Sultans of Swing

The Persistence of the Bullwhip Effect

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1. Management Summary

(I) Purpose

Back in 1919, demand amplification was observed for the first time. Vast amounts of research have been conducted about the bullwhip effect since Forrester's (1958) pioneering contributions in the 1950s. Despite the huge theoretical contributions of the last 50 years, supply chains still face large bullwhip-related problems nowadays. Companies located upstream the supply chain either face stock-outs, idle time, and redundancies because of excessive demand; or overcapacity, low productivity, and thus high costs due to sluggish demand. *If companies appear to know so much about the bullwhip effect, why do they still face this degree of demand amplification?* This thesis studies the bullwhip effect from a semiconductor manufacturers' point of view during one of the most interesting periods in history, the largest downturn since the 1930s. Four research questions are addressed to explore the persistence of the bullwhip effect: (1) Different causes of the bullwhip effect are identified in existing literature (*Which types of causes with respect to the bullwhip effect can be distinguished?*). (2) The bullwhip effect is empirically studied (*To what extent can the bullwhip effect be observed in the automotive supply chain?*). (3) Mitigation of the bullwhip effect is investigated (*What policies can be implemented in order to reduce or eliminate the negative consequences of this demand amplification?*). (4) Finally, knowledge is expanded about the persistence of the bullwhip effect by addressing the last research question (*What reasons can be identified for not implementing suggested solutions to the bullwhip effect?*).

(II) Design

Research question (1) is theoretical from nature and is addressed by reviewing literature about the bullwhip effect. In contrast, (2) involves empirical quantitative research. Time series are gathered and analyzed in the specific case setting of this research, a semiconductor manufacturer in the automotive supply chain. The mitigation of the bullwhip effect (3) is studied by simulating a system dynamics model. A generic supply chain model of Sterman (2000) is adjusted to represent the observed supply chain. The model validated by determining the r-square, and simulated to investigate policy outcomes. The last research question (4) is qualitative and exploratory from nature. Management is interviewed in order to determine what impedes them from taming the bullwhip effect.

(III) Findings

With respect to research question (1), literature generally distinguishes between two types of causes with respect to the bullwhip effect. On one hand *operational* causes of the bullwhip effect are identified. On the other hand, a *behavioral* perspective is chosen, focusing on cognitive limitations and bounded rationality. Question (2) observes the bullwhip effect in the automotive supply chain. With a peak-to-trough amplification ratio of 2.7 and a year-on-year amplification ratio of 6.8, the occurrence of the bullwhip effect is empirically observed. Regarding research question (3) the effects

of reducing order lead-time and end-market focus have been tested. Reduced order lead-time decreases the production start rate peak-to-trough from 94% to 52%, whereas the material order rate peak-to-trough ratio is reduced from 94% to 43%. The average inventory and throughput time decrease as well as a consequence of reducing order lead-time. With respect to end-market focus, the production start peak-to-trough ratio decreases from 94% to 43%. In research question (4) the hypothesis emerges that organizational roadblocks impede companies to act in accordance with the vast amount of knowledge about the bullwhip effect. Resistance exists with respect to anti-cyclical investing. However, the truth of anti-cyclical investing is known at the company since unintended anti-cyclical investing partially pulled them through the crisis. Still, organizational aspects such as interest alignment and short-termism are involved in impeding these practices in the future.

(IV) Relevance

The contribution of the first research question (1) is minimal, since it reviews existing literature. Research question (2) once again confirms the existence and persistence of the bullwhip effect. More than 50 years after the pioneering research of Forrester, replicating the bullwhip-effect remains important to prove that supply chains still face these problems nowadays. Research question (3) replicates how to mitigate the bullwhip effect. Both using end-market (point-of-sale) data and reducing lead-time are confirmed to be bullwhip-mitigating policies. The exploratory research question (4) contributes to existing knowledge by exploring roadblocks for companies to diminish the bullwhip-effect. Organizational factors -such as short-termism and interest alignment- are provided little attention in existing literature. However, these factors might play an important role in the persistence of the bullwhip effect.

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2. Introduction

Surviving a downturn is often cited as the number issue in supply chains (Yuan et al.,2010). When considering surviving downturns at companies located upstream the supply chain, the well-known bullwhip effect arises. Already back in 1919, Procter & Gamble observed that the demand for diapers displayed an amplified variation upstream (Schmenner, 2001; Zhou et al., 2007). Since the pioneering research by Jay W. Forrester during 1950s this phenomenon of upstream demand variability was called the Forrester effect. Lee et al. (1997a; 1997b) labeled this phenomenon the bullwhip-effect. Great deal of research has been conducted about this subject. Various authors shed light on this subject from different perspectives. Generally, existing literature about the bullwhip effect distinguishes two causes. On one hand, *operational* causes have been studied extensively (Forrester, 1958; Geary et al.,2006; Lee et al., 1997b; Lee et al., 1997a). Broadly speaking, *operational* causes involve technical inefficiencies of both the supply chain structure (e.g. perception delays) as well as the internal structure of a company (e.g. manufacturing delays). On the other hand, *behavioral* causes of the bullwhip effect are handled (Croson & Donohue, 2003, 2005, 2006; J. Sterman, 2000; J. D. Sterman, 1989). This perspective emphasizes the complexity of supply chains in combination with the bounded rationality of decision makers. Wide ranges of solutions have been suggested to cope with the bullwhip effect. Those solutions include practices such as Information sharing (Chen et al., 2000), lead-time reduction (Cachon & Fisher, 2000), vendor managed inventory programs (Claassen et al., 2008), every day low pricing (Lee et al., 1997a; Lee et al., 1997b) & collaborative planning forecasting and replenishment (Aviv, 2001).

However, despite the vast amount of theoretical contributions to knowledge about the phenomenon, supply chains still face bullwhip-related problems nowadays. Under-swings characterized by overcapacity are rapidly followed by over-swings associated with constraint capacity. At a prominent semiconductor manufacturer, the chips sold to the automotive industry decreased with 64% as a result of the 24% decrease in car sales between June ‘08 and January ‘09. According to Lee et al. (1997a; 1997b) demand signaling is the most important cause of the bullwhip effect. Companies tend to lose sight on the true demand in the market place and anticipate on the direct received orders, which are inevitably distorted. “The bullwhip effect taught us that we should not just take incoming demand or order signals at their face values. But instead, we really need to understand what is behind such signals” (Lee, 2010). Yet, in practice, these theoretical contributions to taming the bullwhip effect still seem to be hard to realize.

If companies appear to know so much about the bullwhip effect, why do these firms still face this degree of demand amplification? This thesis focuses on studying the causes of the bullwhip effect by looking at the phenomenon in the make-to-forecast automotive industry from a semiconductor manufacturers’ point of view.

1. *Which types of causes with respect to the bullwhip effect can be distinguished?*
   This question is from nature theoretical. A literature study about the bullwhip effect will be carried out. All relevant contributions with respect to this topic will be taken into account. First the bullwhip effect in general is defined in this section. Then, literature will be studied in order to conclude whether a distinction can be made with respect to several types of bullwhip causes.

2. *To what extent can the bullwhip effect be observed in the automotive supply chain?*
   Data about the automotive industry both within the case company as well as outside the case company will be gathered in order to display the extent of demand amplification. This section includes descriptions of the automotive industry, semiconductor industry, and the recent historical developments within these industries.

3. *What policies can be implemented in order to reduce or eliminate the negative consequences of this demand amplification?*
   A system dynamics model is 'built' which simulates the dynamics in this supply chain. The model is an adjusted version of the 2 stages supply chain model of Sterman (2000). On one hand, this model tests whether the theoretical causes of the bullwhip effect could lead to the recent behavior in the automotive supply chain. On the other hand, the model provides the opportunity to test alternative policies to reduce or eliminate negative consequences of the bullwhip effect.

4. *What reasons can be identified for not implementing suggested solutions to the bullwhip effect?*
   Finally, the main question will be addressed: *If companies appear to know so much about the theory, why do firms still face this degree of demand amplification?* By conducting interviews, motives for not carrying out bullwhip reducing policies are identified. In other words, organizational barriers are identified which impede implementing suggested solutions.

These questions will be answered by focusing on the period of January 2007 till May 2010, incorporating one of the most interesting periods in the automotive industry in the history, namely the largest downturn since the 1930s.

3. Literature

This chapter is about the bullwhip effect in general. By distinguishing several causes of the bullwhip effect, the first research question is dealt with. First, the bullwhip effect will be introduced with a definition, a short description of the history, and an illustration. Next, two dominating perspectives – *behavioral* and *operational* - on the bullwhip effect are discussed. Then, an organizational view on the bullwhip effect is introduced. Finally, a short review is made of mitigating the bullwhip effect.

3.1. Definition

Magnification of order oscillations as one moves up the supply chain (Croson & Donohue, 2005). Increased demand variability when moving further upstream (Chen et al., 2000). Distortions in demand information as we proceed away from the consumer (Metters, 1997). The variability of the inflow to the industry (production) is greater than the variability of the outflow from the industry (demand) (Cachon et al., 2007). Fluctuations in the order sequence are usually greater upstream than downstream (Ouyang, 2007). These researchers all define the topic of this thesis, the bullwhip effect.

This phenomenon is known for a long time. Today, bullwhip effect is so commonly accepted that it is called the first law of supply chain dynamics (Kouvelis et al., 2006). The bullwhip effect can be split up into demand distortion and variance amplification (Lee et al., 1997a; Lee et al., 1997b). Opinions about the main cause differ in today's literature. Information dissymmetry (Xu et al., 2007), too complex fragmented supply chains (Vandenbosch & Sapp, 2010), or a combination of both information dissymmetry and inefficient supply chains is regarded as main cause (Hwarng & Xie, 2008; Steckel et al., 2004). Companies tend to lose sight on what is truly happening in the end-market. Because of the various delays in perception, manufacturing lead-time, order lead-time, and even financial reporting, it is hard for decision-makers to understand this complex dynamics and make the right decisions.

The bullwhip effect is characterized by over-swings and under-swings in demand as one moves upstream the supply chain (figure 2). The former is associated by stock outs and often

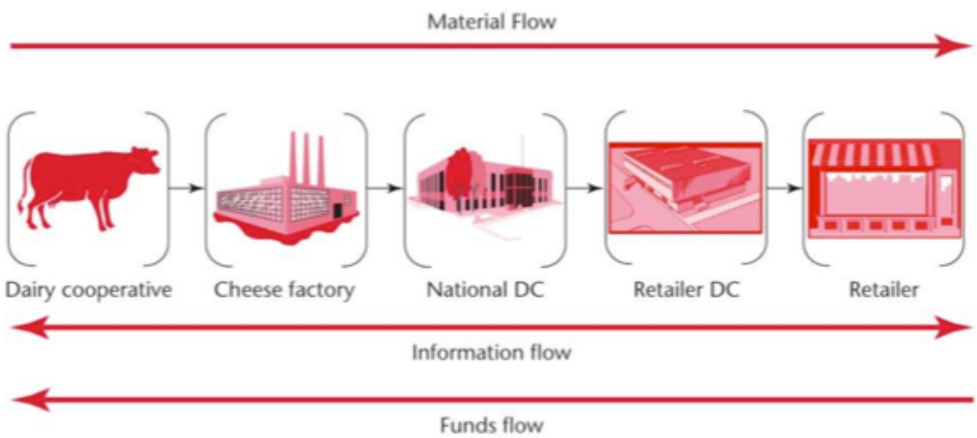
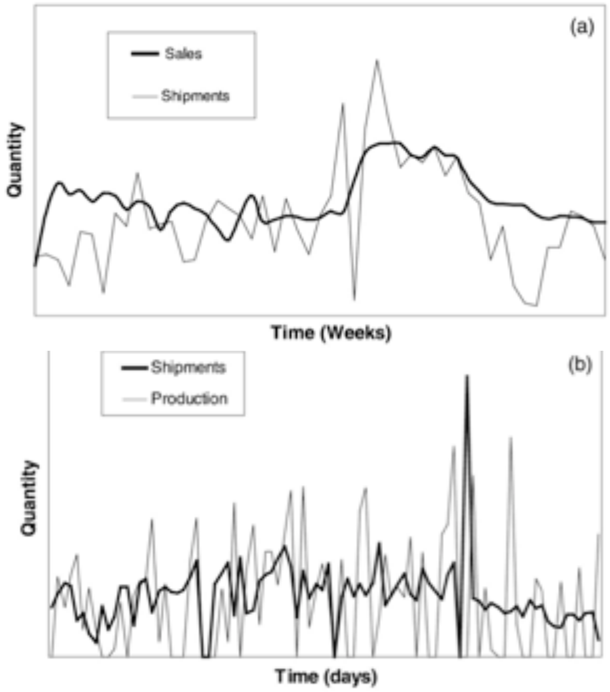


Figure 1: Illustration of a supply chain (Harrison & Hoek, 2008)

followed by (needless) ramping up of capacity and production. While the latter is related to overcapacity which means (needless) idle time and redundancies. In total, the bullwhip effect has more negative effects which cause the following inefficiencies: Excessive inventories throughout the supply chain; poor customer service due to stock outs; lost revenues because of shortages; low productivity of invested capital; responding by adjusting capacity instead of eliminating demand peaks; increased transportation costs; and missed production schedules (Carlsson & Fullér, 2000). Learning effects in the upswing and lay-off costs in the downswing together with inefficiencies during ramp ups are side effects of bullwhip behavior (Geary et al., 2006).

Figure 2: The bullwhip effect illustrated (Dejonckheere et al., 2003)



A: Retail sales vs. Shipments OEM

B: Shipments OEM vs. Production OEM

Already back in 1919, Procter & Gamble observed that the demand for diapers displayed an amplified variation upstream (Schmenner, 2001; Towill et al., 2007). Almost half a century ago researchers started writing about this phenomenon (Forrester, 1958, 1961; Magee, 1956). By using different examples Forrester (1958,1961) recognized that basic forms and policies used by organizations gave rise to characteristic and undesirable behaviors in the supply chain. The variance of demand to manufacturers exceeds the variance of consumer demand. Forrester (1958,1961) recognized that this was larger for manufacturers than for retailers. For a long time this phenomenon was known as the *Forrester Effect*. Nowadays, as a result of propagation of certain authors (Lee et al., 1997a; Lee et al., 1997b) it is known and referred to as the bullwhip effect.

