Solving the Bullwhip Effect in Supply Networks by incentivizing behaviour through decentralized Forecast Accuracy Discount agreements

A simulation case study within the Supply Chain of the Technische Unie

Abstract:
Current research towards solutions on the Bullwhip Effect have focused mainly on the systemic and operational causes of the Bullwhip Effect, resulting in solutions that require high levels of organizational integration, central coordination and information sharing. However, Such solutions are not always feasible within actual complex Supply Network structures, effective within the bounded rational self-optimizing behaviour of companies, acceptable towards the strategic perception of sensitivity of operational information, nor suitable within the authority and responsibility structures of organizations. Therefore we have developed Forecast Accuracy Discount agreements as decentralized solutions which financially incentivize customers to smoothen their purchase orders by rewarding predictable ordering according to previously shared forecasts of their own expected future orders. We use a simulation model based on a case study to test the effects of the agreements on the operational behaviour of both suppliers and customers and the outcomes on the operational performance to demonstrate that the agreements are able to create Pareto Improvements for both parties and incentivize them to adopt the agreements and further exploit the potential benefits by adjusting their operational systems to further synchronize their operations.

Keywords: Bullwhip Effect, Supply Networks, Supply Chain Management, Incentivizing, Decentralized coordination, Forecast Accuracy Discount agreements

1. Introduction

Due to the emergence of global markets and more sophisticated products after the Second World War, companies and scholars in the field of Operations Research and Logistics Management extended their scope of interests to an inter-organizational level (Simatupang and Sridharan 2002). In 1961 Forrester published the results of an internal and inter-organizational systems dynamics study towards operational processes of companies in his book "Industrial Dynamics" (Forrester 1961). In this book he describes the increase of variability of placed orders at suppliers in relation to the received orders by customers and contributes the effect to the lack of inter Supply Chain coordination and the incompetence of managers to cope with the complex non-linear interactions. With this observation, Forrester became known as the first author to describe the phenomenon that would become known as the Bullwhip Effect. Although some authors include the variations in inventory and productions in the definition of this phenomenon (Agrawal, Sengupta et al. 2009; Springer and Kim 2010; Ciancimino, Cannella et al. 2012), there is general consensus on the definition of the Bullwhip Effect being *"…the tendency of orders to increase in variation as one moves up in a supply chain"* (Croson and Donohue 2006).

Empirical proof for the Bullwhip Effect was mainly found in the eighties (Blinder 1982; Blanchard 1983; Burbidge 1984; Caplin 1985; Blinder 1986; Kahn 1986; West 1986; McKenney and Clark 1995). The most well-known cases in which the Bullwhip Effect was empirically demonstrated were Pampers at Proctor&Gamble, printers at Hewlett Packard and pasta at Barilla (Lee, Padmanabhan et al. 1997; Simchi-Levi, Kaminsky et al. 2003). The MIT Beer game (Sterman 1989) is the most famous experimental demonstration of the Bullwhip Effect. In these cases author discovered the significant effect of the Bullwhip Effect on the reliability and costs of individual companies and Supply Chains. Increasing variations in orders makes demand for suppliers less predictable and increases the chances on stock outs (Croson and Donohue 2006), while on the other hand the amplified variations in orders, inventories and production increases the operational costs due to contingencies and the necessary investments in capacities for transportation, storage and production assets (Lee, Padmanabhan et al. 1997).

Since the nineties the research focus of Bullwhip Effect extended to understanding the causes of the Bullwhip Effect and finding solutions for the problem. Also more in depth research was conducted towards the quantitative effect of specific factors, such as lead times (Chen, Drezner et al. 2000; Chen, Ryan et al. 2000; Disney and Towill 2003; Zhang 2004; Luong 2006; Duc, Luong et al. 2008; Agrawal, Sengupta et al. 2009; Sodhi and Tang 2011), systemic demand patterns (Luong and Phien 2007; Sodhi and Tang 2011), forecasting methods (Chen, Ryan et al. 2000; Disney and Towill 2003; Liu and Wang 2007; Wright and Yuan 2008), ordering policies (Baganha and Cohen 1998; Dejonckheere, Disney et al. 2003; Dejonckheere, Disney et al. 2004), batch sizes (Lee, Padmanabhan et al. 1997; Fisher 2000; Raghunathan 2001; Simatupang and Sridharan 2002; Agrawal, Sengupta et al. 2009), product properties (Fransoo J. C. and Wouters 2000), Supply Network structures (Sucky 2009) and knowledge (Croson and Donohue 2006).

Common research focus of scholars

During these proceedings in research towards the Bullwhip Effect, the focus has become to lie on the operational systemic behaviour of Supply Chain parties within given organizational and operational structures. Researchers that assume fully rational behaviour of actors have used analytical methods, Filter Theory, Control Theory and discrete or continuous simulation models to investigate the effects of changes in the above described aspects, assuming actors to systematically follow fixed procedures in forecasting and ordering (Geary, Disney et al. 2006). Such procedures are sometimes optimization methods or heuristics within the given situation of information asymmetry. Other researchers have researched the effect of bounded rational actors according to the definition of Simon (1997) using real life experiments in which the organizational and operational structure are static and given (Sterman 1989; Croson and Donohue 2003; Nienhaus, Ziegenbein et al. 2003; Croson and Donohue 2006).

Causes of the Bullwhip Effect

The identified causes for the Bullwhip Effect follow this research focus. Lee, Padmanabhan et al. (1997) identify the four most commonly accepted causes of the Bullwhip Effect based on strategic interactions of fully rational actors in a situation of information asymmetry: Demand signal processing, order Batching, Rationing gaming and price fluctuations and Demand signal processing refers to the dynamic ordering behaviour of companies as a response to the incoming orders of customers. The delay in information flows and material flows creates an overreaction which is the source of upward and downward fluctuations in orders. Order batching refers to the tendency of companies to consolidate their demand in larger orders which are ordered in lower frequencies. Rationing gaming arises when customers experience frequent stock outs and perceive supply to be unreliable. As a result they structurally overstate their needs to assure product availability when suppliers ration their deliveries according to order sizes in cases of stock outs. Price variations are a source of strategic forwards buying which causes concentration of order quantities in periods of low pricing.

Sodhi and Tang (2011) research the causes for the Bullwhip Effect in the case of full information transparency and full rationality of actors in order to distinguish the core causes of the Bullwhip Effect. They find a Core Bullwhip Effect that is only present when demand is uncertain and lead times are larger than zero. Additionally they describe an incremental Bullwhip Effect that is caused by operational deviations from theoretical ideal order sizes in the situation of perfect information symmetry and full rationality of actors caused by lags in information sharing, necessary batch sizes and operational inaccuracies

In addition to these two models, the existence of the Bullwhip Effect is explained by bounded rationality leading to behavioural errors in operational behaviour (Andraski 1994). Sterman (1989) demonstrates in his experiment that participants of the Beer Game misperceive given information. Croson and Donohue (2003) and Croson and Donohue (2006) explain this misperception by the reduced recency and saliency of feedback information, meaning the feedback to be delayed and unclear. From a more generic perspective Holweg and Disney (2005), Holweg, Disney et al. (2005) and Lapide (2001) demonstrate that bounded rationality prevents companies to understand well how to benefit from external collaboration and demand visibility in Supply Chains.

Solutions of the Bullwhip Effect

Also the proposed solutions for the Bullwhip Effect focus on changing the operational structure in which actors behave. First of all, scholars have proposed to internally change the planning functions of companies, such as making forecasting methods more accurate (Metters 1997; Luong 2006) and smoother (Chen, Ryan et al. 2000; Disney and Towill 2003). Also changes in inventory management (Baganha and Cohen 1998), ordering policies (Chen and Disney 2003; Dejonckheere, Disney et al. 2003; Disney and Towill 2003; Cannella and Ciancimino 2010), Order Penetration Points (Disney and Towill 2003), production policies (Disney and Towill 2003) and transportation policies (Lee and Whang 2006) are changes in Supply Chain structures which are proposed as solutions. Also scholars have proposed shortening lead times (Van Ackere, Larsen et al. 1993; Lee, Padmanabhan et al. 1997; Fransoo J. C. and Wouters 2000; Croson and Donohue 2006; Sodhi and Tang 2011) and improving the accuracy (Disney, Naim et al. 2000; Sudhir and Chandrasekharan 2005; Strozzi, Bosch et al. 2007; Sodhi and Tang 2011) and flexibility (Burbidge 1981; Lee 2004) of operations.

