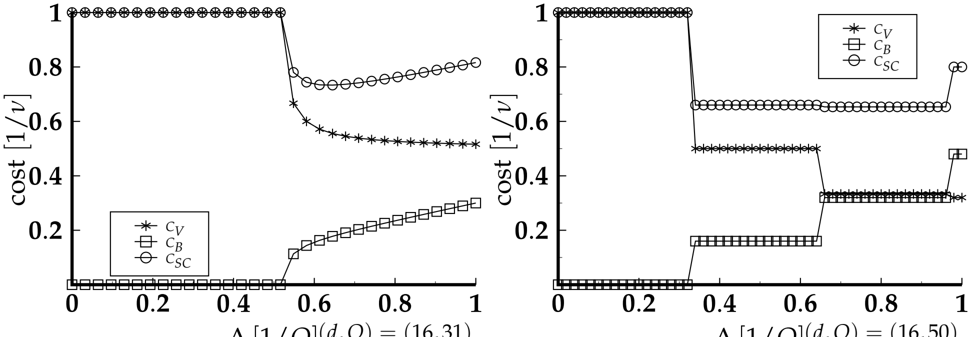


Figure 5.3: Supply chain costs for vendor, buyer and total costs as a function of the inventory capacity Δ.

Figure 5.3 demonstrates that indeed —for inventory capacity exceeding a period's demand— the vendor's transport costs decrease when the inventory capacity increases. The additional inventory capacity allows more efficient vendor optimal inventory cycles. A consequence of delivering the goods more efficiently is that inventory is stored at the buyer's and hence the buyer's inventory holding costs increase. We indicate the minimum total supply chain costs by indicated C^*_{SC}, occurring at inventory capacity Δ^*. For truck-size $Q = 31$ (the graph on the left of Figure 5.3) the total supply chain costs are minimal for $\Delta^* = 20$. For $Q = 50$ (right graph) a range of inventory capacities, $33 \leq \Delta^* \leq 48$, leads to minimum supply chain cost.

A lower bound to the supply chain costs is found by assuming that the truck's capacity is infinite, the inventory capacity is unconstrained and time is continuous. In that case, straightforward *economic order quantity* (EOQ) calculations can be used (see Harris (1913) or Silver et al. (1998)) to determine the minimum cost. With $C_{SC} = (T-1)hd/2 + \nu/T$, minimum costs are achieved when $T^* = \sqrt{2\nu/(hd)} - hd/2$. The minimum costs for the supply chain then is

$$C^{EOQ}_{SC} = \sqrt{2\nu hd} - \frac{h\,d}{2}\,. \tag{5.22}$$

For the problem that is considered in this chapter, with trucks of limited size, limited capacity for inventory, and discrete time, the optimal total supply chain costs (C^*_{SC}) can be determined exactly for every value of demand d in $1 \leq d \leq Q$. Using the same costs parameters for transport and holding costs as in Figure 5.3, we now plot the optimal —minimum— supply chain costs C^*_{SC} as a function of d in Figure 5.4 on the top row, together with C^{EOQ}_{SC}. The graphs on the left of Figure 5.4 show the cost-function for a truck of size $Q = 31$, the optimal costs for $Q = 50$ are plotted in the graphs on the right-hand side. The supply chain costs using the economic order quantity as in (5.22) are plotted as comparison. In the bottom row of Figure 5.4, the minimum (Δ^-) and maximum (Δ^+) values for Δ^* to achieve these minimum costs are plotted.

A few characteristics of the graphs are noted. The supply chain costs per unit of time increase as a function of demand. The total optimal supply chain costs per period under capacity constraints on inventory and truck size and with discrete time-periods (C^*_{SC}) is always higher than the optimal EOQ supply chain cost. Further, the costs per period never exceed the costs of a truck-ride. The reason for this is that it is always possible to deliver demand each period, so that inventory holding charges are avoided. When demand exceeds a certain level, this upper bound for $C_{SC} = \nu$ is reached. Above this threshold for demand, delivering in each time-period is more cost effective than holding inventory. So inventory capacity has no value in this case. In this situation, demand is such that $(k, T) = (1, 1)$ is the

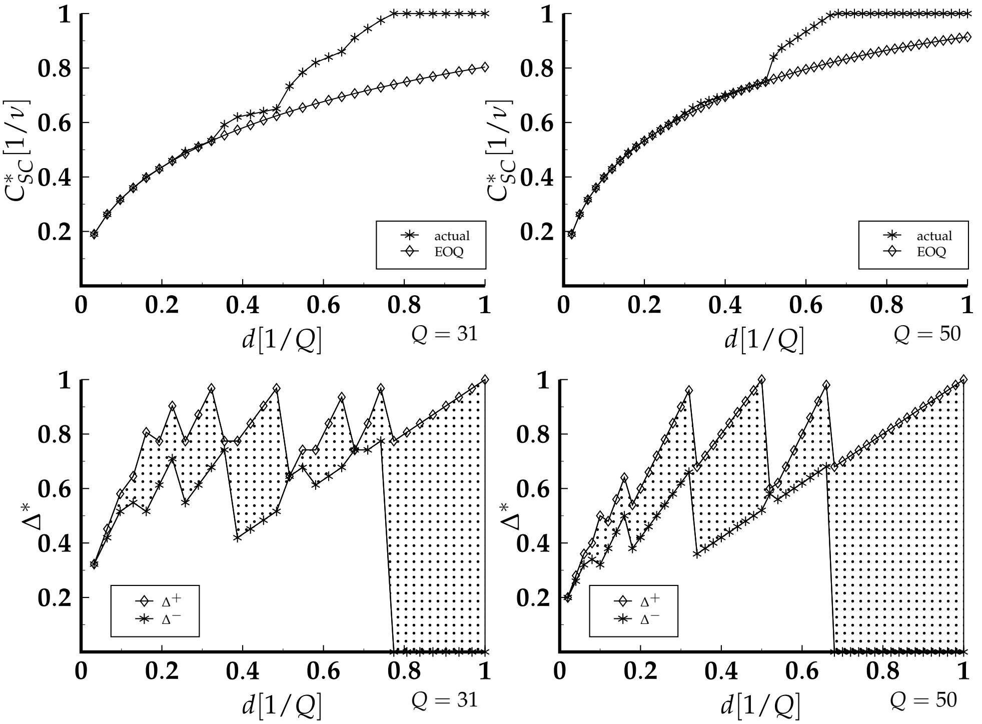


Figure 5.4: Upper row: actual minimum supply chain costs and EOQ supply chain costs versus demand. Bottom row: the patterned area indicates the inventory capacity Δ^- and Δ^+ versus demand that is optimal for the vendor.

most efficient inventory cycle. In order to derive a lower bound for the threshold demand above which this is true, we derive a lower bound for C_{SC} first.

The vendor's costs $C_V(k, T)$ equals $\nu\, k/T$. The buyer only bears inventory holding costs. A lower bound for the buyer's average inventory in cycle (k, T) is presented next.

For $k = 1$ the average inventory is simply $I = (T-1)\, d/2$. For $k > 1$ the size of all replenishments equals $a = \lfloor Q/d \rfloor$ plus a remainder smaller than d. Therefore, one replenishment plus the existing inventory can cover demand for either $\tau = a$ or $\tau = a + 1$ periods, after which the next replenishment is due. The sum of inventory-periods between such replenishments is $\tau(\tau-1)d/2$ plus the remainder before the next replenishment. Let x be the number of times the between-replenishment duration is a and $k - x$ the number of times a replenishment lasts $a + 1$ periods.

Then $T = x\,a + (k-x)\,(a+1)$. A lower bound $I(a)$ on the average inventory as a function of a in a cycle (k,T) is the sum of the inventory-periods between replenishments divided by T

$$I(a) = \frac{1}{2T}\left\{(xa(a-1)d + (k-x)a(a+1)d + ak(k-1))\right\},$$

where the last term is a result of the fact that no state can be visited twice in a inventory cycle. Therefore, the inventory just before the next replenishment is at least $1, 2, 3, \ldots, k-1$, once for a duration of at least a periods.

Rewriting the lower bound $I(a)$ and substituting $x = k(a+1) - T$ leads to

$$\begin{aligned} I(a) &= \frac{d\,a}{2T}(-2x + k(a+1)) + ak\frac{k-1}{2T} \\ &= \frac{d\,a}{2T}(2T - k(a+1)) + ak\frac{k-1}{2T}. \end{aligned}$$

Since $a < T/k < a+1$ it must be that $T/k - 1 < a \leq T/k$. The minimum of $I(a)$ for $a = T/k$ and $a = T/k - 1$ is a lower bound on the average inventory. Evaluating $I((T-k)/T)$ and $I(T/k)$ gives

$$I\left(\frac{T-k}{k}\right) = \frac{d(T-k)}{2kT}T + \left(\frac{T}{k} - 1\right)\frac{k(k-1)}{2T}, \quad \text{and} \tag{5.23a}$$

$$I(\frac{T}{k}) = \frac{d(T-k)}{2k} + \frac{T}{k}\frac{k(k-1)}{2T}. \tag{5.23b}$$

The minimum value for $I(a)$ is found for Eq.(5.23a). This leads to a lower bound on the average inventory for $k > 1$:

$$I_{LB} = \frac{d(T-k)}{2k} + \frac{1}{2T}(T-k)(k-1).$$

When $k = 1$, the average inventory is in fact equal to $I_{LB}(1,T)$. Therefore I_{LB} is in fact a lower bound for all inventory cycles (k,T).

For any (k,T), the supply chain costs satisfy $C_{SC}(k,T) \geq \frac{k\nu}{T} + hI_{LB}$. For $C_{SC}(1,1) \leq C_{SC}(k,T)$ the optimal solution for the supply chain is to ship each period. Shipping each period occurs when

$$\nu \leq \frac{k\nu}{T} + \frac{d\,h(T-k)}{2k} + \frac{h}{2T}\,(T-k)\,(k-1).$$

That is,

$$d \geq \frac{k}{T}\frac{2\nu + h - h\,k}{h}.$$

As argued on page 131, the maximum possible value for k equals $d-1$. This leads to $d \geq k/T(2\nu/h + 1 - (d-1)h/h)$ or

$$d \geq \frac{k}{k+T}\frac{2(\nu+h)}{h} \; .$$

Since $k \leq T-1$, it must be that $0 < k/(k+T) < 1/2$. The maximum is $1/2$, therefore when d satisfies

$$d \geq \frac{(\nu+h)}{h} \, , \tag{5.24}$$

the supply chain optimal inventory cycle is $(k,T) = (1,1)$.

The lowest value of C_{SC} occurs at $d = 1$. For $d = 1$, the truck's and inventory capacity limits have minimal influence on the costs, so the EOQ supply chain costs can be used as an estimate to $C_{SC}(d = 1)$. The supply-chain costs with T discrete and capacity constraints is

$$C_{SC}(1,T) \geq \sqrt{2\nu h} - h/2 \; .$$

In between the lowest and highest values for C_{SC} , the costs increase in a piecewise concave manner, a result of the iterative reduction of the problem in Algorithm Truck.

Figure 5.5 shows C^*_{SC} for different values of the parameters ν, h, and Q. The default parameters are $h = 1$, $\nu = 50$, $Q = 50$. The total costs are the linear sum of the transport costs and the inventory holding costs, which is why only the ratio of ν and h affects C_{SC} . In the graphs on the left of Figure 5.5, the ratio between ν and h is modified by varying the costs of deploying a truck, $\nu = \{10, 25, 50, 100\}$. In the graph on the right-hand side of Figure 5.5, the impact of the size of the truck is depicted, with $Q = \{25, 50, 100, 150\}$.

In line with the discussion above, for ν lower, less benefits of scale economies can be realized and regular shipping becomes optimal even when demand is low. In that case, maximum supply chain costs ($C^*_{SC} = \nu$) are reached. For increasing ν, the benefits of realizing economies of scale with more efficient shipment schedules are visible and maximum supply chain costs apply only at higher levels of demand. Further, C^*_{SC} at $d = 1$ increases as ν decreases and is invariant to changes in Q as long as $Q \gg 1$.

So far, supply chain optimal costs have been considered. A problem with practical implementation of this is that in order to reach this solution the buyer incurs more costs than in the case where he makes no inventory capacity available. Therefore, in order to make inventory cycles that lead to lower supply chain costs feasible

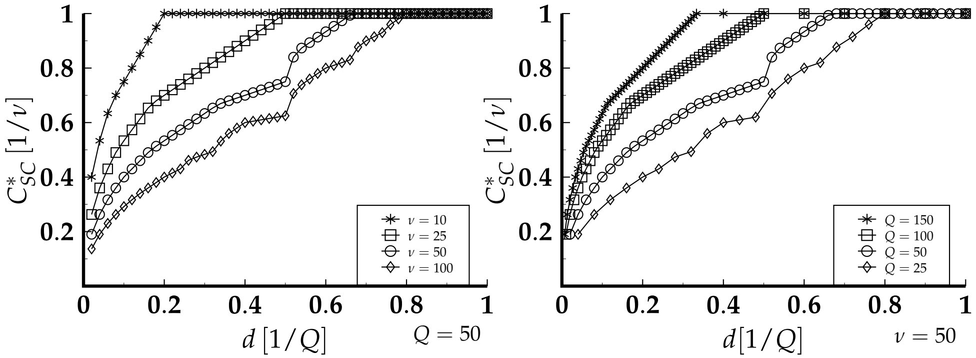


Figure 5.5: Minimum supply chain costs as a function of demand for different values of ν (left) and different values of Q (right).

for the buyer, some compensation to make the inventory capacity available should be given. The vendor benefits of the efficiency gains and realizes all of the supply chain's cost savings. The cost savings depend on Δ, so therefore the vendor can transfer an amount of money to the buyer that depends on Δ. Ideally, such transfer fee leads to a situation in which the buyer selects Δ^* to minimize his local cost, such that C^*_{SC} is realized. In that case complete supply chain coordination is achieved. We study the performance of a transfer fee depending on Δ in the next section.

5.4 Aligning Incentives

A transfer function is proposed that is based on the cost savings that the vendor is able to achieve. A first approximation for the vendor's cost savings as a function of Δ is based on the number of periods of demand that can be placed in inventory. We indicate the vendor's approximated cost savings per period by $\mathcal{S}_V$. The domain of interest is $0 \leq \Delta \leq Q$, since inventory bandwidth above Q is never used. A simple case arises when the vendor ships each time-period to fulfil the number of periods allowed by Δ, so $C_V = \nu/T = \nu/(\lfloor(\Delta-1)/d\rfloor + 1)$, so the vendor's cost savings compared to the costs in a base-stock policy are $\mathcal{S}_V = \nu - C_V$, so

$$\mathcal{S}_V = \nu\left(1 - \frac{1}{\lfloor(\Delta-1)/d\rfloor + 1}\right) = \nu\frac{\lfloor(\Delta-1)/d\rfloor}{\lfloor(\Delta-1)/d\rfloor + 1}\,.$$

As long as $\Delta \leq Q - d$, these cost savings are exact as under this condition, full trucks are never feasible and $k = 1$ (Case 1 in Section 5.3.2). For $Q - d < \Delta \leq Q$, the transport efficiency might be improved using inventory cycles as derived in the previous section. However, the maximum gain by an inventory cycle where $k \neq 1$ is limited. With $T = \lfloor (\Delta - 1)/d \rfloor + 1)$ for $k = 1$, the effort e of any cycle $k \neq 1$ is bound by $e < 1/(T+1)$, since the complete demand for an extra period cannot be stored in Δ. Therefore, the following bounds for the cost savings apply

$$\nu \frac{\Delta - 1 - d}{\Delta - 1} < \mathcal{S}_V \leq \nu \frac{\Delta - 1}{\Delta - 1 + d}, \qquad 0 \leq \Delta \leq Q\,. \tag{5.25}$$

In Figure 5.6, the vendor's actual cost savings, taken from the graph on the right-hand side of Figure 5.3 are plotted together with $\mathcal{S}_V$ and the upper and lower bounds on the cost savings. Clearly, the vendor's cost savings are between the bounds of Eq. (5.25).

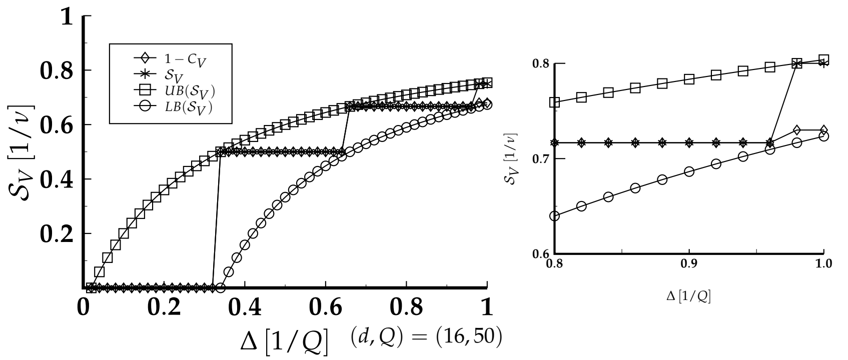


Figure 5.6: The actual vendor's cost savings, compared to the approximated cost savings $\mathcal{S}_V$ and the upper and lower bounds (UB and LB) for this approximation as function of Δ. Inset: close-up of the region $0.8 \leq \Delta \leq 1$.

We study the case where the vendor offers this bound of the supply chain cost savings as a transfer to the buyer in order to make inventory capacity available. By offering at most the cost savings the vendor realizes, he ensures not affecting his own performance negatively. Still, an issue with simply offering the lower bound of expected cost savings is that nearly all of the supply chain's cost savings end-up with the buyer. To manage this, the vendor introduces a linear parameter β to control the fraction of the approximated savings that are transferred to the buyer. A transfer payment is assumed never to be negative. The transfer function is expressed as

$$\mathcal{T}(\Delta,\beta) = \begin{cases} \beta\,\nu\left(1-\frac{d}{\Delta-1}\right), & d < \Delta \leq Q \\ 0, & \text{otherwise.} \end{cases}$$

with $0 \leq \beta \leq 1$. The transfer is paid from the vendor to the buyer, so the buyer's expenses (E_B) become the costs for holding inventory minus the transfer, so $E_B = C_B - \mathcal{T}(\Delta,\beta)$. The vendor's expenses equal the costs of transport plus the transfer, so $E_V = C_V + \mathcal{T}(\Delta,\beta)$. In the case $\beta = 0$ there is no transfer and thus no coordination. This is the base-case. When $\beta = 1$, the vendor transfers the maximum amount of the lower bound to the buyer and maximum supply chain coordination under a transfer is expected. By setting $0 < \beta < 1$, the buyer has flexibility to control the amount transferred and thus the supply chain costs as well as his private costs.

5.4.1 Analysis of Decisions with Transfer when $\Delta \leq Q - d$

When the vendor offers transfer function $\mathcal{T}(\Delta,\beta)$, the sequence of decisions that are made by the vendor and the buyer becomes

1. vendor determines β^*
2. buyer determines Δ^*
3. vendor determines $\sigma_V^* = (k, T)$.

Note that the objective that we consider here is to minimize the total supply chain cost, so the vendor selects β^* such that the supply chain costs are minimized. The optimal values are determined in the opposite direction from the flow of decisions:

$$\begin{aligned} \sigma_V^* &= \underset{\sigma_V}{\operatorname{argmin}}\, C_V(\sigma_V(\Delta(\beta))) \\ \Delta^*(\beta) &= \underset{\Delta}{\operatorname{argmin}}\, E_B(\sigma_V^*, \Delta, \beta) \\ \beta^* &= \underset{\beta}{\operatorname{argmin}}\, C_{SC}(\sigma_V^*, \beta, \Delta^*)\ . \end{aligned}$$

In the theoretical analysis of the decisions under a transfer under Case 1 in Section 5.3.2, the inventory capacity is limited, $\Delta \leq Q - d$, so full trucks are never delivered. Then, $k = 1$ and $T = \lfloor(\Delta-1)/d\rfloor + 1$. The vendor's costs are $C_V = \nu/T$ and the buyer's expenses are $E_B = min_\Delta\{h\bar{I}(\Delta) - \mathcal{T}(\beta,\Delta)\}$. For $\Delta \leq Q - d$, the average inventory is known to be $\bar{I}(T) = (T-1)d/2$. The cost structure of E_B is such that the inventory costs increase with the floor of the periods of demand that fit in the inventory capacity. At the same time the amount that is transferred increases monotonously with inventory capacity. Therefore, the buyer selects Δ such that the floor nearly jumps to the next integer, so

$$\frac{\Delta - 1}{d} = \frac{n\,d + (d-1)}{d}\,, \quad n \in \mathbb{N}\,,$$

so $\Delta = (n+1)d$ with $n \in \mathbb{N}$. For $\Delta < d$, there is no transfer and the buyer's costs are zero. Otherwise, $\mathcal{T} = \beta\nu(1 - d/\Delta)$, so

$$E_B^* = \begin{cases} 0 & \text{for } \Delta < d \\ \min_n \left\{ n\frac{hd}{2} - \beta\nu(1 - \frac{1}{n+1}) \right\} & \text{for } d \leq \Delta < Q\,. \end{cases}$$

The minimum costs achievable for the buyer is found by allowing n to be continuous and by solving for $\frac{\partial C_B}{\partial n} = 0$. Write $\alpha = \sqrt{(h\,d)/2\nu}$. Then

$$n^* = \sqrt{\beta}/\alpha - 1\,. \tag{5.26}$$

For $\beta < \alpha^2$, n^* would be negative, which is not feasible. In this case, it must be that $n^* = 0$. No transfer is made. The supply chain costs equal $C_{SC} = \nu$. The resulting minimal expenses for the buyer are then

$$E_B^* = \begin{cases} 0 & \text{for } \beta < \alpha^2 \\ \nu\left(2\alpha\sqrt{\beta} - \alpha^2 - \beta\right) & \text{for } \beta \geq \alpha^2\,. \end{cases}$$

So with the vendor's costs $C_V = \nu/T = \nu/(n+1)$, the supply chain costs are $C_{SC} = \nu/(n^*+1) + n^* hd/2$. Note that the total supply chain costs may never exceed ν as it is always possible not to store inventory and ship each period. This condition $C_{SC} \leq \nu$ makes $C_{SC} = \nu$ when $\beta < \alpha$. Further, from $n^* \geq 0$ we know that $\beta > \alpha^2$ which is always fulfilled as long as $\beta \geq \alpha$ and $\beta \leq 1$. So the supply chain costs of our system where the buyer determines the inventory capacity that is made available are

$$C_{SC} = \begin{cases} \nu\alpha\left(\sqrt{\beta} + \frac{1}{\sqrt{\beta}} - \alpha\right) & \text{for } 0 \leq \beta < \alpha \\ \nu & \text{for } \alpha \leq \beta \leq 1\,. \end{cases}$$

The supply chain costs for this system can be compared to the solution that is found using EQO analysis (Eq. (5.22)), $C_{SC}^{EOQ} = \nu\alpha(2-\alpha)$ shows that for $\beta = 1$

supply chain coordination is achieved, as then $C_{SC} = C_{SC}^{EOQ}$. Note that this is still under the assumption that $\Delta < Q - d$. For $\beta < 1$, it might be possible that C_{SC}^* is realized under a transfer scheme, but this depends on the parameters and on how n^* is rounded.

5.4.2 Supply Chain Coordination

Using different values for parameters Q, v and h, the decisions and costs of the two supply chain partners can be determined exactly. The buyer's minimum costs depend on β, which is used to select the optimal value for Δ that minimizes the buyer's expenses. This Δ determines the vendor's most efficient inventory cycle and thus the vendor's cost. The sum of these are the total supply chain costs C_{SC} under the transfer mechanism. The total supply chain costs are compared to the optimal supply chain costs, C_{SC}^*, that are derived as discussed in Section 5.3.4 on page 142. The relative supply chain costs $(C_{SC}(\beta)/C_{SC}^*) - 1$ are considered in the comparison. Figure 5.7 shows the relative supply chain costs in relation to the optimal supply chain costs C_{SC}^* for the uncoordinated case ($\beta = 0$) on the left-hand side and for the case where $\beta = 1$ on the right-hand side. The relative supply chain costs range in the non-coordination case range from over 400% above C_{SC}^* for small demand to the 0% difference for $d \approx Q$. In the coordinated case, the maximum deviation from the optimal supply chain costs is 20% for the cases considered here, at approximately $d \approx Q/2$. For $Q = 50$, the average deviation from C_{SC}^* in case of no coordination is 52%. In the case $\beta = 1$, the supply chain costs are within 1.4% of C_{SC}^* on average.