The well-known *Beer Distribution Game* provides a nice illustration of the bullwhip effect. Sterman (1992, 2000; 1989) uses to the beer game to illustrate demand amplification. Furthermore, wide ranges of authors (Hwarng & Xie, 2008; Steckel et al., 2004; Wu & Katok, 2006) use the beer game to study, discover, and quantify the bullwhip effect. In this simulation game participants play the roles of four distinct echelons within the beer industry. Four roles exist within this game, namely brewer, retailer, wholesaler, and distributor. On the basis of limited information, players should base ordering decisions to their direct supplier. No matter whether the game is played with students, managers, or economists; the results of the game point out that demand is amplified when one moves further upstream.

3.2. Distinguishing different perspectives

Throughout the literature, in general, two categories of explanations and causes have been advanced. On one hand, *operational* causes are identified by several authors (Geary et al., 2006; Lee et al., 1997a; Lee et al., 1997b). Authors referring to operational causes emphasis that the bullwhip effect stems from rational, goal seeking, optimizing behavior. These operational causes include structural inefficiencies such as lead-time, non-synchronized control systems, and the number of echelons in the supply chain. Authors studying operational causes (e.g. Lee et al., 1997a) focus on removing and adjusting the inter-organizational and institutional infrastructure and related processes.

On the other hand, a *behavioral* perspective is chosen on the bullwhip effect. Especially those authors (Croson & Donohue, 2003, 2005, 2006; J. Sterman, 2000; J. D. Sterman, 1989) who study behavioral operations take such a perspective on the bullwhip effect. Behavioral operations is an approach that integrates social and cognitive psychology theory with studying operations (Gino & Pisano, 2008). This field of study concludes that performance in operations management cannot only be explained by taking an *operational* perspective (Bendoly et al., 2006; Boudreau et al., 2003; Gino & Pisano, 2008; Loch & Wu, 2007). The *behavioral* perspective, usually studied in the laboratory due to the possibility to eliminate operational causes, focuses on bounded rationality of decision makers. Due to cognitive limitations, the rational behavior of decision makers turns out to be non optimal, which triggers the bullwhip effect. Next to the bounded rationality of decision makers, another *behavioral* perspective can be chosen to inspect the occurrence of the bullwhip effect. In other areas, the influence of organizational factors is studied extensively. However, with respect to the bullwhip effect, this perspective is largely ignored.

3.3. Operational Perspective

Nine operational causes of the bullwhip effect are summed which are labeled operational in the existing literature about the bullwhip effect. In the end, it can be questioned to what extent each operational cause is purely operational or overlaps largely with behavioral causes. Ambiguity exists about the use of the term 'operational' in different contexts.

Besides lead-time, to which the bullwhip effect is directly related (examples: Lee et al., 2000; Lee et al., 1997; Cachon & Fisher, 2000; Hwarng, 2008; Forrester, 1958), four main factors are identified which encourage the bullwhip effect (Lee et al., 1997a, 1997b). Order batching; phantom orders due to shortage gaming; forward buying initiated by price promotions; and distorted demand throughout the supply chain due to demand signal processing can be considered as bullwhip encouraging factors. These causes of the bullwhip effect will be handled briefly.

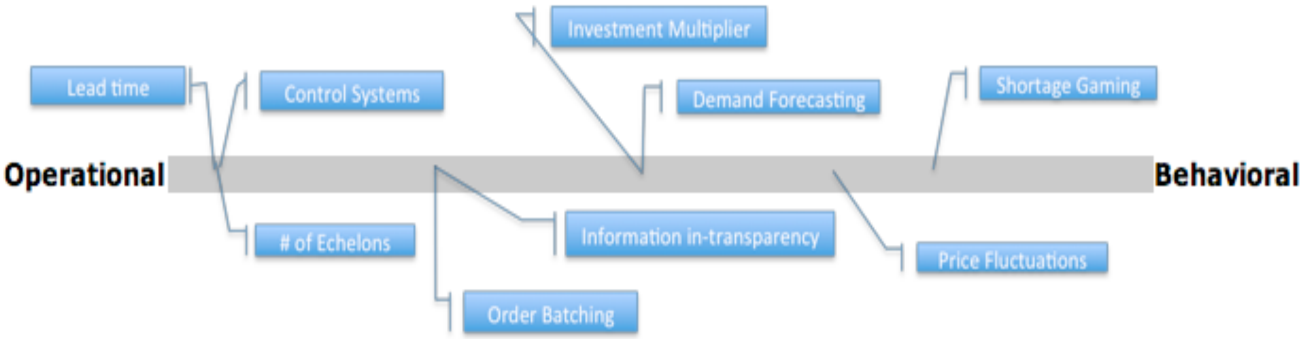
First, order batching can be named as one of the operational causes of the bullwhip effect (Baganha & Cohen, 1998). Firms are inclined to wait with ordering until they can spread the high fixed costs across a full truckload of products. This optimizing behavior results in volatile periodic ordering patterns. Additionally, order batching is also associated with surges in demand coinciding with evaluation cycles of the performance of sales representatives. This is known as the "hockey-stick" phenomenon. Second, when a supplier is only partially able to fulfill orders from a client, often shortage gaming occurs (Cachon & Lariviere, 1999). Clients exaggerate their real needs in order to make sure they are provided with enough supply. As soon as the supplier has eliminated its shortages, this demand bubble explodes. Third, forward buying arrangements due to price discounts trigger the amplification of the variability in demand (Sogomonian & Tang, 1993). 80 percent of the transactions in the grocery industry are made in such an arrangement (Lee et al., 1997a, 1997b). Products are bought in advance of requirements because of attractive pricing offers. During the period following the price discount, inventory will be used as a buffer. Finally, demand signal processing is considered as a major source of the bullwhip effect. Frequently updating sales forecasts on the basis of customer demand data has shown to encourage the bullwhip effect (Chen et al., 2000). When forecasting is based on recent customer demand, forecasts are updated when new orders arrive. As a result of forecast updating, parameters of inventory replenishment are also adjusted. Companies used to justify investing in inventory by arguing that it absorbs and dampens demand variability. This does not hold anymore. The variance of the production is higher than the variance of the sales, since desired safety stock and desired inventory will rise as well when the demand fluctuates (Baganha & Cohen, 1998; Kahn, 1987). Therefore, due to misinterpretation of received orders, the more upstream the chain a firm is located, the higher the order fluctuations compared to the end-market demand variability.

Including the previous five operational factors, Geary et al. (2006) sum up a list of operational factors contributing to the bullwhip effect. The first four factors summed up are ascribed to Forrester (1958). First of all, inappropriate control systems contribute to the amplification of demand. Control systems should reflect accurate and timely information. Otherwise inefficient decisions are made and perception delays are long. Second, a lack of information transparency influences the amplification in a supply chain. Up-to-date information should be accessible by the players in a supply chain. Because of the enhanced transparency and removed information delays, decisions can be made on the basis of up-to-date accurate information instead of guessing. Third, the more echelons within a supply chain, the higher the whip generally will be. Next, an additional factor called a multiplier situation can be uncovered which only holds in specific settings, such as the machine tool industry (Anderson Jr. et al., 2000). Orders in such a situation trigger direct demand

Table 1: Overview of 'operational' causes of the bullwhip-effect

'Operational' causes bullwhip effect	
Order Batching	Aggregation of orders due to high fixed costs or "hockey stick" phenomenon
Shortage Gaming	Exaggerating real needs in time of shortage to safeguard enough supply
Price Fluctuations	Booming orders in times of discount followed by a bust afterwards
Demand Forecasting	Inventory reductions & building due to inaccurate forecasts and misinterpretation of incoming orders
Non Synchronized Control Systems	Control systems can reinforce the bullwhip effect by being non-synchronized or out-of-date
Excessive Lead Time	Lead time in general is directly related to the degree of demand amplification
Lack of Information Transparency	Sub-optimal decisions arise from a lack of information transparency
# Of Echelon	The more echelons, the more stock points within a chain which fluctuate along with demand
Investment Multiplier	**In certain situations orders initiate direct amplification**

Figure 3: To what extent are the causes truly operational? A classification attempt.



amplification. For example, a manufacturer with ten equipment machines might choose to replace its machines on a ten-year cycle. So every year a new machine tool is ordered to replace an old one. When the manufacturer chooses to expand his capacity by ten percent, he orders two machine tools that year. The 10% increase in capacity at his side results in a 100% increase at his supplier.

As stated earlier, these operational causes identified in leading bullwhip literature are labeled operational. Causes such as lead-time, # of echelons, and non-synchronized control systems comply with the definition of operational causes, namely, structural inefficiencies in the supply chain. However, other factors such as shortage gaming and price fluctuations are prone to be classified *behavioral* rather than hardcore operational. To distinguish between the extents to which each factors deserves to be labeled operational, figure 3 is created.

3.4. Behavioral Perspective

3.4.1. Cognitive causes

Next to operational factors, *behavioral* explanations of the bullwhip effect occur. The *behavioral* perspective on the bullwhip effect largely focuses on cognitive limitations, often referred to as bounded rationality. Cognitive limitations of rational decision-makers result into suboptimal decisions that give rise to demand amplification. Individuals are bounded by rationality with respect to lagged, indirect, and non-linear feedback loops of the complex supply chain (Sterman, 1989, 2000). Several authors (Cronin & Gonzalez, 2007; Cronin et al., 2009; Sweeney & Sterman, 2000) made clear that even very simple stock-flow questions are problematic to highly educated people with a strong mathematics background. For example, sketching a graph of the water level in a bathtub in accordance with the inflow and outflow seemed in more than half of the situations too hard. Cronin et al. (2009) state that this is largely due to the 'correlation heuristic', a type of pattern matching in which one wrongly assumes that the output pattern of a system (e.g. water level) looks like the input pattern (the combined in- and outflows). If highly educated people already seem to have problems with fairly simple stock-flow questions, one can imagine that the complex supply chain structures form large obstacles for the cognitive capacities of decision-makers.

Since simple stock & flow problems are problematic, cognitively grasping the complexity of a supply chain will be a tough job. Supply chains per definition consist of lagged feedback due to delays. Among others, manufacturing lead-time, ordering lead-time, and perception delays occur. Behavioral studies show that participants have an inability to account for these time delays in decision-making; more specifically, they tend to underweight the value of orders that are placed but not yet received, called supply line. These delays between action and result thus negatively influences the ability of decision-makers to correct for prior errors in the supply line (Bloomfield et al., 2007).

Mental models of decision-makers are bounded with respect to more issues. For example, with respect to the previously mentioned shortage gaming. Supplier lead-time and customer lead-time are treated as exogenous factors by decision-makers (J. Sterman, 2006). In other words, decision-makers regard the lead-times of their supply chain partners as out of their control. "Each firm reasons that it is responsible for only a small part of the supplier's total supply chain, so changes in its orders won't affect supplier lead times" (J. Sterman, 2006). If all firms behave in accordance with this view and keep shortage gaming, in reality, a positive feedback loop is closed which strongly affects supplier lead-times. This rational goal seeking behavior in the end harms these parties. The complexity of today's supply chains worsens this situation. Supply chains nowadays have fragmented structures with numerous parties adding value. This ultra-competitive environment is prone to opportunistic behavior of parties who aim to maximize their own interest (Vandenbosch & Sapp, 2010). Local situations are optimized instead of entire systems because of opportunistic behavior & cognitive limitations (Wyman, 2006).

Additionally, in general, managers tend to over-react to demand changes (Disney et al., 2005). They often try to read "too much signal" when looking at demand history. This behavioral cause of the bullwhip effect is largely comparable to the operational demand signal processing. Both the operational context as the human behavior falls short in correctly interpreting demand signals.

Instead of changing institutional and inter-organizational infrastructure, authors focusing on behavioral causes (Croson & Donohue, 2003, 2005, 2006; J. Sterman, 2000; J. D. Sterman, 1989) suggest changing one's behavior by providing decision makers with more information or by organizational learning. Organizations should aim at improving mental models and adjusting decision making to account for interdependency, feedback, time delays, and other complex parts of modern supply chains.

3.4.2. Organizational Causes

Beside the operational causes of the bullwhip effect and the behavioral cognitive limitations of decision-makers, a third view on the bullwhip effect can be chosen. This perspective focuses on hurdles for companies to implement bullwhip effect reducing policies. What reasons do companies have for 'ignoring' the vast amount of literature written about it? Huge deal is written about organizational behavior and organizational research. This field of study is very broad and extensive and will not be reviewed entirely. Two examples from organizational literature are discussed and linked to the bullwhip effect. The majority of behavioral literature about the bullwhip effect focuses on bounded rationality and cognitive limitations. Only little attention has been paid to organizational factors allowing demand amplification to occur.

Organizations might encourage people to ignore the consequences of today's actions on the long-term performance. Incentive schemes, top-down set goals, and fragmented organizational interests, all influence decision-makers and could lead to behave opportunistic and to ignore *doing what is right*. These organizational factors can neither be labeled as operational factors nor as cognitive limitations of these decision-makers. The organizational perspective is neither about the operational factors (inability *to do so* due to operational limitations) nor about cognitive factors (inability *to do so* due to bounded rationality). In contrast, the organizational view could focus on interest alignment (willingness *to do so*) and on organizations impeding employees to *do what is right* by focusing on the wrong targets (not allowed *to do so*). In other words, on situations where employees prefer individual goals rather than organizational goals, and situations where organizations enforce them to act at the expense of the long-term organizational interests. These two bullwhip-related examples from the broad field of organizational research are concisely described in the next paragraphs.

Interest alignment (1) is associated with the agency theory. A firm should make sure that employees are motivated to behave in line with the organizational goals so that potential performance is translated into actual performance. It is all about the degree to which employees are motivated to behave in lines with the organizational goals. (Gottschalg & Zollo, 2007). The agency problem, often referred to as principle-agent problem, has been addressed frequently in the past. Influencing contributions concluded that conflicts arise frequently between organizational and individual goals (Alchian & Demsetz, 1972; Eisenhardt, 1989; Fama & Jensen, 1983; Jensen & Meckling, 1976).

Short-termism (2) is related to pressure within organizations to focus on the 'wrong' goals. Decisions and outcomes could pursue actions that are best for short-term but suboptimal for long run performance (Laverty, 1996). According to Marginson (2008) short-termism due to detriment of long-term goals can be differentiated from short-termism due to cognitive limitations. Laverty (1996) discusses several explanation of short-termism which include flawed management practice, managerial opportunism, stock market myopia, and information asymmetry.