Also, inter-organizational changes are proposed by scholars. The integration of companies (Lee, Padmanabhan et al. 1997; Geary, Disney et al. 2006; Sodhi and Tang 2011) or centralized coordination of operational planning (Lee and Billington 1992; Towill 1996; Lee, Padmanabhan et al. 1997; Lee, Padmanabhan et al. 1997; Fransoo J. C. and Wouters 2000) would reduce the information asymmetry between companies. This can also be achieved by sharing information about Point of Sale data (Lee, Padmanabhan et al. 1997; Chen, Ryan et al. 2000; Fransoo J. C. and Wouters 2000; Croson and Donohue 2003; Croson and Donohue 2006), availability of resources (Simatupang and Sridharan 2002; Croson and Donohue 2006) and performances and financial information (Simatupang and Sridharan 2002).

Many scholars propose predefined methods, such as Vendor Managed Inventories (Çetinkaya and Lee 2000), Collaborative Planning, Forecasting and Replenishment (Holmstrom, Framling et al. 2000), Continuous Replenishment (Simatupang and Sridharan 2002), Efficient Consumer Response (Cachon and Fisher 1997), Synchronized Supply Chains (Anderson and Lee 1999; Ciancimino, Cannella et al. 2012), Synchronized Consumer Response, Supply Chain Reengineering/Business Process Redesign (Berry, Naim et al. 1995), Rapid Replenishment, Quick Response Manufacturing (Lee, So et al. 2000). Most of these methods combine the principles of internal change of operations with inter-organizational integration and information exchange.

Towards an extended problem focus

Although most scholars demonstrate the effectiveness of their solutions for all involved Supply Chain parties in their research, most companies are hesitant to implement their solutions. Companies do focus their strategies on Supply Chain cooperation and synchronization (Anderson and Lee 1999) and the quantity and quality of shared information in Supply Chains increases (Croson and Donohue 2006). Reality, however, also shows that companies are hesitant to initiate collaborative programs. Tsay and Lovejoy (1999) conclude that implemented solutions for synchronization of Supply Chains have often turned out to result in counterproductive outcomes. We believe this is caused by the limited scope of scholars who focus solely on the operational direct causes of the Bullwhip Effect, but ignore the barriers which exist on the tactical and strategic decision making level of companies.

Therefore we have extended our scope to find not only the causes for the existence of the Bullwhip Effect, but also for the persistence of the problem. We have explored organizations as nodes in complex Supply networks rather than single Supply Chains. Organizations are modelled as groups of divisions which behave as independent actors in hierarchical structures in which positions, responsibilities, authorities, procedures and rules are top down assigned to them. These actors are considered to be self-interested and bounded rational, meaning that they have a limited perceived reality and perception of available decision making options based on their available information and competences and external institutions. Within their perceived reality, actors compare their expected outcomes of decision on their interests and make decisions accordingly to these aspects. The outcomes of past decisions will add to their knowledge. This actor model is based on the 'Internal Action Situation Framework' of Ostrom (2005). This exploration has led to the restructuring of problem perspectives in which the existence and persistence of the Bullwhip Effect can be explained. Essentially we have identified four additional barriers for companies to cooperate and share information to solve the Bullwhip Effect and synchronise their operations.

Supply Network complexity

Companies are often part of complex Supply Networks with large numbers of suppliers and customers. Collaboration and information sharing with all these parties is therefore unfeasible (Stank, Keller et al. 2001; Holweg, Disney et al. 2005), because companies do not have the resources and benefits do not outweigh the investment costs, especially for the often numerous smaller customers and suppliers. Additionally, the uncertainty of long term future cooperation with these parties opposes unacceptable investment risks (Fransoo J. C. and Wouters 2000). Finally, any centralization of coordination in Supply Networks creates the problem of delineating cooperation boundaries.

Self-interested and local optimizing companies

The Bullwhip Effect is known to propagate upstream Supply Chains. This implies that any improvement made in the reduction of order variances will benefit all upstream parties, however the actor that reduces the amplification of order variances will act like an inventory buffer and experience higher average inventories and related costs. Therefore in general, downstream parties do not have direct incentives to reduce the Bullwhip Effect for upstream parties. Since actors are known to be self-interested actors which optimize their local internal environment (Fiala 2005; Disney and Lambrecht 2008; Ouyang and Daganzo 2008), they will not adopt system wide optimal behaviour which reduces the Bullwhip Effect unless they are compensated for their additional costs in higher inventories. Because most downstream parties are distributors without production activities, they will only optimize their transportation and inventory costs through for example the principles of Economic Order Quantities, which further exacerbates the Bullwhip Effect.

Competitive commercial relationships

From an economic perspective, the synchronization of operations between suppliers and buyers has positive externalities: Any improvement in operations made by one Supply Chain party, positively influences others. There are structural incentives for alignment and integration operations, which includes information sharing. However, the commercial relation of the same parties has negative externalities. There is a structural conflict between purchasers and sales representatives in prices and quantities (Simatupang and Sridharan 2002). Sharing information to achieve synchronization of Supply Chain operations weakens the strategic bargaining position from a commercial seller-buyer relation, especially information that reveals financial and marketing positions. This dilemma creates a barrier to share information and cooperate (Fransoo J. C. and Wouters 2000; Cachon and Lariviere 2001; Holweg, Disney et al. 2005).Gupta, Steckel et al. (2002) have experimentally proved that information transparency does lead to strategic behaviour of actors and inferior Supply Chain outcomes due to the interaction of individual behaviour.

Internal coordination of company divisions

The goals and performance metrics which incentivize the behaviour of individual departments within companies are a cause for both the existence and persistence of the Bullwhip Effect. Especially sales divisions are incentivized to push inventories downstream (Simatupang and Sridharan 2002), overstate their customers expected needs, create price promotions and negotiate quantum discounts, which disrupts the demand of customers and flows of goods. Purchase divisions are incentivized to capitalize on price promotions and quantum discounts through forward buying. On the other hand operational divisions are not incentivized through performance metrics and areas of responsibilities to improve the performance of the inter-organizational alignment of companies. This creates a barrier to engage in inter-organizational cooperation (Holweg, Disney et al. 2005; Fu and Zhu 2010). The risk averse nature of economic actors (Ostrom 2010), resistance against change (Bowersox 1990) and managerial inertia (Simatupang and Sridharan 2002) amplifies these barriers.

With the extension of the causes of the Bullwhip Effect with these four barriers, one is able to better explain why companies are hesitant to implement commonly proposed solutions and why their results are disappointing. First of all, internal changes in the operational system and planning functions are blocked by the incentives that internal organizational coordination structures provide to operational and commercial division. Also from the perspective of local optimization, adapting the operational system to reduce the amplification of demand variations does not always benefits the company itself, however reducing lead times and improving the flexibility and accuracy of processes does. Secondly, the perceived strategic importance of operational, commercial and financial information retains companies from sharing it. Again, the self-optimizing nature of companies and internal organizational structures disincentivize actors within organizations to adopt solutions for the Bullwhip Effect. Also, the complex Supply Network structure creates a barrier for implementation. The third solution group, centralized coordination and organizational integration has the same barriers as information sharing, although they are expected to be even stronger since these solutions are more radical.

Reading guide

In this article we propose and evaluate Forecast Accuracy Discount (FAD) agreements as decentralized solutions which solve the Bullwhip Effect through financially incentivizing customers to order in accordance to prior forecasted expected order totals. In the next chapter we will elaborate on the research approach and methods which are used to define and evaluate these agreements. In chapter 3 the design and mechanisms of the FAD agreements are discussed. Then in chapter 4 the simulation model is elaborated, followed by the approach towards testing the effects of FAD agreements using this model. Chapter 5 summarizes the results and Chapter 6 concludes on the effects of the FAD agreements on the behaviour of Supply Chain parties and results on the Bullwhip Effect.