In the non-coordinated situation, the relative costs of not coordinating the supply chain decrease with increasing demand. As the size of the per period demand becomes comparable to the capacity of the truck, the truck-size constraints becomes important. The relative extra costs when the buyer and vendor do not coordinate decrease to zero as demand approaches the truck's capacity.

The vendor can determine the fraction β that is transferred to the buyer. The relative supply chain costs for different values of β compared to C_{SC}^* are plotted in Figure 5.8. The costs for $\beta = \{0.25, 0.50, 0.75, 1\}$ are derived. The total supply chain costs decrease when β increases. This is in line with the theoretical derivation of section 5.4.1 for $\Delta \leq Q - d$ and is intuitively understood. When a larger fraction of the supply chain cost savings's (when β is closer to 1) is transferred to the party who incurs the extra costs (the buyer), the resulting solution and total supply chain costs decrease and go nearer to C_{SC}^*.

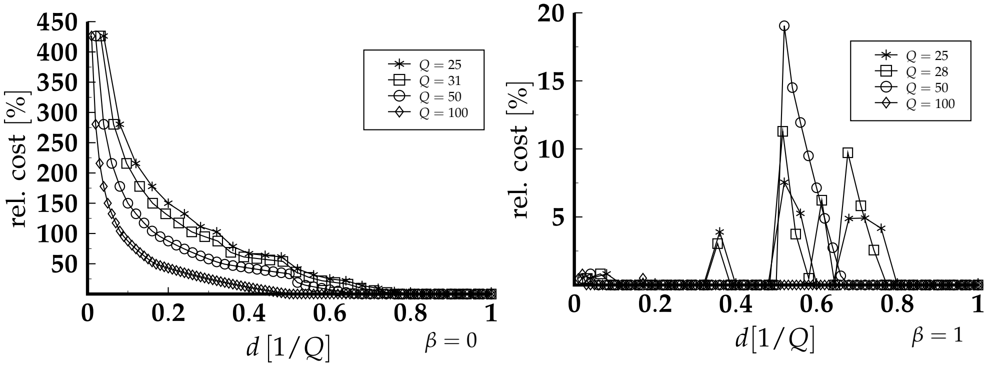


Figure 5.7: The total supply chain costs relative to the optimal supply chain costs for $\beta = 0$ (no-coordination) and $\beta = 1$. ($h = 1$, and $\nu = 50$).

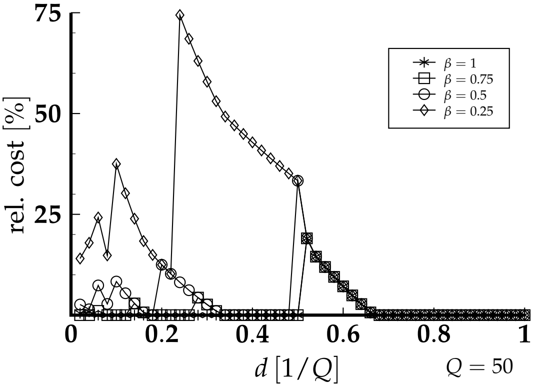


Figure 5.8: The total supply chain costs relative to the optimal supply chain costs $((C_{SC}(\beta) - C^*_{SC})/C^*_{SC})$ for different fractions β ($h = 1$, $\nu = 50$)

5.4.3 Vendor Optimal Coordination

A selfish vendor, aiming to maximize his own profits, can determine the parameter β in the transfer function $\mathcal{T}(\Delta, \beta)$ to minimize his private costs, rather than to aim for achieving the lowest total supply chain cost. Lower values of β allows a greater fraction of the cost savings to flow to the vendor, albeit at the cost of overall cost-savings. The sequence of decisions remains as before, with the only difference that the selfish vendor selects β^* to be the result of a minimization of the vendor's own expenses instead of the total supply chain costs, so

$$\beta^* = \operatorname*{argmin}_{\beta} C_V(\sigma^*_V(\Delta(\beta))) + \mathcal{T}(\beta, \Delta^*) \ .$$

In continuation of the analysis in Section 5.4.1, this can be analyzed analytically for the case where $\Delta < Q - d$, so that full trucks are never feasible. The vendor's total expenses are $E_V = C_V + \mathcal{T}(\beta, \Delta)$. As before, the optimal value for n, determined by the buyer $n^* = \sqrt{(2\nu\beta)/(hd)} - 1$. Thus

$$\begin{aligned} E_V &= \nu \left(\frac{1}{n+1} + \beta(1 - \frac{1}{n+1}) \right) \\ &= \nu \sqrt{\frac{hd}{2\nu\beta}} + \nu\beta - \nu\sqrt{\frac{hd\beta}{2\nu}} \,. \end{aligned}$$

To simplify the equations, $\alpha = \sqrt{(hd)/(2\nu)}$ as before. The vendor selects β^* to minimize his expenses, so

$$\begin{aligned} \beta^* &= \operatorname*{argmin}_{\beta} E_V \\ &= \operatorname*{argmin}_{\beta} \left(\sqrt{\frac{1}{\beta}} - \sqrt{\beta} \right) \nu\alpha + \nu\beta \,. \end{aligned} \tag{5.27}$$

The minimum is found when the derivative equals zero, so when $2\nu\beta^{3/2} - \alpha\nu(1 + \beta) = 0$. Two of the three roots of this equation are complex, the remaining solution yields a real value for β. The optimal value for β that is calculated theoretically under the constraint that $\Delta \leq Q - d$ and n continuous is indicated by $\hat{\beta}^*$.

$$\hat{\beta}^* = \frac{1}{36} \left(\sqrt[3]{54\,\alpha + \alpha^3 + 6\,\sqrt{81\,\alpha^2 + 3\,\alpha^4}} + \frac{\alpha^2}{\sqrt[3]{54\,\alpha + \alpha^3 + 6\,\sqrt{81\,\alpha^2 + 3\,\alpha^4}}} + \alpha \right)^2 ,$$

so $\hat{\beta}^*$ depends on α only. The second derivative of $E_V(\hat{\beta})$ to $\hat{\beta}$ is positive for $0 \leq \hat{\beta} \leq 1$ and $\alpha \geq 0$, meaning that the optimum is a local minimum to the vendor's expenses. The optimal value $\hat{\beta}^*$ starts at 0 when $\alpha = 0$. At $\alpha = 1$ the optimal fraction $\hat{\beta}^* = 1$. Further, the constraints on the fraction that is shared, $0 \leq \hat{\beta}^* \leq 1$ force $\alpha \leq 1$. When $\alpha > 1$ the holding costs dominate and demand is delivered every period.

The relation between $\hat{\beta}^*$ and α is plotted in Figure 5.9. Further, we know from Section 5.4.1 that when $\hat{\beta} < \alpha$ there is no transfer and no coordination. To illustrate this condition, the line $\hat{\beta} = \alpha$ is also plotted. Indeed, $\hat{\beta}^*(\alpha) \geq \alpha$ on $0 \leq \alpha \leq 1$. The plot shows that $\hat{\beta}^*$ increases almost linearly with α. This means that as the ratio $(hd)/\nu$ increases, the vendor has to increase the share of the cost savings in order to persuade the buyer to make inventory capacity available. This makes intuitively sense: when the costs of transport versus holding inventory is high, the vendor can keep a large fraction of the cost savings. On the other hand, when inventory holding costs are high compared to the costs of transport, the vendor has to transfer most of the cost savings to the buyer.

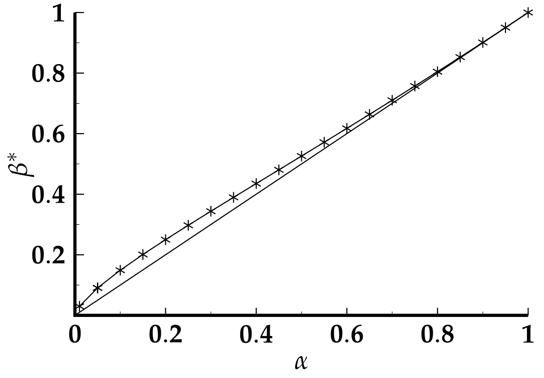


Figure 5.9: The optimal value for $\hat{\beta}^*$ for different values of $\alpha = \sqrt{(hd)/(2\nu)}$ for the case where $\Delta \leq Q - d$.

In Figure 5.10 the optimal value β^* that is derived numerically as a function of d is plotted for values $Q = \{31, 50, 100\}$ together with the theoretical $\hat{\beta}^*$. Note that the truck size in the calculation of $\hat{\beta}^*$ is infinite. For d small, all three experimental curves are similar, indicating that β^* in this region depends only on h and ν. When d reaches $Q/2$, the fraction β^* starts to differ. This is a result of the inventory cycles that might be possible if more inventory cacity is made available. The theoretical optimal $\hat{\beta}^*$ increases with the square of d. Figure 5.11 shows the expenses (savings) for the buyer and the expenses for the selfish vendor as a function of d for different truck-size $Q = \{31, 50, 100\}$ and $h = 1$, $\nu = 50$.

We derived the supply chain costs for a transfer function in which $\beta = 1$ and the costs for a transfer function that is optimal for the vendor, so $\beta = \beta^*$. These costs are compared to the optimal supply chain cost, as would be achieved under an omnipotent supply chain coordinator. Figure 5.12 shows the results. The top row of Figure 5.12 shows the relative total supply chain costs in relation to the optimal supply chain costs for a vendor-optimal sharing fraction, β^*, and for $\beta = 1$. The bottom row of Figure 5.12 plots the savings for the vendor ($\mathcal{S}_V(\beta)$) for vendor-optimal β^* and $\beta = 1$. For the transfer function with $beta = 1$, the maximum deviation from supply chain optimal costs is 20% for certain values of d and $Q = 0$, while for many values of d, supply chain-optimal costs are realized. On average over d, the deviation is below 1.5%. The majority of the cost savings, over

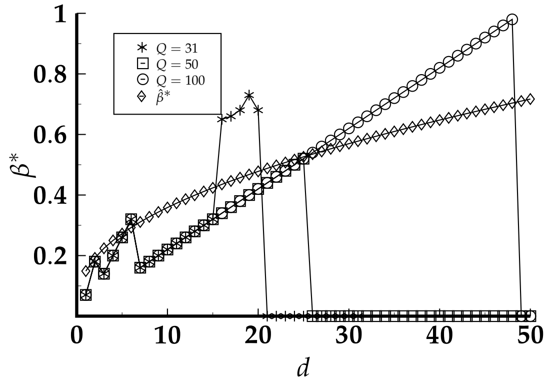


Figure 5.10: The optimal value for β^* and the theoretical optimal $\hat{\beta}^*$ as a function of d.

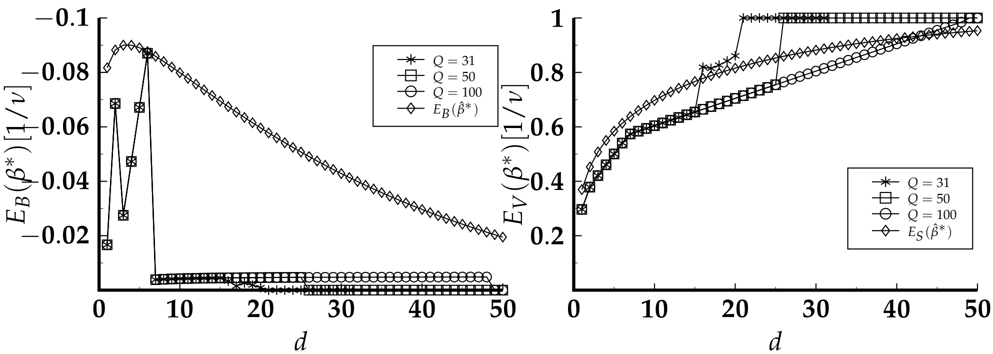


Figure 5.11: The expenses as a function of d, based on β^* determined by a selfish vendor for different truck-size Q and the calculated $\hat{\beta}^*$. On the left-hand side, the buyer's expenses (note that these are in-fact savings, so negative expenses) and on the right-hand side the vendor's expenses.

90% flow to the buyer. Under a selfish buyer with transfer function $\beta = \beta^*$, the supply-chain costs are at least the costs of $\beta = 1$. The potential cost savings from further coordination are highest for low values of demand compared to the truck's capacity. This makes intuitively sense, as the risk of an inefficient truck-ride is high for $d \ll Q$. However, the majority of the share of the cost savings now flow to the vendor.

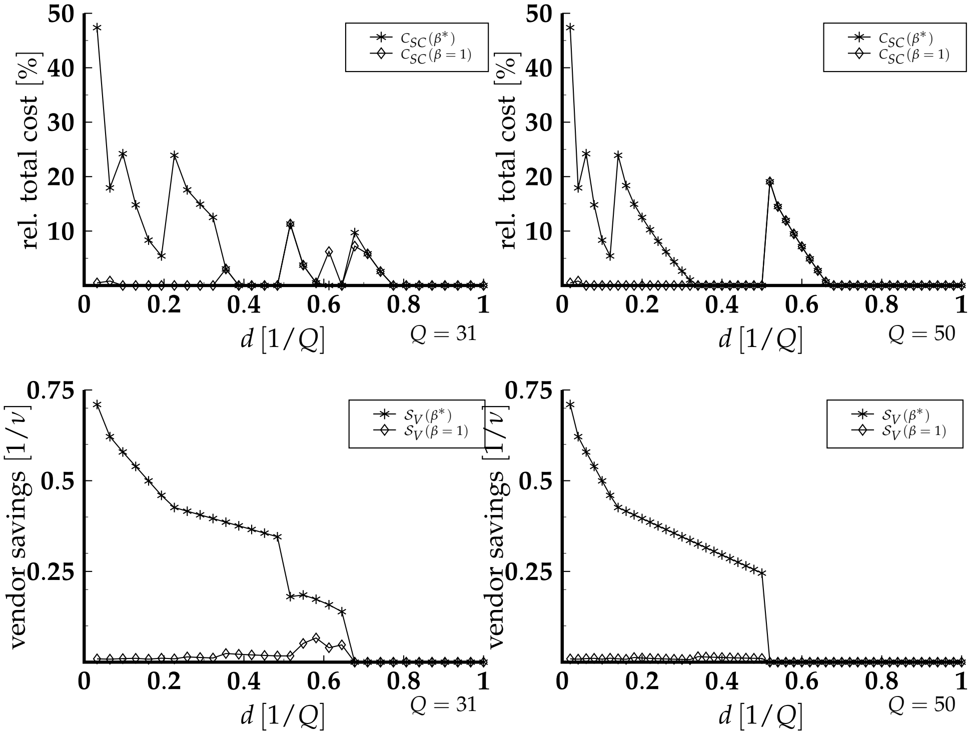


Figure 5.12: In the top row: relative total supply chain costs in relation to optimal supply chain costs for a transfer function with vendor optimal sharing fraction, β^*, and $\beta = 1$. The bottom row displays the savings for the vendor ($\mathcal{S}_V(\beta)$) for vendor optimal β^* and $\beta = 1$. Further $h = 1$, $\nu = 50$.

5.5 Conclusions

In general, a problem in shifting decision authority under advanced supply-chain collaboration arrangements is that the decisions one party takes may affect the other party's costs. A buyer in a VMI arrangement faces holding costs for inventory that is placed at the buyer, under authority of the vendor. In order to maintain some form of control over these costs, the buyer tends to enforce financial compensations or conditions on minimum and maximum inventory levels. Instead, under a VOI arrangement, the vendor bears the costs for holding the buyer's inventory, so the buyer does not need to face the risk of incurring costs over which the buyer has no control. In the VOI situation, the vendor is responsible for all relevant supply chain decisions as well as for all costs resulting from these decisions that affect the vendor and the buyer. The vendor has echelon operational autonomy and is able to fully coordinate supply chain decisions for optimal supply chain performance (Bernstein et al., 2006).

As reported by for instance Fry et al. (2001) and Kaipia et al. (2002), a buyer who faces the costs for holding inventory may set limits to the inventory capacity. In this manner, the buyer retains some responsibility on supply chain decisions and affects supply chain coordination. The limits that are set by the buyer determine the vendor vendor's leverage to control the supply chain and function to transfer part of the savings from the vendor to the buyer. We have built on this concept. We consider a system of a vendor and a buyer, and assume that demand from the buyer is constant. Transport between vendor and buyer takes place in trucks of limited capacity. The buyer determines constraints on the capacity that is made available to the vendor to store the buyer's inventory.

We have analyzed supply chain coordination in this model of a dyad of a vendor and buyer. To this end, we have first developed an exact algorithm to derive the optimal supply chain decisions for a given amount of storage capacity at the buyer. With that, we have assessed the performance of the supply chain under an optimal policy as a function of the storage capacity that the buyer makes available. Additional storage capacity can lead to cost savings and thus represents value. The vendor offers incentives to the buyer to coerce him to increase the storage capacity that is made available. Two cases are considered: an altruistic vendor aiming to optimize total supply chain costs and an opportunistic vendor optimizing for individual minimum costs. We have proposed a transfer function as a function of storage capacity that is based on a lower bound for the cost savings. The altruistic vendor offers this transfer fully to the buyer as an incentive to increase storage capacity for supply chain coordination. We conclude that the incentive fully coordinates supply chain decisions when $\Delta \leq Q - d$. The supply chain costs under the incentive scheme deviate less than 1.5% on average over d, and less than 20% for any value of d in the numerical examples we examined. The main share (approximately 90%) of the cost savings from coordinating the supply chain under VMI flow to the buyer. In practice, this is expected to occur only when the buyer is in a power position or if there are other benefits for the vendor that are external to the model considered. We find that a vendor with some leverage over the buyer can keep a bigger portion of the benefits. The vendor offers a proportion of the aforementioned transfer function to the buyer as an incentive. This proportion is optimized to minimize the vendor's costs. The average deviation from supply chain optimal costs in that case is around 6%. The main share of the cost savings are gathered by the supplier in this case.

The concept of coordination through incentive alignment via inventory capacity of **Chapter 5** is a simple and therefore potentially powerful method to coordinate supply chain operations. Both parties preserve some authority on supply chain decisions. The model can be improved further and made more convincing to practitioners by modeling stochastic demand instead of constant demand.

Chapter 6

Conclusions and Discussion

We have studied collaboration arrangements in practice and theory. To this end, the conditions for collaboration and benefits of collaboration as they are perceived in practice are uncovered. We have created a conceptual model of the mechanisms behind conditions for collaboration arrangements and benefits of collaboration arrangements. Transport tariffs, as a specific example of benefits derived of coordinated decision-making in collaboration arrangements, have been investigated in detail. We have demonstrated how transport tariffs can be derived based on a simple model. We have explored and analyzed supply chain coordination via a simple inventory-level-based incentive scheme. In this chapter, we review how the findings contribute to the objective of the dissertation to contribute to the understanding of the mechanisms behind the constraints and consequences of collaboration arrangements.

This chapter is organized as follows. In Section 6.1, we review the results and limitations of the research by returning to the four research questions of Section 1.3. After that, we discuss the results in relation to the original objectives in Section 6.2. Finally, we point out avenues for future research in Section 6.3.

6.1 Results

6.1.1 Collaboration in Practice

To improve the understanding of collaboration arrangement in supply chains, we have started this research by analyzing observations of collaboration arrangements in practice. The first research question formulated in Section 1.3 addresses the conditions and benefits of collaborative arrangement in practice.

RQ1: *What are the conditions for and the benefits of collaboration arrangements in practice?*

We have analyzed literature describing empirical research on collaboration between supply chain partners in practice in **Chapter 2**. The methodology in the reviewed articles that are based on empirical results of collaboration includes surveys, interviews, and case studies. Based on this literature, we have proposed a structured associative model for drivers of collaboration in supply chains.

Based on the definitions and description of collaboration arrangements by especially Clark and Hammond (1997), Cachon and Fisher (1997), Sabath et al. (2001), Stank et al. (1999), Le Blanc et al. (2006) and Claassen et al. (2008), we categorize collaboration forms into four main categories: conventional, Factory Gate Pricing, Vendor Managed Inventories (VMI) and Collaborative Planning and Forecasting.

Drivers of collaboration arrangements are differentiated into conditions for collaboration and benefits of collaboration. We further distinguish operational and strategic drivers of supply chain collaboration.

The first operational condition for supply chain collaboration follows mainly Lamb (1997), Kulp (2002), andClaassen et al. (2008) and is related to the *richness of the information* that is exchanged between supply chain partners. Collaboration is positively associated with information exchange that contains more valuable content. The *quality of the information* exchanged is a second operational condition for collaboration, following Clark and Hammond (1997), Dong and Xu (2002) and Kulp (2002).

We identified three strategic conditions necessary for VMI in the reviewed literature. The first strategic condition is the *ability* of a firm to join an advanced collaboration arrangement. This is related to firm size (Vergin and Barr, 1999), experience with advanced collaboration arrangements (Vergin and Barr, 1999, Peck and Juttner, 2000), and the state of ICT systems in the firm (Daugherty et al., 1999, Corbett et al., 1999, Kaipia et al., 2002, Claassen et al., 2008). The second strategic condition is the *strategic fit* between the partnering firms. The fit depends on the strategic position and the strategic match of the firms. This depends on the strategic position a firm currently has and the anticipated position that results from collaboration (Fiocca, 1982, Cox, 2001, de Leeuw and Fransoo, 2009). Trust between the firms is a very important factor in the strategic fit (Corbett et al., 1999, Lambert et al., 1999, Narayanan and Raman, 2004). The third strategic condition is the *product fit* of the products concerned in the advanced collaboration arrangement. The product fit depends on the market characteristics and competitiveness (see Bensaou (1999), Olsen and Ellram (1997a), Dong et al. (2007) and de Leeuw and Fransoo (2009)). Furthermore, supply risks and demand fluctuations contribute to the product fit for the collaboration arrangement (Kaipia et al., 2002, Holweg et al., 2005).

Benefits are the second important factor that drives advanced collaboration arrangements. As with the conditions for collaboration, we have separated the benefits of collaboration into operational and strategic benefits. Operational benefits of collaboration apply to the improved efficiency of operational activities such as *transportation*, *production*, or *holding inventories*, according to the findings of mainly Cachon and Fisher (1997), Vergin and Barr (1999), Kaipia et al. (2002), and Disney and Towill (2003a). The *service level* at the buyer remains at least constant, as reported in Cachon and Fisher (1997), and Peck and Juttner (2000), or even improves compared to the conventional arrangement, as reported by Kaipia et al. (2002) and Tyan and Wee (2003).

We identify three main types of strategic benefits that result from advanced supply-chain collaboration arrangements. The first type of strategic benefit from collaboration is found in an improved *strategic position* of a firm. The strategic position can improve due to improved customer intimacy, according mainly to Lamb (1997), Corbett et al. (1999) and Challener (2000). As reported by Vergin and Barr (1999) and de Leeuw and Fransoo (2009), a lock-in effect, where transacting via the advanced collaboration arrangement increases the relative costs for the buyer to switch vendors, further strengthens the strategic position of a vending firm. The second type of strategic benefit of collaboration applies to the improved *marketing knowledge* that the vending firm obtains as a result of the richness and quality of data exchange that occurs in advanced collaboration arrangements, as reported by Collins (1997), and Vergin and Barr (1999). The third type of strategic benefit of collaboration results from a reduction in the *overhead* required to manage inventories and replenishments for the buyers, as discussed by Aichlymayr (2000) .