3.5. Dealing with the Bullwhip Effect

Research question four deals with mitigating the bullwhip effect. To establish a theoretical foundation to address this research question, briefly most important strategies to alleviate the bullwhip effect in existing literature are described. Among alternative policies to mitigate the bullwhip effect - including vendor managed inventory programs (Claassen et al., 2008), every day low pricing (Lee et al., 1997a; Lee et al., 1997b), and collaborative planning forecasting and replenishment (Aviv, 2001) - existing literature refers most frequently to lead-time reduction and information sharing as strategies to mitigate the bullwhip effect.

It is essential to make sure one's own activities are defect-free so that the actual orders are delivered right and on time (Childerhouse et al., 2008). Not only inter-firm variables should be taken into account. Intra-firm variables are relevant in studying inter-firm division of relations (Takeishi, 2001). Since the bullwhip effect is directly related to lead-time (e.g. Lee et. al, 1997; Forrester, 1958), one of the intra-firm initiatives to counteract the bullwhip effect is reducing the lead-times (E.g. Cachon & Fisher, 2000; Hwarng & Xie, 2008; Lee et al., 2000). Next to the stand-alone benefits, reducing lead-time is complementary to information sharing. Of what benefit is it to know next week's demand, if next week's production had to be decided two months ago? (Gilbert, 2005).

Information sharing within the supply chain is one of the most important and studied policies towards reducing volatility[1]. The majority of articles about the bullwhip effect advocate information sharing across supply chains. Sharing data allows members of the supply chain to better interpret the orders they receive. Especially how the orders of customers are composed from actual end market orders and stock replenishments. With this knowledge, errors in demand interpretations can be prevented (Croson & Donohue, 2003). Sharing point-of-sale data is one often-heard remedy for the bullwhip effect. By using point-of-sale data, what is truly behind incoming demand or order signals can be understood instead of taking these issues at their face values, which is very important (Lee,

[1] Look at (Chan & Chan, 2010) for an overview of studies focusing on supply chain coordination & information sharing

2010). Sharing information opens the door for numerous initiatives (e.g. Quick Response, Efficient Consumer Response, and Continuous Replenishment Programs) suggested in bullwhip-related literature. Besides the upstream party, the downstream party also benefits from information sharing thanks to price reductions (Lee et al., 2000).

The degree of information sharing can be used as a proxy for the relationship a firm has with its up or downstream partner. Opportunities exist with respect to improving the relationship between customer and supplier (Childerhouse et al., 2008). Poor supplier relationships and low and indifferent service levels are statistically significantly correlated with demand amplification. Therefore, downstream inventory information and direct customer demand information significantly reduces order oscillation throughout the supply chain (Chen et al., 2000; Croson & Donohue, 2005). Especially at upstream sites, this performance improvement occurs as a result of information exchange (Croson & Donohue, 2006; Kotabe et al., 2003).

3.6. Conclusion

Literature in general distinguishes between two types of perspectives/causes. On one hand operational causes of the bullwhip effect occur. This type of causes consists of structural operational inefficiencies in both firms and supply chains, and states that the bullwhip effect occurs due to rational, goal seeking, and optimizing behavior. On the other hand, a *behavioral* perspective on the bullwhip effect is present which largely stems from researchers who study behavioral operations. This line of thinking focuses on bounded rationality of decision makers. Due to cognitive limitations, the rational behavior of decision makers turns out to be non optimal, which triggers the bullwhip effect. The influence of the organization is studied extensively in other fields of research. However, with respect to the bullwhip effect, this perspective is largely ignored.

4. Methodology

Beside the first research question, which is already addressed with secondary research, the three remaining research questions are discussed separately with respect to methodology. The research questions have different goals, which are achieved by using different methodologies, but have in common that they are part of the same case study. By combining quantitative research, qualitative interviews, and system dynamics simulation, this research can be labeled as triangulation (Saunders et al., 2007).

Research questions (2) and (3) both concern applied research, which aims to replicate existing research in a different context by studying the persistence of the bullwhip effect and its mitigation. After describing the case setting and characteristics the semiconductor industry, the automotive industry will be studied by examining the short-term history. Next to relevant studies with respect to this subject, reports from associations such as Strategy Analytics and IHS Global Insight are studied in order to do so. Data is gathered about the period starting from January 2007 until May 2010, incorporating the largest dip in the automotive supply chain since the 1930s. Quantitative time series of this period are empirically collected about semiconductor sales to the automotive market; the car production during this period; and about end-market car sales. By gathering these time series, research question (2) is addressed (*To what extent the bullwhip effect can be observed in the automotive supply chain?).*

By adjusting an existing system dynamics model of Sterman (2000), a model is established that represents the automotive supply chain. This model is created by observing the real world practices, interviewing individuals responsible for a wide range of relevant aspects such as marketing, supply chain management, operations, capacity planning, forecasting, and so on. Both semi-structured formal interviews and informal unstructured interviews are conducted in order to gather the requested information. By using the aggregated automotive end-market as input, the fit between the actual historical trend and the simulated trend is determined. Research question (3) (*What policies can be implemented in order to reduce or eliminate the negative consequences of this demand amplification?)* is addressed by simulating the system dynamics model with respect to bullwhip-related mitigation policies.

Finally, research question (4) has an exploratory nature. By using semi-structured interviews, roadblocks and hurdles with respect to mitigating the bullwhip effect are discovered. The question (*What reasons can be identified for not implementing suggested solutions to the bullwhip effect?)* is addressed by discussing operational, cognitive, and organizational factors as well as implementation issues.

5. Case

This chapter provides a total description of the case study of this thesis. Section 4.1 provides a short company description. Further on, in section 4.2 the semiconductor industry is introduced. Characteristics of this industry are concisely described. Since the automotive business unit of NXP is subject of interest, subsequently, the automotive industry is discussed. On one hand, the automotive business unit is described from NXPs perspective. On the other hand, recent developments and trends within this business are discussed later on. This provides the context of this study. Finally, the bullwhip effect in the automotive supply chain is addressed.

5.1. Company description

NXP Semiconductors was created on 29 September 2006 from Philips Semiconductors Product Division of the Royal Philips Group. NXP became a legal separate entity owned by a range of private investment companies. Royal Philips Electronics retained a minority stake in NXP. NXP is one of the world's leading semiconductor suppliers. With approximately 28.000 employees in more than 25 countries and posted sales of $3.8 billion, NXP is one of the world's leading semiconductor suppliers. The company provides High Performance Mixed Signal and Standard Product solutions that leverage its leading RF, Analog, Power Management, Interface, Security and Digital Processing expertise. These innovations are used in a wide range of automotive, identification, wireless infrastructure, lighting, industrial, mobile, consumer and computing applications. NXP's vision is:

A sustainable world where trusted NXP technology makes life safe, entertaining and convenient. (Source: Company Manual 18-08-2009)

Our vibrant media technologies make it easy to bring your product ideas to life. Creating better sensory experiences for consumers: brilliant images, crisp clear sound, and easy sharing of information in homes, cars, and mobile devices. All with exceptional effectiveness and efficiency. With NXP as a partner, you can be more successful by bringing products to life that deliver better sensory experiences. (Source: Company Manual 18-08-2009)

NXP is divided in business, core and supporting processes as depicted in Figure 4

- Business processes

The business processes are the four horizontal represented business units, namely Standard Products, Identification, Automotive, and High Performance Mixed Signal. Each BU is responsible for a group of Business Lines. These are responsible for the design and manufacturing of groups of products and form the entrepreneurial entities of the organization. Although all of the Business Lines produce semiconductors, they differ a lot from each other in terms of sales volume, geographical location, and even product characteristics in some cases.

- Core processes and supporting processes

Besides these four business processes, there are three core processes. These are Product Creation, Order Fulfillment, and Sales & Marketing. Finally there are several supporting processes.

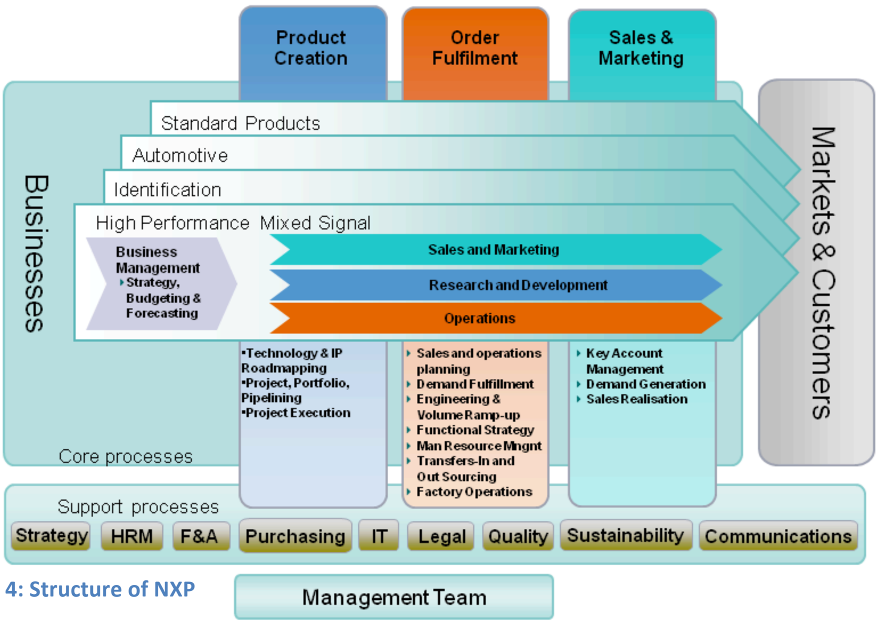
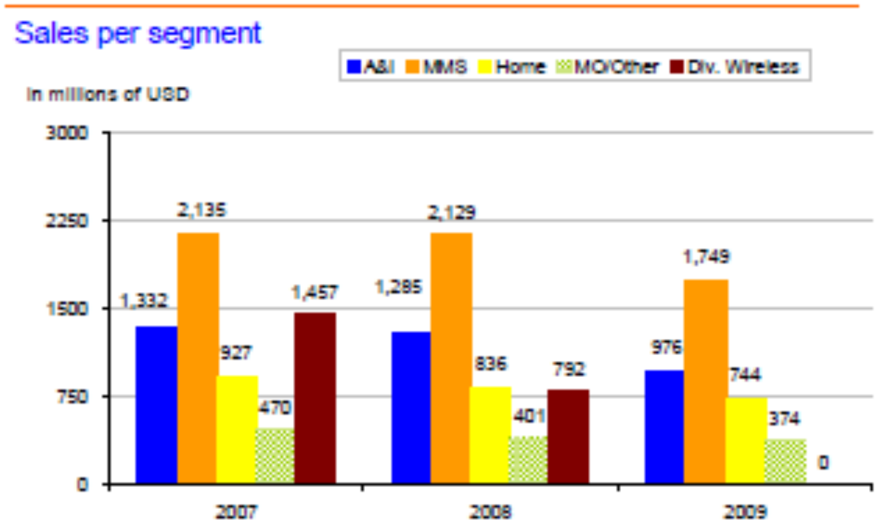


Figure 4: Structure of NXP

5.1.1. Product types and sales per segment

NXP produces microprocessors. The ones with very complex electronic circuits of transistors, resistors and diodes on it are called Integrated Circuits (ICs), which can be customer specific products or application specific products. The customer specific products are made especially for a customer and will not be sold to other customers. The application specific products are made for a specific application, e.g. for a car sensor. The ones with only one single function on it are called discrete or commodities which are mainly part of the Business Unit Standard Products. These products are used in many applications and are bought by many customers. Figure 5 depicts the sales per segment over the last few years. This sales figure does not depict the same business units as reported earlier, because the business units were reconfigured last year. At that time, NXP consisted of the business units Automotive & Identification, Multi Market Systems, Home, and Wireless. In 2009 the Automotive Business unit of NXP excluding the Identification division recorded for $616 million. Overall, NXPs turnover accounted for $3,843 million. Thus, with a 16% share of the total sales volume of the company, the automotive Business Unit can be called substantial.

Figure 5: Sales per segment Annual Report 2009 From NXP.com



5.1.2. The supply chain of NXP

Semiconductor manufacturing is one of the industries that require most advanced technology (Lee, 2001). Semiconductor manufacturing is a complex supply chain consisting of wafer fabrication facilities, assembly and test facilities, warehouses, and distribution centers which are all distributed throughout the world. These different activities are illustrated in figure 6[2], which represents the global supply chain of NXP. The sequential production steps are shown together with the associated lead times per activity. The production process is conducted in batches. There are two main processes related to this supply chain labeled as front-end and back-end. The front-end part of the process diffusion of takes place, which creates wafers containing dies. Within the front-end, wafers are produced that contain the dies via a diffusion process. Within the back-end, the wafers are further processed by testing and assembling the dies into final products via respectively the pre-testing, sawing, assembly and final testing processes. The finished products are subsequently transferred to the industrial warehouse and then to regional distribution centers. The largest and most important NXP customers are supported by a so-called customer program. A vendor-managed inventory is established in order to increase service and efficiency.