2. A new research approach

In order to overcome the problems that most centralized solutions have in complex Supply Networks we have explored the possibilities of decentralized agreements between suppliers and customers in which the emergent behaviour of interactions among all actors in the network results in system wide reduction of the Bullwhip Effect through the principles of self-organization in networks (Prehofer and Bettstetter 2005). Some author have also considered agreements as solution for the Bullwhip Effect (Whang 1995; Lariviere, Tayur et al. 1999; Tsay and Lovejoy 1999), however research within this focus is limited. We also have identified that the barriers for implementing common solutions lie in the strategic behaviour of self-interested of companies and their divisions. Therefore we have focussed on defining arrangements that indirectly incentivize productive behaviour of actors rather than directly instructing or constraining them. We also believe creating incentive structures which aligns the interests of all parties in reducing the Bullwhip Effect, lead to more fundamental long term changes in operational structures.

We have explored the possibilities of decentralized agreements within Supply Networks which reduce the Bullwhip Effect by incentivizing productive behaviour of actors and overcome the strategic barriers for adopting common solutions that have been presented in the introduction. We have operationalized this research problem by defining the goals and requirements of the design. We consider the design to be successful when it reduces the negative effects caused by the Bullwhip Effect, which are essentially lower customer service levels and higher total costs. The increased variations in orders lead to higher variations in inventories and production as well, increasing the operational, capacity investment and contingency costs for transportation, warehousing and production all together. The aim of our research was to find a solution that reduces the sum of all costs for all involved parties, while maintaining or improving the service levels. This is a common practice in operations management (Duc, Luong et al. 2008). For the design itself we have defined requirements for acceptability by all involved actors and institutions, feasibility within common Supply Networks and companies and general applicability to most products and Supply Networks.

For both the design of the Forecast Accuracy Discount Agreement as the testing of this agreement, we have used a case study approach based on a pragmatistic epistemology using mixed qualitative and quantitative methods. For the definition of the designs the case study was complemented with a theoretical literature research and for testing the effects of the FAD agreements a discrete simulation model was made according to the empirical situation of the case study. The case study concerned a specific product group of a strategic supplier , supplied to the Technische Unie, a Dutch based wholesaler which is a subsidiary company of the Sonepar Holding. The Technische Unie is a wholesaler with a focus on tailored distribution of components for installations in buildings to contractors. The specific supplier within this case study has requested to remain anonymous and will be referred to as “supplier” in the text and “LG” in the data tables in the annexes. For a small selection of seven products which are representative for the entire product portfolio which this supplier provides to the Technische Unie, the effects of the FAD agreements on the operational performance of both these parties were simulated and the outcomes were used to evaluate their incentivized behaviour.

3. Forecast Accuracy Discount agreements

The idea of dampening the feedback of forecast errors into future orders has been proposed by many scholars in the field of control theory (Chen and Disney 2003; Dejonckheere, Disney et al. 2003; Disney and Towill 2003; Cannella and Ciancimino 2010). These scholars propose an adjusted order-up-to policy in which customers systematically only order a fraction of the desired order quantity to bring the inventory back to their desired level. Although they demonstrate the beneficial effects of such policies on the Bullwhip Effect, actual application of these ideas are scarce. The Forecast Accuracy Discount agreements are designed with the similar idea to smoothen orders by financially incentivizing customers to do so. The core idea is that the supplier provides the customer discounts on their purchase prices when their orders are according to previously provided forecast of their expected orders. The discount percentage depends on the accuracy of the actual order totals towards the predictions of the customer. A very similar idea was developed by Eppen and Iyer (1997) to incentivize retailers in the apparel industry to truthfully indicate their expected sales quantities of seasonal collections to clothing manufacturers, however the idea has never been researched as a solution to the Bullwhip Effect.

Such Forecast Accuracy Discount arrangements directly incentivize strategic cost optimizing behaviour in placing orders and strategic risk averse behaviour towards indicating expected future orders, which both contribute to the reduction of oscillations in order quantities. Indirectly, the arrangements incentivize the customers to change their operational processes regarding ordering policies and inventory management. They will more likely adopt methods that will smoothen their orders, while unexpected demand deviations are buffered by dynamic inventory quantities. These arrangements can be explained as mechanisms in which suppliers are willing to pay for the Bullwhip Effect reducing behaviour of customers. As long as the cost reductions for the supplier outweigh the extra costs for customers, a discount configuration can be found that redistribute cost and incomes so that both the supplier as the customer experience a reduction of costs, while maintaining or improving their service levels.

Agreement mechanism

During the agreement the customer provides the supplier with forecasts of expected total order quantities of future time intervals, for example weeks, which must be defined before a deadline of a certain number of these time intervals, for example four weeks, called the forecast sharing horizon The customer remains free to place any orders before the deadlines provided by the supplier, unlike other proposed arrangements to solve the Bullwhip Effect. (Bassok and Anupindi 1995; Bassok and Anupindi 1997; Lee, Padmanabhan et al. 1997).The discount percentage the customer receives over the total ordered quantities in a forecast interval, then depends on the deviation between the forecasted quantity and actual ordered quantities in that period. Also, both parties have to agree on a maximum discount that will be granted when the customer orders exactly the forecasted amounts. They also have to agree upon a deviation bound. When order quantities have larger deviations from the forecasts than these bounds, no discounts will be given anymore. Deviations within these bounds will result in a discount that is a fraction of the maximum discount, equal to the fraction of the deviation towards the set bounds. Figure 1 visualizes this discount structure.

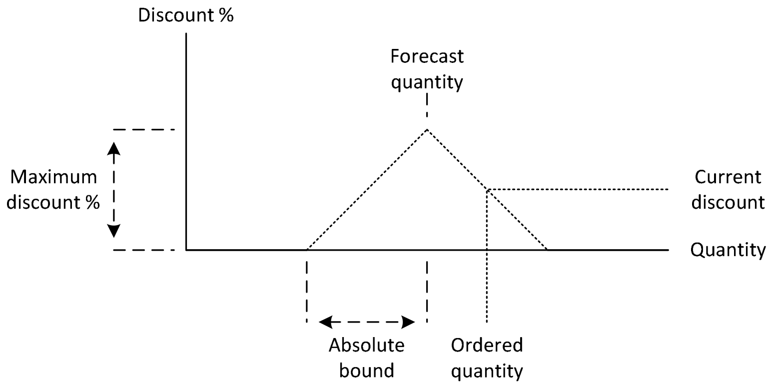

Figure 1: Visualization of the mechanism of Forecast Accuracy Discounting agreements

Initially, the FAD mechanism is expected to incentivize the customer to share its actual expected orders according to its own forecasts, inventory positions and ordering policies. Later on, forecast inaccuracies change the proposed orders according to the ordering policies of the customer. The customer is then expected to find a cost optimum between ordering according to its shared forecast and receiving maximum discounts and ordering according to its ordering policy, which assures local optimal operational costs. This will effectively dampens any deviations from the forecasted orders. More indirectly, the FAD agreements incentivize the customer to start sharing forecasts that will increase their chances to be able to order according to it. These forecast are expected to be smoother according to long term expected mean demand or their markets. Also customers are expected to adapt their ordering policies by increasing order frequencies in order to be able to better predict their own orders.

Forecast sharing time intervals, horizons, discount bounds and the maximum discounts are parameters which are periodically renegotiated by the two parties. Short forecast sharing time intervals are expected to be preferred by both the supplier, because it increases the information accuracy of orders, and the customer, because it enables spreading expected quantities over multiple periods, increases the expected discounts. For the discount bounds, the parties will probably arrive at a reasonable figure related to the average order quantities and historical deviations. The maxim discounts are expected to be negotiated to a level where it both benefits the customer and supplier by reducing their total costs. Finally the interests for the forecast sharing horizon are uncertain. Therefore we have included the effects of different forecast horizons in the evaluation of the design in the simulation of the case study.

Additional conditions

In order to assure the effectiveness of the Forecast accuracy agreement it is first of all important to offer customers minimal lot sizes and order increments which are small enough to enable them to smoothen orders and increase order frequencies. Because the physical properties of the operational system of the supplier is determining the minimum possible quantities, they will have to decide upon this figure. Reducing minimum lot sizes and increment is also proposed by other authors as a solution of the Bullwhip Effect (Cachon 1999; Fransoo J. C. and Wouters 2000; Simatupang and Sridharan 2002; Sodhi and Tang 2011), as well as increasing order frequencies (Fransoo J. C. and Wouters 2000). Also suppliers will have to commit to deliver on due dates rather than before them to assure operational benefits in predictability and planning capabilities for the customer. In order to make the agreements more effective, agreements upon shortening lead times are possible too. Finally, counterproductive incentives should be removed in the FAD agreement by abandoning quantum discounts on single orders to disincentivize order batching (Lee, Padmanabhan et al. 1997) and adopt rationing policies which are not discriminatory to order registration dates to incentivize last minute ordering.