We endorse the notion of van der Vaart and van Donk (2008) that basic agreement on definitions and constructs used in survey-based research concerning supply chain integration is needed in order to improve the consistency and comparability of results and conclusions from survey-based research. This allows researchers to validate and strengthen previous conclusions and to build further on these. We proposed and discussed constructs to measure the variables in the model. These constructs can be used to validate observations that are based on conclusions in the empirical literature.

As mentioned above, a limitation of the empirical research methodology that is used to derive the associative model on collaboration in practice, is the issue of consistency of basic definitions and measures in the reviewed literature, as noted by van der Vaart and van Donk (2008). We have contributed to establishing consistency in the broader research methodology by proposing an overall conceptual model for collaboration in practice, combined with a set of constructs to test and validate the relations in this model. The empirical data are gathered via methods of survey research, case-study research or interviews of employees in firms that are knowledgeable or responsible for supply chain management. Consequently, another limitation of this research is that these data are based on perceptive rather than absolute measures. Perceptive measures are difficult to validate and can be unreliable projections of reality (Ketokivi and Schroeder, 2004). Furthermore, allocating identified business consequences of collaboration to specific collaboration dyads is ambiguous. This ambiguity results from the fact that benefits often result from scale economies that apply to multiple buyers, resulting from multiple —possibly both advanced and conventionally arranged— dyads. The expert opinion on benefits of collaboration is further compromised as a result of extrinsic fluctuations in the business environment. Finally, an intrinsic limitation of using an empirical research methodology approach is the descriptive nature of such methodology. The model of collaboration in practice that we have derived contains associative links between conditions and benefits of collaboration. Understanding the mechanisms that are behind conditions and benefits of collaboration requires analytical modeling.

6.1.2 Analyzing Collaboration

After having explored the practice of supply chain collaboration, the next step is to understand the mechanisms behind collaboration. Therefore, we have reviewed and structured recent analytical literature on advanced collaboration arrangements to answer the second research question in **Chapter 3**.

RQ2: *In a supply chain collaboration arrangement, what are the mechanisms that translate the conditions for and the form of such arrangement into benefits? In particular, how does this translation happen in situations where economies of scale and capacitated resources are manifest?*

Collaboration arrangements between firms in a supply chain can be used to coordinate operational decisions in the supply chain. As argued by, among others, Goyal (1976), Monahan (1984) and Lee and Rosenblatt (1986), coordination of supply chain decisions reduces supply chain inefficiencies and thus reduces costs. Transacting on markets with price mechanisms as a coordinating instrument for supply chain decisions (Coase, 1937) may be considered a loose form of collaboration between vendor and buyer. However, supply chain decisions can be more accurately coordinated when firms decide to engage in tighter forms of collaboration. In the extreme, a supply chain centrally managed by an omnipotent supply chain manager can realize full coordination of supply chain decisions by optimizing total supply chain performance (Clark and Scarf, 1960, Eppen and Schrage, 1981, Federgruen and Zipkin, 1984a). In contrast to a centrally coordinated supply chain, firms in advanced collaboration arrangements function as separate firms and maintain some individual responsibility for their supply chain operations. We have argued that the potential costs savings and performance improvements by closing the gap between a centrally coordinated supply chain and a supply chain of firms that collaborate loosely gives rise to advanced forms of supply chain collaboration.

Based on the main factors of supply chain coordination —quantity of replenishments, timing of replenishments and inventory requirements as identified by Li et al. (2005)— we have argued that supply-chain collaboration arrangements consist of agreements between a vendor and a buyer on exchange of information and a division of decision authority.

We conclude from operations research models that collaboration leads to benefits in production efficiency, transport efficiency and inventory efficiency, without compromising service levels, see among others Dong and Xu (2002), Cheung and Lee (2002), Bernstein et al. (2006), Çetinkaya and Lee (2000), and Axsäter (2001). The division of the benefits resulting from collaborating is not trivial, as argued by, for instance, Corbett and de Groote (2000). We have concluded that advanced collaboration arrangements have to be economically attractive to each of the parties for them to join. We have introduced the condition for individual rationality for advanced collaboration arrangements. Two ways to realize individual rationality of an arrangement are discussed: incentive alignment and dominance. First, individual rationality can be achieved by sharing the benefits in such a way that no party is worse-off with the advanced collaboration arrangement. Alignment of incentives to coordinate supply chain decision-making is researched by among others Corbett and de Groote (2000), Cachon (2003), Narayanan and Raman (2004) and Corbett et al. (2004). Narayanan and Raman (2004) describes how a vendor can use some form of incentive alignment to *buy* responsibility. In that case, a vendor offers buyers financial incentives to coerce the buyers into changing the operational decisions in a manner that is favorable to the vendor. Depending on positions of strategic dominance and the dependence on the business relation, a dominant party can deviate from this principle and take a bigger portion of the benefits (see Cox (2001)). This is the second way to make joining a collaboration arrangement rational for each party: individual rationality is achieved by continuation of business rather than financial compensation.

In general, the party with most decision authority in the dyad is best off in terms of profits and costs (Fry et al., 2001, Kaipia et al., 2002). In a VMI arrangement, the vendor dominates the dyad. However, in order to coerce the buyer into accepting this change in authority the buyer must be certain not to be worse off as a result. In practice therefore, the buyer may maintain some control by setting the vendor's boundary conditions for managing the VMI arrangement as described by Fry et al. (2001), Claassen et al. (2008). Alternatively, a buyer may forfend all decision authority by demanding the vendor to manage the buyer's stock point under consignment, VOI, so that all inventory holding costs disappear for the buyer (Piplani and Viswanathan, 2003). Based on these findings from the analytical literature on supply chain collaboration, we have presented a conceptual model in Figure 2.2.

6.1.3 Practice and Theory Combined

To synthesize an overall picture of collaboration, we build upon the results of the research on the first two research questions. We combine the conditions and benefits of collaboration in practice from **Chapter 2**, as shown in Figure 2.2, with the resulting analytical model of **Chapter 3**, as shown in Figure 3.4. Figure 6.1 shows the resulting combined model. On the left, the conditions to make advanced collaboration arrangements work are presented. These are split between operational conditions, on top, and strategic conditions, at the bottom of the figure. The collaboration arrangement is defined by agreement on the exchange of information and decision authority, as shown in the center of the figure. The two forms of individual rationality, dominance and incentive alignment, ensure economical rationality for each firm to participate in the arrangement. Finally, on the right, the benefits that such collaboration arrangement may provide are shown, the operational benefits on the top-right and strategic benefits at the bottom. The solid connections in Figure 6.1 indicate that these connections are backed by analytical models. The dashed relations are associative. Specifically, analytical models in the literature support the empirically expected positive relation between the benefits of collaboration and operational conditions for information richness and information quality. Further, we have discussed analytical models in the literature that support the operational benefits that were found in practice. These included efficiency gains in production, transport and inventory management. We have not found analytical research studies in which strategic benefits from supply chain collaboration have been modeled. Even though advanced collaboration arrangements such as VMI improve supply chain efficiency, such arrangements are implemented only when it is individually rational for each supply chain partner to join the collaborative effort. Dominance in the dyad and incentives drive individual rationality for a firm.

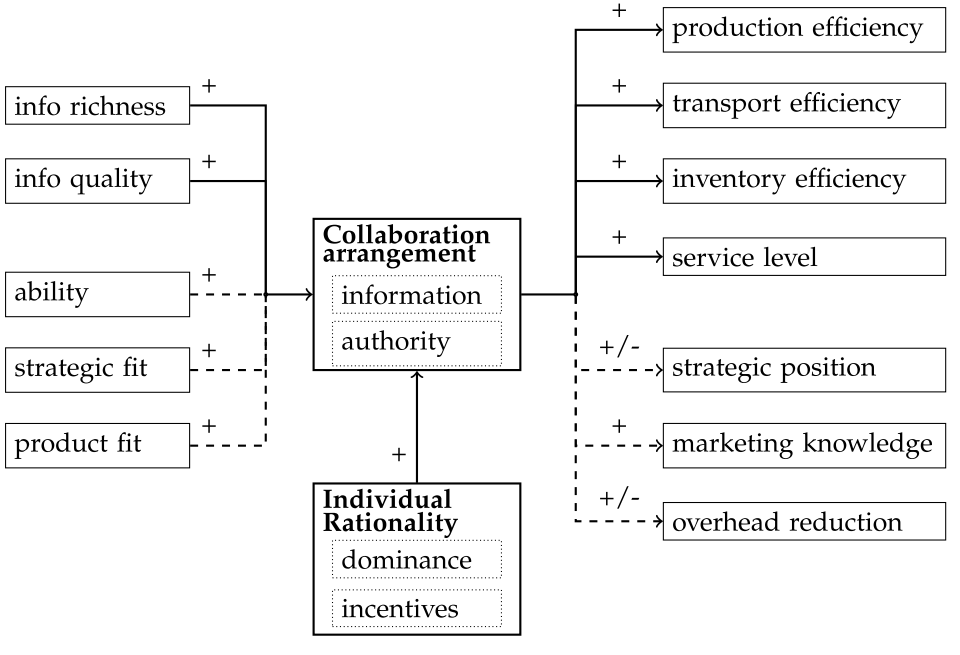


Figure 6.1: Combined Model of conditions and benefits that are associated with collaboration arrangements in theory and practice. The solid connections are analytically modeled, the dashed relations are associative.

We note a few limitations on the resulting combined model. Often, an underlying assumption in analytical models with respect to information sharing is that the quality of information is perfect and that information becomes available simultaneously to both vendor and the buyer. Further, we assume that supply chain partners in the dyad act in an economically rational way, implying that firms will collaborate in any advanced supply chain arrangement as long as no adverse effects occur. As already mentioned in Section 1.4, an 'important shortcoming of idealized problems is that the effect of the human factor on the performance of the operational process is largely neglected' (Bertrand and Fransoo, 2002). Models necessarily simplify reality to make them analytically tractable and in order to gain generic insight into and understanding of the interaction and mechanisms behind certain observations. The choices made to simplify reality so that it can be modeled hold the intrinsic risk of neglecting parameters that are significant to the analysis. Despite their apparent relevance based on empirical research, some conditions are omitted in analytical models as a result of the complexity involved in modeling such considerations. To give an example of such a problem, consider the following question: How does one model economically irrational behavior of a firm without making the model appear artificial and arbitrary? In conclusion, the challenge inherent in modeling reality with analytical models to understand mechanisms behind supply chain collaboration is compounded by the difficulty in measuring, verifying and validating theoretically expected outcomes with results in practice or with results of realistic and repeatable experiments. The complexity and interdependency of a firm's supply chain performance with its environment, the unavoidable fluctuations in the market, combined with sociological behavior of humans involved in supply chain management make repeatable predictions and validation of operational benefits of collaboration arrangements a challenging task. However, despite these shortcomings of analytical modeling, the generic understanding and knowledge that can be derived from an idealized model may lead to valuable insights into the solution of operational problems.

6.1.4 Transport Tariffs

Part of the potential costs savings from coordination are realized by optimizing transportation logistics between vendor and buyer. In the analytical literature, the cost of transport are often modeled as a fixed fee per truck-ride, independent of the volume that is transported, dependent on the traveled distance only. Any arrangement in which the vendor can control and thus improve on shipment sizing and timing will therefore be favorable to the vendor. The complexity of deriving the potential efficiency gains in transport through economizing on timing, quantity and routing is compounded by the complexity of translating transport effort into costs. Specifically, part of the potential cost savings on transport from shipping more efficient shipment quantities —that is, fuller trucks— can also be realized by using third-party logistics providers. This is because these parties can offer discounted transport tariffs for shipments of size less-than-a-truckload in size. This implies that analytical models, in which a fixed fee per truck-ride is assumed, overestimate the benefits in transport costs savings that result from advanced collaboration arrangements. The third research question concerns transport tariffs.

RQ3: *How can tariffs for transportation of less-than-a-truckload quantities be modeled to coordinate the usage of trucks efficiently?*

In **Chapter 4**, we have studied the consolidation of multiple orders of size Less-Than-a-Truck-Load (LTL) on a single link. We have derived transport tariffs based on allocation of the carrier's costs and based on the carrier's profit maximization. Tariffs based on cost allocation apply to a situation of private carriage, while tariffs based on profit maximization apply to common carriage. Under private carriage, the shipper and carrier are part of the same firm and transport tariffs function to coordination transport requirements within the firm. In the case of transport with a common carrier, an external party assumes the role of carrier. This party sets transport tariffs that are attractive to shippers by sharing part of the efficiency gains. We show that tariffs with properties that are expected and required in practice can be derived using relatively simple models.

We have proposed and analyzed three allocation mechanisms as a basis for transport tariffs: marginal, Shapley and semi-proportional allocation of costs for tariffs based on cost allocation. We have found only a limited number of studies on the properties of transport tariffs. Langley Jr. (1980) analyzed the effects of several functional forms for transport tariffs that he proposed. Arcelus and Rowcroft (1991), Swenseth and Godfrey (1996), Tyworth and Zeng (1998) and Smith et al. (2007) analyzed transport tariffs by fitting proposed transport tariff functions on actual tariffs. Based on these studies, we have identified properties that transport tariffs should comply with, listed in Table 6.1. The tariff based on the marginal or Shapley cost allocation is not sub-additive. This means that it might be beneficial to split a larger order into multiple smaller orders, which is undesirable for a carrier. The tariff that is based on semi-proportional cost allocation complies with all properties for transport tariffs we identified. The carrier recovers its costs for transport using this tariff. The tariff is symmetrical in the order-arrival sequence. The rate that is charged for transport under this tariff increases strictly based on order-size.

Table 6.1: Overview of expected properties for different cost-allocation transport tariff functions (reprint of Table 4.2).

Tariff Property	marginal	Shapley	semi-proportional
Monotonically increasing rate	+	+	+
Recover total costs	-	+	+
Sub-additivity	-	-	+
Monotonically decreasing rate per unit	-	-	+

The transport rate per unit decreases monotonically as a function of order-size, due to scale economies. Finally, this tariff function is sub-additive, meaning that it is not efficient to split an order into multiple smaller orders.

We find that all proposed tariff functions strongly depend on the order arrival rate, especially at small order-sizes. The reason for this is that a carrier can ship an order of the smallest size at zero cost when there is already a commitment to dispatch a truck. Only when no other orders have arrived during a dispatch period does a small order trigger the need to deploy a truck. As a result, the transport rate that the carrier charges to transport a small-sized order is reduced when the order-arrival rate increases. The possibilities to fill trucks efficiently increases for a carrier at high order-arrival rates —when many orders arrive within a dispatch period. The transport rate per unit is constant and equivalent to the truck's costs divided by the truck's capacity in the limit where the carrier leaves no space unused in truck-rides.

We have analyzed transport tariffs for a carrier who maximizes profits. In this case, transport tariffs are such that only a part of the cost savings from consolidating shipments are relayed back to the shippers. The remaining part of the savings represent the carrier's profits. We have presented numerical examples of tariffs for a profit-maximizing carrier. The market is modeled by setting a price-dependent probability that the shipper grants the carrier a shipment. The resulting tariff function behaves in line with the properties for transport tariffs that are mentioned above.

We conclude that the cost savings from transport efficiency gained by implementing an advanced collaboration arrangement are highest when a vendor is using private carriage. In this case, the vendor collects all of the benefits from the opportunities that arise from consolidating shipments and transporting more efficiently. For a vendor who used to ship with common carriers, a part of the efficiency gains from consolidating multiple orders is already realized by the common carrier and reflected in the tariffs on the market. Consequently, the potential savings on transport costs from implementing advanced collaboration arrangements such as VMI or FGP are lower.

The main limitation in this research on transport tariffs is that the model considers transport on a single link only. We have not taken into account consolidation opportunities from transport routes to multiple destinations in close proximity to each other. We expect the generic shape and properties of the transport function to be similar, but the additional potential to economize transport would lead to reduced transport tariffs compared to the tariffs derived for transport on a single link. Further, although each truck of the carrier has a limited capacity, the total number of trucks available to the carrier in our model is assumed to be infinite. When a carrier only has a limited number of trucks that can be used, the problem will be to set tariffs at such level that not only the loading per truck is optimized, but also the usage of the number of trucks. A side-remark to this research is that firms often work with contracts that are based on the total annual transport needs and transport tariffs, rather than considering transport tariffs based on an order of specific size. Such annual contracts further contribute to the complexity of assessing the cost savings from implementing VMI arrangements in a supply chain. However, the research in this chapter contributes to a further understanding of the cost factors behind transport tariffs. The findings on transport tariffs can support setting up and assessing the value of annual contracts for transport services.

6.1.5 Incentive Alignment

The fourth research question deals with the incentive alignment to alter the decision authority in collaboration arrangements.

RQ4: *How can supply chain decisions be coordinated with a simple incentive scheme between vendor and buyer in the case of transport by capacity-constrained trucks?*

In general, a problem in shifting decision authority under advanced supply chain collaboration arrangements is that the decisions one party makes may affect the other party's costs. A buyer in a VMI arrangement faces holding costs for inventory that is located at the buyer, under authority of the vendor. In order to maintain some form of control over these costs, the buyer tends to enforce financial compensations or conditions on minimum and maximum inventory levels. Instead, under a VOI arrangement, the vendor bears the costs for holding the buyer's inventory, so the buyer does not need to face the risk of incurring costs over which the buyer has no control. In the VOI situation, the vendor is responsible for all relevant supply chain decisions as well as for all costs resulting from these decisions that affect the vendor and the buyer. The vendor has echelon operational autonomy and is able to fully coordinate supply chain decisions for optimal supply chain performance (Bernstein et al., 2006).

As reported by, for instance, Fry et al. (2001), a buyer who faces the costs of holding inventory may set limits on the inventory capacity. In this manner, the buyer retains some responsibility on supply chain decisions and affects supply chain coordination. The limits that are set by the buyer determine the vendor's leverage to control the supply chain and function to transfer part of the savings from the vendor to the buyer. We have built on this concept in **Chapter 5**. We consider a system of a vendor and a buyer, and we assume constant demand from the buyer. Transport between vendor and buyer takes place in trucks of limited capacity. The buyer determines constraints on the capacity that is made available to the vendor to store the buyer's inventory.

We have analyzed supply chain coordination in this model of a dyad of a vendor and buyer. To this end, we have first developed an exact algorithm to derive the optimal supply chain decisions for a given amount of storage capacity that the buyer makes available. With that, we have assessed the performance of the supply chain under an optimal policy as a function of the storage capacity that the buyer makes available. Additional storage capacity can lead to cost savings and thus represents value. The vendor offers incentives to the buyer to coerce him to increase the storage capacity that is made available. Two cases are considered: an altruistic vendor aiming to optimize total supply chain costs and an opportunistic vendor optimizing to reach individual minimum costs. We have proposed a transfer function as a function of storage capacity that is based on a lower bound for the cost savings. The altruistic vendor offers to transfer this incentive completely to the buyer as an incentive to increase storage capacity for supply chain coordination. We conclude that the incentive does coordinate supply chain decisions. On average, the supply chain costs under the incentive scheme deviate less than 1.5% from the optimal total supply chain costs. The main share (approximately 90%) of the cost savings from coordinating the supply chain under VMI flow to the buyer. In practice, this is expected to occur only when the buyer is in a power position or if there are other benefits for the vendor that are external to the model considered. We find that a vendor with some leverage over the buyer can keep a bigger portion of the benefits. The vendor offers a proportion of the aforementioned transfer function to the buyer as an incentive. This proportion is optimized to minimize the vendor's costs. The average deviation from supply chain optimal costs in that case is around 6%. The main share of the cost savings are reaped by the supplier in this case.

6.2 Discussion

The objective of this thesis, as stated in Section 1.3, has been to contribute to

- the exploration of the conditions for and the consequences of advanced collaboration arrangements in practice,
- and the understanding of the mechanisms behind the constraints and consequences of collaboration arrangements.

We have discussed how collaboration in a supply chain to coordinate decisions can range from internal coordination within a firm, where an entrepreneur drives coordination, to collaboration on external markets, where pricing mechanisms drive coordination. Arrangements between different firms to collaborate on a market can range from loose collaboration on transaction basis on a market to tightly collaborating firms sharing all their relevant information and decision authority. We have argued that the main characteristics defining collaboration arrangements are agreements on the exchange of information and on the authority to make decisions that affect the supply chain. In Chapter 2, we have identified four basic types of supply-chain collaboration arrangements based on the division of authority around triggering and arranging replenishments: conventional arrangement, VMI, FGP, and CPFR. However, we have noted that decision authority is rarely clearly divided between firms. Each firm aims to maintain some control, at least over the supply chain operations that affect their costs. This is why many collaboration arrangements are studied and implemented that deviate more or less from the four basic types. To illustrate this point, under VMI a buyer might not be comfortable bearing the costs of holding his inventory, as the inventory management is done by the vendor. Under VOI, the buyer mitigates this problem by channeling the inventory holding costs to the vendor. Alternatively, the buyer may set minimum and maximum levels within which the vendor has to maintain the inventory to control his inventory costs.

We have synthesized a conceptual model combining conditions for collaboration arrangements and the benefits that are realized as a result of collaboration, shown in Figure 6.1. This is based on the results from empirical literature and research in Chapter 2 as well as on results from analytical research in Chapter 3. Our conceptual model displays the factors that drive the advanced supply-chain collaboration arrangements between firms. We have shown both empirical results and analytical models that explain the mechanisms for the drivers that are related to the supply chain operations. We have identified the richness and the quality of the information that is exchanged as the operational conditions. The operational benefits that drive collaboration are the increased efficiency of transportation for replenishments, increased efficiency of production planning and the increased efficiency of inventory management, which results in lower average inventory levels, while maintaining at least the same service level at the buyer. The relations that we have identified between the conditions and benefits of a strategic nature are more complex to analyze. Analytical understanding remains for future research. An issue with this model is that the field of research of operations management, according to Bertrand and Fransoo (2002), "still lacks a well-defined, shared methodological framework for identifying and measuring the relevant characteristics of real-life operational processes." As van der Vaart and van Donk (2008) note, there is little consistency in the basic definitions and constructs that are used to measure impact and integration in practical research on collaboration. Our model contributes towards achieving consensus among the research community on the definitions and constructs to be used to analyze advanced collaboration arrangements. In Chapter 2 we have discussed how the relations in the model can be measured and validated empirically by means of survey research.

In Chapter 3, we have argued that analytical literature generally overestimates the benefits of implementing VMI compared to a conventional setting in transport costs. This is because analytical models rarely take into account the fact that firms may use the services of a third-party logistics provider, who consolidates freight from several sources on intelligently selected transport routes. The efficiency gains that are realized by the third-party logistics provider will be partially passed on to the shipping firm. This is not taken into account when transport costs are modeled by a simple fixed fee per truck-ride, independent of the shipped quantity. We conclude that while a vendor with private carriage can realize the full potential transport savings under advanced collaboration arrangements, the potential savings in transport costs for a vendor using common-carriage are lower. To understand the background of the tariffs a carrier charges to a shipper for consolidating freight, in Chapter 4 we developed a simple model by which tariffs for a common carrier and a private carrier are determined. Properties for transport tariffs in practice are identified. We present a mechanism to derive transport tariffs that comply to all identified properties required for transport tariffs.

In Chapter 5, we have demonstrated how decisions in supply chains can be coordinated via a simple incentive scheme. For this, we have considered a VMI arrangement, in which the buyer determines the capacity that the vendor has available for managing the inventory. The vendor offers an incentive to the buyer that depends on the inventory capacity. We conclude that the supply chain costs are on average less than 1.5% more than the costs of a centrally coordinated supply chain when an altruistic vendor —that is, a vendor who optimizes for total supply chain performance— organizes the coordination. In these cases, over 90% of the benefits resulting from the coordination are reaped by the buyer. We have shown that with this form of incentive alignment in the case of an opportunistic vendor who optimizes his private costs, still coordinates supply chain decisions. The resulting costs are approximately 6% above the costs of a centrally coordinated chain, but in this case, the lion's share of the savings is enjoyed by the vendor.