The different production steps can be described as follows (Lee, 2001):

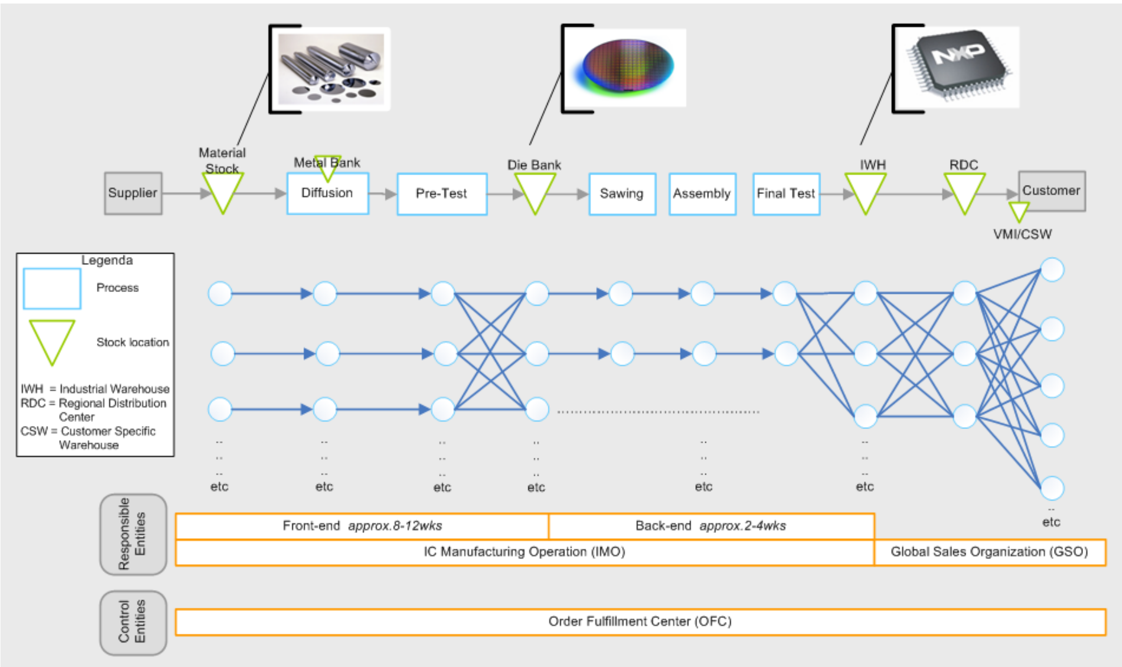
- Diffusion: The material stock consists of wafers consisting of raw silicium. At the diffusion process new thin layers are bonded or baked onto the wafers. This is done using diffusion furnaces, high-pressure oxidation, and rapid thermal processing. The diffusion process, consisting of 300 to 400 process steps, takes place in semiconductor fabrication facilities, called wafer-fabs.

[2] Figure 6 is outdated since nowadays testing is done in the back-end part of the process

- Pre-test: The back-end process starts by testing wafers before they are further processed. Each finished wafer may contain several hundred actual devices or dies. A probe tester uses needle-like 'probes' to contact the bonding pads (the circuit connection points) on each die to check its operation
- Sawing: Wafers are first sawn into individual dies. The marked (non-functional) dies are discarded and the functional dies are passed on to assembly.
- Assembly: Once separated into individual dies, the functional dies are attached to a lead frame and aluminum or gold leads are attached via thermal compression or ultrasonic welding. Sealing the dies into a ceramic or plastic enclosure completes the assembly.
- Final testing: After assembly, the dies are tested once more for electric properties. After the final test, the final products are packaged in boxes and temporarily stored in the industrial warehouse, located at the assembly and test plant.
- Distribution and Shipping: To get the products from the IWH to the customer's gate, two different shipping concepts are used:
    - Direct Shipment: this is the fastest way of shipment and the customer is directly delivered from the Industrial Warehouse. This shipment can be seen as the NXP default shipment stream and the objective is to go to 100% direct shipment.
    - Transshipment: means that the finished goods are first stored in the Regional Distribution Centre before they are delivered to the customer's dock or to a Customer Specific Warehouses where the inventory is managed by the vendor.

In general, parts of the industrial process are spread over more than one geographical location. The front-end operations are performed in the waferfabs. The back-end operations are performed in the assembly plants. These fabs and plants are located in several spots around the world.

Figure 6 Figure 2.3: NXP's supply chain and control entities



5.2. Semiconductor Industry

In 1947 Bell Laboratory researchers invented the point contact transistor (Schaller, 1996). As years passed by, the US Army subsidized the development of silicon transistors since existing designs were rapidly affected by heat. The demand for the handheld calculator during the 1970s meant a burst in the semiconductor demand (Okada, 1995). Today, semiconductors are found in almost every electronic product. Cohen et al. (2003) briefly describe the semiconductor business. It is a highly capital intensive industry. The expenditures for new production equipment are the largest item on the earning statements of chip manufacturers. Due to these high fixed costs, underutilization can have a devastating influence on the financial situation of these manufacturers. With respect to supply chain characteristics it can be said that intense coordination between the buyer and supplier is extremely important in the semiconductor industry. This is due to the uncertainty and volatility in the microprocessor market as well as the complex, rapidly evolving technology of wafer processing (Terwiesch et al., 2005).

The industry can be characterized by the following points (Geng and Jiang,(2009):

1 Rapidly changing technologies

Technology as well as products changes quickly in this industry. New equipment is almost continuously needed to be able to produce these new products. As product life cycles become shorter, rapid change is needed to be up to date and productive. In 1965, Moore saw an exponential growth in the number of transistors per integrated circuit. He predicted that this trend would continue with a doubling period of approximately 18 months, Schaller (1996) determined that "Moore's law" survived the previous 31 years. Products become increasingly complex, more and more products and service appear which consist of integrated circuits, whereas the product lifecycle keeps decreasing.

2 Market volatility

Highly volatile demand is caused by severe bullwhip effects in the semiconductor business. The long capacity adjustment delays deteriorate these effects. The demand for semiconductors is highly cyclical. Periods of rapid growth are followed by eras of underutilization. As an upstream company in the supply chain, high variability in demand due to bullwhip effects occurs. Forecasting is very difficult and customers do not always commit to their demand. Furthermore, in the semiconductor business, it is often either all or nothing. Either being designed in to produce chips for all iPhones, or not selling chips for the iPhone at all. The consequences of important design-ins can be far reaching and since there is no intermediate between the two extreme ends, it reinforces the volatility of the business.

3 Asset-intensive

Capital utilization is an aspect of great importance in this industry due to the fact that huge capital investments are required to build new plants. New equipment and tools have to be ordered several months ahead. It takes almost a year to expand or build a new fab. Together with the huge capital costs, it is a hard job to decide when to expand capacity on the basis of hardly accurate two-year forecasts.

4 Long manufacturing lead-times

Within the semiconductor industry, the common lead-time for producing end products is generally between 10 and 16 weeks. In contrast, customers expect much shorter lead times when ordering semiconductors. This forces the industry to strategically manage inventory at various stages in the pipeline. Customer order decoupling points are introduced to shorten lead times by partly producing forecasts-driven (Push) and partly on the basis of orders (Pull).

5.3. The Automotive Industry

5.3.1. From NXPs point of view

However, as shown in the previous section, NXP serves four main business units. Characteristics of these four business units differ a lot among each other. With respect to this study, only the automotive business unit is relevant. From NXPs perspective, this business unit can be described according to the following characteristics.

1 High & consistent quality

As became clear quickly, the automotive industry can be called the most demanding client of NXP. Chips made for the automotive industry are tested thoroughly over and over again. The testing to ensure certain quality levels of chips within the BU automotive is stricter than at the other BUs. Consequences are high when cars are not functioning properly. The huge impact of Toyota's braking systems malfunction shows why quality levels are so strict in the automotive industry. This distinguishes the automotive industry from other industries. Problems with a few parts per million in the mobile phone business can be ignored and routinely dealt with, whereas the same ppm in the automotive business could lead to million dollar claims and high scale call backs. Obviously, a chip producer would not want their products to be associated with such issues and malfunctions.

2 Long life & production cycles

In contrast to mobile phones, which are newly introduced every six months and have a short lifetime, new cars are introduced per brand averagely every 5 years and have even longer lifecycles. Combined with the high quality standards this results into relatively certain prospects. The high demanded quality is reflected into the switching costs of car manufacturers. When a company's chip is designed-in into a certain car model, it is really hard for a car manufacturer to switch to another chip. Because of quality issues, long testing and development cycles have been passed before a certain chip is qualified to be designed-in into a specific car model. It could take more than a year for a car manufacturer to switch to a new chip. Therefore, when a chip is finally designed-in, high certainty exists that NXP will deliver the chip the coming years.

3 *Stability*

Among other served industries by NXP, the automotive industry can be considered a relatively stable industry. This is in line with the long life and production cycles. The dynamics in this relatively stable market increased significantly during the last few years. Before the recent economic downturn, it was not even necessary to pay full time attention to the month-to-month and quarter-to-quarter forecasts. Only once a year, the developments and forecasts of the global car industry were reviewed. Since the economic downturn, the market has become more volatile. Whether these dynamics are permanent or not remains the question. If the market stays more dynamically than before, it will pay to spend time forecasting and observing early warnings indicating shifts in trend. Anticipating in a early stage on downwards or upwards changing market can be a source of competitive advantage. Being able to ramp up earlier; cut costs while competition keeps overproducing; and especially looking beyond the fads can be crucially important.

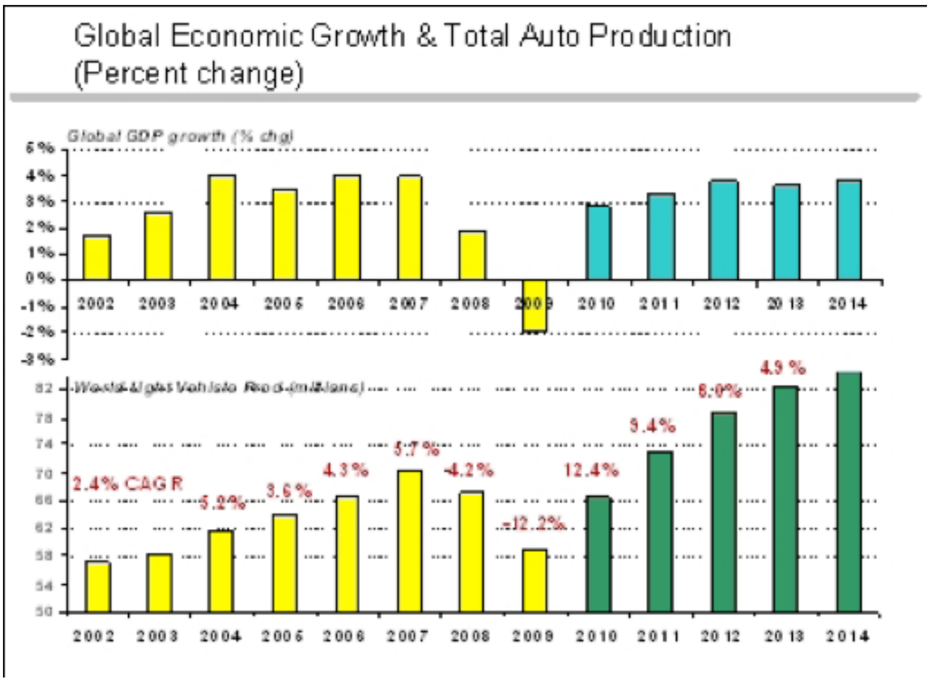
4 *Belt stops are killing*

Among various NXP supply chains, the automotive supply chain is very expensive. Of course, no matter which supply chain is investigated, stock-outs are never desired. Still, consequences of stock-outs are more severe than business units such as identification and standard products. Huge costs are incurred when an automotive production line is down due to a lack of parts such as semiconductors.

5.3.2. 2007-2010: A Real-world test signal for the bullwhip effect[3]

It takes some time to sketch the situation as it is and as it was the last years in the automotive industry. As more industries do, the automotive industry is closely related the Global GDP levels. Figure 7 compares the percentage change in global economic growth with the percentage change in the total auto production. Upswings in global economic growth are followed by increased car production, whereas downswings in global GDP are followed by cutbacks. The other way around, upswings and downswings in the automotive industry on their turn significantly influence the global GDP levels. Though, the first relationship seems to be the case. As a result, it is logical that the recent economic crisis has a huge impact on the automotive industry. The economic crisis is illustrated by the following figure 8. Consumer confidence, world trade, production, employment, and retail as well as OEM purchasing dropped dramatically in a short period of time. The crisis was often called the worst crisis since the great depression in the 1930s.

Figure 7: Global economic growth compared vs. Auto production (IHS Global insight Report: World Automotive, 2010)



3 Appendix B elaborates on more general trends in the Automotive Industry including environmental issues, modularization, and decreasing lifecycles