Suitability of the design towards the described barriers

Forecast Accuracy discount agreements are expected to overcome the before mentioned four implementation barriers that other solutions for the Bullwhip Effect have. Because FAD agreements are decentralized, flexible to adapt, simple to understand and require little additional organizational effort to operate, they are more suitable to implement in uncertain dynamic and complex Supply Networks. The shared order forecasts does not contain any additional strategic information and are therefore not sensitive to competitive relations and the redistribution of financial benefits through the discounts incentivizes the parties to seek new local operational optima’s which increase the system wide Supply Chain performance. Finally, the FAD agreements do not interfere with the organizational structure, however once adopted, they provide financial incentives to redefine internal responsibilities and authorities of organizations to fully benefit from their potential.

4. Simulation model

The effects of Forecast Accuracy Discount agreements were tested using an empirical, discrete, event based simulation model of the case study. The model simulates the Supply Chain operations for seven products which are representative for the entire product group over 2012 using a discrete, incremental time logic of days. In the model the Technische Unie and the supplier are simplified as single sites in which the Technische Unie only holds inventories of trade product, which it receives of the supplier and sends to customers. The supplier is modelled as a production site. It receives materials of suppliers, stores them, manufactures them into finished products, which are then stored and send to the Technische Unie and other customers. For some products the supplier is only a distributor with a structure that resembles the Technische Unie.

Model logic

The simulation model contains the flows and storage of goods and information through state variables. Every day a number of processes are performed by the supplier and the Technsiche Unie which defines the flows and mutations of goods and information. A situation of information asymmetry is present in the model, by limiting the availability of state variables for the processes of the two companies. The model operates three types of processes for both companies every day in a fixed order: First the flows of goods are defined between inventory points based on production and purchase orders, backlogs and availability. The model assumes every flow can be performed within one day, which is empirically valid in the case study. Then the backlogs and inventories are updated according to the flows. Finally, production and purchase orders are planned and then defined according to the ordering policy procedures using available data about expected customer demand and current inventories and backlogs. The model does not have any capacity constraints and all processes are fully deterministic. Also these assumptions are valid for the case study within the empirical situation over 2012.

Demand and forecasting

The model uses the actual historical demand of the selected products for customers of the Technische Unie and customers of the supplierother than the Technische Unie. In order to assess the sensitivity of the simulation outcomes towards specific contingencies in demand over 2012, such as incidental exceptionally high customer demand, the demand distribution and seasonality has been analysed for each product and 1000 representative samples have been defined. The model also uses historical forecasts instead of a forecasting function which provide forecasted demand totals for 13 periods of four weeks. Simplifying the forecasting function was possible, because the forecasts of both companies are solely dependent on the historical demand of that period in the previous years, which are outside the scope of the model. For the sampled demand, the periodical demand total has been scaled through the seasonality to match the empirical totals, which ensures theoretical identical forecasts.

Planning functions

The Technische Unie uses a (S, s) ordering policy, which works with variable order intervals and quantities, but aims for a fixed Mean Days Between Orders. It uses the forecasts, current inventories, backlogs and already placed orders to define the days in which the inventories are expected to fall below the safety stock and then plans an order due date on that day. The order quantity is fitted to create expected order intervals equal to the desired Mean Days Between Orders. The Technische Unie uses a system of dynamic safety stocks which are based on the historical forecast errors in the given forecasting period. In the simulation model the historical forecasts are used as input. The supplier uses a (s, Q) ordering policy, which plans orders with variable time intervals and fixed quantities for both production and purchase orders. Dependent on the position of the Order Penetration Point at either materials or finished products, the orders are defined by combining the forecasted customer demand with actual customer orders, together with inventories, backlogs and already placed orders. Also this system calculates the expected moment in which the inventory falls below the safety stock and places an order due on that day. Time fences, based on the lead times of production or suppliers, are used to define the first possible due dates. Also the supplier has dynamic safety stocks, however they are only changed four times per year. Also for the supplier, the historical safety stocks were used.

FAD functions

For the functioning of the Forecast Accuracy Discount agreements two processes were added based on realistic heuristics in the case study. First, the definition of shared forecasted quantities of the Technische Unie is simulated through sharing the actual expected orders per week according to their ordering policy. In simulation cases where the FAD agreements are active, the ordering policies are adjusted following a heuristic in which the Technische Unie always orders according to its forecasts unless more is required. The additional order quantities are then kept to a minimum. The second added process is the redefinition of forecasts by the supplier based on the shared forecasts. This process uses the heuristic to fully replace the initial expected demand of the Technische Unie by its shared forecasts, assuming them to be more reliable. Market shares of the Technische Unie are used to define which share of the forecasts needs to be replaced.

Performance measurement

In order to define the effects of the FAD agreements on service levels, total costs and the Bullwhip Effect, we have defined three major Key Performance Indicators to measure these aspects for both the Technische Unie as the supplier. Additionally we have defined KPI's to indicate the effects on fluctuations in inventories, production and orders and the functioning of the FAD agreements itself. For service levels, we have defined two indicators: the percentage of total order quantities that was delivered on time to customers and the number of days in which no additional backlogs were created. As a major cost indicator we have defined the inventory turnover rate as the ration between the total demand over 2012 divided by the daily average inventory. Finally the Bullwhip Effect was measured by calculating the amplification ratio of the standard deviation of customer orders and placed orders, standardized by their daily mean values to correct for inequalities in customer orders and placed orders using weekly time intervals.

Equation (1-4) show the method in which the standardized oscillation *O* at echelon level i is calculated, based on mean *μ* and standard deviation *σ*, containing the total demand *D* within each time interval *n* with a length *T* of 7 days over a total *N* of 52 time intervals. The values of D_n are the sum of the individual demands *d* at times *t* within the specified time intervals of D_n.

(1) $O_i = \frac{\sigma_i}{\mu_i}$

(2) $\mu_i = \frac{1}{N} \sum_{n=1}^{N} (D_n)$

(3) $\sigma_i = \sqrt{\frac{1}{N} \sum_{n=1}^{N} (D_n - \mu_i)^2}$

(4) $D_n = \sum_{t=(n-1)T}^{nT} (d_t)$

The amplification *A* at echelon *i* is defined by dividing the standardized oscillations of placed orders by those of the incoming orders, as shown in equation (5)

(5) $A_i = \frac{O_{i+1}}{O_i}$

In order to gain further insight in the effect of the FAD agreements on fluctuations in inventories, production and transportation and their related costs, we have defined the KPI's for the average, maximum and days of flows through these functions which respectively provide insight in contingency, capacity investment and resource utilization costs. Specifically for inventories the flows have been divided in inbound and outbound flows and additionally the average inventories were calculated to indicate the inventory carrying costs. Finally we have defined two KPI's indicating the accuracy of the shared forecasts by the Technische Unie by stating the average forecast deviation and the average provided discounts by the supplier. These have been normalized to be comparable among the different products.

Product selection

Exploratory empirical research towards the case study has revealed that Bullwhip Effect values for the Technische Unie are significantly dependent on the products' lead times in relation to the order intervals of customers, order increment sizes in relation to yearly total demand and the logistical classification as either fast or slow moving products. Fast moving products, long relative lead times and high relative increments were found to be product properties which correlate with higher Bullwhip Effect values. We have created two groups for each product property in which Bullwhip Effect values were significantly different for the Technische Unie and have selected products from each of the eight categories. Table 1 displays these categories and the selected products. A total of six cases were created, because empirically no slow moving products existed with lead times shorter than the order intervals due to the inventory management policies of the Technische Unie.