6.3 Areas for Future Research

The research presented here contributes to a further understanding of the coordination of supply chain decisions via advanced collaboration arrangements. However, interesting areas for future research remain.

The conceptual model for collaboration arrangements in practice found in **Chapter 2** can be further validated and improved. Following van der Vaart and van Donk (2008), we have argued that the complexity of a multitude of varying occurrences of collaborating arrangements and the ambiguity of definitions used limit the ability to 'build-upon' previous research and therefore limit progress. The conceptual model we presented, with the proposed measurements to validate it, can be used as a foundation to build upon. Future research, via large-scale surveys or in-depth interviews with experts in practice may lead to stronger support for and improvements of the relations in the model and the measurements. The strategic conditions and benefits could serve as focal areas, as these relations and conditions so far have been: 1)surveyed using multiple varying definitions and constructs, and 2) difficult to understand and prove analytically. For this, we propose a dual approach. First, the strategic relations in the conceptual model for collaboration can be tested in multiple large-scale surveys, across multiple industries and multiple countries. As is clear from the model based on understanding collaboration in **Chapter 3**, the analytical understanding of strategic conditions and results of collaboration remains a challenge. The strategic conditions and benefits are hard to define properly. More empirical results may improve the ability to model these conditions for analytical understanding. To overcome the difficulty of modeling the strategic benefits over the short- and long-term, we propose that longitudinal empirical studies be set up to research the development of the strategic position of firms over time.

The transport tariffs that we derive from a simple model in **Chapter 4** lead to two directions for future research. The first direction is the further refinement of the model for deriving transport tariffs. In particular, the carrier can be modeled to include freight consolidation due to routing. Further, the total number of trucks that is available to the carrier can be made finite in the model. This way, one achieves a situation that holds some similarity to the problem of demand management with stable tariffs. The second direction for future research based on transport tariffs is to analyze the implementation of the resulting quantity dependent LTL-transport tariffs in operational models in order to calculate the cost benefits of collaboration. The resulting benefits of collaboration are expected to be lower, but more realistic, since part of the cost-savings from transport consolidation are already realized.

The concept of coordination through incentive alignment via inventory capacity in **Chapter 5** is a simple and therefore potentially powerful method to coordinate supply chain operations. Both parties preserve some authority on supply chain decisions. The model can be improved and made more convincing to practitioners by modeling stochastic demand instead of constant demand.

In the research of this thesis, the unit of analysis is the buyer-vendor dyad. A vendor with multiple buyers can transact with multiple vendor-buyer dyads. In future research, it would be interesting to take into account the interaction between dyads in a supply-chain collaboration arrangement. The operational decisions that are made in one dyad may affect the operational performance of another dyad of the same vendor. For a system consisting of a vendor and multiple buyers, this explains the performance gap between a centrally coordinated supply chain that covers the decisions of all dyads, and the performance of a supply chain where decisions are coordinated on the level of multiple dyads. The buyer-dependent business environment will determine the performance gap between centrally and dyad-coordinated supply chains. Future research may study the buyer-dependent environmental factors that make it worthwhile to consider coordination on a higher level than the dyad.

The trend of moving from products to services may also lead to interesting research directions. Instead of delivering a physical product that the customer uses to satisfy needs, firms increasingly focus on delivering the service to satisfy needs instead of the product. To give an example of where this applies, consider the car manufacturing industry, where high plant utilization rates are necessary to break even. The cars that are manufactured are ultimately bought by a customer who has to buy a car to satisfy his mobility needs. If we extent the concept of collaboration through VMI all the way to the customer, we can imagine a car manufacturer that is no longer selling cars, but that sells mobility instead. While demand for new cars swings with economic indicators, the mobility needs of the end-customers remain less perturbed. A manufacturer who makes it his business to ensure a guaranteed service level of mobility to the end customer thus may realize a more stable and thus more efficient supply chain compared to the current business model. On top of that, such a manufacturer may pro-actively manage the maintenance of such vehicles, and may even join forces with the customer to drive more efficiently and safely to the destination. Similar arguments can be made for other services relying on capital intensive production enablers. Therefore, further research in the potential gains and the pitfalls of even more intense and tight advanced collaboration arrangements to coordinate decision-making in the supply chain remains an interesting avenue to explore.

Appendix A

Cost Allocation and Simulation of Transport Tariffs

A.1 Allocation Details

A.1.1 Marginal Allocation

The marginal procedure for allocating costs can more formally be described as follows. The impact of the last arrived order being of size q, is $\tau_{|\mathcal{O}|}(\mathcal{O}, q)$. Now take the average of $\tau_{|\mathcal{O}|}(\mathcal{O}, q)$ for the cases where $q_{|\mathcal{O}|} = q$ to arrive at the rate $T(q)$ to be applied to an order of size q: $T(q) = \mathbb{E}\left(\tau_{|\mathcal{O}|}(\mathcal{O}, q)\middle| q_{|\mathcal{O}|} = q\right)$.

A.1.2 Shapley Allocation

The Shapley procedure for allocating costs can more formally be described as follows. Choose ℓ such that $1 \leq \ell \leq |\mathcal{O}|$ and compute

$$\overline{\tau}(\mathcal{O}, q) = \frac{1}{|\mathcal{O}|!} \sum_{\sigma \in \Pi_{|\mathcal{O}|}} \tau_{\sigma^{-1}(\ell)}(\mathcal{O}_\sigma, q)$$

where $\mathcal{O}_\sigma = (q_{\sigma(1)}, \cdots, q_{\sigma(|\mathcal{O}|)})$ and $\Pi_{|\mathcal{O}|}$ is the set of permutations of $|\mathcal{O}|$ elements. Note that $\overline{\tau}(\mathcal{O}, q)$ does not depend on the choice of ℓ with $1 \leq \ell \leq |\mathcal{O}|$. Also note that in case $q \notin \mathcal{O}$ then $\overline{\tau}(\mathcal{O}, q) = 0$ as $\tau_{\sigma^{-1}(\ell)}(\mathcal{O}_\sigma, q) = 0$ for any $\sigma \in \Pi_{|\mathcal{O}|}$.
Now take the average of $\overline{\tau}(\mathcal{O}, q)$ for the cases where $q \in \mathcal{O}$ to arrive at the rate $T(q)$ to be applied to an order of size q: $T(q) = \mathbb{E}(\overline{\tau}(\mathcal{O}, q)|q \in \mathcal{O})$. Further note

from $\#(\mathcal{O}) = \sum_{k=1}^{|\mathcal{O}|} \tau_k(\mathcal{O}, q_k) = \#(\mathcal{O}_\sigma) = \sum_{k=1}^{|\mathcal{O}_\sigma|} \tau_k(\mathcal{O}_\sigma, q_{\sigma(k)})$ that

$$\begin{aligned}
\sum_{k=1}^{|\mathcal{O}|} \overline{\tau}(\mathcal{O}, q_k) &= \frac{1}{|\mathcal{O}|!} \sum_{k=1}^{|\mathcal{O}|} \sum_{\sigma \in \Pi_{|\mathcal{O}|}} \tau_{\sigma^{-1}(\ell)}(\mathcal{O}_\sigma, q_k) \\
&= \frac{1}{|\mathcal{O}|!} \sum_{\sigma \in \Pi_{|\mathcal{O}|}} \sum_{k=1}^{|\mathcal{O}|} \tau_{\sigma^{-1}(k)}(\mathcal{O}_\sigma, q_k) \\
&= \frac{1}{|\mathcal{O}|!} \sum_{\sigma \in \Pi_{|\mathcal{O}|}} \sum_{k=1}^{|\mathcal{O}|} \tau_{\sigma^{-1}(\sigma(k))}(\mathcal{O}_\sigma, q_{\sigma(k)}) \\
&= \frac{1}{|\mathcal{O}|!} \sum_{\sigma \in \Pi_{|\mathcal{O}|}} \sum_{k=1}^{|\mathcal{O}|} \tau_k(\mathcal{O}_\sigma, q_{\sigma(k)}) \\
&= \frac{1}{|\mathcal{O}|!} \sum_{\sigma \in \Pi_{|\mathcal{O}|}} \#(\mathcal{O}) = \#(\mathcal{O})
\end{aligned}$$

A.1.3 Semi-proportional Allocation

For an order pool $\mathcal{O} = (q_1, \cdots, q_{|\mathcal{O}|})$ now consider the following recursions, for calculating numbers (α_j), referred to as allocations, and numbers (ρ_j), referred to as remainders,

$$\alpha_j = \min\{w_j \rho_{j-1}, \#(q_j)\} \quad \text{and} \quad \rho_j = \rho_{j-1} - \alpha_j \tag{A.1}$$

with ρ_0 some given positive number and weights given by $w_j = q_j/(q_j + \cdots + q_{|\mathcal{O}|})$. Note that $w_{|\mathcal{O}|} = 1$. The allocation (α_j) is such that if $q_j = q_{j+1}$ then $\alpha_j = \alpha_{j+1}$. The next theorem shows that allocating α_j to order q_j is efficient provided orders are sorted according to decreasing size. Here, an order pool $\mathcal{O} = (q_1, \cdots, q_{|\mathcal{O}|})$ is said to be sorted if $q_1 \geq q_2 \geq \cdots q_{|\mathcal{O}|}$. The pool is said to have LTL orders only if $q \leq F$ for all $q \in \mathcal{O}$. Note that in an LTL-orders only pool $\#(q) = 1$ for any q in that order pool.

Theorem 4. *Let $\mathcal{O} = (q_1, q_2, \cdots, q_{|O|})$ be a sorted order pool with LTL orders only. Then*

$$\sum_j \alpha_j = \rho_0 \tag{A.2}$$

for any $\rho_0 \leq |\mathcal{O}|$ where the allocations α_j are computed from (A.1).

Proof. Start by noting that $\rho_n = \rho_0 - \sum_{j=1}^n \alpha_j$ and so $\sum_{j=1}^n \alpha_j = \rho_0$ is equivalent to $\rho_n = 0$.

The proof now proceeds by induction on $|\mathcal{O}|$. Note that the theorem holds evidently when $|\mathcal{O}| = 1$. Now assume that Equality (A.2) holds for all sorted order pools containing $n-1$ or less LTL orders and consider a sorted order pool $\mathcal{O} = (q_1, q_2, \cdots, q_n)$ with LTL orders only. Apply recursion (A.1) to $\mathcal{O}$ with starting value $\rho_0 = |\mathcal{O}| = n$. Now

$$\rho_1 = n - \min\left\{\frac{q_1}{q_1 + \cdots + q_n} n, 1\right\} = \max\left\{\frac{q_2 + \cdots + q_n}{q_1 + q_2 + \cdots + q_n} n, n-1\right\} .$$

Note that

$$\begin{aligned} \frac{q_2 + \cdots + q_n}{q_1 + q_2 + \cdots + q_n} n \leq n - 1 \Leftrightarrow\ & (q_2 + \cdots + q_n)n \\ & \leq (q_1 + q_2 + \cdots + q_n)(n-1) \\ \Leftrightarrow\ & 0 \leq q_1(n-1) - (q_2 + \cdots + q_n) \end{aligned}$$

and the last inequality holds from $q_1(n-1) \geq q_2 + \cdots + q_n$ which is evidently true as $q_1 \geq q_j$ for all j. So $\rho_1 \leq n-1$. Now apply recursion (A.1) with starting value $\rho'_0 = \rho_1$ to $\mathcal{O}' = (q_2, \cdots, q_n)$ and denote all the ensuing allocations and remainders with a prime. Clearly $\alpha_j = \alpha'_{j-1}$ and $\rho_j = \rho'_{j-1}$. In particular $\rho_n = \rho'_{n-1}$. By the induction hypothesis the theorem applies to $\mathcal{O}'$ and therefore $\rho_n = \rho'_{n-1} = 0$.
We stil need to prove the theorem when $\rho_0 < n$. It is readily seen that the allocations α_j and the remainders ρ_j are nondecreasing as a function of ρ_0. As allocations and remainders are obviously nonnegative, $\rho_n = 0$ for $\rho_0 < n$ is immediate from $\rho_n = 0$ for $\rho_0 = n$. ■

The following corollary to Theorem 4 is immediate as $\#(\mathcal{O}) \leq |\mathcal{O}|$.

Corollary 3. *Let $\mathcal{O} = (q_1, \cdots, q_{|\mathcal{O}|})$ be a sorted order pool with LTL orders only. Compute allocations α_j to q_j through*

$$\alpha_j = \min\{w_j \rho_{j-1}, \#(q_j)\} \quad \textit{and} \quad \rho_j = \rho_{j-1} - \alpha_j$$

with $\rho_0 = \#(\mathcal{O})$ and $w_j = \frac{q_j}{q_j + \cdots + q_{|\mathcal{O}|}}$. Then $\sum_{j=1}^{|\mathcal{O}|} \alpha_j = \#(\mathcal{O})$.

The semi-proportional allocation of costs to an order pool $\mathcal{O} = (q_1, \cdots, \mathcal{O}_{|\mathcal{O}|}$ can now be detailed as follows. First, set $\alpha'_j = \lfloor q_j / F \rfloor$. Put $q'_j = q_j - \alpha'_j F$ as the remainder of the order after full trucks have been deducted. Consider $\mathcal{O}' = (q'_1, \cdots, q'_{|\mathcal{O}|})$. Let σ be a permutation of $\{1, \ldots, |\mathcal{O}|\}$ such that $q'_{\sigma(1)} \geq \cdots \geq q'_{\sigma(|\mathcal{O}|)}$

and consider $\mathcal{O}'_\sigma = (q'_{\sigma(1)}, \cdots, q'_{\sigma(|\mathcal{O}|)})$. The order pool $\mathcal{O}'_\sigma$ is sorted and has LTL orders only. Apply the recursion (A.1) to $\mathcal{O}'_\sigma$, resulting in

$$\alpha_{\sigma(j)} = \min\{w_{\sigma(j)}\rho_{\sigma(j-1)}, \#(q_\sigma(j))\} \quad \text{and} \quad \rho_{\sigma(j)} = \rho_{\sigma(j-1)} - \alpha_{\sigma(j)}$$

with

$$\rho_{\sigma(0)} \equiv \#(\mathcal{O}') \ .$$

Now the semi-proportional allocation allocates $\tilde{\tau}(\mathcal{O}, q) = \alpha'_j + \alpha_j$ to order $q = q_j \in \mathcal{O}$, setting $\tilde{\tau}(\mathcal{O}, q) = 0$ whenever $q \notin \mathcal{O}$. Take the average of $\tilde{\tau}(\mathcal{O}, q)$ for the cases where $q \in \mathcal{O}$ to arrive at the rate $T(q)$ to be applied to an order of size q: $T(q) = \mathbb{E}(\tilde{\tau}(\mathcal{O}, q)|q \in \mathcal{O})$.

A.2 Simulation details

In the simulations sizes of Poisson order arrivals are generated from gamma distributions with outcomes rounded up to an integer. The common first-fit decreasing heuristic, see Johnson (1974), is used to solve the resulting bin-packing problem of fitting the orders of an order pool into trucks.

Allocation simulations In the allocation simulations truck capacity, Q, is equal to 20. The simulation engine simulates 150,000 inter-dispatch intervals. Note, though, that the rate for size q, $T(q)$, is computed from $\mathbb{E}(.|q \in \mathcal{O})$ and the number of pool instances where $q \in \mathcal{O}$ is less than 150,000. In particular, the occurrence of large order-sizes for a low arrival rate and when working with the small-order-size distribution $\Gamma(2, 1.2)$ is so rare that graphs of the rate for these order sizes is not smooth, see Figure 4.5 on the left.

Discrete event simulation is used to derive transport tariffs. Orders are assumed to arrive according to a compound Poisson process with rate λ and Gamma distributed order-size. The simulation is performed using two order-size distributions: a distribution with predominantly small orders ($\Gamma(2, 1.2)$, average order-size 2.4) and one with slightly greater orders ($\Gamma(2, 5)$, average order-size 10). Both distributions seem realistic to model LTL-transport for a truck of capacity $Q_F = 20$.

Transport performance and average utilization rate depend strongly on the order-arrival process. The utilization rate determines the overall efficiency of transport and with that, the carrier's costs. A plot of the expected average utilization rate for the carrier as a function of the order arrival rate is given in Figure A.1, for

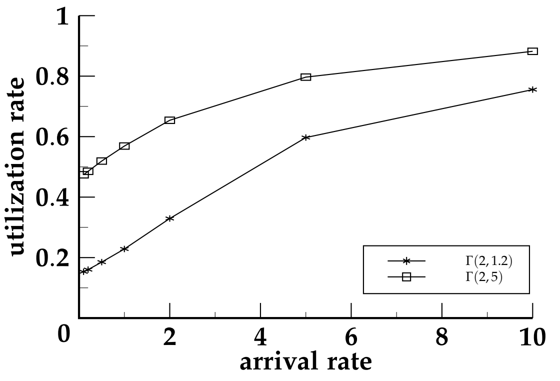


Figure A.1: Average Utilization Rate as function of order-arrival rate. Results are from simulation experiments.

both the small and medium sized order distributions. It shows that the specified order-arrival patterns cover a range of utilization rates from almost 0.1 to 0.9. The plots show that, as expected, the average utilization rate increases in the order arrival rate. This is due to economies of scale: as more orders arrive, there are more consolidation opportunities for the carrier.

Profit maximization For each order size n trial rates are considered making for n^F different tariffs. With $1,500,000$ order pools generated per tariff, the computation time grows quickly with increasing n and F, making the search for the best tariff burdensome. Therefore, the simulations were carried out with $n = 5$ and $Q = 6$. With this choice the number of replications is still $5^6 \times 1,500,000 > 22.5$ billion.

List of Tables

List of Figures

Bibliography

Abdul-Jalbar, B., Gutiérrez, J. M., Sicilia, J. (2008). *Policies for a single-vendor multi-buyer system with finite production rate*. Decision Support Systems, 46(1):84–100.

Achabal, Dale D., McIntyre, Shelby H., Smith, Stephen A., Kalyanam, Kirthi (2000). *A decision support system for vendor managed inventory*. Journal of Retailing, 76(4):430–454.

Aichlymayr, Mary (2000). *Dc mart: Who manages inventory in a value chain?*. Transportation & Distribution, 41(10):60.

Anand, Krishnan S., Mendelson, Haim (1997). *Information and organization for horizontal multimarket coordination*. Management Science, 43(12):1609–1627.

Andel, Tom (1996). *Forge a new role in the supply chain*. Transportation & Distribution, 37(2):107.

Apte, U.M., Viswanathan, S. (2002). *Strategic and technological innovations in supply chain management*. International Journal of Manufacturing Technology and Management, 4(3-4):264–282.

Arcelus, F. J., Rowcroft, J. E. (1991). *Small order transportation costs in inventory control*. Logistics and Transportation Review, 27(1):3.

Axsäter, S. (2001). *A note on stock replenishment and shipment scheduling for vendor-managed inventory systems*. Management Science, 47(9):1306–1310.

Bagchi, Prabir K., Ha, Byoung Chun, Skjoett-Larsen, Tage, Soerensen, Lars Boege (2005). *Supply chain integration: A european survey*. The International Journal of Logistics Management, 16:275–294.

Barratt, Mark, Oliveira, Alexander (2001). *Exploring the experiences of collaborative planning initiatives*. International Journal of Physical Distribution & Logistics Management, 31(4):266.

Bensaou, M. (1999). *Portfolios of buyer-supplier relationships*. Sloan management review, 40(4):35–+.

Bernstein, F., Chen, F. R., Federgruen, A. (2006). *Coordinating supply chains with simple pricing schemes: The role of vendor-managed inventories*. Management Science, 52(10):1483–1492.

Bertazzi, L., Paletta, G., Speranza, M.G. (2005). *Minimizing the total cost in an integrated vendor-managed inventory system*. Journal of Heuristics, 11(5-6 SPEC. ISS.):393–419.

Bertazzi, L., Speranza, M. G. (2005). *Worst-case analysis of the full load policy in the single link problem*. International Journal of Production Economics, 93-94:217–224.

Bertrand, J. W. M., Fransoo, J. C. (2002). *Operations management research methodologies using quantitative modeling*. International Journal of Operations & Production Management, 22(2):241–264.

Bichescu, B. C., Fry, M. J. (2009a). *A numerical analysis of supply chain performance under split decision rights*. Omega-International Journal of Management Science, 37(2):358–379.

——— (2009b). *Vendor-managed inventory and the effect of channel power*. Or Spectrum, 31(1):195–228.

Billera, Louis J., Heath, David C. (1982). *Allocation of shared costs: A set of axioms yielding a unique procedure.*. Mathematics of Operations Research, 7(1):32–39.

Bjork, KM (2006). *Distributor-managed inventory: a way to manage the bullwhip effect*. International Journal of Integrated Supply Management, 2(4):338–355.

Blumenfeld, Dennis E., Burns, Lawrence D., Diltz, J. David, Daganzo, Carlos F. (1985). *Analyzing trade-offs between transportation, inventory and production costs on freight networks*. Transportation Research Part B: Methodological, 19(5):361–380.

Bookbinder, J. H., Higginson, J. K. (2002). *Probabilistic modeling of freight consolidation by private carriage*. Transportation Research Part E-Logistics and Transportation Review, 38(5):305–318.

Buchmann, J. (2000). *Introduction to Cryptography*. Springer, 2nd edition.

Cachon, G. (2001a). *Managing a retailer's shelf space, inventory, and transportation*. Manufacturing and Service Operations Management, 3(3):211–229.

——— (2003). *Supply chain coordination with contracts*. In de Kok, T.G., Graves, S.C. (editors), *Supply Chain Management: Design, Coordination and Operation*, volume 11 of *Handbooks in OR & MS*. Elsevier, Amsterdam.

Cachon, G., Fisher, M. (1997). *Campbell soup's continuous replenishment program: Evaluation and enhanced inventory decision rules*. Production and Operations Management, 6(3):266–276.

Cachon, G. P. (1999). *Managing supply chain demand variability with scheduled ordering policies*. Management Science, 45(6):843–856.

——— (2001b). *Stock wars: Inventory competition in a two-echelon supply chain with multiple retailers*. Operations Research, 49(5):658–674.

——— (2004). *The allocation of inventory risk in a supply chain: Push, pull, and advance-purchase discount contracts*. Management Science, 50(2):222–238.

Cachon, G. P., Fisher, M. (2000). *Supply chain inventory management and the value of shared information*. Management Science, 46(8):1032–1048.

Cachon, G. P., Lariviere, M. A. (2001). *Contracting to assure supply: How to share demand forecasts in a supply chain*. Management Science, 47(5):629–646.

——— (2005). *Supply chain coordination with revenue-sharing contracts: Strengths and limitations*. Management Science, 51(1):30–44.

Cachon, G. P., Randall, T., Schmidt, G. M. (2007). *In search of the bullwhip effect*. M&Som-Manufacturing and Service Operations Management, 9:457–479.

Cachon, G. P., Zipkin, P. H. (1999). *Competitive and cooperative inventory policies in a two-stage supply chain*. Management Science, 45(7):936–953.

Çetinkaya, S., Bookbinder, J. H. (2003). *Stochastic models for the dispatch of consolidated shipments*. Transportation Research Part B-Methodological, 37(8):747–768.

Çetinkaya, S., Lee, C. Y. (2000). *Stock replenishment and shipment scheduling for vendor-managed inventory systems*. Management Science, 46(2):217–232.

Çetinkaya, S., Mutlu, F., Lee, C.-Y. (2006). *A comparison of outbound dispatch policies for integrated inventory and transportation decisions*. European Journal of Operational Research, 171(3):1094–1112.

Challener, C. (2000). *Taking the vmi step to collaborative commerce*. Chemical Market Review, pages 11–12.

Chen, F. (2003). *Information sharing and supply chain coordination*. In de Kok, T.G., Graves, S.C. (editors), *Supply Chain Management: Design, Coordination and Operation*, volume 11 of *Handbooks in OR & MS*, pages 341–421. Elsevier, Amsterdam.

Chen, F. R., Federgruen, A., Zheng, Y. S. (2001). *Coordination mechanisms for a distribution system with one supplier and multiple retailers*. Management Science, 47(5):693–708.