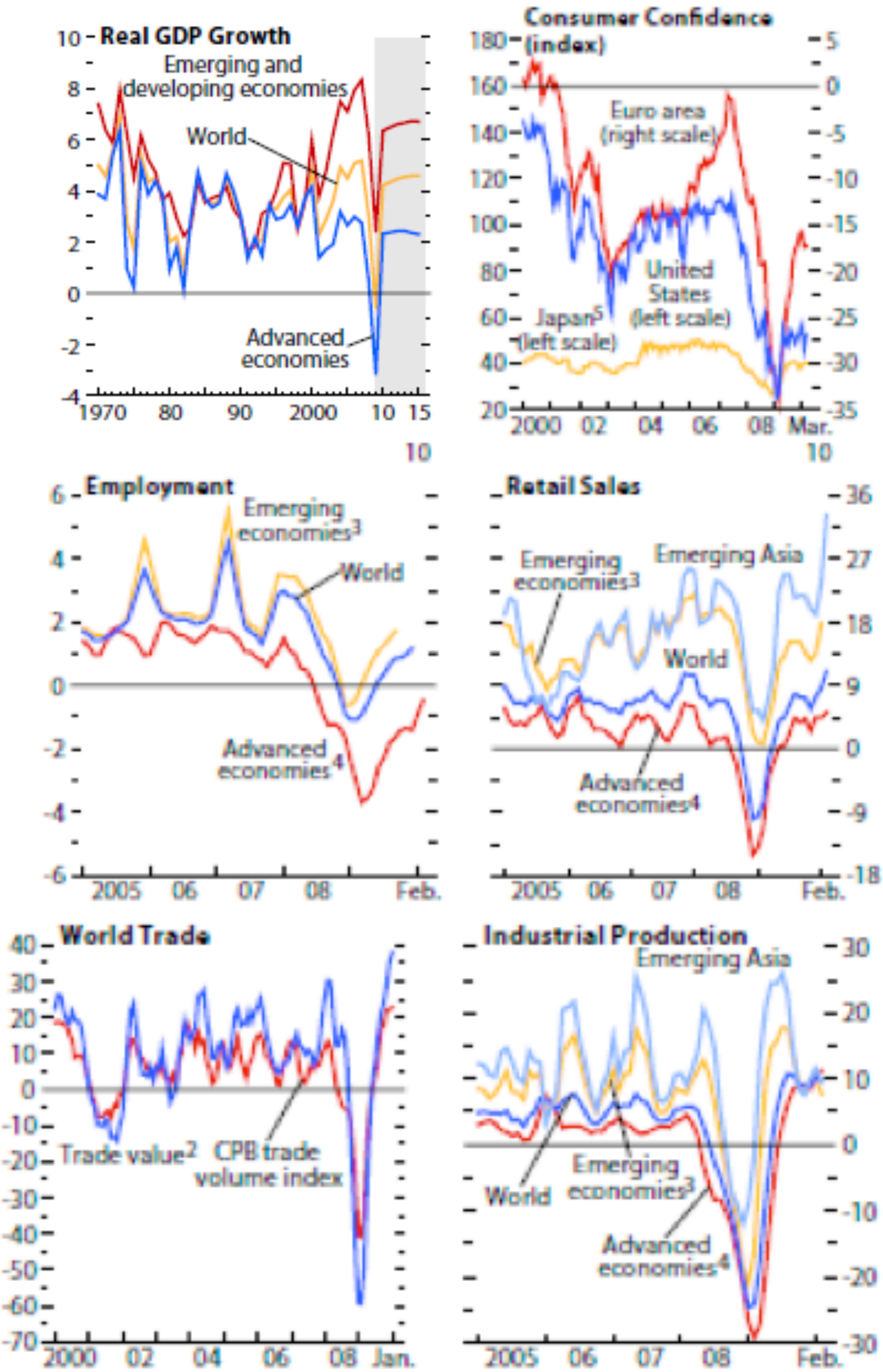


Figure 8: Several graphs from IMF.com illustrating the economic situation

Due to the worldwide economic crisis the automotive industry was hurt severely. At the low point the peak to-trough seasonally-adjusted-annual-rate (SAAR) of sales was no less than 30%. Automotive manufacturers started to destock voluntarily. This had a huge impact on the first and second tier suppliers. The 21% 2009 revenue decline in the automotive semiconductor market was caused by these dramatic cutbacks production to vanished consumer demand caused by the global recession, and inventory destocking. These annual numbers and results should be viewed in the right perspective, as the first two quarters of 2009 were disastrous, whereas the last two quarters represented significant recovery. Destocking is a known phenomenon in times of crisis. Nevertheless, the scale of destocking during this crisis was extraordinary. As becomes clear from figure 10, the prospects with respect to the global GDP kept decreasing from the end of 2008 on. This led to the extraordinary destocking, as the light at the end of the tunnel remained undetectable. The first quarter of 2009 represented the low point for many semiconductor producers as customers used existing inventory to satisfy the hugely decreased end-market demand.

As mentioned, the drop in sales was followed by a large drop in production. The collapse in production in three quarters of time was according to IHS the largest ever observed in the vehicle production world. At the end of the second quarter of 2009, production was down by no less than 13 million units compared to nine months earlier.

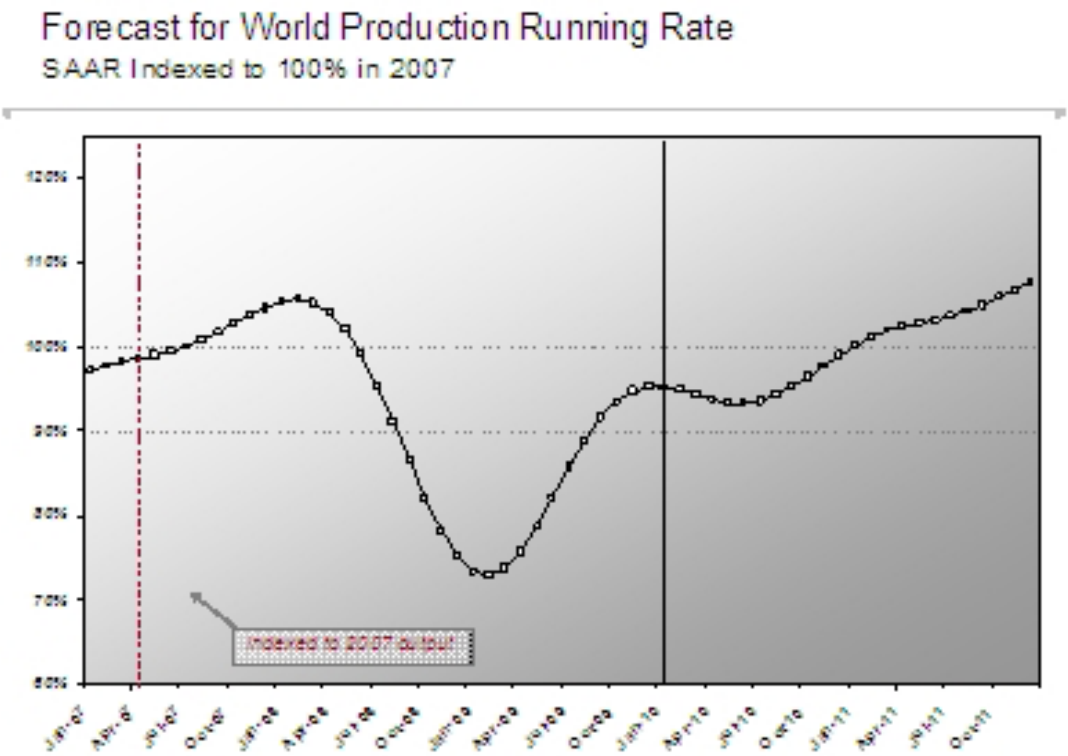
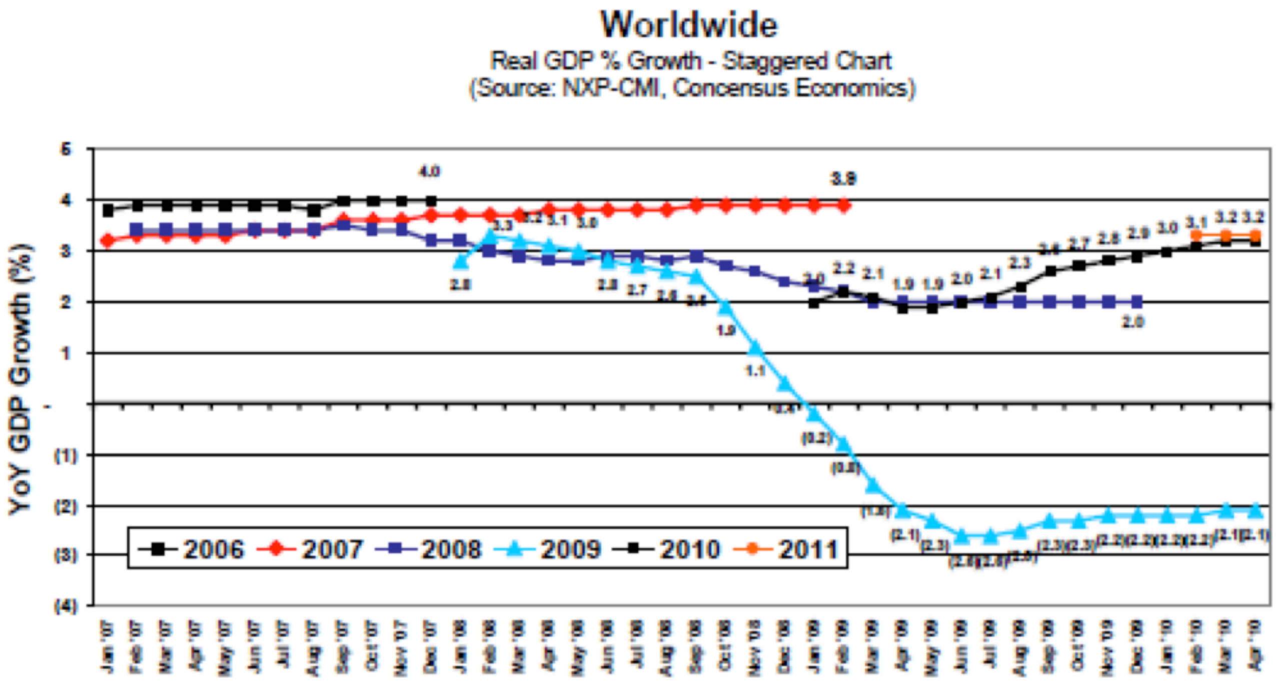


Figure 9: Forecasted car production April 2010 (IHS Global insight Report: World Automotive, 2010)

Figure 10: Yearly world GDP growth forecasts at different points in time (IHS Global insight Report: World Automotive, 2010)



In addition, though the global ramp down of sales is illustrated in the figure 11, the situation in some areas of the world is worse than it seems. In fact, the global in sales dip would have been way larger if the BRIC countries (especially China) would not have accounted for significant increases in sales. Figure 12 demonstrates the trend of the BRIC versus the trend of the triad-established areas. Furthermore, China majorly influences the global charts in 2009 as well by ramping up production during the third quarter by no less than 70%. Taking these facts into account, the global dip in sales can be put in the right perspective and will not be underestimated. According to IHS, it can be concluded that the output of 59.2 million units for 2009 was by far the largest dip in production ever recorded, bigger than the oil crisis in the 70s combined by the Asia crisis of '98.

Figure 11: Global car sales rate (IHS Global insight Report: World Automotive, 2010)

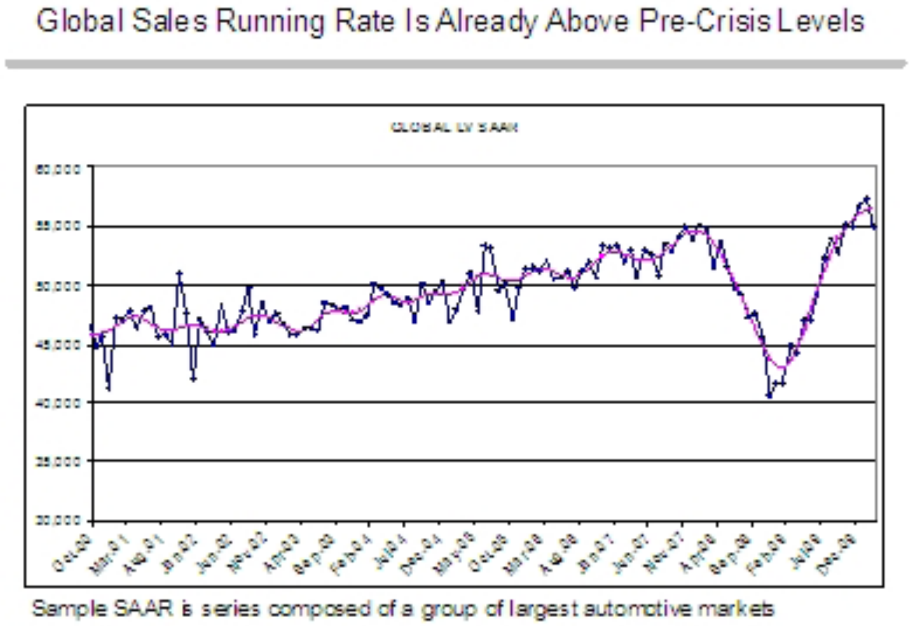
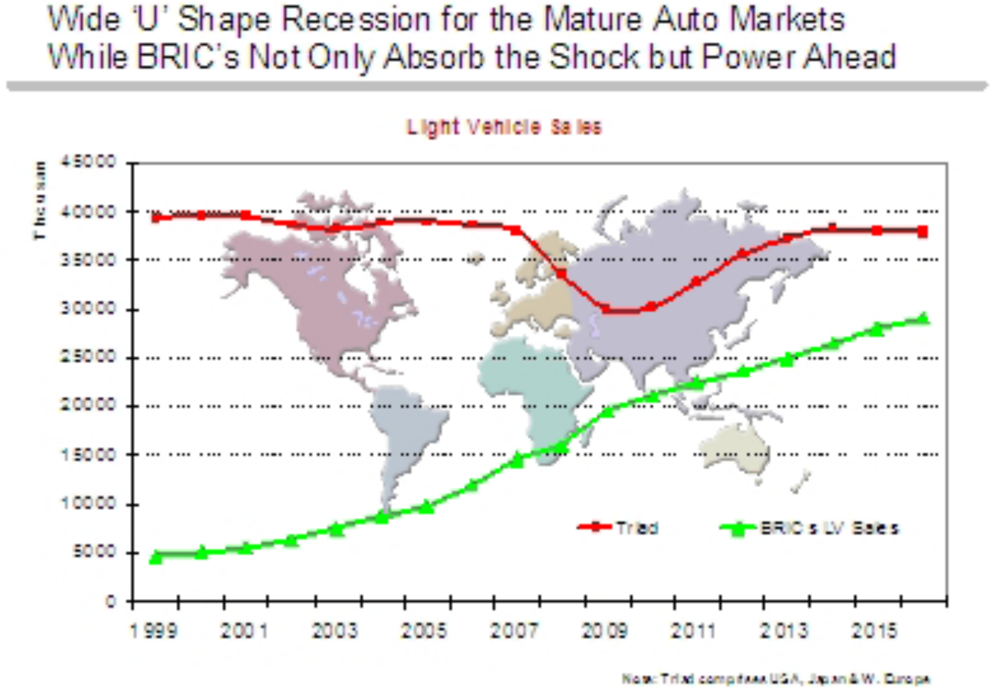


Figure 12: Car sales in BRIC countries vs. triad markets (IHS Global insight Report: World Automotive, 2010)



As time passed by, in no time the global automotive industry was turned around significantly in just nine months time. This unusual recovery was way ahead of the general recovery of the world economy. Nevertheless, it can be explained by pointing to the following 3 factors (IHS, 2010)

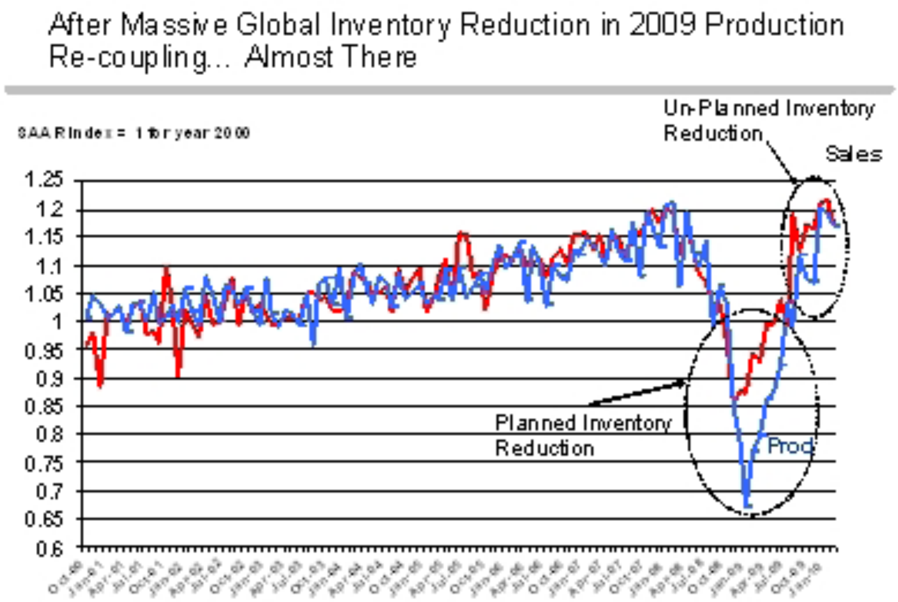
1. The consumer confidence meltdown was prevented as the global financial system was saved from further declining.
2. The extremely good performance in some of the emerging markets. Especially China, but also India and Brazil.
3. Finally and maybe the most important explanation, extensive and effective governmental incentive programs proved to be effective and drove the turnaround in sales.