Logistical category	% Lead time of order intervals	% order increments of total annual orders	Product number
Fast mover (A-D)	<=100%	<=1%	4536827 and 4536835 combined
		1%<=25%	4255030
	>100%	<=1%	4536553
		1%<=25%	4531430
Slow mover (E-F)	<=100%	<=1%	-
		1%<=25%	-
	>100%	<=1%	3407384
		1%<=25%	4256632

Table 1: Product selection for simulation based on product properties according to the Technische Unie

Validation

The model structure, input data and parameters have been validated through expert review by the operational managers of the Technische Unie and the supplier. The outcomes have been validated by empirical comparison of orders placed by the Technische Unie and placed orders, inventories and production by the supplier. For this purpose the model used the historical orders of the Technische Unie as demand input for the supplier rather than the simulated orders to improve the accuracy of the validity assessment.

Simulation approach

We have tested the operational effects of the Forecast Accuracy Discount agreements and according changes in order intervals of the Technische Unie, lead times of the supplier and constraining order and production increments of both parties whenever applicable. We have done this by defining a total of 25 unique simulation cases per product which were simulated using 1000 samples of the demand of customers of the Technische Unie to define the average values of the KPI's and their standard deviations. The 25 unique cases were defined by combining five configurations of order intervals, changed by adjusting the Mean Days Between Orders (MDBO), lead times and increment sizes with five configurations in forecast sharing horizons for the FAD agreements. The outcomes of these cases were both analysed for the Technische Unie as the supplier to define how they incentivize their tactical preferences for conditions in the agreements and strategic behaviour in adjusting their operational structures.

The first five configurations are: 1) the empirical situation, 2) alleviation of increments, 3) alleviation of increments and the MDBO set to 13 days, 4) alleviation of increments and the MDBO set to 7 days and 5) alleviation of increments, the MDBO set to 7 days and the lead times set to 7 days. Appendix I displays the changes for each of the six products in each situation. Exploratory research has revealed that the alleviation of increments is a prerequisite for the other changes to have any effect. Therefore it has been applied to all other cases than the empirical null case. Because the empirical lead times for all of the six products are 13 days, the current situations include all four possible situations in which both order intervals and lead times vary between 7 and 13 days.

The five configurations of the FAD agreements consist of the null case without the agreements and four cases having forecast sharing horizons between 2 and 5 weeks. As described before, the discount bounds and maximum discount percentages are not tested, because they influence the behaviour of actors on a tactical and strategic level. Changing these values does not influence the operational behaviour in the simulation either, however they do influence the outcomes of the forecasting accuracy and provided discount KPI's. The static values of these parameters are displayed in Appendix I too for each product.

5. Simulation results

The simulation results indicate that both the Technische Unie and the supplier are simultaneously able to reduce their Bullwhip Effect and fluctuations in inventories, production and orders, while maintaining their service levels. This can be achieved by adopting Forecast Accuracy Discount Agreements with longer forecast sharing horizons of 5 weeks in combination with alleviating constraining increments, reducing order intervals of the Technische Unie and lead times of the supplier to an equal level of 13 or 7 days and raising their safety stock levels to maintain acceptable service levels. This general finding is supported by a number of findings.

First of all, a comparison of all simulation cases towards their empirical null cases confirms a well-known principle that higher inventories always lead to equal or higher service levels and vice versa. Appendix II displays an assessment of all cases without active FAD agreement according to this principle which confirms the principle, implying that service levels can be adjusted by changing the average inventories by adjusting safety stock levels. Secondly, a sole analysis of the effects of alleviating increments reveals that it reduces the Bullwhip Effect and fluctuations in inventories, production and orders for the Technische Unie and the supplier, but also may lead to lower inventories and service levels, however this can be corrected by raising safety stocks. Appendix III contains a table with the sole effects of alleviating increments for all six products, confirming this finding. Furthermore, complementing the alleviated increments with shorter order intervals further reduces fluctuations in inventories, production and orders and average inventories for the Technische Unie and The supplier. Appendix IV displays the additional effects of changes in the Mean Days Between Orders of the Technische Unie confirming decreases in these fluctuations when order intervals are reduced and increased fluctuations when order intervals are increased. Finally the reduction of both order intervals and lead times from 13 days to 7 days does reduces fluctuations in inventories, production and orders and average inventories for the Technische Unie and The supplier in some cases for fast moving products. Appendix V displays the relative effects of such a simultaneous reductions. This results in the general finding that both the Technische Unie and The supplier benefit from alleviating their constraining increments, reducing order intervals and lead times accordingly as long as they adjust their safety stocks to maintain service levels

The effects of the Forecast Accuracy Discount agreement mechanisms towards the different situations in order intervals, lead times and increments are variable and dependent on the forecast sharing horizon. When taking into account that service levels and average inventories can be corrected by adjusting safety stocks, Pareto Improvements towards the empirical null case for both the Technische Unie as The supplier can only be achieved in all cases when order intervals and lead times are both either 13 or 7 days and increments are alleviated. In these cases the best results are obtained when forecast sharing horizons are longer, in this case 5 weeks. In all cases higher forecast sharing horizons always lead to higher forecasting accuracy towards The supplier and higher obtained discounts by the Technische Unie. Appendix VI visualizes these results. This results in the general finding that both parties benefit from higher forecasting horizons and it contributes to the optimal situations for order intervals, lead times and increments.

Implementing Forecast Accuracy Discount agreements with the according conditions to alleviate constraining increments and reducing order intervals and lead times to an equal acceptable level in accordance with raising the safety stock levels to maintain original service levels may result in higher average inventories for both the Technische Unie as The supplier, which results in higher inventory holding costs, however lower fluctuations in inventories, production and orders will reduce the capacity investment costs and contingency costs of handling, manufacturing and transportation. These benefits are expected to be higher for The supplier as a manufacturer as for the Technische Unie as a distributor, especially because the shared forecast create more demand predictability for The supplier, however the discounts which the Technische Unie receives will compensate this inequality. This creates a Pareto Improvement in total operational costs and service levels for both The supplier as the Technische Unie.

Incentivized behaviour

Given the static systemic operational behaviour and the assumed applied heuristics, both the technische Unie as the supplier have aligned interests to adopt the Forecast Accuracy Discount agreements and reduce the increments, order intervals and lead times as much as realistically possible on the short term, given the physical constraints of their current operational system. The incentive to shorten order intervals and lead times is however weaker for slow moving products. On the long term The supplier has incentives to adapt the physical structure of its operational systems to suit smaller series sizes and more frequent and faster delivery whenever necessary. The Technische Unie is incentivized to adopt ordering policies which follow fixed order intervals to better suit the forecast sharing intervals.

For the conditions of the FAD agreements, the simulation shows that both the Technische Unie as The supplier prefer long time horizons, because it increases the predictability of the orders of the Technische Unie for The supplier and its increases the discounts for the Technische Unie. The simulation outcomes show that the Technische Unie is incentivized to follow the principals of honest forecast sharing and ordering according to their forecasts unless higher quantities are required.

For defining the discount bounds and the maximum discount percentages, the Technische Unie have constructive conflicting interests which will lead to optimal values. The Technische Unie will prefer higher bounds and maximum discount values and will only accept values that will lead to sufficient discount to reduce total costs. The supplier will prefer lower bounds and maximum discount values, but will have to provide enough maximum discounts and tolerance in the bounds to interest the Technische Unie. Then again, these minimal requirements of the Technische Unie should be small enough to remain total cost benefits for The supplier.

6. Conclusions

Assuming full rationality of actors, Forecast Accuracy Discount agreements reduce the Bullwhip Effect by incentivizing 1) daily operational behaviour, given the conditions of the Forecast Accuracy Discount agreement and operational structure of their organizations, 2) tactical behaviour regarding their preferences towards defining the conditions of the Forecast Accuracy Discount agreements and redefining their own planning parameters, given the operational structure of their organizations and 3) strategic behaviour regarding redefining their planning policies and physical operational systems in order to increase their benefits from the agreements.

From an operational perspective, the customer is incentivized to order as much as possible according to its shared order forecasts unless higher order quantities are strictly necessary to prevent stock outs. The customer is also incentivized to keep deviations to a minimum in order to receive maximum discounts. The customer is also incentivized to share its forecast honestly according to its own expectations, however in case of deviations the customer is incentivized to adjust its order forecasts to the average expected demand. This operational behaviour reduces the fluctuations in orders and increases the demand predictability for the supplier. Furthermore, the customer is incentivized to increase its safety stock levels to allow more accurate ordering towards its forecasts while maintaining its service levels.