Chen, F. R., Samroengraja, R. (2004). *Order volatility and supply chain costs*. Operations Research, 52(5):707–722.

Cheung, K. L., Lee, H. L. (2002). *The inventory benefit of shipment coordination and stock rebalancing in a supply chain*. Management Science, 48(2):300–306.

Cheung, W., Wong, Y.M., Leung, L.C. (2001). *Strategic service network design for dhl hong kong*. Interfaces, 31(4):1–14.

Claassen, M. J. T., van Weele, A. F., van Raaij, E. M. (2008). *Performance outcomes and success factors of vendor managed inventory (vmi)*. Supply Chain Management-an International Journal, 13(6):406–414.

Clark, Andrew J., Scarf, Herbert (1960). *Optimal policies for a multi-echelon inventory problem*. Management Science, 6(4):475–490.

Clark, T.H., Hammond, J.H. (1997). *Reengineering channel reordering processes to improve total supply-chain performance*. Production and Operations Management, 6(3):248–265.

Coase, R. H. (1937). *The nature of the firm*. Economica, 4(16):386–405.

Cohen, M.A., Ho, T.H., Justin Ren, Z., Terwiesch, C. (2003). *Measuring imputed cost in the semiconductor equipment supply chain*. Management Science, 49(12):1653–1670.

Collins, Richard (1997). *Ecr - breaking china in the us supermarket industry*. Supply Chain Management, 2:92–98.

Cooke, James Aaron (1998). *Vmi: Very mixed impact?*. Logistics Management and Distribution Report, 37(12):51.

Cooper, M.C., Lambert, Douglas M, Pagh, Janus D (1997). *Supply chain management: More than a new name for logistics*. International Journal of Logistics Management, 8(1):1–14.

Corbett, C. J., Blackburn, J. D., van Wassenhove, L. N. (1999). *Case study - partnerships to improve supply chains*. Sloan Management Review, 40(4):71–+.

Corbett, C. J., de Groote, X. (2000). *A supplier's optimal quantity discount policy under asymmetric information*. Management Science, 46(3):444–450.

Corbett, C. J., Zhou, D. M., Tang, C. S. (2004). *Designing supply contracts: Contract type and information asymmetry*. Management Science, 50(4):550–559.

Cottrill, K. (1997). *Reforging the supply chain*. Journal of Business Strategy, 18(6):35–39.

Cox, A. (2001). *Understanding buyer and supplier power: A framework for procurement and supply competence*. Journal of Supply Chain Management, 37(2):8–15.

Curtis, G., Drew (2000). *What it takes to implement and maintain successful supplier-managed inventory programs*. Hospital Materiel Management Quarterly, 21(4):25.

Daugherty, Patricia J, Myers, Matthew B., Autry, Chad W (1999). *Automatic replenishment programs: An empirical examination*. Journal of Business Logistics, 20(2):63.

de Kok, A. G., van Donselaar, K. H., van Woensel, T. (2008). *A break-even analysis of rfid technology for inventory sensitive to shrinkage*. International Journal of Production Economics, 112(2):521–531.

de Kok, Ton, Janssen, Fred, van Doremalen, Jan, van Wachem, Erik, Clerkx, Mathieu, Peeters, Winfried (2005). *Philips electronics synchronizes its supply chain to end the bullwhip effect*. Interfaces, 35(1):37–48.

de Leeuw, Sander, Fransoo, Jan (2009). *Drivers of close supply chain collaboration: One size fits all?*. International Journal of Operations & Production Management, 29:720–739.

Disney, S. M., Potter, A. T., Gardner, B. M. (2003). *The impact of vendor managed inventory on transport operations*. Transportation Research Part E-Logistics and Transportation Review, 39(5):363–380.

Disney, S. M., Towill, D. R. (2003a). *The effect of vendor managed inventory (vmi) dynamics on the bullwhip effect in supply chains*. International Journal of Production Economics, 85(2):199–215.

——— (2003b). *Vendor-managed inventory and bullwhip reduction in a two-level supply chain*. International Journal of Operations & Production Management, 23(5-6):625–651.

Dong, Y., Xu, K. F. (2002). *A supply chain model of vendor managed inventory*. Transportation Research Part E-Logistics and Transportation Review, 38(2):75–95.

Dong, Y., Xu, K. F., Dresner, M. (2007). *Environmental determinants of vmi adoption: An exploratory analysis*. Transportation Research Part E-Logistics and Transportation Review, 43(4):355–369.

ECR Europe (1996). *European value chain analysis study, final report*. Technical report, Efficient Consumer Response Europe.

Eppen, G.D., Schrage, L. (1981). *Centralized ordering policies in a multi-warehouse system with lead times and random demand*. In Schwarz, L.B. (editor), *Multi-level Production/Inventory Systems: Theory and Practice*, pages 51–67. North-Holland Publishing Co., Netherlands.

Erlenkotter, Donald (1989). *An early classic misplaced: Ford w. harris's economic order quantity model of 1915*. Management Science, 35(7):898–900.

Federgruen, Awi, Zipkin, Paul (1984a). *Combined vehicle routing and inventory allocation problem*. Operations Research, 32(5):1019–1037.

——— (1984b). *Computational issues in an infinite-horizon, multiechelon inventory model*. Operations research, 32(4):818–836.

Fiocca, Renato (1982). *Account portfolio analysis for strategy development*. Industrial Marketing Management, 11(1):53–62.

Fleischmann, Bernhard (1993). *Designing distribution systems with transport economies of scale*. European Journal of Operational Research, 70(1):31–42.

Forrester, Jay W. (1958). *Industrial dynamics*. Harvard Business Review, 36(4):37–66.

Fry, M.J., Kapuscinski, R., Olsen, T.L. (2001). *Coordinating production and delivery under a (z, z)-type vendor-managed inventory contract*. Manufacturing and Service Operations Management, 3(2):151–173.

Gadde, L., Snehota, I. (2000). *Making the most of supplier relationships*. Industrial marketing Management, 29(4):305–316.

Garicano, Luis, Kaplan, Steven N. (2001). *The effects of business-to-business e-commerce on transaction costs*. Journal of Industrial Economics, 49(4):463.

Gaukler, Gary M., Seifert, Ralf W., Hausman, Warren H. (2007). *Item-level rfid in the retail supply chain*. Production and Operations Management, 16(1):65–76.

Gavirneni, S., Kapuscinski, R., Tayur, S. (1999). *Value of information in capacitated supply chains*. Management Science, 45(1):16–24.

Geary, S., Disney, S.M., Towill, D.R. (2006). *On bullwhip in supply chains–historical review, present practice and expected future impact*. International Journal of Production Economics, 101(1):2–18.

Goffin, K., Lemke, F., Szwejczewski, M. (2006). *An exploratory study of 'close' supplier-manufacturer relationships*. Journal of Operations Management, 24(2):189–209.

Goyal, S.K. (1976). *An integrated inventory model for a single-supplier single-customer problem*. International Journal of Production Research, 15(0):107–11.

Hall, Randolph W. (1987). *Consolidation strategy: Inventory, vehicles and terminals*. Journal of Business Logistics, 8(2):57.

Hall, Randolph W., Racer, Michael (1995). *Transportation with common carrier and private fleets: system assignment and shipment frequency optimization*. IIE Transactions (Institute of Industrial Engineers), 27(2):217–225.

Harrington, L. (1996). *Consignment selling: trend or another wild idea?*. Transportation & Distribution, .(.):45–48.

Harris, Ford W. (1913). *How many parts to make at once*. Factory, The Magazine of Management, 10(2):135–136,152.

——— (1990). *How many parts to make at once*. Operations research, 38(6):947–950.

Hätönen, Jussi, Eriksson, Taina (2009). *30+years of research and practice of outsourcing - exploring the past and anticipating the future*. Journal of International Management, 15(2):142–155.

Higginson, James K, Bookbinder, James H (1994). *Policy recommendations for a shipment-consolidation program*. Journal of Business Logistics, 15(1):87.

Hobma, L. (2001). *Vmi in the chemical industry*. Dutch Society of Logistic Management (in Dutch with English summary), page 63.

Holcomb, Tim R., Hitt, Michael A. (2007). *Toward a model of strategic outsourcing*. Journal of Operations Management, 25(2):464–481.

Holweg, Matthias, Disney, Stephen, Hölmstrom, Jan, Smäros, Johanna (2005). *Supply chain collaboration: Making sense of the strategy continuum*. European Management Journal, 23(2):170–181.

Huang, B., Ye, Z. (2010). *The effects of lumpy demand and shipment size constraint: A response to "revisit the note on supply chain integration in vendor-managed inventory"*. Decision Support Systems, 48(2):421–425.

Hung, J. S., Fun, Y. P., Li, C.-C. (1995). *Inventory management in the consignment system*. Production and Inventory Management Journal, 36(4):1–6.

Jackson, G.C. (1981). *Evaluating order consolidation strategies using simulation*. Journal of Business Logistics, 2(2):110–138.

Jin, Yue, Muriel, Ana (2009). *Single-warehouse multi-retailer inventory systems with full truckload shipments*. Naval Research Logistics, 56(5):450–464.

Johnson, David S. (1974). *Approximation algorithms for combinatorial problems.*. Journal of Computer and System Sciences, 9(3):256–278.

Kaipia, R., Holmstrom, J., Tanskanen, K. (2002). *Vmi: What are you losing if you let your customer place orders?*. Production Planning & Control, 13(1):17–25.

Ketokivi, M.A., Schroeder, R.G. (2004). *Perceptual measures of performance: Fact or fiction?*. Journal of Operations Management, 22(3):247–264.

Kraljic, P. (1983). *Purchasing must become supply management*. Harvard Business Review, ?(Sep-Oct):109–117.

Kuik, R., Verheijen, B. (2010). *Modeling transportation tariffs on a single shipping lane*. submitted to International Journal of Production Economics.

Kuk, G. (2004). *Effectiveness of vendor-managed inventory in the electronics industry: determinants and outcomes*. Information & Management, 41(5):645–654.

Kulp, S. C. (2002). *The effect of information precision and information reliability on manufacturer-retailer relationships*. Accounting Review, 77(3):653–677.

Kulp, S. C., Lee, H.L., Ofek, E. (2004). *Manufacturer benefits from information integration with retail customers*. Management Science, 50(4):431–444.

Lamb, M. R. (1997). *Vendor managed inventory: customers like the possibilities*. Metal Center News, 37(2):42–49.

Lambert, Douglas M, Cooper, Martha C (2000). *Issues in supply chain management*. Industrial Marketing Management, 29(1):65–83.

Lambert, Douglas M, Cooper, Martha C, Pagh, Janus D (1998). *Supply chain management: Implementation issues and research opportunities*. International Journal of Logistics Management, 9(2):1.

Lambert, Douglas M, Emmelhainz, Margaret A, Gardner, John T (1999). *Building successful logistics partnerships*. Journal of Business Logistics, 20(1):165.

Langley Jr., C. John (1980). *The inclusion of transportation costs in inventory models: Some considerations.*. Journal of Business Logistics, 2(1):106.

LARIVIERE, MARTIN A., PORTEUS, EVAN L. (2001). *Selling to the Newsvendor: An Analysis of Price-Only Contracts*. Manufacturing Service Operations Management, 3(4):293–305.

LE BLANC, H. M., CRUIJSSEN, F., FLEUREN, H. A., DE KOSTER, M. B. M. (2006). *Factory gate pricing: An analysis of the dutch retail distribution*. European Journal of Operational Research, 174(3):1950–1967.

LEE, H., ÖZER, O. (2007). *Unlocking the value of rfid*. Production and Operations Management, 16(1):40–64.

LEE, H. L. (2004). *The triple-a supply chain*. Harvard Business Review, 82(10):102–+.

LEE, H. L., PADMANABHAN, V., WHANG, S. J. (1997). *Information distortion in a supply chain: The bullwhip effect*. Management Science, 43(4):546–558.

LEE, HAU L., ROSENBLATT, MEIR J. (1986). *A generalized quantity discount pricing model to increase supplier's profits*. Management Science, 32(9):1177–1185.

LEE, HAU L, SO, KUT C, TANG, CHRISTOPHER S (2000). *The value of information sharing in a two-level supply chain*. Management Science, 46(5):626.

LENG, M. M., ZHU, A. (2009). *Side-payment contracts in two-person nonzero-sum supply chain games: Review, discussion and applications*. European Journal of Operational Research, 196(2):600–618.

LERNER, A. P. (1934). *The concept of monopoly and the measurement of monopoly power*. The Review of Economic Studies, 1(3):157–175.

LI, CHUNG-LUN, HSU, VERNON NING, XIAO, WEN-QIANG (2004). *Dynamic lot sizing with batch ordering and truckload discounts*. Operations research, 52(4):639–654.

LI, SUHONG, RAO, S. SUBBA, RAGU-NATHAN, T. S., RAGU-NATHAN, BHANU (2005). *Development and validation of a measurement instrument for studying supply chain management practices*. Journal of Operations Management, 23(6):618–641.

LI, XIUHUI, WANG, QINAN (2007). *Coordination mechanisms of supply chain systems*. European Journal of Operational Research, 179(1):1–16.

Lummus, R. R., Vokurka, R. J. (1999). *Defining supply chain management: a historical perspective and practical guidelines*. Industrial Management & Data Systems, 99(1-2):11–17.

McAfee, Andrew, Brynjolfsson, Erik (2008). *Investing in the it, that makes a competitive difference*. Harvard Business Review, 86(7/8):98–107.

Mentzer, J.T. S. Min, Zacharia., Z.G. (2000). *The nature of interfirm partnering in supply chain management*. Journal of Retailing, 76(4):549–568.

Meredith, Jack (1989). *Building operations management theory through case and field research*. Journal of Operations Management, 16:441–454.

Monahan, J.P. (1984). *A quantity discount pricing model to increase vendor profits*. Management Science, 30(6):720–726.

Narayanan, V.G., Raman, A. (2004). *Aligning incentives in supply chains*. Harvard Business Review, 82(11):94–102.

Nolan, Kevin (1997). *For marmon/keystone, vmi offers real procurement solutions*. Metal Center News, 37(2):50.

Oh, Joongsan, Rhee, Seung-Kyu (2008). *The influence of supplier capabilities and technology uncertainty on manufacturer-supplier collaboration*. International Journal of Operations & Production Management, 28(6):490.

Olsen, R. F., Ellram, L. M. (1997a). *A portfolio approach to supplier relationships*. Industrial Marketing Management, 26(2):101–113.

Olsen, R.F., Ellram, L.M. (1997b). *Buyer-supplier relationships: alternative research approaches*. European Journal of Purchasing & Supply Management, 3(4):221–231.

Özener, Okan Örsan, Ergun, Özlem, Savelsbergh, Martin (2010). *Allocating cost of service to customers in inventory routing*. submitted to Operations Research. URL `http://www2.isye.gatech.edu/people/faculty/Martin_Savelsbergh/publications/irp-costallocation.pdf`.

Pasternack, Barry Alan (1985). *Optimal pricing and return policies for perishable commodities*. Marketing Science, 4(2):166–176.

Peck, Helen, Juttner, Uta (2000). *Strategy and relationships: Defining the interface in supply chain contexts*. International Journal of Logistics Management, 11(2):33.

Peels, R., Udenio, M., Fransoo, J.C., Wolfs, M., Hendrikx, T. (2009). *Responding to the lehman wave: Sales forecasting and supply management during the credit crisis*. BETA Working Paper Series, (297).

Peters, H.J.M. (editor) (1992). *Axiomatic bargaining theory*, volume 9 of *Theory and decision library. Series C, Game Theory, Mathematical Programming and Operations Research*. Kluwer Academic Publishers, Dordrecht.

Piplani, R., Viswanathan, S. (2003). *A model for evaluating supplier-owned inventory strategy*. International Journal of Production Economics, 81-82:565–571.

Pohlen, L., Terrance, Goldsby, J., Thomas (2003). *Vmi and smi programs: How economic value added can help sell the change*. International Journal of Physical Distribution & Logistics Management, 33(7):565.

Prahalad, C. K., Hamel, Gary (1990). *The core competence of the corporation*. Harvard Business Review, 68(3):79.

Raghunathan, S., Yeh, A.B. (2001). *Beyond edi: Impact of continuous replenishment program (crp) between a manufacturer and its retailers*. Information Systems Research, 12(4):406–419.

Rai, A., Patnayakuni, R., Seth, N. (2006). *Firm performance impacts of digitally enabled supply chain integration capabilities*. Mis Quarterly, 30(2):225–246.

Ray, Keli, Swanson, Curt (1996). *Supplier-managed inventory: Schedule sharing*. Hospital Materiel Management Quarterly, 17(4):48.

Reve, T. (1990). *The firm as a nexus of internal and external contracts*. In Aoki, Masahiko, Gustafsson, Bo, Williamson, Oliver E (editors), *The firm as a nexus of treaties*. Sage, London.

Röller, Lars-Hendrik, Waverman, Leonard (2001). *Telecommunications infrastructure and economic development: A simultaneous approach*. The American Economic Review, 91(4):909–923.

Rosling, K. (1989). *Optimal inventory policies for assembly systems under random demands*. Operations Research, 37(4):565–579.

Sabath, Robert E, Autry, Chad W, Daugherty, Patricia J (2001). *Automatic replenishment programs: The impact of organizational structure*. Journal of Business Logistics, 22(1):91.

Sheffi, Yosef (1990). *Third party logistics: Present and future prospects*. Journal of Business Logistics, 11(2):27.

Silver, E.A., Pyke, D.F., Peterson, R. (1998). *Inventory Management and Production Planning and Scheduling*. John Wiley & Sons, New York, third edition.

Smith, D.L., Campbell, J.F., Mundy, R. (2007). *Modeling net rates for expedited freight services*. Transportation Research Part E, 43:192–207.

Sodhi, ManMohan S., Son, Byung-Gak (2009). *Supply-chain partnership performance*. Transportation Research Part E: Logistics and Transportation Review, 45(6):937–945.

Speranza, M. G., Ukovich, W. (1994). *Minimizing transportation and inventory costs for several products on a single link*. Operations Research, 42(5):879–894.

Stackelberg (1952). *The theory of the market economy*.

Stank, P., Theodore, Daugherty, Patricia J, Ellinger, E., Alexander (1999). *Marketing/logistics integration and firm performance*. International Journal of Logistics Management, 10(1):11. 09574093.

Stank, Theodore P, Daugherty, Patricia J (1997). *The impact of operating environment on the formation of cooperative logistics relationships*. Transportation Research. Part E, Logistics & Transportation Review, 33:53.

Swatman, Paula M. C., Swatman, Paul A., Fowler, Danielle C. (1994). *A model of edi integration and strategic business reengineering*. The Journal of Strategic Information Systems, 3(1):41–60.

Swenseth, S. R., Godfrey, M. R. (2002). *Incorporating transportation costs into inventory replenishment decisions*. International Journal of Production Economics, 77(2):113–130.

Swenseth, Scott R, Godfrey, Michael R (1996). *Estimating freight rates for logistics decisions*. Journal of Business Logistics, 17(1):213.

TAYLOR, T. A. (2006). *Sale timing in a supply chain: When to sell to the retailer*. Manufacturing and Service Operations Management, 8(1):23–42.

TERSINE, RICHARD J., BARMAN, SAMIR (1991). *Economic inventory/transport lot sizing with quantity and freight rate discounts*. Decision Sciences, 22(5):1171.

THOMAS, D. J., GRIFFIN, P. M. (1996). *Coordinated supply chain management*. European Journal of Operational Research, 94(1):1–15.

TOPTAL, A., CETINKAYA, S. (2008). *Quantifying the value of buyerâĂŞvendor coordination: Analytical and numerical results under different replenishment cost structures*. European Journal of Operational Research, 187(3):785–805.

TSAY, A.A., NAHMIAS, S., AGRAWAL, NARENDRA (1999). *Modeling supply chain contracts: A review*. In TAYUR, S., GANESHAN, R., MAGAZINE, M. (editors), *Quantitative Models for Supply chain Management*, pages 299–336. Kluwer Academic Publishers, MA.

TSAY, ANDY A, AGRAWAL, NARENDRA (2000). *Channel dynamics under price and service competition*. Manufacturing and Service Operations Management, 2(4):372.

TYAN, J., WEE, H. M. (2003). *Vendor managed inventory: A survey of the taiwanese grocery industry*. Journal of Purchasing and Supply Management, 9(1):11–18.

TYWORTH, J. E., ZENG, A. Z. (1998). *Estimating the effects of carrier transit-time performance on logistics cost and service*. Transportation Research Part a-Policy and Practice, 32(2):89–97.

VAN DER VAART, TACO, VAN DONK, DIRK PIETER (2008). *A critical review of survey-based research in supply chain integration*. International Journal of Production Economics, 111(1):42–55.

VAN DER VLIST, P., BROEKMEULEN, R. (2006). *Retail consolidation in synchronized supply chains*. Zeitshrift für Betriebswirtschaft, 76:165–176.

VAN DER VLIST, P., KUIK, R., VERHEIJEN, B. (2007). *Note on supply chain integration in vendor-managed inventory*. Decision Support Systems, 44(1):360–365.

VAN NORDEN, L., VAN DE VELDE, S. V. (2005). *Multi-product lot-sizing with a transportation capacity reservation contract - production, manufacturing and logistics*. European Journal of Operational Research, 165(1):127–138.

Vergin, Roger C, Barr, Kevin (1999). *Building competitiveness in grocery supply through continuous replenishment planning: Insights from the field*. Industrial Marketing Management, 28(2):145.

Verheijen, H. J. J., Prins, M. W. J. (1999a). *Contact angles and wetting velocity measured electrically*. Review of Scientific Instruments, 70(9):3668–3673.

——— (1999b). *Reversible electrowetting and trapping of charge: Model and experiments*. Langmuir, 15(20):6616–6620.

Waller, M., Johnson, M.E., Davis, T. (1999). *Vendor managed inventory in the retail supply chain*. Journal of Business Logistics, 20(1):183–203.

Wang, W. T, Wee, H. M, Tsao, H. S J. (2010). *Revisiting the note on supply chain integration in vendor-managed inventory*. Decision Support Systems, 48(2):419–420.

Wang, Yunzeng, Gerchak, Yigal (2003). *Capacity games in assembly systems with uncertain demand*. Manufacturing Service Operations Management, 5(3):252–267.

Whang, Seungjin (1995). *Coordination in operations: A taxonomy*. Journal of Operations Management, 12(3-4):413–422.

Williamson, O. (2008). *Outsourcing: Transaction cost economics and supply chain management**. Journal of Supply Chain Management, 44(2):5.

Williamson, Oliver E. (1979). *Transaction-cost economics: The governance of contractual relations*. The Journal of law & economics, 22(2):233–262.

Yao, Y., Evers, P. T., Dresner, M. E. (2007a). *Response to "note on supply chain integration in vendor managed inventory"*. Decision Support Systems, 44(1):366–367.

Yao, Y., Evers, P.T., Dresner, M.E. (2007b). *Supply chain integration in vendor-managed inventory*. Decision Support Systems, 43(2):663–674.

Samenvatting (Summary in Dutch)

Bedrijven in een supply chain kunnen de efficiëntie van de verrichtingen van de supply chain verbeteren en de kosten verlagen door het coördineren van beslissingen met partners in de supply chain. Hiervoor kunnen verschillende samenwerkingsvormen tussen bedrijven gebruikt worden. In dit proefschrift onderzoeken we de coördinatie van supply chain beslissingen door samenwerkingsvormen. We focussen op de koper-verkoper dyade. Het doel van het onderzoek in dit proefschrift is het leveren van een bijdrage aan het onderzoek naar de condities voor en de consequenties van geavanceerde samenwerkingsvormen tussen bedrijven, zowel vanuit de praktijk als vanuit de theorie.