The turnaround in the form of governmental incentive schemes to boost the car market led to an unanticipated positive effect in the end-market. According to IHS, between 7% and 8% of all global vehicle sales resulted directly from the specific automotive stimulus adopted by governments all over the world. In august 2009 a percentage of no less than 12 to 15% of the vehicles was bought because of the incentive schemes. The voluntary destocking of car manufacturers was suddenly changed to involuntary destocking. Figure 13 illustrates the voluntary as well as the involuntarily destocking. Sales went down dramatically, followed by a significantly amplified inventory reduction. In order to keep up with the boosted end-market demand, the production levels were ramped up and exceeded sales in order to restock again. Clearly, the pressure to upstream parties such as NXP was huge. In no time, a desperate period of extensive plant shutdowns turned around to shortages and inability to satisfy the ramped up demand. So it can be concluded that the world wide vehicle production at least should match the world wide vehicle sales during this year, since every manufacturer has to build each vehicle due to the low inventory position. As a result, supplier are faced with booming times of business.

5.3.3. Bullwhip effect at NXP

Figure 14 and 15 represent the indexed trends of the global automotive sales, global automotive production, and the NXP of the Automotive BU. After an anticipated seasonal dip in the sales in 2008, the global car sales started decreasing. The peak-to-trough dip was no less than 24% from June '08 to January '09. The global car production showed a more dramatically decreasing trend during the same period. A peak-to-trough dip of more than 47% occurred. Finally, the sales of the Automotive BU of NXP decreased by 64% during the same period. Thus the 24% decrease in car sales was amplified with factor 2.7 to a 64% decrease in NXP sales.

Figure 13: Car production vs. Car sales (IHS Global insight Report: World Automotive, 2010)



Although the sales and production started rising from the beginning of 2009 on and thus the bottom was already reached, NXP faced a terrible 2009-year. Despite the rising sales figures, 2009 accounted for a 27% loss with respect to 2008. The year-on-year numbers of the global car sales and production showed less dramatic numbers. Global car sales decreased 4% and production 12%. Thus, upstream amplification effects are largely visible. Year-on-year the amplification ratio of the decrease in car sales was no less than 6.8.

Figure 14: Bullwhip effect in the automotive supply chain (zoomed in)

Figure 15: Bullwhip effect in the automotive supply chain (zoomed out)

6. Model

This chapter focuses on the system dynamics model used for simulating the automotive supply chain. Section 6.1 explains the original model. Section 6.2 subsequently shows how it is adapted. Next, section 6.3 is about the validation of the model.

6.1. Sterman's supply chain model

The generic supply chain model, which is used to model and simulate NXP's supply chain, is designed by Sterman (2000). Appendix C shows what the model originally looks like and D elaborates on the algebraic calculations of the model. It originally is a generic supply chain model, which consists of two parties: the manufacturer and the supplier. The 'Customer Orders' box enables a modeler to include a variety of different customer order patterns. These customer orders flow in at the order backlog of the manufacturer, visible in the box 'Production & Inventory 2'. The customer orders determine the desired shipment rate. The finished goods inventory and minimum order processing time determine how much will be shipped. Discrepancies between actual inventory & desired inventory; current production rate & expected customer orders; and desired raw material inventory & actual raw material inventory, determine in the end how much is ordered from the supplier. The model takes shortage gaming into account by comparing the current material delivery delay with the common delivery delay of the supplier. When the current delay exceeds the common delay, the manufacturer is encouraged to order more. Additionally, problems with having a range of different products in stock are also taken into account. When the aggregated maximum shipment rate according to the inventory is equal to the aggregated desired shipment rate, it is assumed that this desired shipment rate couldn't be met due to product-mix problems.

Eventually, the manufacturers orders flow in at the supplier order backlog. The boxes 'Supplier 1' and 'Supplier 2' together represent the supplier part of this model. The supplier has a similar internal supply chain as just explained. The supply chain model tries to approach the reality of decision-making. Several delays and parameters such as manufacturing cycle time and safety stock coverage are firm/industry specific. These parameters and firm/industry specific delays can be adjusted to customize the model in order to represent a certain supply chain, which is the supply chain of the Automotive BU in this case.

6.2. Adaptation of the model

As Cachon & Fisher (2000) point out, incorporating non-identical parties eventually make a model too complex to analyze. Aggregation is needed in order to perceive the big pictures and to prevent flooding in too many details. In line with the statement, aggregation is the keyword in the adapted supply chain model. Additional to the supplier and manufacturer, a third party is introduced. The first echelon of the adapted model is clearly the original equipment manufacturer (OEM), in this case the automotive manufacturer. As an input to the OEM, orders from the automotive market flow in. The second tier of the model represents the module maker. As a result of modularization, parties as NXP do not deliver products to OEMs. So, the module maker produces modules that are delivered to the OEM. In turn, the module maker orders the chips at the semiconductor manufacturer, NXP in this case.

After the inflow of cars is transformed via modules in a relative inflow at the semiconductor tier, the sales of the semiconductor echelon are multiplied by NXP's market share, the average semiconductor value per car, and a small correction due to NXP's product mix[4]. This adaptation aims to calibrate the model to the real life situation. The model starts at equilibrium since the situation was stable in the beginning of 2007. So car production and car sales were more or less in balance.

The following factors and parameters are partially assumed and partially determined by interviewing relevant stakeholders from the automotive BU. These factors represent the base case scenario.

Table 2: Parameters of the used system dynamics model

	Explanation	OEM	Module maker	NXP
Supply line adjustment time	The rate at which material order rate is adjusted to correct a non optimal # materials on order	2	2	N/A
Material inventory adjustment time	The rate at which material order rate is adjusted to correct a non optimal # material inventory	2	2	2
Minimum material inventory coverage	Time required to prepare materials and thus minimum inventory	1	1	1
Material safety stock coverage	# Of weeks inventory besides minimum inventory coverage is targeted to maintain just in case	2	2	2
Material delivery delay perception time	The delay in perceiving and responding to changes in supplier lead times	4	4	N/A
Manufacturing cycle time	The average delay between the start and completion of production	6	2	8
WIP adjustment time	The rate at which # of production starts is adjusted to correct a non optimal # WIP inventory	2	2	2

[4] NXP does not sell all the existing chips, which are assembled in a car. Furthermore, NXP can not be called on of the price fighters in the industry. The correction mark is determined by creating an equilibrium between the NXP actual sales and model sales. This is reasonable since the automotive market was fairly stable at that time.

Inventory adjustment time	The rate at which # production starts is adjusted to correct a non optimal # finished goods inventory	15	15	15
Minimum order processing time	Time it takes to process and ship orders from inventory and thus the minimum inventory	6	2	7
Safety stock coverage	# Weeks expected demand which is targeted to maintain beside normal order processing time. Buffer against possibility that demand variations cause shipments to fall below orders.	2	2	4
Time to average order rate	Rate at which changes in demand are reflected in future expected order rate	12	12	12
Target delivery delay	Target delivery time	6	2	7

6.3. Validation

According to Sterman (2000) no model can ever be validated. Validation implies that that a model is supported by an objective truth. By definition, Sterman says, all models are wrong since they are limited and simplified representations of the real world. In contrast, useful, illuminating, and convincing should rather be used than the term valid. Although validation seems impossible and all models are wrong, the purpose is to build the best possible model despite inevitable limitations. Focusing on the limitations and areas of improvement by using tests will enhance and eventually 'validate' the model.

One of the most widely used measures of fit is the R^2, the coefficient of determination. R^2 measures the fraction of variance explained by the model. Two R^2s are measured in this case. The fit between 'Model car production' and the 'actual car production' as well as the fit between the 'Model NXP shipment value' and the 'Actual NXP sales value'. Figure 16 and 17 show the 'Model car production' and the 'actual car production' as well as 'Model NXP shipment value' and the 'Actual NXP sales value'. Eventually, 82% of the variance of the car production is explained by the model and 73% of the variance of the NXP sales. These levels of R-square are respectable and show that the model fits properly.

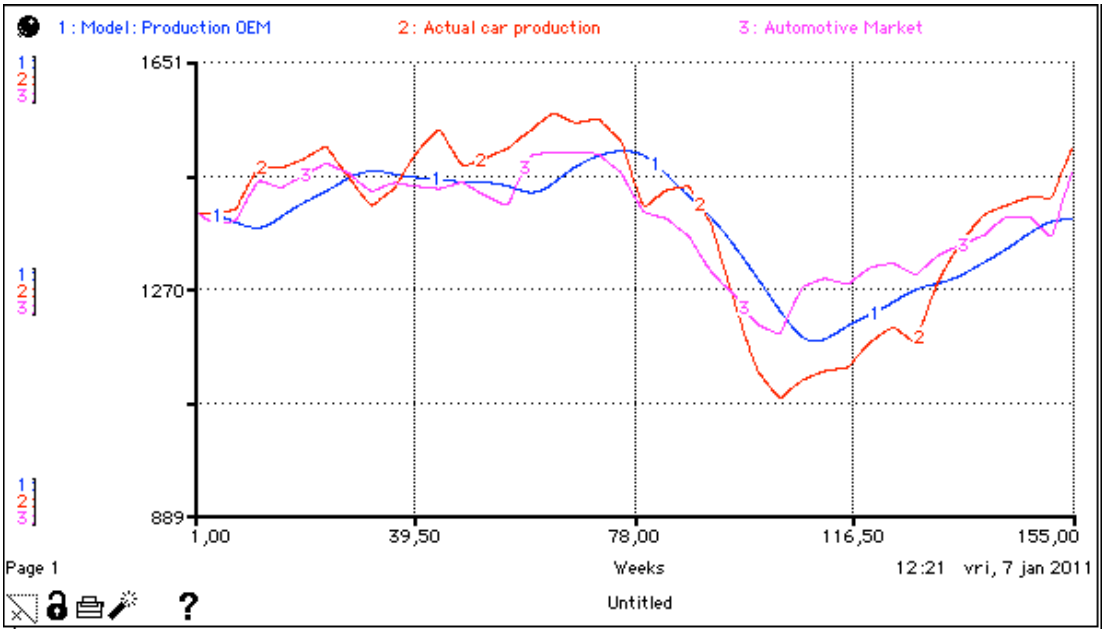
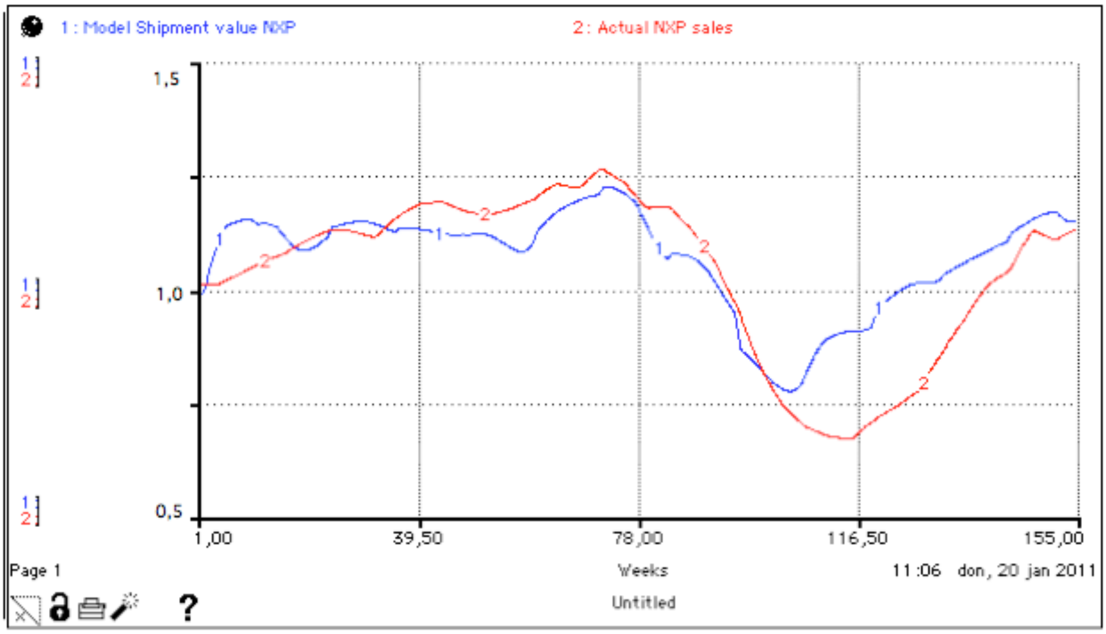


Figure 16: Model value for car production, actual car production value, and the car sales

Figure 17: Model shipment value NXP vs. Actual NXP sales (indexed)



7. Simulation Analysis

In this chapter, the model is used in order to simulate two different scenarios, namely a (1) 'reduced order lead-time scenario' and an (2) 'end-market focus scenario'. These scenarios will be compared to the base case, of which the parameters are presented in the previous chapter. Section 7.1 introduces the scenarios and explains the performance indicators. Then, in section 7.2 and 7.3 the scenarios are analyzed followed by a short conclusion.

7.1. Scenario analysis

Scenario (1) simulates what the impact is of reducing NXP's order lead-time. Both the 'target delivery delay' and the 'minimum orders processing time' within NXP are varied between the initial order lead-time and the shortest possible lead-time, respectively 7 and 1 week(s). In reality, this reduction in order lead-time could be achieved through creating a finished goods stock and thereby shifting the 'order decoupling point ahead'.