From a tactical perspective both the customer and the supplier have aligned incentives to alleviate constraining order and internal production constraints. The customer has incentives to lower the order intervals and time intervals for which it shares order forecasts to the lead time of product. Furthermore it benefits both the supplier and the customer when both order intervals, forecast sharing intervals and lead times can be further reduced, especially for fast moving products. Also for the forecast sharing horizon both customers as suppliers have the aligned incentives to adopt longer horizons, preferably up to the total throughput time of the operational system of the supplier. For the discount bounds and maximum discount percentage in the Forecast Accuracy Discount agreement, the supplier and customer have conflicting interests, however they are expected to lead to a constructive outcome. The supplier prefers short bounds and low maximum discount, where the customer prefers these values to be as large as possible. The definition of these values will be the outcome of tactical negotiations and are expected to result in a situation where the transferred discounts result in total cost improvement for both parties.

Finally, from a strategic perspective, both the supplier as customer have incentives to adopt the Forecast Accuracy Discount agreements. Furthermore, the supplier has the incentives to adapt the physical structure of its operational systems to suit smaller series sizes which allow smaller increments in the future, as well as adapting its operational structure to support shorter lead times whenever possible. The customer has the incentives to revise its ordering policies towards a system with fixed order intervals and variable quantities to suit the nature of the Forecast Accuracy Discount agreements.

The above described behaviour assumes rational actors which are aware of the effects of Forecast Accuracy Discount agreement, however the validity of this rationality assumption is questionable. Most organizations operate from old industrial paradigms based on the principles of scales of economies and the ability of centralized control. Initially, organizations may not understand the potential benefits of adopting Forecast Accuracy Discount agreement and even when they do, there will be barriers to change. Due to the distribution of responsibilities and authorities in organizations, it may be in the interests of some divisions not to adopt the agreement. Especially for commercial divisions the Forecast Accuracy Discount agreements may be perceived as a threat for their authorities and performance. Also, priorities of organizations may lie at other issues, causing a lack of available resources to implement the agreements. Finally, in commercial relations where customers have strong power positions and are able to multisource at numerous suppliers, these cooperative agreements may not be in the interest of customers.

The Forecast Accuracy Discount agreements alone are not able to overcome these paradigm and interests barriers alone. It will require the understanding of its benefits and commitment of organizations to adopt them. Their simple nature, however, makes them more easy to understand and implement than previously proposed solutions for the Bullwhip Effect that require elaborate integration, centralization of coordination and the trust to share sensitive information. Therefore we propose Forecast Accuracy Discount agreements as a new solution for the Bullwhip Effect which is more feasible within the complex nature of today’s Supply Networks that grow in complexity, more suitable to the local-optimizing nature of organizations within Supply Networks, more acceptable towards the sensitive nature of operational information and easier to implement within the common authority and responsibility structures of organizations. We invite scholars to further research, criticise and refine the ideas of Forecast Accuracy Discount agreements and we invite companies to pilot these ideas to assess their empirical effectiveness in reducing the Bullwhip Effect and synchronizing Supply Chains.

7. Acknowledgements

We would like to specially show our gratitude to the Technische Unie and their supplier for their cooperation and investment in this research.

Appendix I: Simulation cases

Case names	**4536827 and 4536835**	**4255030**	**4536553**	**4531430**	**3407384**	**4256632**
Null case	Empirical	Empirical	Empirical	Empirical	Empirical	Empirical
Increment alleviation (IA):						
TU ordering increment		Fr 20 to 1		Fr 2000 to 25		Fr 10 to 1
LG production series size	Fr 600 to 15		Fr 600 to 30			Fr 7 to 1
LG replenishment series size	Fr 1200 to 150	Fr 160 to 20	N/A	Fr 12000 to 500	Fr 80 to 20	Fr 10 to 1
IA + MDBO = 13						
MDBO	Fr 14 to 13	Fr 28 to 13	Fr 7 to 13	Fr 7 to 13	Fr 28 to 13	Fr 28 to 13
IA + MDBO = 7						
MDBO	Fr 14 to 7	Fr 28 to 7			Fr 28 to 7	Fr 28 to 7
IA + MDBO = 7 + LT = 7						
MDBO	Fr 14 to 7	Fr 28 to 7			Fr 28 to 7	Fr 28 to 7
Lead time	Fr 13 to 7	Fr 13 to 7	Fr 13 to 7	Fr 13 to 7	Fr 13 to 7	Fr 13 to 7

Definition of five configurations of order intervals, lead times and increment sizes. Blank for no changes.

FAD parameters	**4536827 and 4536835**	**4255030**	**4536553**	**4531430**	**3407384**	**4256632**
Forecasting horizon	2, 3, 4, 5 weeks	2, 3, 4, 5 weeks	2, 3, 4, 5 weeks	2, 3, 4, 5 weeks	2, 3, 4, 5 weeks	2, 3, 4, 5 weeks
Maximum discounts	2%	2%	2%	2%	2%	2%
Discount bounds	400 units	20 units	180 units	2000 units	30 units	10 units

Definition of five configurations of FAD parameters. Only the forecast horizons are changed.

Appendix II: Assessment of correlation between service levels and inventories

		Nullcase		Increment Alleviation		IA + MDBO = 13		IA + MDBO = 7		IA + MDBO = 7 + LT = 7	
		TU	LG	TU	LG	TU	LG	TU	LG	TU	LG
4536827 and 4536835	Service level definition 1			Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive
	Service level definition 2			Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive
4255030	Service level definition 1			Positive	Neutral*	Positive	Neutral*	Positive	Neutral*	Positive	Neutral*
	Service level definition 2			Positive	Neutral*	Positive	Neutral*	Positive	Neutral*	Positive	Neutral*
4536553	Service level definition 1			Neutral**	Positive	Positive	Positive	Neutral**	Positive	Positive	Positive
	Service level definition 2			Neutral**	Positive	Positive	Positive	Neutral**	Positive	Positive	Positive
4531430	Service level definition 1			Neutral*	Positive	Neutral*	Positive	Neutral*	Positive	Neutral*	Positive
	Service level definition 2			Neutral*	Positive	Neutral*	Positive	Neutral*	Positive	Neutral*	Positive
3407384	Service level definition 1			Neutral**	Neutral*	Positive	Neutral*	Positive	Neutral*	Positive	Neutral*
	Service level definition 2			Neutral**	Neutral*	Positive	Neutral*	Positive	Neutral*	Positive	Neutral*
4256632	Service level definition 1			Positive	Neutral*	Positive	Neutral*	Positive	Neutral*	Positive	Neutral*
	Service level definition 2			Positive	Neutral*	Positive	Neutral*	Positive	Neutral*	Positive	Neutral*

*: Service levels remain at 100%

**: Case identical to the null case

Correlation form found of the relative changes towards the empirical null case for both service level definitions, all products and exclusive to cases without active FAD agreements.