We beginnen in Hoofdstuk 2 met een inventarisatie en categorisatie van samenwerkingsvormen zoals deze in de praktijk bestaan, door middel van een literatuurstudie van surveys, case-studies en interviews. Hieruit volgt een overzicht van de condities voor geavanceerde vormen van samenwerking en voordelen van deze samenwerkingsvormen. De twee belangrijkste samenwerkingsvormen in dit proefschrift, waarmee bedrijven in supply chains werken, zijn de conventionele situatie en Vendor Managed Inventories (VMI). In de conventionele situatie verloopt de communicatie tussen de koper en de verkoper via bestellingen van de koper. De verkoper levert vervolgens het gevraagde binnen de afgesproken voorwaarden. Bij VMI wordt de voorraad van de koper door de verkoper bestuurd, inclusief de bepaling van de tijd en de hoeveelheid van de belevering van artikelen aan de koper. De grotere mate van coördinatie van supply chain beslissingen die mogelijk is onder VMI kan leiden tot hogere efficiëntie in vergelijking met de coördinatie in de conventionele samenwerkingsvorm. Dit uit zich in lagere kosten voor transport, productie of voor het aanhouden van voorraden, bij minimaal gelijkblijvende service niveaus aan de klanten van de koper. Bedrijven onderscheiden ook in de praktijk strategische voordelen in geavanceerde samenwerkingsvormen. De strategische positie ten opzichte van andere bedrijven in de supply chain kan verbeteren, doordat er nauwer samengewerkt wordt. In geavanceerde vormen van samenwerking wordt informatie vaker en in meer detail uitgewisseld. Een consequentie hiervan is dat de verkoper veel meer gedetailleerde marktkennis krijgt, hetgeen een strategisch voordeel kan zijn. Als derde strategisch voordeel voor kopers geldt dat zij minder hulpmiddelen nodig hebben voor het management van de voorraden.

We onderscheiden op een operationeel vlak twee condities voor het aangaan van geavanceerde samenwerkingsvormen: de kwaliteit en de rijkdom van de informatie die uitgewisseld wordt.

Op een strategisch vlak onderscheiden we drie condities voor het aangaan van geavanceerde samenwerkingsvormen. Ten eerste de mogelijkheden van een bedrijf om een geavanceerde vorm van samenwerking aan te gaan. Dit hangt onder meer af van de grote van een bedrijf, de ervaring met samenwerkingsvormen en de status van de ICT systemen in een bedrijf. Ten tweede is een strategische match tussen de bedrijven nodig. Deze hangt af van vertrouwen tussen de bedrijven en de strategische positie van bedrijven en de verandering daarvan voor en na het aangaan van samenwerking. De derde strategische conditie is de product fit, die van markt en product karakteristieken zoals de volatiliteit van de vraag en de typische levenscyclus van het product. In de onderzoekswereld bestaat een gebrek aan consensus over de modellen en bepalende parameters waarmee onderzoek naar samenwerking tussen bedrijven onderzocht wordt. Als conclusie uit de onderzoeken in de literatuur stellen we een raamwerk voor waarmee samenwerking onderzocht kan worden.

In Hoofdstuk 3 analyseren we de condities voor en de voordelen van coördinatie van supply chain beslissingen door samenwerking, door bestudering van de analytische literatuur. Coördinatie van beslissingen door samenwerking via transacties op een markt is de meest losse samenwerkingsvorm. Het onderbrengen van transacties binnen de eigen organisatie is de meest nauwe vorm van samenwerking. Onder deze laatste vorm van aansturing, met een allesbepalende supply chain manager, kunnen beslissingen voor de supply chain dyade optimaal gecoördineerd worden. Onder VMI en afgeleide samenwerkingsvormen kunnen beslissingen beter afgestemd worden dan via een markt, maar niet noodzakelijk net zo goed als onder een centraal bestuurde supply chain. We beargumenteren dat een samenwerkingsvorm bestaat uit een akkoord over de te delen informatie en verdeling van de autoriteit om beslissingen te nemen.

We concluderen dat de operationele condities voor samenwerking die in de praktijk gevonden zijn analytisch onderbouwd kunnen worden. De kwaliteit en de rijkdom van informatie kwaliteit en de rijkdom van informatie bepalen in de modellen voor samenwerking de verbeteringen in efficiëntie door coördinatie. We identificeren als extra conditie voor het aangaan van geavanceerde samenwerkingsvormen dat het individueel economisch rationeel moet zijn voor elk bedrijf om te participeren in de samenwerking. Individuele economische rationaliteit kan op twee manieren gerealiseerd worden. Ten eerste, doordat de positie van een bedrijf zodanig is dat het economisch voordeliger is een verzoek van een dominant bedrijf om samenwerking aan te gaan op te volgen. De tweede manier waarop samenwerking economisch rationeel wordt voor een bedrijf is als de voordelen van samenwerking in de vorm van financiële compensatie gedeeld worden. In het geval van de tweede manier koopt een partij die de meeste voordelen kan realiseren bij toename van beslisautoriteit in feite deze autoriteit door het aanbieden van een financiële compensatie. In het geval van pure VMI neemt de verkoper de volledige verantwoordelijkheid voor de voorraden van de koper over, maar subtielere vormen van deling van beslisautoriteit en financiële compensatie bestaan. In Hoofdstuk 5 bestuderen we een vorm waarin de compensatie die verkoper de koper aanbiedt afhankelijk is van de hoeveelheid voorraad die de verkoper bij de koper mag neerleggen.

De operationele voordelen op het gebied van transport-, productie- en voorraadmanagement worden door de analytische modellen onderbouwd. Een belangrijk deel van de kostenvoordelen uit samenwerking volgt uit efficiëntievoordelen in transport. In de modellen waarin de efficiëntievoordelen op het gebied van transport door coördinatie van beslissingen geanalyseerd wordt, worden de kosten voor transport vaak gemodelleerd als vaste kosten per rit, onafhankelijk van het volume dat vervoerd wordt. Dit laatste kan, omdat transportkosten vaak relatief onafhankelijk zijn van hoe vol een vrachtwagen beladen is. Hierdoor leidt elke samenwerkingsvorm waarin de verkoper meer controle over de tijd en kwantiteit van afleveringen krijgt in potentie tot vollere vrachtwagens en dus direct tot kostenbesparingen van de verkoper. Het bepalen van de grootte van deze kostenvoordelen is complex, niet alleen vanwege het probleem van het toewijzen van transportkosten op een route met afleveringen voor meerdere klanten, maar ook omdat de verkoper het transport via een derde partij, een third-party logistics provider (3PL), zou kunnen organiseren. Deze 3PL kan lagere transporttarieven voor orders van grootte less-than-a-truckload (LTL) aanbieden, doordat zij verschillende orders van verschillende aanbieders combineren. Hierdoor wordt een deel van de kostenvoordelen uit efficiëntere belading van vrachtwagens dat mogelijk is vanwege coördinatie van beslissingen, door de 3PL gerealiseerd. Als transportkosten gemodelleerd worden als vaste tarieven in plaats van de lagere, volume afhankelijke, tarieven die de 3PL aanbiedt, dan worden de voordelen die door supply chain coördinatie bereikt kunnen worden, overschat. We onderzoeken in Hoofdstuk 4 daarom hoe volume afhankelijke transporttarieven waarmee het gebruik van bijvoorbeeld vrachtwagens gecoördineerd wordt, gemodelleerd kunnen worden.

Een aantal eigenschappen waaraan transporttarieven voldoet komt naar voren uit de literatuur: het tarief stijgt monotoon bij toenemend volume; de tarieven zijn zodanig dat de vervoerder de kosten gemiddeld volledig terugverdient; de transporttarieven zijn subadditief, dit betekent dat het nooit voordelig is om een bestelling in meerdere kleinere bestellingen te splitsen; en tot slot de kosten per volume eenheid dalen monotoon bij toenemend volume. We hebben drie vormen van kostenallocatie als basis voor transporttarieven geanalyseerd. Ten eerste wordt een marginale kostenallocatie bekeken, waarbij de marginale kosten van een order berekend worden. Ten tweede wordt kostenallocatie bestudeerd op basis van de Shapley, een gewogen marginale kostenberekening. In beide gevallen zijn de tarieven niet subadditief. De derde kosten allocatie wijst kosten zodanig toe dat deze proportioneel in verhouding zijn met het totale volume, waarbij de kosten van een volledige vrachtwagen als bovengrens gelden. In numerieke simulaties laten we zien dat deze semi-proportionele allocatie voldoet aan alle gestelde voorwaarden. De vorm van de tarieffunctie is sterk afhankelijk van de hoeveelheid orders die per tijdseenheid bij de vervoerder binnen komt. Als er veel orders binnenkomen kan de vervoerder de vrachtwagens efficiënt vullen en lopen de kosten lineair op in het volume. Als er weinig orders binnenkomen, dan is de kans om de vrachtwagen efficiënt te vullen klein en worden de tarieven onafhankelijk van het volume.

We hebben transporttarieven geanalyseerd voor een vervoerder die kosten toewijst alsof dit een interne afdeling van een bedrijf is, en voor een vervoerder die als onafhankelijke partij de winst probeert te maximaliseren. In dit geval vloeit slechts een deel van het kostenvoordeel dat de vervoerder realiseert terug naar de opdrachtgever. We laten door middel van numerieke voorbeelden zien dat dit deel afhankelijk is van de competitie in de markt, door de kans te modelleren dat een opdrachtgever met een vervoerder zaken doet, afhankelijk te maken van het tarief dat gevraagd wordt.

We concluderen dat de besparingen uit transportefficiëntie door coördinatie van supply chain beslissingen in samenwerkingsvormen het grootst is als de verkoper het vervoer in eigen hand regelt. In dit geval vloeien alle verbeteringen in de gemiddelde vervoersefficiëntie terug naar de verkoper. Als de verkoper het vervoer via een 3PL organiseert, zijn voordelen van samenwerken nog steeds mogelijk, maar minder groot.

In Hoofdstuk 5 bestuderen we hoe een eenvoudig financieel compensatieschema de beslissingen in een supply chain kan coördineren voor het geval van vervoer per vrachtwagen met beperkte capaciteit. In een VMI samenwerkingsvorm heeft de verkoper het volledige beheer van de voorraad van de koper. De verkoper zou in theorie veel meer voorraad bij de koper kunnen neerleggen dan hetgeen voor de koper optimaal is. Om toch enige zeggenschap te houden, bestuderen we hier een samenwerkingsvorm waarin de koper bepaalt hoeveel ruimte er is om voorraad neer te leggen. Omdat het voor de verkoper gunstig kan zijn om meer ruimte te hebben, zodat grotere hoeveelheden per keer geleverd kunnen worden, biedt de verkoper een financiële compensatie aan, afhankelijk van de hoeveelheid ruimte die beschikbaar is. We bestuderen de effecten op de coördinatie van supply chain beslissingen in deze vorm, in een model waarin de vervoerscapaciteit van een vrachtwagen gelimiteerd is.

We hebben een algoritme ontwikkeld waarmee de optimale supply chain beslissingen voor een gegeven maximum voorraad bij de koper bepaald kunnen worden. Hiermee hebben we de resultaten op de supply chain als functie van de maximum voorraad bij de koper bepaald. Verhoging van de maximale voorraad kan leiden tot kostenverlaging, vanwege hogere transportefficiëntie, en heeft dus waarde voor de verkoper. We beschouwen twee soorten verkopers: een altruïstische, die optimaliseert voor het resultaat van de verkoper-koper dyade en een opportunistische verkoper, die zijn eigen winst maximaliseert.

De altruïstische verkoper biedt de voordelen die gerealiseerd worden volledig als financiële compensatie aan de koper aan, ter motivatie om voldoende ruimte voor de voorraad beschikbaar te stellen. We concluderen dat hiermee de supply chain beslissingen gecoördineerd worden. Gemiddeld zijn de supply chain kosten minder dan 1.5% hoger dan de optimale supply chain kosten bij centrale aansturing. Het grootste deel van de besparingen (90 %) komt terecht bij de koper. In de praktijk is dit alleen een realistisch scenario als de koper machtig is ten opzichte van de verkoper.

De opportunistische verkoper, die het zich kan veroorloven een groter deel van de voordelen te houden, modelleren we door de verkoper slechts een deel van de gerealiseerde voordelen als compensatie aan de koper te laten geven. Omdat de verkoper weet wat de kosten van de koper zijn, heeft de verkoper dit deel geoptimaliseerd om zijn winst te maximaliseren. In dit geval zijn de supply chain kosten in ons numeriek voorbeeld gemiddeld 6% boven de optimale kosten bij centrale aansturing. In dit geval wordt het leeuwendeel van de voordelen door de verkoper gesoupeerd.

About the Author

Bas Verheijen was born in Cuijk, the Netherlands, on March 28, 1975. He obtained his pre-university education (Atheneum) at the Merlet College in Cuijk in 1993. Bas studied Applied Physics at the Eindhoven University of Technology, the Netherlands. During his studies, he spent four months in Sydney, Australia, to research optical fibers. He conducted research for his Master's project at Philips Research on the electro-wetting effect, obtaining his Master's degree in 1999. The results of this research appeared in two articles (Verheijen and Prins (1999a), and Verheijen and Prins (1999b)).

Bas then worked as an associate research fellow at the Gintic Institute of Manufacturing Technology in Singapore, in the laser research group. In 2000, he joined SSMC, a new semiconductor waferfab in Singapore, where he worked in process engineering and enjoyed his role as a linking pin for technology transfers from the mother-fab at Philips Semiconductors in Nijmegen to SSMC.

In February 2003, Bas became a PhD candidate at the Department of Decision and Information Sciences of the Rotterdam School of Management, Erasmus University. He co-organized the 8th International Workshop on Distribution Logistics in 2004. He has attended and presented his research at major international conferences and workshops, such as the International Society for Inventory Research in Budapest, Hungary the 3rd US-European Workshop on Logistics and Supply Chain Management in 2005 in Berkeley, California, and the International Workshop of Distribution Logistics (IWDL) in 2006 in Brescia, Italy. A paper that is based on Chapter 4 is currently under review at the International Journal for Production Economics.

Bas is currently working for NXP Semiconductors in Eindhoven, The Netherlands, managing international projects in supply chain management.

ERIM Ph.D. Series Research in Management

Erasmus Research Institute of Management (ERIM)

ERIM Electronic Series Portal: http://hdl.handle.net/1765/1

Agatz, N.A.H., **Demand Management in E-Fulfillment,**
Promotor: Prof.dr.ir. J.A.E.E. van Nunen,
EPS-2009-163-LIS, ISBN: 978-90-5892-200-7, http://hdl.handle.net/1765/15425

Althuizen, N.A.P., **Analogical Reasoning as a Decision Support Principle for Weakly Structured Marketing Problems,**
Promotor: Prof.dr.ir. B. Wierenga,
EPS-2006-095-MKT, ISBN: 90-5892-129-8, http://hdl.handle.net/1765/8190

Alvarez, H.L., **Distributed Collaborative Learning Communities Enabled by Information Communication Technology,**
Promotor: Prof.dr. K. Kumar,
EPS-2006-080-LIS, ISBN: 90-5892-112-3, http://hdl.handle.net/1765/7830

Appelman, J.H., **Governance of Global Interorganizational Tourism Networks: Changing Forms of Co-ordination between the Travel Agency and Aviation Sector,**
Promotors: Prof.dr. F.M. Go & Prof.dr. B. Nooteboom,
EPS-2004-036-MKT, ISBN: 90-5892-060-7, http://hdl.handle.net/1765/1199

Asperen, E. van, **Essays on Port, Container, and Bulk Chemical Logistics Optimization,**
Promotor: Prof.dr.ir. R. Dekker,
EPS-2009-181-LIS, ISBN: 978-90-5892-222-9, http://hdl.handle.net/1765/1

Assem, M.J. van den, **Deal or No Deal? Decision Making under Risk in a Large-Stake TV Game Show and Related Experiments,**
Promotor: Prof.dr. J. Spronk,
EPS-2008-138-F&A, ISBN: 978-90-5892-173-4, http://hdl.handle.net/1765/13566

Baquero, G, **On Hedge Fund Performance, Capital Flows and Investor Psychology,**
Promotor: Prof.dr. M.J.C.M. Verbeek,
EPS-2006-094-F&A, ISBN: 90-5892-131-X, http://hdl.handle.net/1765/8192

Berens, G., **Corporate Branding: The Development of Corporate Associations and their Influence on Stakeholder Reactions,**
Promotor: Prof.dr. C.B.M. van Riel,
EPS-2004-039-ORG, ISBN: 90-5892-065-8, http://hdl.handle.net/1765/1273

Berghe, D.A.F. van den, **Working Across Borders: Multinational Enterprises and the Internationalization of Employment,**
Promotors: Prof.dr. R.J.M. van Tulder & Prof.dr. E.J.J. Schenk,
EPS-2003-029-ORG, ISBN: 90-5892-05-34, http://hdl.handle.net/1765/1041

Berghman, L.A., **Strategic Innovation Capacity: A Mixed Method Study on Deliberate Strategic Learning Mechanisms,**
Promotor: Prof.dr. P. Mattyssens,
EPS-2006-087-MKT, ISBN: 90-5892-120-4, http://hdl.handle.net/1765/7991

Bezemer, P.J., **Diffusion of Corporate Governance Beliefs: Board Independence and the Emergence of a Shareholder Value Orientation in the Netherlands,**
Promotors: Prof.dr.ing. . F.A.J. van den Bosch & Prof.dr. H.W. Volberda,
EPS-2009-192-STR, ISBN: 978-90-5892-232-8, http://hdl.handle.net/1765/192

Bijman, W.J.J., **Essays on Agricultural Co-operatives: Governance Structure in Fruit and Vegetable Chains,**
Promotor: Prof.dr. G.W.J. Hendrikse,
EPS-2002-015-ORG, ISBN: 90-5892-024-0, http://hdl.handle.net/1765/867

Bispo, A., **Labour Market Segmentation: An investigation into the Dutch hospitality industry,**
Promotors: Prof.dr. G.H.M. Evers & Prof.dr. A.R. Thurik,
EPS-2007-108-ORG, ISBN: 90-5892-136-9, http://hdl.handle.net/1765/10283

Blindenbach-Driessen, F., **Innovation Management in Project-Based Firms,**
Promotor: Prof.dr. S.L. van de Velde,
EPS-2006-082-LIS, ISBN: 90-5892-110-7, http://hdl.handle.net/1765/7828

Boer, C.A., **Distributed Simulation in Industry,**
Promotors: Prof.dr. A. de Bruin & Prof.dr.ir. A. Verbraeck,
EPS-2005-065-LIS, ISBN: 90-5892-093-3, `http://hdl.handle.net/1765/6925`

Boer, N.I., **Knowledge Sharing within Organizations: A situated and Relational Perspective,**
Promotor: Prof.dr. K. Kumar,
EPS-2005-060-LIS, ISBN: 90-5892-086-0, `http://hdl.handle.net/1765/6770`

Boer-Sorbán, K., **Agent-Based Simulation of Financial Markets: A modular, Continuous-Time Approach,**
Promotor: Prof.dr. A. de Bruin,
EPS-2008-119-LIS, ISBN: 90-5892-155-0, `http://hdl.handle.net/1765/10870`

Boon, C.T., **HRM and Fit: Survival of the Fittest!?,**
Promotors: Prof.dr. J. Paauwe & Prof.dr. D.N. den Hartog,
EPS-2008-129-ORG, ISBN: 978-90-5892-162-8, `http://hdl.handle.net/1765/12606`

Braun, E., **City Marketing: Towards an Integrated Approach,**
Promotor: Prof.dr. L. van den Berg,
EPS-2008-142-MKT, ISBN: 978-90-5892-180-2, `http://hdl.handle.net/1765/13694`

Brito, M.P. de, **Managing Reverse Logistics or Reversing Logistics Management?,**
Promotors: Prof.dr.ir. R. Dekker & Prof.dr. M. B. M. de Koster,
EPS-2004-035-LIS, ISBN: 90-5892-058-5, `http://hdl.handle.net/1765/1132`

Brohm, R., **Polycentric Order in Organizations: A Dialogue between Michael Polanyi and IT-Consultants on Knowledge, Morality, and Organization,**
Promotors: Prof.dr. G. W. J. Hendrikse & Prof.dr. H. K. Letiche,
EPS-2005-063-ORG, ISBN: 90-5892-095-X, `http://hdl.handle.net/1765/6911`

Brumme, W.-H., **Manufacturing Capability Switching in the High-Tech Electronics Technology Life Cycle,**
Promotors: Prof.dr.ir. J.A.E.E. van Nunen & Prof.dr.ir. L.N. Van Wassenhove,
EPS-2008-126-LIS, ISBN: 978-90-5892-150-5, `http://hdl.handle.net/1765/12103`

Budiono, D.P., **The Analysis of Mutual Fund Performance: Evidence from U.S. Equity Mutual Funds,**
Promotor: Prof.dr.ir. M.J.C.M. Verbeek,
EPS-2010-185-F&A, ISBN: 978-90-5892-224-3, `http://hdl.handle.net/1765/1`

Burgers, J.H., **Managing Corporate Venturing: Multilevel Studies on Project Autonomy, Integration, Knowledge Relatedness, , and Phases in the New Business Development Process,**
Promotors: Prof.dr.ir. F.A.J. Van den Bosch & Prof.dr. H.W. Volberda,
EPS-2008-136-STR, ISBN: 978-90-5892-174-1, `http://hdl.handle.net/1765/13484`

Campbell, R.A.J., **Rethinking Risk in International Financial Markets,**
Promotor: Prof.dr. C.G. Koedijk,
EPS-2001-005-F&A, ISBN: 90-5892-008-9, http://hdl.handle.net/1765/306

Chen, C.-M., **Evaluation and Design of Supply Chain Operations Using DEA,**
Promotor: Prof.dr. J.A.E.E. van Nunen,
EPS-2009-172-LIS, ISBN: 978-90-5892-209-0, http://hdl.handle.net/1765/1

Chen, H., **Individual Mobile Communication Services and Tariffs,**
Promotor: Prof.dr. L.F.J.M. Pau,
EPS-2008-123-LIS, ISBN: 90-5892-158-1, http://hdl.handle.net/1765/11141

Chen, Y., **Labour Flexibility in China's Companies: An Empirical Study,**
Promotors: Prof.dr. A. Buitendam & Prof.dr. B. Krug,
EPS-2001-006-ORG, ISBN: 90-5892-012-7, http://hdl.handle.net/1765/307

Damen, F.J.A., **Taking the Lead: The Role of Affect in Leadership Effectiveness,**
Promotor: Prof.dr. D.L. van Knippenberg,
EPS-2007-107-ORG, , http://hdl.handle.net/1765/10282

Daniševská, P., **Empirical Studies on Financial Intermediation and Corporate Policies,**
Promotor: Prof.dr. C.G. Koedijk,
EPS-2004-044-F&A, ISBN: 90-5892-070-4, http://hdl.handle.net/1765/1518

Delporte-Vermeiren, D.J.E., **Improving the Flexibility and Profitability of ICT-enabled Business Networks: An Assessment Method and Tool,**
Promotors: Prof.mr.dr. P.H.M. Vervest & Prof.dr.ir. H.W.G.M. van Heck,
EPS-2003-020-LIS, ISBN: 90-5892-040-2, http://hdl.handle.net/1765/359

Derwall, J.M.M., **The Economic Virtues of SRI and CSR,**
Promotor: Prof.dr. C.G. Koedijk,
EPS-2007-101-F&A, ISBN: 90-5892-132-8, http://hdl.handle.net/1765/8986

Diepen, M. van, **Dynamics and Competition in Charitable Giving,**
Promotor: Prof.dr. Ph.H.B.F. Franses,
EPS-2009-159-MKT, ISBN: 978-90-5892-188-8, http://hdl.handle.net/1765/14526

Dietz, H.M.S., **Managing (Sales)People towards Perfomance: HR Strategy, Leadership & Teamwork,**
Promotor: Prof.dr. G.W.J. Hendrikse,
EPS-2009-168-ORG, ISBN: 978-90-5892-210-6, http://hdl.handle.net/1765/1