Scenario (2) is about using available knowledge about the end-market. What happens if NXP anticipates on fluctuations in the end-market instead of following changes in direct demand? This scenario uses the end-market as input in the forecasting process instead of the direct customer demand. In the end, the end market determines how many chips will end up in the sold cars. Throughout the supply chain this demand pattern is amplified and distorted and arrives at an upstream party such as NXP. Instead of trying to match this distorted amplified demand by ramping up and down, NXP could also use the end-market as a driver for their production.

Four performance indicators are taken into account when evaluating the results of the scenarios. As a performance indicator for cost, average inventory is used. The higher the average inventory the more inventory costs are incurred. Holding, obsolescence & interest costs are part of inventory costs. The peak-to-trough ratios for both 'material order rate' and 'production starts' are used as performance measures for measuring the extent to which the bullwhip effect is mitigated. The decrease in 'material order rate' volatility means a direct decrease of the bullwhip effect, whereas a drop in 'production starts' volatility can be interpreted as an indirect decrease of the bullwhip effect. Finally, the average inventory/shipments ratio is used as a performance measure for customer lead-time. This ratio determines how quickly ownership is changed of current inventory.

The results of the scenarios should be considered taking a few things in into account. The simulation model does not work with a fixed capacity. This means that the shipment rate of NXP will not differ since NXP will be able to ramp up and down easily in the simulations. Table 3 provides a sensitivity analysis which shows that the average shipment rate and peak-to-trough shipment rate remain more or less equal regardless of the order lead-time or degree of end-market focus. This especially influences the impact of the huge dip after the global crisis. By looking at the 'production start rate' and 'material order rate', the variable capacity limitation is taken into account. If the 'production start rate' and 'material order rate' display a more stable pattern, it is less likely that situations of under-capacity and stock-outs occur.

Sensitivity Analysis: Shipment rate							
Shipment rate ROLT				Shipments rate end-market			
Weeks	Peak-trough	Avg.	%	% End-market	Peak-trough	Avg.	%
7	-518	1.364	-38%	0%	-518	1.381	-38%
6	-511	1.371	-37%	25%	-514	1.380	-37%
5	-502	1.375	-36%	50%	-512	1.380	-37%
4	-496	1.377	-36%	75%	-503	1.379	-36%
3	-498	1.379	-36%	100%	-493	1.379	-36%
2	-500	1.380	-36%				
1	-490	1.381	-36%				

Table 3: Sensitivity analysis of the impact of the scenario's on the shipment rate of NXP

7.2. Reduced order lead-time

Scenario (1) simulates what the impact is of reducing NXP's order lead-time. As stated, both the 'target delivery delay' and the 'minimum orders processing time' are varied between 7 weeks and one week to inspect the influence of reducing order lead-time. In reality, this reduction in order lead-time could be achieved through e.g. operating more efficiently, or by shifting the 'order decoupling point' ahead by initiating so called customer programs. Customer programs within NXP are different variations of the well-known 'vendor managed inventory' structure. Customer programs work with a order lead-time of three weeks. Therefore special interest is paid to the associated simulation run.

Figure 18 and 19 display the effect of reducing lead-time on respectively the 'material order rate' and the 'production start rate'. Table 4 lists the effect of this policy on each of the performance indicators. The peak-trough-columns show the absolute value decrease of the variable from the peak (+/- April 2008) to the trough (+/- January 2009). The percentage-column expresses this decrease in percentage of the average value of the variable. At last, the average inventory and the average throughput time are listed in the table. Both the graphs and the table display the results of a sensitivity analysis. It is not only tested whether reducing order lead-time in general is beneficial, it is also tested which degree of reducing order lead-time is favorable. So the performance indicators are compared when varying the order lead-time between 7 weeks and 1 week.

Originally, the base case scenario displays a volatile ordering pattern of NXP customers. High peaks are followed by strong dips in ordering. Averagely, the material order rate does not differ to a large extent between the 7 simulation runs. However, compared to the base case scenario, it becomes clear that the variability of the material order pattern keeps decreasing as the order lead-time reduces. Three weeks order lead-time leads to a 43% peak-to-trough ratio instead of the original 94%. In practice, the capital costs are huge while it takes a lot of time and money to expand capacity. Situations of underutilization and stock-outs will not be surprising when looking at the base case scenario. Since the order lead-time is reduced, NXP is better able to anticipate on demand changes. This increase in agility results in a smoother ordering pattern of customers, which is desirable.

The results of the variability in production starts suggest the same. The variability in production starts decreases as order lead-time decreases. Three weeks of order lead-time corresponds with 54% peak-to-trough ratio instead of the original 94%. However, compared to the material order rate, the marginal impact of lead-time reduction on the production start rate decreases, suggesting diminishing marginal returns.

By looking at the average inventory, it can be concluded that reducing order-lead time has a positive effect on the inventory costs. Since the inventory coverage in the model is based on the order lead-time, the decrease in inventory costs is a clear consequence of reducing the lead-time. The same holds for throughput time, as order lead-time decreases, the inventory decreases, and thus the time it takes for NXP to ship its inventory decreases as well.

Generally, reduced order lead-time reduces upstream amplification effects. When it comes to direct orders of customer and production starts, a radically less volatile pattern is visible. The volatility of the demand waves decreases and NXP is better able to react on these demand changes. Consequently, customers do not feel the urge to over- and under order as much as in the base case scenario.

Table 4: Sensitivity analysis of the impact reducing lead-time on different performance indicators

Sensitivity Analysis: Reduced Order Lead Time								
	Production start			Material order rate			Inventory	Throughput time
OLT	Peak-trough	Avg.	%	Peak-trough	Avg.	%	Avg.	Avg.
7	-1303	1381	-94%	-1301	1392	-94%	12762	9,26
6	-1084	1379	-79%	-1061	1388	-76%	11318	8,23
5	-894	1377	-65%	-841	1385	-61%	9882	7,21
4	-757	1375	-55%	-654	1381	-47%	8456	6,19
3	-710	1372	-52%	-588	1377	-43%	7037	5,18
2	-674	1367	-49%	-535	1372	-39%	5628	4,17
1	-659	1360	-48%	-498	1365	-36%	4228	3,17

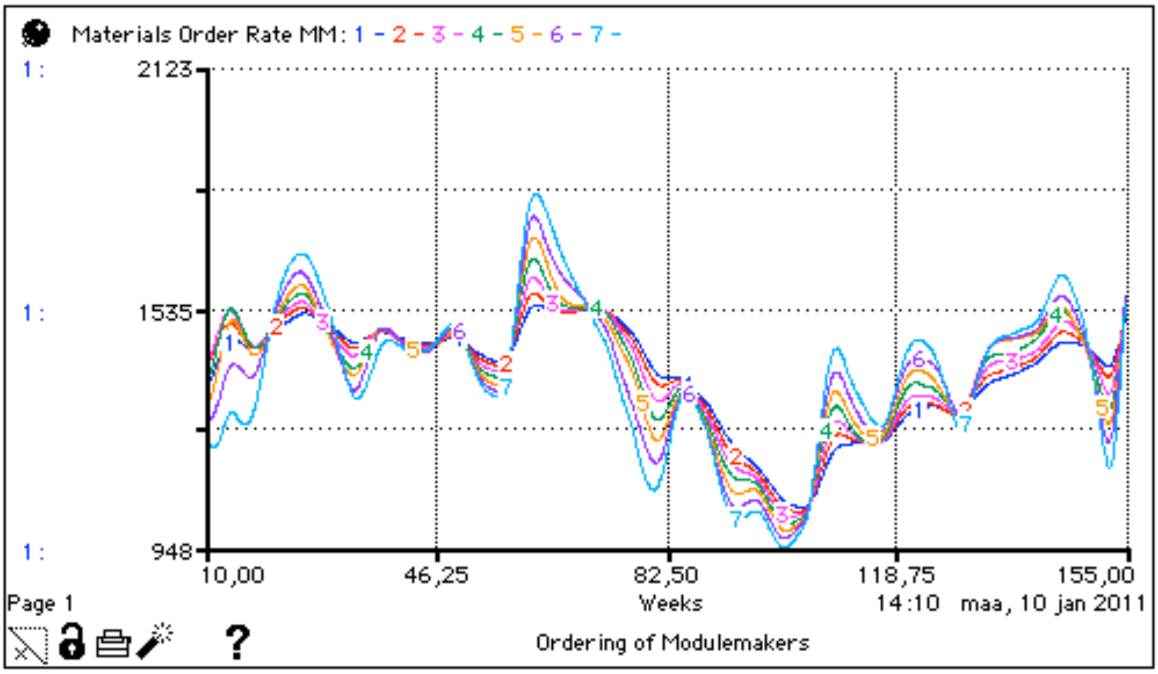


Figure 18: Sensitivity analysed of impact reduced order lead-time on material order rate

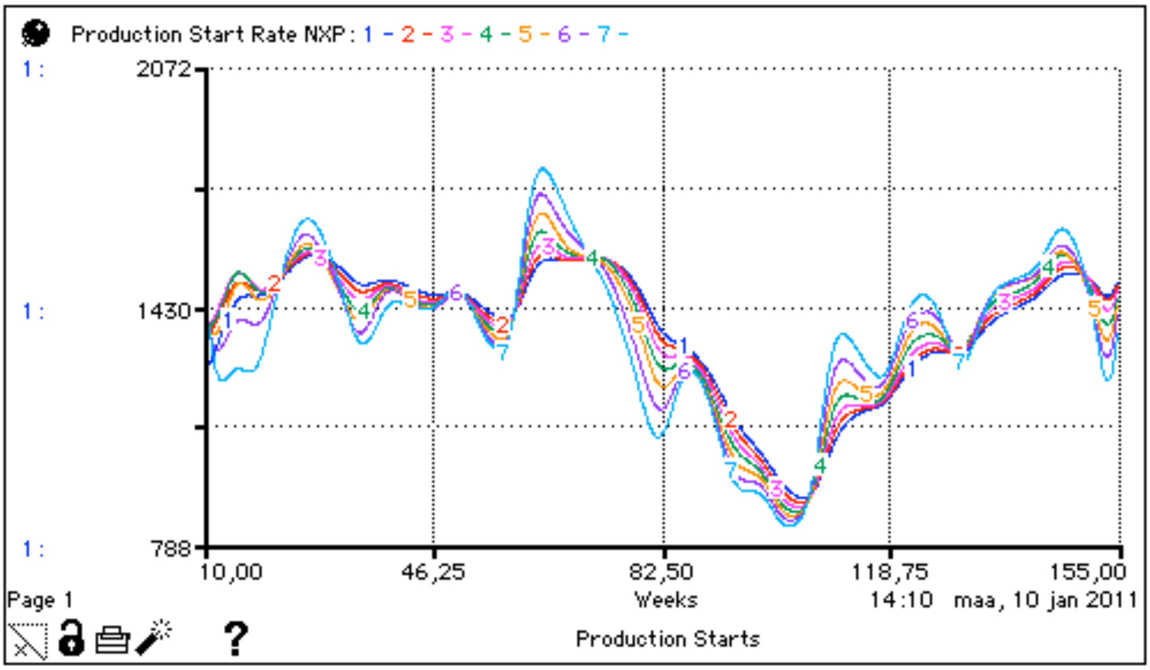


Figure 19: Sensitivity analysed of impact reduced order lead-time on production start rate

7.3. End-market focus

Scenario (2) is about using available knowledge about the end-market. What happens if NXP anticipates on fluctuations in the end-market instead of following changes in direct demand? In the model, instead of direct orders from module makers, the end-market is used as input in the forecasting process. Figure 20 and 21 display the effect of end market focus on respectively the 'material order rate' and the 'production start rate'. Table 5 lists the effect of this policy on each of the performance indicators: production starts, material order rate, average inventory, and throughput time. Again, a sensitivity analysis is conducted which compares implementing different degrees of end-market focus. For example, 25% means that direct demand is for 75% used as input in the forecasting process.

By implementing end-market focus, forecasts will no longer be dominated by the distorted orders of direct customers. NXP will look further ahead and observe changes in the end-market. Thus, focusing on the end market instead of direct customers when forecasting. After all, the end-market itself initiates the fluctuations (apart from endogenous bullwhip creation). In addition, the end-market is often an early indicator for changes in demand patterns. Throughout the supply chain, dozens of individuals are spending a lot of time on optimizing and managing the demand. Demand managers, planners, account managers, and so on, put significant effort in the process. Still, the demand is amplified and it remains very hard to cope with the volatile demand. As Andraski (1994) said: *Problems in supply chains are 80% human and 20% technology*.

Sensitivity Analysis: End-market focus								
	Production start			Material order rate			Inventory	Throughput time
%	Peak-trough	Avg.	%	Peak-trough	Avg.	%	Avg.	Avg.
0%	-1.303	1381	-94%	-1301	1392	-94%	12762	9,26
25%	-1.081	1380	-78%	-1303	1393	-94%	12756	9,28
50%	-863	1379	-63%	-1302	1396	-93%	12759	9,31
75%	-662	1376	-48%	-1297	1400	-93%	12772	9,35
100%	-591	1372	-43%	-1293	1403	-92%	12793	9,39

Table 5: Sensitivity analysis of the degree of end-market focus on different performance indicators

Following the end-market fluctuations instead of the direct demand results into smoother production patterns. When the large dip occurred 2008-2009, following the end-market would have resulted into a less dramatic ramp down. This is reflected in the peak-trough ratio in table 5 and in figure 20 and 21. Following the end-market results into a 43% peak-trough ratio, whereas using direct demand as input leads to a 94% production peak-trough ratio. However, with respect to the material order rate, inventory, and throughput time; following the end-market has negligible influence. In practice however, NXP is constrained with respect to capacity. Since reducing capacity and especially building capacity take a lot of time and involves significant costs, the smoother the production pattern, the better NXP can cope with fluctuations. Ramping down production less dramatically than the direct demand ramps down, inevitably leads to inventory. When demand pulls on again, this inventory can be utilized. The scenario translates the highly volatile demand pattern of direct customers into a dampened production schedule of NXP. In fact, it does not reduce the bullwhip effect but increases the ability to cope with it.