Appendix III: Relative effect of alleviation of increments

		4536827 & 4536835		4255030		4536553		4531430		3407384		4256632	
Increment Alleviation (IA):													
TU ordering increment				20 to 1				2000 to 25				10 to 1	
LG production series sizes		600 to 15				600 to 30						7 to 1	
LG replenishment series sizes		1200 to 150		160 to 20		N/A		12000 to 500		80 to 20		10 to 1	
		TU	LG	TU	LG	TU	LG	TU	LG	TU	LG	TU	LG
General KPI's													
Service level	By perc of total quantities delivered on time	0,01	-0,11	-0,02	0	0	0	0	-0,1	0	0	-0,04	0
	By perc of days without any backlogs	0,01	-0,23	-0,02	0	0	0	0	-0,04	0	0	-0,04	0,02
Inventory turnover	Times per year for finished products	-0,02	2,55	0,21	0,61	0	2	0,49	2,44	0	0,16	0,53	2,63
	Times per year for materials		1,58		N/A		0		N/A		N/A		-0,03
Bullwhip Effect	Amplification on weekly level	0	0,56	0,19	0,43	0	N/A	0,64	0,64	0	0,19	0,28	N/A
Inventory KPI's													
Average inventory	Average of finished products	-0,02	0,72	0,18	0,38	0	0,67	0,33	0,71	0	0,14	0,35	0,73
	Average of materials		0,61		N/A		0		N/A		N/A		0
Max inventory	Maximum of finished products	-0,05	0,46	0,2	0,33	0	0,47	0,19	0,53	0	0,15	0,33	0,15
	Maximum of materials		0,49		N/A		0		N/A		N/A		0
Average inbound	Average inbound of materials/products	0,09	0,74	0,32	0,72	0	N/A	0,81	0,91	0	0,46	0,49	N/A
Max inbound	Maximum inbound of materials/products	0,02	0,51	0,3	0,45	0	N/A	0,62	0,79	0	0,19	0,27	N/A
Inbound frequency	Number of inbounds of materials/products	0,1	2,72	0,43	2,38	0	N/A	3,85	8,4	0	0,79	0,87	N/A
Average outbound	Average outbound of finished products	0,01	0,14	-0,01	0,07	0	0	0	0,38	0	0	0,01	0,27
Max outbound	Maximum outbound of finished products	0,03	0	0	0	0	0	0	0,25	0	0	0,07	0
Outbound frequency	Number of outbounds of finished products	0,01	0,17	-0,01	0,07	0	0	0	0,6	0	0	0,01	0,35
Production KPI's													
Average production	Average production quantity		0,67		N/A		0,74		N/A		N/A		0,62
Max production	Maximum production quantity		0,41		N/A		0,51		N/A		N/A		0
Production frequency	Number of production runs		1,95		N/A		2,76		N/A		N/A		1,43
Ordering KPI's													
Average orders	Average order quantity	0	0,74	0,32	0,72	0	N/A	0,82	0,91	0	0,46	0,49	N/A
Max orders	Maximum order quantity	0	0,51	0,3	0,45	0	N/A	0,62	0,79	0	0,19	0,27	N/A
Order frequency	Number of orders	0	2,72	0,43	2,38	0	N/A	4,29	8,4	0	0,79	0,87	N/A
FAD KPI's													
Forecast deviation	Average forecast deviation												
	Av forecast deviation as a perc of av demand												
Discount percentage	Average discount percentage												
	Av disc perc as a perc of the max poss discount												

Percentage differences of increment alleviation cases towards the empirical null cases, normatively expressed.

Appendix IV: Relative effect of changes in order intervals

		4536827 & 4536835		4255030		4536553		4531430		3407384		4256632	
IA + MDBO = 13													
MDBO		Fr 14 to 13		Fr 28 to 13		Fr 7 to 13		Fr 7 to 13		Fr 28 to 13		Fr 28 to 13	
		TU	LG	TU	LG	TU	LG	TU	LG	TU	LG	TU	LG
General KPI's													
Service level	By perc of total quantities delivered on time	-0,01	0	-0,03	0	0,01	0	0	0,01	-0,13	0	-0,05	0
	By perc of days without any backlogs	-0,01	0,01	-0,03	0	0,01	0	0	-0,03	-0,13	0	-0,05	0,02
Inventory turnover	Times per year for finished products	0,06	0	0,3	0	-0,19	0,02	-0,08	-0,01	0,35	0	0,3	0
	Times per year for materials		0,02		N/A		0		N/A		N/A		-0,02
Bullwhip Effect	Amplification on weekly level	0,09	-0,04	0,34	-0	-0,61	N/A	-0,41	0,03	0,1	-0,01	0,23	N/A
Inventory KPI's													
Average inventory	Average of finished products	0,05	0	0,23	0,01	-0,23	0,01	-0,08	-0,02	0,26	0	0,23	0,02
	Average of materials		0,02		N/A		0		N/A		N/A		0
Max inventory	Maximum of finished products	0,04	0,02	0,23	0	-0,26	-0,07	-0,01	0	0,06	0	0,2	0
	Maximum of materials		0,01		N/A		0		N/A		N/A		0
Average inbound	Average inbound of materials/products	0,06	0,01	0,47	-0,02	-0,71	N/A	-0,65	-0,01	0,38	0,04	0,42	N/A
Max inbound	Maximum inbound of materials/products	0,05	0,04	0,31	0	-0,43	N/A	-0,51	0,01	0,06	0,01	0,17	N/A
Inbound frequency	Number of inbounds of materials/products	0,06	0,01	0,86	-0,02	-0,41	N/A	-0,39	0	0,59	0,03	0,67	N/A
Average outbound	Average outbound of finished products	-0,01	0,02	-0,01	0,15	0	-0,26	0	-0,18	0,05	0,18	0,02	0,28
Max outbound	Maximum outbound of finished products	0	0,03	0,01	0	0,03	-0,2	0	0,03	-0,04	0	0,06	0
Outbound frequency	Number of outbounds of finished products	-0,01	0,02	-0,01	0,18	0	-0,21	0	-0,15	0,06	0,21	0,02	0,37
Production KPI's													
Average production	Average production quantity		0,02		N/A		-0,28		N/A		N/A		0,29
Max production	Maximum production quantity		0,01		N/A		-0,19		N/A		N/A		0
Production frequency	Number of production runs		0,02		N/A		-0,21		N/A		N/A		0,4
Ordering KPI's													
Average orders	Average order quantity	0,07	0,01	0,47	-0,02	-0,71	N/A	-0,65	-0,01	0,38	0,04	0,42	N/A
Max orders	Maximum order quantity	0,03	0,04	0,31	0	-0,43	N/A	-0,51	0,01	0,06	0,01	0,17	N/A
Order frequency	Number of orders	0,07	0,01	0,86	-0,02	-0,41	N/A	-0,39	0	0,59	0,03	0,67	N/A
FAD KPI's													
Forecast deviation	Average forecast deviation												
	Av forecast deviation as a perc of av demand												
Discount percentage	Average discount percentage												
	Av disc perc as a perc of the max poss discount												

Percentage differences of increment alleviation cases with MDBO's of 13 days towards the sole increment alleviation cases, normatively expressed.

		4536827 & 4536835		4255030		4536553		4531430		3407384		4256632	
IA + MDBO = 7													
MDBO		Fr 14 to 7		Fr 28 to 7						Fr 28 to 7		Fr 28 to 7	
		TU	LG	TU	LG	TU	LG	TU	LG	TU	LG	TU	LG
General KPI's													
Service level	By perc of total quantities delivered on time	-0,12	-0,04	-0,05	0	0	0	0	0	-0,19	0	-0,07	0
	By perc of days without any backlogs	-0,14	-0,04	-0,04	0	0	0	0	0	-0,19	0	-0,07	0,03
Inventory turnover	Times per year for finished products	0,53	0,05	0,47	0	0	0	0	0	0,52	-0	0,44	0
	Times per year for materials		0,13		N/A		0		0		N/A		-0,02
Bullwhip Effect	Amplification on weekly level	0,42	-0,33	0,48	-0,01	0	N/A	0	N/A	0,17	-0,03	0,33	N/A
Inventory KPI's													
Average inventory	Average of finished products	0,34	0,05	0,32	0,01	0	0	0	0	0,34	0,01	0,3	0,02
	Average of materials		0,12		N/A		0		0		N/A		0
Max inventory	Maximum of finished products	0,24	0,08	0,32	0	0	0	0	0	0,1	0	0,27	0
	Maximum of materials		0,13		N/A		0		0		N/A		0
Average inbound	Average inbound of materials/products	0,32	0,06	0,63	-0,02	0	N/A	0	N/A	0,58	0,04	0,57	N/A
Max inbound	Maximum inbound of materials/products	0,08	0,21	0,4	0	0	N/A	0	N/A	0,1	0,01	0,22	N/A
Inbound frequency	Number of inbounds of materials/products	0,45	0,05	1,64	-0,02	0	N/A	0	N/A	1,32	0,03	1,23	N/A
Average outbound	Average outbound of finished products	-0,08	0,15	-0,01	0,26	0	0	0	0	0,1	0,33	0,03	0,41
Max outbound	Maximum outbound of finished products	-0,09	0,08	0,01	0	0	0	0	0	-0,06	0	0,09	0
Outbound frequency	Number of outbounds of finished products	-0,07	0,17	-0,01	0,35	0	0	0	0	0,11	0,48	0,03	0,68
Production KPI's													
Average production	Average production quantity		0,15		N/A		0		0		N/A		0,42
Max production	Maximum production quantity		0,08		N/A		0		0		N/A		0
Production frequency	Number of production runs		0,18		N/A		0		0		N/A		0,7
Ordering KPI's													
Average orders	Average order quantity	0,32	0,06	0,63	-0,02	0	N/A	0	N/A	0,58	0,04	0,57	N/A
Max orders	Maximum order quantity	0,07	0,21	0,4	0	0	N/A	0	N/A	0,1	0,01	0,22	N/A
Order frequency	Number of orders	0,46	0,05	1,64	-0,02	0	N/A	0	N/A	1,32	0,03	1,23	N/A
FAD KPI's													
Forecast deviation	Average forecast deviation												
	Av forecast deviation as a perc of av demand												
Discount percentage	Average discount percentage												
	Av disc perc as a perc of the max poss discount												

Percentage differences of increment alleviation cases with MDBO's of 7 days towards the sole increment alleviation cases, normatively expressed.