Dijksterhuis, M., **Organizational Dynamics of Cognition and Action in the Changing Dutch and US Banking Industries,**
Promotors: Prof.dr.ir. F.A.J. van den Bosch & Prof.dr. H.W. Volberda,
EPS-2003-026-STR, ISBN: 90-5892-048-8, http://hdl.handle.net/1765/1037

Eijk, A.R. van der, **Behind Networks: Knowledge Transfer, Favor Exchange and Performance,**
Promotors: Prof.dr. S.L. van de Velde & Prof.dr. drs. W.A. Dolfsma,
EPS-2009-161-LIS, ISBN: 978-90-5892-190-1, http://hdl.handle.net/1765/14613

Elstak, M.N., **Flipping the Identity Coin: The Comparative Effect of Perceived, Projected and Desired Organizational Identity on Organizational Identification and Desired Behavior,**
Promotor: Prof.dr. C.B.M. van Riel,
EPS-2008-117-ORG, ISBN: 90-5892-148-2, http://hdl.handle.net/1765/10723

Erken, H.P.G., **Productivity, R&D and Entrepreneurship,**
Promotor: Prof.dr. A.R. Thurik,
EPS-2008-147-ORG, ISBN: 978-90-5892-179-6, http://hdl.handle.net/1765/14004

Fenema, P.C. van, **Coordination and Control of Globally Distributed Software Projects,**
Promotor: Prof.dr. K. Kumar,
EPS-2002-019-LIS, ISBN: 90-5892-030-5, http://hdl.handle.net/1765/360

Fleischmann, M., **Quantitative Models for Reverse Logistics,**
Promotors: Prof.dr.ir. J.A.E.E. van Nunen & Prof.dr.ir. R. Dekker,
EPS-2000-002-LIS, ISBN: 35-4041-711-7, http://hdl.handle.net/1765/1044

Flier, B., **Strategic Renewal of European Financial Incumbents: Coevolution of Environmental Selection, Institutional Effects, and Managerial Intentionality,**
Promotors: Prof.dr.ir. F.A.J. van den Bosch & Prof.dr. H.W. Volberda,
EPS-2003-033-STR, ISBN: 90-5892-055-0, http://hdl.handle.net/1765/1071

Fok, D., **Advanced Econometric Marketing Models,**
Promotor: Prof.dr. Ph.H.B.F. Franses,
EPS-2003-027-MKT, ISBN: 90-5892-049-6, http://hdl.handle.net/1765/1035

Ganzaroli, A., **Creating Trust between Local and Global Systems,**
Promotors: Prof.dr. K. Kumar & Prof.dr. R.M. Lee,
EPS-2002-018-LIS, ISBN: 90-5892-031-3, http://hdl.handle.net/1765/361

Gertsen, H.F.M., **Riding a Tiger without Being Eaten: How Companies and Analysts Tame Financial Restatements and Influence Corporate Reputation,**
Promotor: Prof.dr. C.B.M. van Riel,
EPS-2009-171-ORG, ISBN: 90-5892-214-4, http://hdl.handle.net/1765/1

Gijsbers, G.W., **Agricultural Innovation in Asia: Drivers, Paradigms and Performance,**
Promotor: Prof.dr. R.J.M. van Tulder,
EPS-2009-156-ORG, ISBN: 978-90-5892-191-8, http://hdl.handle.net/1765/14524

Gilsing, V.A., **Exploration, Exploitation and Co-evolution in Innovation Networks,**
Promotors: Prof.dr. B. Nooteboom & Prof.dr. J.P.M. Groenewegen,
EPS-2003-032-ORG, ISBN: 90-5892-054-2, `http://hdl.handle.net/1765/1040`

Gong, Y., **Stochastic Modelling and Analysis of Warehouse Operations,**
Promotors: Prof.dr. M.B.M. de Koster & Prof.dr. S.L. van de Velde,
EPS-2009-180-LIS, ISBN: 978-90-5892-219-9, `http://hdl.handle.net/1765/1`

Govers, R., **Virtual Tourism Destination Image: Glocal Identities Constructed, Perceived and Experienced,**
Promotors: Prof.dr. F.M. Go & Prof.dr. K. Kumar,
EPS-2005-069-MKT, ISBN: 90-5892-107-7, `http://hdl.handle.net/1765/6981`

Graaf, G. de, **Tractable Morality: Customer Discourses of Bankers, Veterinarians and Charity Workers,**
Promotors: Prof.dr. F. Leijnse & Prof.dr. T. van Willigenburg,
EPS-2003-031-ORG, ISBN: 90-5892-051-8, `http://hdl.handle.net/1765/1038`

Greeven, M.J., **Innovation in an Uncertain Institutional Environment: Private Software Entrepreneurs in Hangzhou, China,**
Promotor: Prof.dr. B. Krug,
EPS-2009-164-ORG, ISBN: 978-90-5892-202-1, `http://hdl.handle.net/1765/15426`

Groot, E.A. de, **Essays on Economic Cycles,**
Promotors: Prof.dr. Ph.H.B.F. Franses & Prof.dr. H.R. Commandeur,
EPS-2006-091-MKT, ISBN: 90-5892-123-9, `http://hdl.handle.net/1765/8216`

Guenster, N.K., **Investment Strategies Based on Social Responsibility and Bubbles,**
Promotor: Prof.dr. C.G. Koedijk,
EPS-2008-175-F&A, ISBN: 978-90-5892-206-9, `http://hdl.handle.net/1765/1`

Gutkowska, A.B., **Essays on the Dynamic Portfolio Choice,**
Promotor: Prof.dr. A.C.F. Vorst,
EPS-2006-085-F&A, ISBN: 90-5892-118-2, `http://hdl.handle.net/1765/7994`

Hagemeijer, R.E., **The Unmasking of the Other,**
Promotors: Prof.dr. S.J. Magala & Prof.dr. H.K. Letiche,
EPS-2005-068-ORG, ISBN: 90-5892-097-6, `http://hdl.handle.net/1765/6963`

Hakimi, N.A, **Leader Empowering Behaviour: The Leader's Perspective: Understanding the Motivation behind Leader Empowering Behaviour,**
Promotor: Prof.dr. D.L. van Knippenberg,
EPS-2010-184-ORG, , `http://hdl.handle.net/1765/17701`

Halderen, M.D. van, **Organizational Identity Expressiveness and Perception Management: Principles for Expressing the Organizational Identity in Order to Manage the Perceptions and Behavioral Reactions of External Stakeholders,**
Promotor: Prof.dr. S.B.M. van Riel,
EPS-2008-122-ORG, ISBN: 90-5892-153-6, `http://hdl.handle.net/1765/10872`

Hartigh, E. den, **Increasing Returns and Firm Performance: An Empirical Study,**
Promotor: Prof.dr. H.R. Commandeur,
EPS-2005-067-STR, ISBN: 90-5892-098-4, `http://hdl.handle.net/1765/6939`

Hermans, J.M., **ICT in Information Services, Use and Deployment of the Dutch Securities Trade, 1860-1970,**
Promotor: Prof.dr. drs. F.H.A. Janszen,
EPS-2004-046-ORG, ISBN 90-5892-072-0, `http://hdl.handle.net/1765/1793`

Hessels, S.J.A., **International Entrepreneurship: Value Creation Across National Borders,**
Promotor: Prof.dr. A.R. Thurik,
EPS-2008-144-ORG, ISBN: 978-90-5892-181-9, `http://hdl.handle.net/1765/13942`

Heugens, P.P.M.A.R., **Strategic Issues Management: Implications for Corporate Performance,**
Promotors: Prof.dr.ir. F.A.J. van den Bosch & Prof.dr. C.B.M. van Riel,
EPS-2001-007-STR, ISBN: 90-5892-009-9, `http://hdl.handle.net/1765/358`

Heuvel, W. van den, **The Economic Lot-Sizing Problem: New Results and Extensions,**
Promotor: Prof.dr. A.P.L. Wagelmans,
EPS-2006-093-LIS, ISBN: 90-5892-124-7, `http://hdl.handle.net/1765/1805`

Hoedemaekers, C.M.W., **Performance, Pinned down: A Lacanian Analysis of Subjectivity at Work,**
Promotors: Prof.dr. S. Magala & Prof.dr. D.H. den Hartog,
EPS-2008-121-ORG, ISBN: 90-5892-156-7, `http://hdl.handle.net/1765/10871`

Hooghiemstra, R., **The Construction of Reality: Cultural Differences in Self-serving Behaviour in Accounting Narratives,**
Promotors: Prof.dr. L.G. van der Tas RA & Prof.dr. A.Th.H. Pruyn,
EPS-2003-025-F&A, ISBN: 90-5892-047-X, `http://hdl.handle.net/1765/871`

Hu, Y., **Essays on the Governance of Agricultural Products: Cooperatives and Contract Farming,**
Promotors: Prof.dr. G.W.J. Hendrkse & Prof.dr. B. Krug,
EPS-2007-113-ORG, ISBN: 90-5892-145-1, `http://hdl.handle.net/1765/10535`

Huij, J.J., **New Insights into Mutual Funds: Performance and Family Strategies,**
Promotor: Prof.dr. M.C.J.M. Verbeek,
EPS-2007-099-F&A, ISBN: 90-5892-134-4, http://hdl.handle.net/1765/9398

Huurman, C.I., **Dealing with Electricity Prices,**
Promotor: Prof.dr. C.D. Koedijk,
EPS-2007-098-F&A, ISBN: 90-5892-130-1, http://hdl.handle.net/1765/9399

Iastrebova, K, **Manager's Information Overload: The Impact of Coping Strategies on Decision-Making Performance,**
Promotor: Prof.dr. H.G. van Dissel,
EPS-2006-077-LIS, ISBN: 90-5892-111-5, http://hdl.handle.net/1765/7329

Iwaarden, J.D. van, **Changing Quality Controls: The Effects of Increasing Product Variety and Shortening Product Life Cycles,**
Promotors: Prof.dr. B.G. Dale & Prof.dr. A.R.T. Williams,
EPS-2006-084-ORG, ISBN: 90-5892-117-4, http://hdl.handle.net/1765/7992

Jansen, J.J.P., **Ambidextrous Organizations,**
Promotors: Prof.dr.ir. F.A.J. Van den Bosch & Prof.dr. H.W. Volberda,
EPS-2005-055-STR, ISBN: 90-5892-081-X, http://hdl.handle.net/1765/6774

Jaspers, F.P.H., **Organizing Systemic Innovation,**
Promotor: Prof.dr.ir. J.C.M. van den Ende,
EPS-2009-160-ORG, ISBN: 978-90-5892-197-), http://hdl.handle.net/1765/14974

Jennen, M.G.J., **Empirical Essays on Office Market Dynamics,**
Promotors: Prof.dr. C.G. Koedijk & Prof.dr. D. Brounen,
EPS-2008-140-F&A, ISBN: 978-90-5892-176-5, http://hdl.handle.net/1765/13692

Jiang, T., **Capital Structure Determinants and Governance Structure Variety in Franchising,**
Promotors: Prof.dr. G. Hendrikse & Prof.dr. A. de Jong,
EPS-2009-158-F&A, ISBN: 978-90-5892-199-4, http://hdl.handle.net/1765/14975

Jiao, T., **Essays in Financial Accounting,**
Promotor: Prof.dr. G.M.H. Mertens,
EPS-2009-176-F&A, ISBN: 978-90-5892-211-3, http://hdl.handle.net/1765/1

Jong, C. de, **Dealing with Derivatives: Studies on the Role, Informational Content and Pricing of Financial Derivatives,**
Promotor: Prof.dr. C.G. Koedijk,
EPS-2003-023-F&A, ISBN: 90-5892-043-7, http://hdl.handle.net/1765/1043

Kaa, G. van, **Standard Battles for Complex Systems: Empirical Research on the Home Network,**
Promotors: Prof.dr.ir. J. van den Ende & Prof.dr.ir. H.W.G.M. van Heck,
EPS-2009-166-ORG, ISBN: 978-90-5892-205-2, `http://hdl.handle.net/1765/1`

Keizer, A.B., **The Changing Logic of Japanese Employment Practices: A Firm-Level Analysis of Four Industries,**
Promotors: Prof.dr. J.A. Stam & Prof.dr. J.P.M. Groenewegen,
EPS-2005-057-ORG, ISBN: 90-5892-087-9, `http://hdl.handle.net/1765/6667`

Kijkuit, R.C., **Social Networks in the Front End: The Organizational Life of an Idea,**
Promotor: Prof.dr. B. Nooteboom,
EPS-2007-104-ORG, ISBN: 90-5892-137-6, `http://hdl.handle.net/1765/10074`

Kippers, J., **Empirical Studies on Cash Payments,**
Promotor: Prof.dr. Ph.H.B.F. Franses,
EPS-2004-043-F&A, ISBN: 90-5892-069-0, `http://hdl.handle.net/1765/1520`

Klein, M.H., **Poverty Alleviation through Sustainable Strategic Business Models: Essays on Poverty Alleviation as a Business Strategy,**
Promotor: Prof.dr. H.R. Commandeur,
EPS-2008-135-STR, ISBN: 978-90-5892-168-0, `http://hdl.handle.net/1765/13482`

Knapp, S., **The Econometrics of Maritime Safety: Recommendations to Enhance Safety at Sea,**
Promotor: Prof.dr. Ph.H.B.F. Franses,
EPS-2007-096-ORG, ISBN: 90-5892-127-1, `http://hdl.handle.net/1765/7913`

Kole, E., **On Crises, Crashes and Comovements,**
Promotors: Prof.dr. C.G. Koedijk & Prof.dr. M.J.C.M. Verbeek,
EPS-2006-083-F&A, ISBN: 90-5892-114-X, `http://hdl.handle.net/1765/7829`

Kooij-de Bode, J.M., **Distributed Information and Group Decision-Making: Effects of Diversity and Affect,**
Promotor: Prof.dr. D.L. van Knippenberg,
EPS-2007-115-ORG, , `http://hdl.handle.net/1765/10722`

Koppius, O.R., **Information Architecture and Electronic Market Performance,**
Promotors: Prof.dr. P.H.M. Vervest & Prof.dr.ir. H.W.G.M. van Heck,
EPS-2002-013-LIS, ISBN: 90-5892-023-2, `http://hdl.handle.net/1765/921`

Kotlarsky, J., **Management of Globally Distributed Component-Based Software Development Projects,**
Promotor: Prof.dr. K. Kumar,
EPS-2005-059-LIS, ISBN: 90-5892-088-7, `http://hdl.handle.net/1765/6772`

Krauth, E.I., **Real-Time Planning Support: A Task-Technology Fit Perspective,**
Promotors: Prof.dr. S.L. van de Velde & Prof.dr. J. van Hillegersberg,
EPS-2008-155-LIS, ISBN: 978-90-5892-193-2, http://hdl.handle.net/1765/14521

Kuilman, J., **The Re-Emergence of Foreign Banks in Shanghai: An Ecological Analysis,**
Promotor: Prof.dr. B. Krug,
EPS-2005-066-ORG, ISBN: 90-5892-096-8, http://hdl.handle.net/1765/6926

Kwee, Z., **Investigating Three Key Principles of Sustained Strategic Renewal: A Longitudinal Study of Long-Lived Firms,**
Promotors: Prof.dr.ir. F.A.J. Van den Bosch & Prof.dr. H.W. Volberda,
EPS-2009-174-STR, ISBN: 90-5892-212-0, http://hdl.handle.net/1765/1

Langen, P.W. de, **The Performance of Seaport Clusters: A Framework to Analyze Cluster Performance and an Application to the Seaport Clusters of Durban, Rotterdam and the Lower Mississippi,**
Promotors: Prof.dr. B. Nooteboom & Prof. drs. H.W.H. Welters,
EPS-2004-034-LIS, ISBN: 90-5892-056-9, http://hdl.handle.net/1765/1133

Le Anh, T., **Intelligent Control of Vehicle-Based Internal Transport Systems,**
Promotors: Prof.dr. M.B.M. de Koster & Prof.dr.ir. R. Dekker,
EPS-2005-051-LIS, ISBN: 90-5892-079-8, http://hdl.handle.net/1765/6554

Le-Duc, T., **Design and Control of Efficient Order Picking Processes,**
Promotor: Prof.dr. M.B.M. de Koster,
EPS-2005-064-LIS, ISBN: 90-5892-094-1, http://hdl.handle.net/1765/6910

Leeuwen, E.P. van, **Recovered-Resource Dependent Industries and the Strategic Renewal of Incumbent Firm: A Multi-Level Study of Recovered Resource Dependence Management and Strategic Renewal in the European Paper and Board Industry,**
Promotors: Prof.dr.ir. F.A.J. Van den Bosch & Prof.dr. H.W. Volberda,
EPS-2007-109-STR, ISBN: 90-5892-140-6, http://hdl.handle.net/1765/10183

Lentink, R.M., **Algorithmic Decision Support for Shunt Planning,**
Promotors: Prof.dr. L.G. Kroon & Prof.dr.ir. J.A.E.E. van Nunen,
EPS-2006-073-LIS, ISBN: 90-5892-104-2, http://hdl.handle.net/1765/7328

Li, T., **Informedness and Customer-Centric Revenue Management,**
Promotors: Prof.dr. P.H.M. Vervest & Prof.dr.ir. H.W.G.M. van Heck,
EPS-2009-146-LIS, ISBN: 978-90-5892-195-6, http://hdl.handle.net/1765/14525

Liang, G., **New Competition: Foreign Direct Investment and Industrial Development in China,**
Promotor: Prof.dr. R.J.M. van Tulder,
EPS-2004-047-ORG, ISBN: 90-5892-073-9, http://hdl.handle.net/1765/1795

Liere, D.W. van, **Network Horizon and the Dynamics of Network Positions: A Multi-Method Multi-Level Longitudinal Study of Interfirm Networks,**
Promotor: Prof.dr. P.H.M. Vervest,
EPS-2007-105-LIS, ISBN: 90-5892-139-0, http://hdl.handle.net/1765/10181

Loef, J., **Incongruity between Ads and Consumer Expectations of Advertising,**
Promotors: Prof.dr. W.F. van Raaij & Prof.dr. G. Antonides,
EPS-2002-017-MKT, ISBN: 90-5892-028-3, http://hdl.handle.net/1765/869

Londoño, M. del Pilar, **Institutional Arrangements that Affect Free Trade Agreements: Economic Rationality Versus Interest Groups,**
Promotors: Prof.dr. H.E. Haralambides & Prof.dr. J.F. Francois,
EPS-2006-078-LIS, ISBN: 90-5892-108-5, http://hdl.handle.net/1765/7578

Maas, A.A., **van der, Strategy Implementation in a Small Island Context: An Integrative Framework,**
Promotor: Prof.dr. H.G. van Dissel,
EPS-2008-127-LIS, ISBN: 978-90-5892-160-4, http://hdl.handle.net/1765/12278

Maas, K.E.G., **Corporate Social Performance: From Output Measurement to Impact Measurement,**
Promotor: Prof.dr. H.R. Commandeur,
EPS-2009-182-STR, ISBN: 978-90-5892-225-0, http://hdl.handle.net/1765/1

Maeseneire, W., **de, Essays on Firm Valuation and Value Appropriation,**
Promotor: Prof.dr. J.T.J. Smit,
EPS-2005-053-F&A, ISBN: 90-5892-082-8, http://hdl.handle.net/1765/6768

Maeseneire, W., **de, Essays on Firm Valuation and Value Appropriation,**
Promotor: Prof.dr. J.T.J. Smit,
EPS-2005-053-F&A, ISBN: 90-5892-082-8, http://hdl.handle.net/1765/6768

Mandele, L.M., **van der, Leadership and the Inflection Point: A Longitudinal Perspective,**
Promotors: Prof.dr. H.W. Volberda & Prof.dr. H.R. Commandeur,
EPS-2004-042-STR, ISBN: 90-5892-067-4, http://hdl.handle.net/1765/1302

Meer, J.R. van der, **Operational Control of Internal Transport,**
Promotors: Prof.dr. M.B.M. de Koster & Prof.dr.ir. R. Dekker,
EPS-2000-001-LIS, ISBN: 90-5892-004-6, http://hdl.handle.net/1765/859

Mentink, A., **Essays on Corporate Bonds,**
Promotor: Prof.dr. A.C.F. Vorst,
EPS-2005-070-F&A, ISBN: 90-5892-100-X, http://hdl.handle.net/1765/7121

Meyer, R.J.H., **Mapping the Mind of the Strategist: A Quantitative Methodology for Measuring the Strategic Beliefs of Executives,**
Promotor: Prof.dr. R.J.M. van Tulder,
EPS-2007-106-ORG, ISBN: 978-90-5892-141-3, http://hdl.handle.net/1765/10182

Miltenburg, P.R., **Effects of Modular Sourcing on Manufacturing Flexibility in the Automotive Industry: A Study among German OEMs,**
Promotors: Prof.dr. J. Paauwe & Prof.dr. H.R. Commandeur,
EPS-2003-030-ORG, ISBN: 90-5892-052-6, http://hdl.handle.net/1765/1039

Moerman, G.A., **Empirical Studies on Asset Pricing and Banking in the Euro Area,**
Promotor: Prof.dr. C.G. Koedijk,
EPS-2005-058-F&A, ISBN: 90-5892-090-9, http://hdl.handle.net/1765/6666

Moitra, D., **Globalization of R&D: Leveraging Offshoring for Innovative Capability and Organizational Flexibility,**
Promotor: Prof.dr. K. Kumar,
EPS-2008-150-LIS, ISBN: 978-90-5892-184-0, http://hdl.handle.net/1765/14081

Mol, M.M., **Outsourcing, Supplier-relations and Internationalisation: Global Source Strategy as a Chinese Puzzle,**
Promotor: Prof.dr. R.J.M. van Tulder,
EPS-2001-010-ORG, ISBN: 90-5892-014-3, http://hdl.handle.net/1765/355

Mom, T.J.M., **Managers' Exploration and Exploitation Activities: The Influence of Organizational Factors and Knowledge Inflows,**
Promotors: Prof.dr.ir. F.A.J. Van den Bosch & Prof.dr. H.W. Volberda,
EPS-2006-079-STR, ISBN: 90-5892-116-6, http://hdl.handle.net/1765

Moonen, J.M., **Multi-Agent Systems for Transportation Planning and Coordination,**
Promotors: Prof.dr. J. van Hillegersberg & Prof.dr. S.L. van de Velde,
EPS-2009-177-LIS, ISBN: 978-90-5892-216-8, http://hdl.handle.net/1

Mulder, A., **Government Dilemmas in the Private Provision of Public Goods,**
Promotor: Prof.dr. R.J.M. van Tulder,
EPS-2004-045-ORG, ISBN: 90-5892-071-2, http://hdl.handle.net/1765/1790

Muller, A.R., **The Rise of Regionalism: Core Company Strategies Under The Second Wave of Integration,**
Promotor: Prof.dr. R.J.M. van Tulder,
EPS-2004-038-ORG, ISBN: 90-5892-062-3, http://hdl.handle.net/1765/1272

Nalbantov, G.I., **Essays on Some Recent Penalization Methods with Applications in Finance and Marketing,**
Promotor: Prof. dr P.J.F. Groenen,
EPS-2008-132-F&A, ISBN: 978-90-5892-166-6, http://hdl.handle.net/1765/13319

Nederveen Pieterse, A., **Goal Orientation in Teams: The Role of Diversity,**
Promotor: Prof.dr. D.L. van Knippenberg,
EPS-2009-162-ORG, , http://hdl.handle.net/1765/15240

Nguyen, T.T., **Capital Structure, Strategic Competition, and Governance,**
Promotor: Prof.dr. A. de Jong,
EPS-2008-148-F&A, ISBN: 90-5892-178-9, http://hdl.handle.net/1765/14005

Niesten, E.M.M.I., **Regulation, Governance and Adaptation: Governance Transformations in the Dutch and French Liberalizing Electricity Industries,**
Promotors: Prof.dr. A. Jolink & Prof.dr. J.P.M. Groenewegen,
EPS-2009-170-ORG, ISBN: 978-90-5892-208-3, http://hdl.handle.net/1765/1

Nieuwenboer, N.A. den, **Seeing the Shadow of the Self,**
Promotor: Prof.dr. S.P. Kaptein,
EPS-2008-151-ORG, ISBN: 978-90-5892-182-6, http://hdl.handle.net/1765/14223

Ning, H., **Hierarchical Portfolio Management: Theory and Applications,**
Promotor: Prof.dr. J. Spronk,
EPS-2007-118-F&A, ISBN: 90-5892-152-9, http://hdl.handle.net/1765/10868

Noeverman, J., **Management Control Systems, Evaluative Style, and Behaviour: Exploring the Concept and Behavioural Consequences of Evaluative Style,**
Promotors: Prof.dr. E.G.J. Vosselman & Prof.dr. A.R.T. Williams,
EPS-2007-120-F&A, ISBN: 90-5892-151-2, http://hdl.handle.net/1765/10869

Nuijten, I., **Servant Leadership: Paradox or Diamond in the Rough? A Multidimensional Measure and Empirical Evidence,**
Promotor: Prof.dr. D.L. van Knippenberg,
EPS-2009-183-ORG, , http://hdl.handle.net/1765/17628

Oosterhout, J., **van, The Quest for Legitimacy: On Authority and Responsibility in Governance,**
Promotors: Prof.dr. T. van Willigenburg & Prof.mr. H.R. van Gunsteren,
EPS-2002-012-ORG, ISBN: 90-5892-022-4, http://hdl.handle.net/1765/362

Oostrum, J.M., **van, Applying Mathematical Models to Surgical Patient Planning,**
Promotor: Prof.dr. A.P.M. Wagelmans,
EPS-2009-179-LIS, ISBN: 978-90-5892-217-5, http://hdl.handle.net/1765/1

Paape, L., **Corporate Governance: The Impact on the Role, Position, and Scope of Services of the Internal Audit Function,**
Promotors: Prof.dr. G.J. van der Pijl & Prof.dr. H. Commandeur,
EPS-2007-111-MKT, ISBN: 90-5892-143-7, http://hdl.handle.net/1765/10417

Pak, K., **Revenue Management: New Features and Models,**
Promotor: Prof.dr.ir. R. Dekker,
EPS-2005-061-LIS, ISBN: 90-5892-092-5, `http://hdl.handle.net/1765/362/6771`

Pattikawa, L.H, **Innovation in the Pharmaceutical Industry: Evidence from Drug Introduction in the U.S.,**
Promotors: Prof.dr. H.R.Commandeur,
EPS-2007-102-MKT, ISBN: 90-5892-135-2, `http://hdl.handle.net/1765/9626`

Peeters, L.W.P., **Cyclic Railway Timetable Optimization,**
Promotors: Prof.dr. L.G. Kroon & Prof.dr.ir. J.A.E.E. van Nunen,
EPS-2003-022-LIS, ISBN: 90-5892-042-9, `http://hdl.handle.net/1765/429`

Pietersz, R., **Pricing Models for Bermudan-style Interest Rate Derivatives,**
Promotors: Prof.dr. A.A.J. Pelsser & Prof.dr. A.C.F. Vorst,
EPS-2005-071-F&A, ISBN: 90-5892-099-2, `http://hdl.handle.net/1765/7122`

Poel, A.M. van der, **Empirical Essays in Corporate Finance and Financial Reporting,**
Promotors: Prof.dr. A. de Jong & Prof.dr. G.M.H. Mertens,
EPS-2007-133-F&A, ISBN: 978-90-5892-165-9, `http://hdl.handle.net/1765/13320`

Popova, V., **Knowledge Discovery and Monotonicity,**
Promotor: Prof.dr. A. de Bruin,
EPS-2004-037-LIS, ISBN: 90-5892-061-5, `http://hdl.handle.net/1765/1201`

Pouchkarev, I., **Performance Evaluation of Constrained Portfolios,**
Promotors: Prof.dr. J. Spronk & Dr. W.G.P.M. Hallerbach,
EPS-2005-052-F&A, ISBN: 90-5892-083-6, `http://hdl.handle.net/1765/6731`

Prins, R., **Modeling Consumer Adoption and Usage of Value-Added Mobile Services,**
Promotors: Prof.dr. Ph.H.B.F. Franses & Prof.dr. P.C. Verhoef,
EPS-2008-128-MKT, ISBN: 978/90-5892-161-1, `http://hdl.handle.net/1765/12461`

Puvanasvari Ratnasingam, P., **Interorganizational Trust in Business to Business E-Commerce,**
Promotors: Prof.dr. K. Kumar & Prof.dr. H.G. van Dissel,
EPS-2001-009-LIS, ISBN: 90-5892-017-8, `http://hdl.handle.net/1765/356`

Quak, H.J., **Sustainability of Urban Freight Transport: Retail Distribution and Local Regulation in Cities,**
Promotor: Prof.dr. M.B.M. de Koster,
EPS-2008-124-LIS, ISBN: 978-90-5892-154-3, `http://hdl.handle.net/1765/11990`

Quariguasi Frota Neto, J., **Eco-efficient Supply Chains for Electrical and Electronic Products,**
Promotors: Prof.dr.ir. J.A.E.E. van Nunen & Prof.dr.ir. H.W.G.M. van Heck,
EPS-2008-152-LIS, ISBN: 978-90-5892-192-5, http://hdl.handle.net/1765/14785

Radkevitch, U.L, **Online Reverse Auction for Procurement of Services,**
Promotor: Prof.dr.ir. H.W.G.M. van Heck,
EPS-2008-137-LIS, ISBN: 978-90-5892-171-0, http://hdl.handle.net/1765/13497

Rinsum, M. van, **Performance Measurement and Managerial Time Orientation,**
Promotor: Prof.dr. F.G.H. Hartmann,
EPS-2006-088-F&A, ISBN: 90-5892-121-2, http://hdl.handle.net/1765/7993

Roelofsen, E.M., **The Role of Analyst Conference Calls in Capital Markets,**
Promotors: Prof.dr. G.M.H. Mertens & Prof.dr. L.G. van der Tas RA,
EPS-2010-190-F&A, ISBN: 978-90-5892-228-1, http://hdl.handle.net/1765/1

Romero Morales, D., **Optimization Problems in Supply Chain Management,**
Promotors: Prof.dr.ir. J.A.E.E. van Nunen & Dr. H.E. Romeijn,
EPS-2000-003-LIS, ISBN: 90-9014078-6, http://hdl.handle.net/1765/865

Roodbergen, K.J., **Layout and Routing Methods for Warehouses,**
Promotors: Prof.dr. M.B.M. de Koster & Prof.dr.ir. J.A.E.E. van Nunen,
EPS-2001-004-LIS, ISBN: 90-5892-005-4, http://hdl.handle.net/1765/861

Rook, L., **Imitation in Creative Task Performance,**
Promotor: Prof.dr. D.L. van Knippenberg,
EPS-2008-125-ORG, , http://hdl.handle.net/1765/11555

Rosmalen, J. van, **Segmentation and Dimension Reduction: Exploratory and Model-Based Approaches,**
Promotor: Prof.dr. P.J.F. Groenen,
EPS-2009-165-MKT, ISBN: 978-90-5892-201-4, http://hdl.handle.net/1765/15536

Rus, D., **The Dark Side of Leadership: Exploring the Psychology of Leader Self-serving Behavior,**
Promotor: Prof.dr. D.L. van Knippenberg,
EPS-2009-178-ORG, , http://hdl.handle.net/1765/1

Samii, R., **Leveraging Logistics Partnerships: Lessons from Humanitarian Organizations,**
Promotors: Prof.dr.ir. J.A.E.E. van Nunen & Prof.dr.ir. L.N. Van Wassenhove,
EPS-2008-153-LIS, ISBN: 978-90-5892-186-4, http://hdl.handle.net/1765/14519

Schaik, D. van, **M&A in Japan: An Analysis of Merger Waves and Hostile Takeovers,**
Promotors: Prof.dr. J. Spronk & Prof.dr. J.P.M. Groenewegen,
EPS-2008-141-F&A, ISBN: 978-90-5892-169-7, `http://hdl.handle.net/1765/13693`

Schauten, M.B.J., **Valuation, Capital Structure Decisions and the Cost of Capital,**
Promotors: Prof.dr. J. Spronk & Prof.dr. D. van Dijk,
EPS-2008-134-F&A, ISBN: 978-90-5892-172-7, `http://hdl.handle.net/1765/13480`

Schramade, W.L.J., **Corporate Bonds Issuers,**
Promotor: Prof.dr. A. De Jong,
EPS-2006-092-F&A, ISBN: 90-5892-125-5, `http://hdl.handle.net/1765/8191`

Schweizer, T.S., **An Individual Psychology of Novelty-Seeking, Creativity and Innovation,**
Promotor: Prof.dr. R.J.M. van Tulder,
EPS-2004-048-ORG, ISBN: 90-5892-077-1, `http://hdl.handle.net/1765/1818`

Six, F.E., **Trust and Trouble: Building Interpersonal Trust Within Organizations,**
Promotors: Prof.dr. B. Nooteboom & Prof.dr. A.M. Sorge,
EPS-2004-040-ORG, ISBN: 90-5892-064-X, `http://hdl.handle.net/1765/1271`

Slager, A.M.H., **Banking across Borders,**
Promotors: Prof.dr. R.J.M. van Tulder & Prof.dr. D.M.N. van Wensveen,
EPS-2004-041-ORG, ISBN: 90-5892-066Ű6, `http://hdl.handle.net/1765/1301`

Sloot, L., **Understanding Consumer Reactions to Assortment Unavailability, Promotors: Prof.dr. H.R. Commandeur,**
Prof.dr. E. Peelen & Prof.dr. P.C. Verhoef,
EPS-2006-074-MKT, ISBN: 90-5892-102-6, `http://hdl.handle.net/1765/7438`

Smit, W., **Market Information Sharing in Channel Relationships: Its Nature, Antecedents and Consequences,**
Promotors: Prof.dr.ir. G.H. van Bruggen & Prof.dr.ir. B. Wierenga,
EPS-2006-076-MKT, ISBN: 90-5892-106-9, `http://hdl.handle.net/1765/7327`

Sonnenberg, M., **The Signalling Effect of HRM on Psychological Contracts of Employees: A Multi-level Perspective,**
Promotor: Prof.dr. J. Paauwe,
EPS-2006-086-ORG, ISBN: 90-5892-119-0, `http://hdl.handle.net/1765/7995`

Speklé, R.F., **Beyond Generics: A closer Look at Hybrid and Hierarchical Governance,**
Promotor: Prof.dr. M.A. van Hoepen RA,
EPS-2001-008-F&A, ISBN: 90-5892-011-9, `http://hdl.handle.net/1765/357`

Srour, F.J., **Dissecting Drayage: An Examination of Structure, Information, and Control in Drayage Operations,**
Promotor: Prof.dr. S.L. van de Velde,
EPS-2010-186-LIS, ISBN: 978-90-5892-226-7 , `http://hdl.handle.net/1765/18231`

Stam, D.A., **Managing Dreams and Ambitions: A Psychological Analysis of Vision Communication,**
Promotor: Prof.dr. D.L. van Knippenberg,
EPS-2008-149-ORG, , `http://hdl.handle.net/1765/14080`

Stienstra, M., **Strategic Renewal in Regulatory Environments: How Inter- and Intra-organisational Institutional Forces Influence European Energy Incumbent Firms,**
Promotors: Prof.dr.ir. F.A.J. Van den Bosch & Prof.dr. H.W. Volberda,
EPS-2008-145-STR, ISBN: 978-90-5892-184-0, `http://hdl.handle.net/1765/13943`

Sweldens, S.T.L.R., **Evaluative Conditioning 2.0: Direct versus Associative Transfer of Affect to Brands,**
Promotor: Prof.dr. S.M.J. van Osselaer,
EPS-2009-167-MKT, ISBN: 978-90-5892-204-5, `http://hdl.handle.net/1765/1`

Szkudlarek, B.A., **Spinning the Web of Reentry: [Re]connecting reentry training theory and practice,**
Promotor: Prof.dr. S.J. Magala,
EPS-2008-143-ORG, ISBN: 978-90-5892-177-2, `http://hdl.handle.net/1765/13695`

Tempelaar, M.P., **Organizing for Ambidexterity: Studies on the Pursuit of Exploration and Exploitation through Differentiation, Integration, Contextual and Individual Attributes,**
Promotors: Prof.dr.ing. . F.A.J. van den Bosch & Prof.dr. H.W. Volberda,
EPS-2010-191-STR, ISBN: 978-90-5892-231-1, `http://hdl.handle.net/1765/18457`

Teunter, L.H., **Analysis of Sales Promotion Effects on Household Purchase Behavior,**
Promotors: Prof.dr.ir. B. Wierenga & Prof.dr. T. Kloek,
EPS-2002-016-MKT, ISBN: 90-5892-029-1, `http://hdl.handle.net/1765/868`

Tims, B., **Empirical Studies on Exchange Rate Puzzles and Volatility,**
Promotor: Prof.dr. C.G. Koedijk,
EPS-2006-089-F&A, ISBN: 90-5892-113-1, `http://hdl.handle.net/1765/8066`

Tuk, M.A., **Is Friendship Silent When Money Talks? How Consumers Respond to Word-of-Mouth Marketing,**
Promotors: Prof.dr.ir. A. Smidts & Prof.dr. D.H.J. Wigboldus,
EPS-2008-130-MKT, ISBN: 978-90-5892-164-2, `http://hdl.handle.net/1765/12702`

Valck, K. de, **Virtual Communities of Consumption: Networks of Consumer Knowledge and Companionship,**
Promotors: Prof.dr.ir. G.H. van Bruggen & Prof.dr.ir. B. Wierenga,
EPS-2005-050-MKT, ISBN: 90-5892-078-X, http://hdl.handle.net/1765/6663

Valk, W. van der, **Buyer-Seller Interaction Patterns During Ongoing Service Exchange,**
Promotors: Prof.dr. J.Y.F. Wynstra & Prof.dr.ir. B. Axelsson,
EPS-2007-116-MKT, ISBN: 90-5892-146-8, http://hdl.handle.net/1765/10856

Verheul, I., **Is There a (Fe)male Approach? Understanding Gender Differences, in Entrepreneurship,**
Prof.dr. A.R. Thurik,
EPS-2005-054-ORG, ISBN: 90-5892-080-1, http://hdl.handle.net/1765/2005

Verwijmeren, P., **Empirical Essays on Debt, Equity, and Convertible Securities,**
Promotors: Prof.dr. A. de Jong & Prof.dr. M.J.C.M. Verbeek,
EPS-2009-154-F&A, ISBN: 978-90-5892-187-1, http://hdl.handle.net/1765/14312

Vis, I.F.A., **Planning and Control Concepts for Material Handling Systems,**
Promotors: Prof.dr. M.B.M. de Koster & Prof.dr.ir. R. Dekker,
EPS-2002-014-LIS, ISBN: 90-5892-021-6, http://hdl.handle.net/1765/866

Vlaar, P.W.L., **Making Sense of Formalization in Interorganizational Relationships: Beyond Coordination and Control,**
Promotors: Prof.dr.ir. F.A.J. Van den Bosch & Prof.dr. H.W. Volberda,
EPS-2006-075-STR, ISBN 90-5892-103-4, http://hdl.handle.net/1765/7326

Vliet, P. van, **Downside Risk and Empirical Asset Pricing,**
Promotor: Prof.dr. G.T. Post,
EPS-2004-049-F&A, ISBN: 90-5892-07-55, http://hdl.handle.net/1765/1819

Vlist, P. van der, **Synchronizing the Retail Supply Chain,**
Promotors: Prof.dr.ir. J.A.E.E. van Nunen & Prof.dr. A.G. de Kok,
EPS-2007-110-LIS, ISBN: 90-5892-142-0, http://hdl.handle.net/1765/10418

Vries-van Ketel, E. de, **How Assortment Variety Affects Assortment Attractiveness: A Consumer Perspective,**
Promotors: Prof.dr. G.H. van Bruggen & Prof.dr.ir. A. Smidts,
EPS-2006-072-MKT, ISBN: 90-5892-101-8, http://hdl.handle.net/1765/7193

Vromans, M.J.C.M., **Reliability of Railway Systems, Promotors: Prof.dr. L.G. Kroon,**
Prof.dr.ir. R. Dekker & Prof.dr.ir. J.A.E.E. van Nunen,
EPS-2005-062-LIS, ISBN: 90-5892-089-5, http://hdl.handle.net/1765/6773

Vroomen, B.L.K., **The Effects of the Internet, Recommendation Quality and Decision Strategies on Consumer Choice,**
Promotor: Prof.dr. Ph.H.B.F. Franses,
EPS-2006-090-MKT, ISBN: 90-5892-122-0, `http://hdl.handle.net/1765/8067`

Waal, T. de, **Processing of Erroneous and Unsafe Data,**
Promotor: Prof.dr.ir. R. Dekker,
EPS-2003-024-LIS, ISBN: 90-5892-045-3, `http://hdl.handle.net/1765/870`

Waard, E.J. de, **Engaging Environmental Turbulence: Organizational Determinants for Repetitive Quick and Adequate Responses,**
Promotors: Prof.dr. H.W. Volberda & Prof.dr. J. Soeters,
EPS-2010-189-STR, ISBN: 978-90-5892-229-8, `http://hdl.handle.net/1765/1`

Wall, R.S., **Netscape: Cities and Global Corporate Networks,**
Promotor: Prof.dr. G.A. van der Knaap,
EPS-2009-169-ORG, ISBN: 978-90-5892-207-6, `http://hdl.handle.net/1765/1`

Watkins Fassler, K., **Macroeconomic Crisis and Firm Performance,**
Promotors: Prof.dr. J. Spronk & Prof.dr. D.J. van Dijk,
EPS-2007-103-F&A, ISBN: 90-5892-138-3, `http://hdl.handle.net/1765/10065`

Weerdt, N.P. van der, **Organizational Flexibility for Hypercompetitive Markets: Empirical Evidence of the Composition and Context Specificity of Dynamic Capabilities and Organization Design Parameters,**
Promotor: Prof.dr. H.W. Volberda,
EPS-2009-173-STR, ISBN: 978-90-5892-215-1, `http://hdl.handle.net/1765/1`

Wennekers, A.R.M., **Entrepreneurship at Country Level: Economic and Non-Economic Determinants,**
Promotor: Prof.dr. A.R. Thurik,
EPS-2006-81-ORG, ISBN: 90-5892-115-8, `http://hdl.handle.net/1765/7982`

Wielemaker, M.W., **Managing Initiatives: A Synthesis of the Conditioning and Knowledge-Creating View,**
Promotors: Prof.dr. H.W. Volberda & Prof.dr. C.W.F. Baden-Fuller,
EPS-2003-28-STR, ISBN: 90-5892-050-X, `http://hdl.handle.net/1765/1042`

Wijk, R.A.J.L. van, **Organizing Knowledge in Internal Networks: A Multilevel Study,**
Promotor: Prof.dr.ir. F.A.J. van den Bosch,
EPS-2003-021-STR, ISBN: 90-5892-039-9, `http://hdl.handle.net/1765/347`

Wolters, M.J.J., **The Business of Modularity and the Modularity of Business,**
Promotors: Prof. mr. dr. P.H.M. Vervest & Prof.dr.ir. H.W.G.M. van Heck,
EPS-2002-011-LIS, ISBN: 90-5892-020-8, `http://hdl.handle.net/1765/920`

Wubben, M.J.J., **Social Functions of Emotions in Social Dilemmas,**
Promotors: Prof.dr. D. De Cremer & Prof.dr. E. van Dijk,
EPS-2009-187-ORG, , http://hdl.handle.net/1765/18228

Xu, Y., **Empirical Essays on the Stock Returns, Risk Management, and Liquidity Creation of Banks,**
Promotor: Prof.dr. M.J.C.M. Verbeek,
EPS-2010-188-F&A, ISBN: 978-905892-227-4, http://hdl.handle.net/1765/18125

Yang, J., **Towards the Restructuring and Co-ordination Mechanisms for the Architecture of Chinese Transport Logistics,**
Promotor: Prof.dr. H.E. Harlambides,
EPS-2009-157-LIS, ISBN: 978-90-5892-198-7, http://hdl.handle.net/1765/14527

Yu, M., **Enhancing Warehouse Perfromance by Efficient Order Picking,**
Promotor: Prof.dr. M.B.M. de Koster,
EPS-2008-139-LIS, ISBN: 978-90-5892-167-3, http://hdl.handle.net/1765/13691

Zhang, X., **Strategizing of Foreign Firms in China: An Institution-based Perspective,**
Promotor: Prof.dr. B. Krug,
EPS-2007-114-ORG, ISBN: 90-5892-147-5, http://hdl.handle.net/1765/10721

Zhu, Z., **Essays on China's Tax System,**
Promotors: Prof.dr. B. Krug & Prof.dr. G.W.J. Hendrikse,
EPS-2007-112-ORG, ISBN: 90-5892-144-4, http://hdl.handle.net/1765/10502

Zwart, G.J. de, **Empirical Studies on Financial Markets: Private Equity, Corporate Bonds and Emerging Markets,**
Promotors: Prof.dr. M.J.C.M. Verbeek & Prof.dr. D.J.C. van Dijk,
EPS-2008-131-F&A, ISBN: 978-90-5892-163-5, http://hdl.handle.net/1765/12703

Erasmus Research Institute of Management - ERIM

VENDOR-BUYER COORDINATION IN SUPPLY CHAINS

Collaboration between firms in order to coordinate supply chain operations can lead to both strategic and operational benefits. Many advanced forms of collaboration arrangements between firms exist with the aim to coordinate supply chain decisions and to reap these benefits. This dissertation contributes to the understanding of the conditions that are necessary for collaboration in such arrangements and the benefits that can be realized of such collaboration arrangements. This dissertation focuses on the vendor-buyer dyad in the supply chain. We identify and categorize collaboration arrangements that exist in practice, based on a review of the literature and combine this with formal analytical models in the literature. An important factor in the benefits of collaboration is the benefit of reduced costs of transport, by realization of economies of scale in the context of capacity-constrained trucks. As a contribution to the understanding of the dependence of transport costs on the volume transported, we demonstrate how transport tariffs for orders of less-than-a-truckload in size on a single link can be deduced from a basic model. The success of a collaboration arrangement depends on agreement about the distribution of decision authority and collaboration-benefits. We study a collaboration arrangement in which the vendor takes responsibility for managing the buyer's inventory and makes it economically attractive to the buyer by offering a financial incentive, dependent on the maximum level the buyer permits to be stocked. This dissertation demonstrates that this incentive alignment leads to considerable cost savings and near-optimal supply chain decisions.

ERIM

The Erasmus Research Institute of Management (ERIM) is the Research School (Onderzoekschool) in the field of management of the Erasmus University Rotterdam. The founding participants of ERIM are Rotterdam School of Management (RSM), and the Erasmus School of Economics (ESE). ERIM was founded in 1999 and is officially accredited by the Royal Netherlands Academy of Arts and Sciences (KNAW). The research undertaken by ERIM is focused on the management of the firm in its environment, its intra- and interfirm relations, and its business processes in their interdependent connections.

The objective of ERIM is to carry out first rate research in management, and to offer an advanced doctoral programme in Research in Management. Within ERIM, over three hundred senior researchers and PhD candidates are active in the different research programmes. From a variety of academic backgrounds and expertises, the ERIM community is united in striving for excellence and working at the forefront of creating new business knowledge.

ERIM PhD Series
Research in Management

Erasmus Research Institute of Management - **ERIM**
Rotterdam School of Management (RSM)
Erasmus School of Economics (ESE)
P.O. Box 1738, 3000 DR Rotterdam
The Netherlands

Tel. +31 10 408 11 82
Fax +31 10 408 96 40
E-mail info@erim.eur.nl
Internet www.erim.eur.nl

Design & layout: B&T Ontwerp en advies (www.b-en-t.nl) Cover Art: S. van Drie Print: Haveka (www.haveka.nl)