Appendix V: Relative effect of simultaneously shortening order intervals and lead times

		4536827 & 4536835		4255030		4536553		4531430		3407384		4256632	
IA + MDBO = 7 + LT = 7													
MDBO		Fr 13 to 7		Fr 13 to 7		Fr 13 to 7		Fr 13 to 7		Fr 13 to 7		Fr 13 to 7	
Lead Time		Fr 13 to 7		Fr 13 to 7		Fr 13 to 7		Fr 13 to 7		Fr 13 to 7		Fr 13 to 7	
		TU	LG	TU	LG	TU	LG	TU	LG	TU	LG	TU	LG
General KPI's													
Service level	By perc of total quantities delivered on time	-0,05	-0,11	-0,01	0	0,01	-0,02	0	-0,02	-0,17	0	-0,06	0
	By perc of days without any backlogs	-0,06	-0,13	-0,01	0	0,01	-0,03	0	0,02	-0,19	0	-0,06	0,01
Inventory turnover	Times per year for finished products	0,31	0,02	0,23	0	0,18	-0,01	0,1	0,01	0,39	-0,01	0,26	0
	Times per year for materials		0,03		N/A		0		N/A		N/A		0
Bullwhip Effect	Amplification on weekly level	0,29	-0,59	0,17	0	0,37	N/A	0,32	-0,04	-0,03	-0,01	0,04	N/A
Inventory KPI's													
Average inventory	Average of finished products	0,24	0,02	0,19	0	0,15	-0,01	0,09	0,01	0,28	0	0,21	0
	Average of materials		0,01		N/A		0		N/A		N/A		0
Max inventory	Maximum of finished products	0,1	-0,25	0,21	0	0,28	0,06	0,01	0	-0,03	0	0,07	0
	Maximum of materials		-0,48		N/A		0		N/A		N/A		0
Average inbound	Average inbound of materials/products	0,33	-0,18	0,28	0	0,45	N/A	0,42	0	0,13	-0,03	0,16	N/A
Max inbound	Maximum inbound of materials/products	-0,04	-0,34	0,05	0	0,36	N/A	0,43	-0,01	-0,03	-0,02	-0,04	N/A
Inbound frequency	Number of inbounds of materials/products	0,48	-0,15	0,36	0	0,79	N/A	0,68	0	0,13	-0,03	0,18	N/A
Average outbound	Average outbound of finished products	-0,02	0,04	0	0,11	0,01	0,23	0	0,17	0,05	0,06	0,01	0,11
Max outbound	Maximum outbound of finished products	0,02	-0,11	0,02	0	0,12	0,16	0	0,02	-0,07	0	0,04	0
Outbound frequency	Number of outbounds of finished products	-0,02	0,04	0	0,12	0,01	0,29	0	0,2	0,05	0,06	0,01	0,12
Production KPI's													
Average production	Average production quantity		-0,02		N/A		0,21		N/A		N/A		0,11
Max production	Maximum production quantity		-0,28		N/A		0,13		N/A		N/A		0
Production frequency	Number of production runs		-0,03		N/A		0,25		N/A		N/A		0,13
Ordering KPI's													
Average orders	Average order quantity	0,25	-0,18	0,28	0	0,41	N/A	0,42	0	0,13	-0,03	0,16	N/A
Max orders	Maximum order quantity	-0,04	-0,34	0,05	0	0,34	N/A	0,43	-0,01	-0,03	-0,02	-0,04	N/A
Order frequency	Number of orders	0,33	-0,15	0,36	0	0,69	N/A	0,69	0	0,13	-0,03	0,18	N/A
FAD KPI's													
Forecast deviation	Average forecast deviation												
	Av forecast deviation as a perc of av demand												
Discount percentage	Average discount percentage												
	Av disc perc as a perc of the max poss discount												

Percentage differences of increment alleviation cases with MDBO's of 7 days and lead times of 7 days towards increment alleviation cases with MDBO's of13 days and lead times of 13 days, normatively expressed.

Appendix VI: Assessment of appropriate forecast horizons

		Nullcase		Increment Alleviation		IA + MDBO = 13		IA + MDBO = 7		IA + MDBO = 7 + LT = 7	
		TU	LG	TU	LG	TU	LG	TU	LG	TU	LG
4536827 and 4536835	BW Effect	Low	High	Low	High	Low	High	High	Low	High	Neutral
	Inventory fluctuations	Low	Low	Low	Low	Low	Low	High	High	High	High
	Prodution fluctuations		Neutral		Low		Low		High		High
	Ordering fluctuations	Low	Neutral	Low	Neutral	Low	Neutral	High	High	High	High
	Forecasting accuracy		High		High		High		High		High
	Discounts received	High		High		High		High		High	
4255030	BW Effect	Neutral	Neutral	Low	Neutral	High	Neutral	High	Neutral	High	Neutral
	Inventory fluctuations	Neutral	Neutral	Low	Low	Neutral	Neutral	High	Neutral	High	High
	Prodution fluctuations		N/A		N/A		N/A		N/A		N/A
	Ordering fluctuations	Neutral	Neutral	Low	Neutral	Neutral	Neutral	High	Neutral	High	High
	Forecasting accuracy		High		High		High		High		High
	Discounts received	High		High		High		High		High	
4536553	BW Effect	High	N/A	High	N/A	Low	N/A	High	N/A	High	N/A
	Inventory fluctuations	High	Neutral	High	Neutral	Low	Low	High	Neutral	High	Neutral
	Prodution fluctuations		Neutral		Neutral		Low		Neutral		High
	Ordering fluctuations	High	N/A	High	N/A	Low	N/A	High	N/A	High	N/A
	Forecasting accuracy		High		High		High		High		High
	Discounts received	High		High		High		High		High	
4531430	BW Effect	High	Neutral	High	Low	Low	Low	High	Low	High	Low
	Inventory fluctuations	Neutral	Neutral	Neutral	Low	Low	Low	Neutral	Low	Neutral	Neutral
	Prodution fluctuations		N/A		N/A		N/A		N/A		N/A
	Ordering fluctuations	High	Neutral	Neutral	Low	Low	Low	Neutral	Low	Neutral	Neutral
	Forecasting accuracy		High		High		High		High		High
	Discounts received	High		High		High		High		High	
3407384	BW Effect	High	Neutral	High	Neutral	High	Neutral	High	Neutral	High	Low
	Inventory fluctuations	Neutral	Neutral	Neutral	Neutral	High	High	High	High	High	High
	Prodution fluctuations		N/A		N/A		N/A		N/A		N/A
	Ordering fluctuations	Neutral	High	Neutral	Neutral	High	High	High	High	High	Neutral
	Forecasting accuracy		High		High		High		High		High
	Discounts received	High		High		High		High		High	
4256632	BW Effect	High	N/A	Low	N/A	High	N/A	High	N/A	High	N/A
	Inventory fluctuations	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	High	High	High	High
	Prodution fluctuations		High		Neutral		Neutral		High		High
	Ordering fluctuations	High	N/A	Neutral	N/A	Neutral	N/A	High	N/A	High	N/A
	Forecasting accuracy		High		High		High		High		High
	Discounts received	High		High		High		High		High	

High / Neutral / Low / N/A	Assessment of appropriate forecasting horizon
Colour	Positive (green), neutral (white) or negative (red) effects of appropriate horizon towards the situation without FAD agreement
Border	Pareto Improvement towards the empirical null case

Qualitative assessment of quantitative results of simulation cases for six KPI groups

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