Figure 20: Sensitivity analysed of impact end-market focus on material order rate

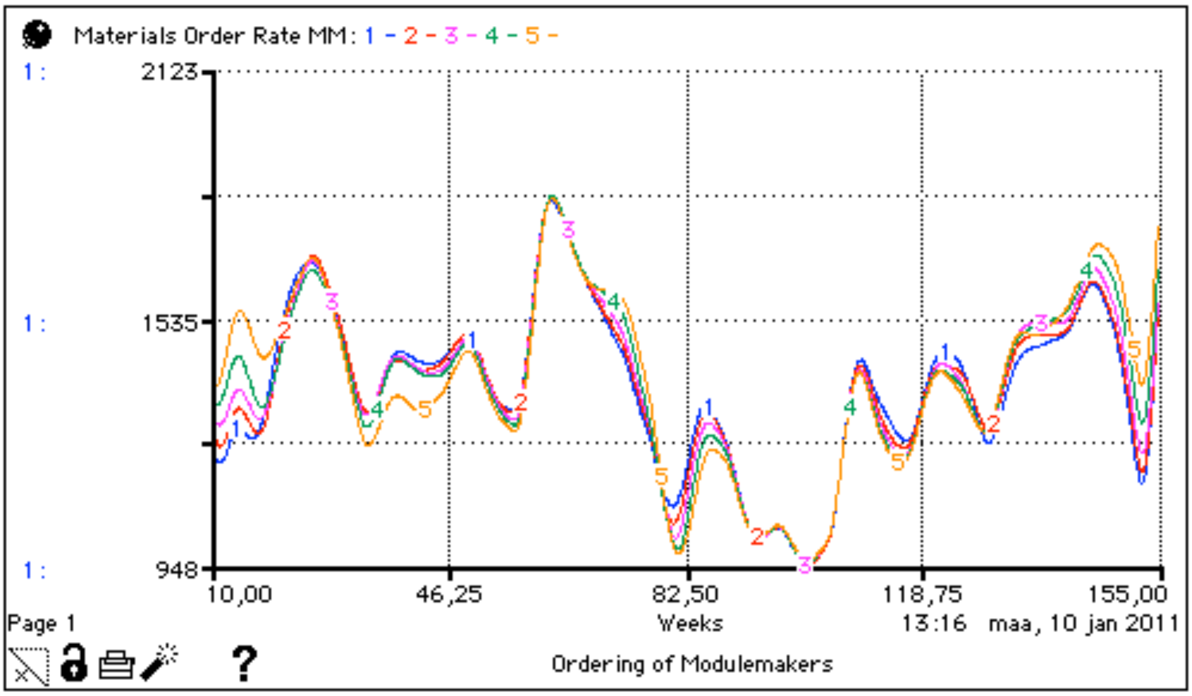
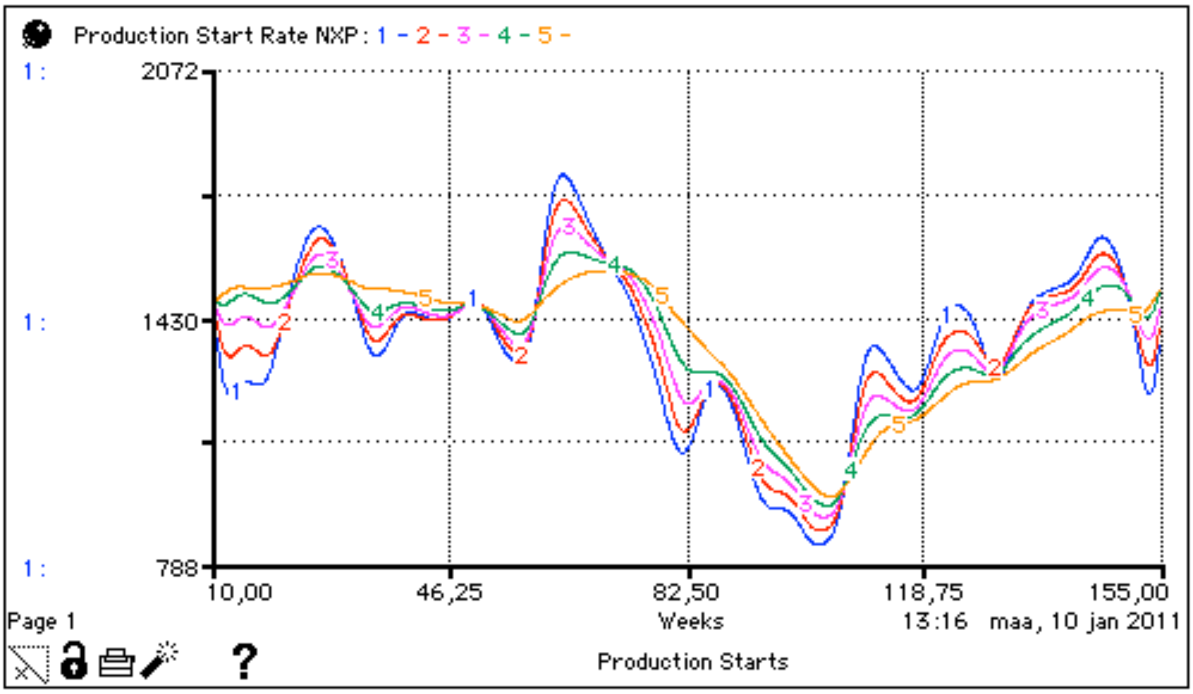


Figure 21: Sensitivity analysed of impact end-market focus on production start rate



8. Organizational Perspective

The question remains, *if companies appear to know so much about demand amplification, why do these firms still face this degree of demand amplification?* What impedes companies such as NXP to implement suggested solutions? What role does the organization play in this process? From discussions with company management emerges the hypothesis that organizational roadblocks lie at the heart of this. The organizational science is a very broad field of study. No attempt will be made to capture the entire spectrum of organizational science. By underpinning the hypothesis with interesting quotes from discussions with management, light will be shed on the influence of a few aspects of organizational science. Since reducing order lead-time is related to operational limitations and roadblocks, implementing end-market focus is the main subject of this chapter.

Resistance against anti-cyclical investing is common and understandably; it is hard to invest during a downturn and even harder to dampen demand in an upturn. The feasibility of implementing end-market focus is questioned. Focusing on the end-market namely means refusing to ramp down with 65% when the car sales drop with 20%. In times of downturns, less radically ramping down than direct customers inevitably leads to inventory building. In times of upturns, convincing customers that orders are not rational compared to the end-market is equal to refusing to fulfill orders. Resistance exists to a large extent within the organization to commit to either of these anti-cyclical policies. Both in situations of upturns and downturns, managing anti-cyclically means contradicting all 'lemmings' moving in the same direction. These 'Lemmings' include buyers, suppliers, stock-traders, and eventually even private equity investors.

> *"In fact, by implementing end-market focus, you suggest that you know it better compared to all other NXP 'Lemmings'. That is hard … Stock traders measure to what extent a company understands its business, in order to determine the value of a company. Increasing inventory will be interpreted as not understanding your business. If you argue why the inventory is increasing, it is the question whether they believe you or not. In the end, more inventory means higher risk … You are like Cassandra in the Greek myth. And it even goes beyond NXP. You are contradicting all data analysts and stock traders who all state that the market is going down. If everyone is reasoning in such a way, clearly my boss is … End-market focus in the upturn is enabled by a reliable order pattern, large ordering volumes, reliable clients, reliable supplier, and enormous amounts of money. In monopoly situations it is possible to behave in such a fashion. Least, if you are each other's most important clients. In all other situations, good luck." (1, 2, 6 & 7)*

However, the company survived the enormous dip of almost 65% because of a combination of luck, timing, and unintended anti-cyclical investing. The company is aware of the core truth in anti-cyclical investing. When the automotive market rapidly went down during 2009, NXP was producing enormous amounts of dies in bridging stock in order to be able to restructure a fab. The temporary capacity loss would be compensated with enormous amounts of dies in stock. Eventually due to this stock, NXP was able to react quickly on the market turn-around and sudden boost in car sales. Competitors were facing the usual slow reaction times common to the semiconductor industry. Constrained by time-consuming capacity adjustment, slow production ramping-up, and long lead-times, competitors had a hard time responding on the sudden boost in car sales. Whereas, NXP used the bridging stock for fulfillment of the boost in orders, and managed to delay restructuring the fab. They kept producing and benefitted from the unintended anti-cyclical investments.

> *"Everyone knows that there is truth in anti-cyclical investing….The reason for NXP to survive the crisis: because of internal issues, we started restructuring and sold a division. Coincidentally, we were building enormous amounts of bridging stock while the market was crashing. So, we were investing during the downturn. We did not invest to cope with the bullwhip effect, or to behave anti-cyclically. We invested to enable restructuring our fabs. In the end, it was very beneficially and it had an anti-cyclical effect." (3 & 4)*

When operating in such a hard industry in terms of lead-times, capacity adjustment, and production planning; responding after the market pulls on is too late. Given that authors (Tan & Mathews, 2010) showed that anti-cyclical operating in the semiconductor industry pays off in the subsequent period. Given that unintended anti-cyclical investing has pulled NXP through the crisis. Given that with respect to the characteristics automotive BU (e.g. relative stability, and long production & cycle times) it is feasible to focus on the end-market. What impedes focusing anti-cyclically on the end-market? True, operational and cognitive factors described in bullwhip literature are involved. Obsolescence of stock, product-mix issues, complexity of supply chains; play a role. However, the organizational aspect cannot be overlooked. Short-termism, interest alignment, and principle-agent problems are involved with respect to fighting the bullwhip effect.

> *"You have to work cross-organizational and a lot of employees are not able to do so. Or refuse to do so. A lot of employees would answer on suggested policies: although you are right and NXP benefits of the policy, I have to look at the interest of my department." (5)*

> *"In the past, companies like us had a much more integral view on the business. Nowadays, all functions within a company are more and more fragmented. It is hard to make decisions correctly. You have to take all those different interest into account. The news, stock traders etcetera are closer to the business than before …. Yes, interests are not always aligned. The financial guy wants limit costs as soon as lags behind. He will not encourage building stock in downturns. When demand is 100 the financial guy will match capacity to 100 as well. Nevertheless, building stock makes sense, since you will face consequences as soon as demand turns around again. Increasing capacity again and hiring people takes a lot of time. However, building stock is costly and closing the fab reduces costs. The production guy is likely to encourage stable production since fast ramping up and down is associated with anxiety in the fabs. So the production guy will reason from a production perspective and the financial guy from a financial perspective. That is logically since it is in accordance with the definition of an organization. However, it could lead to suboptimal decisions in the end." (7 & 10)*

> *"Of course, organizational and politics have influence. I have read an interesting article in ST a while ago. They wrote it was incomprehensible that such a small amount of inventory was present at our clients during the downturn. I have been to one of our clients. These parties have such strict cash flow rules that only minimal amounts of inventory may exist." (8)*

Beside the operational causes of the bullwhip effect and the behavioral cognitive limitations of decision-makers, a third perspective on the bullwhip effect can be chosen. This perspective focuses on hurdles for companies to implement bullwhip effect reducing policies. It focuses on the reasons for not coping with the bullwhip effect in accordance with the vast amount of literature written about it. Only little attention is paid to organizational factors in combination with the occurrence of the bullwhip effect.

9. Discussion & Conclusions

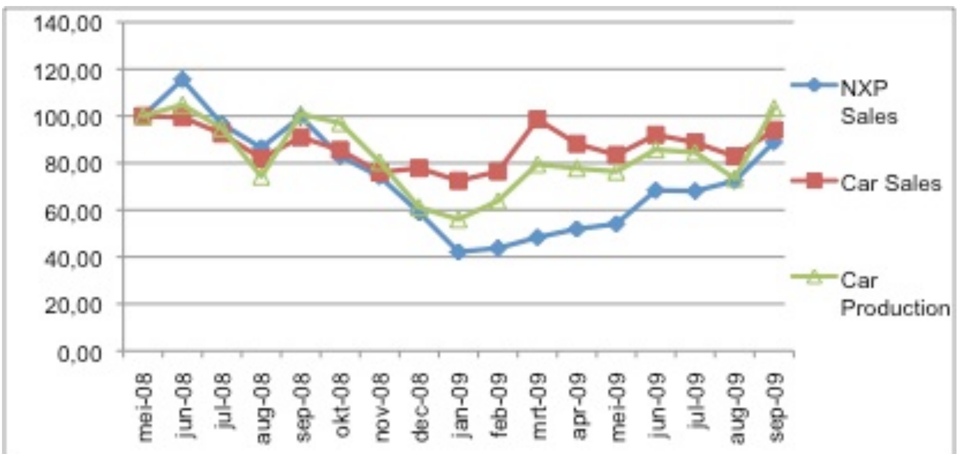
This chapter provides an overview and discussion of the conclusions generated in this Master Thesis. Answers to the four research questions are provided in section 9.1. Thereafter, limitations and implications are presented in section 9.2 and 9.3.

9.1. Findings

With respect to research question (1) (*Which types of causes with respect to the bullwhip effect can be distinguished?*), it can be concluded that literature generally distinguishes between two types of causes with respect to the bullwhip effect. On one hand, *operational* causes are identified by several authors (Geary et al., 2006; Lee et al., 1997a; Lee et al., 1997b). Authors referring to operational causes emphasis that the bullwhip effect stems from rational, goal seeking, optimizing behavior. These operational causes include structural inefficiencies such as lead-time, non-synchronized control systems, and the number of echelons in the supply chain. On the other hand, a *behavioral* perspective is chosen on the bullwhip effect. Especially those authors (Croson & Donohue, 2003, 2005, 2006; J. Sterman, 2000; J. D. Sterman, 1989) who study behavioral operations take such a perspective on the bullwhip effect. This field of study concludes that performance in operations management cannot only be explained by taking an *operational* perspective (Bendoly et al., 2006; Boudreau et al., 2003; Gino & Pisano, 2008; Loch & Wu, 2007).

Next, question (2) (*To what extent can the bullwhip effect be observed in the automotive supply chain?)* once again confirms the persistence of the bullwhip effect. The bullwhip effect is detected in the automotive supply chain. The peak-to-trough dip in the automotive market was less than 24% from June '08 to January '09. The same period displayed a 47% decrease in car production and a 64% decrease in NXP sales. Year-on-year the car sales decreased from 2008 to 2009 with 4%, which led respectively to a 12%car production decrease, and shrinking NXP sales by 27%. Figure x displays the extent to which the bullwhip effect can be observed.

Figure 22: Bullwhip effect in the automotive supply chain (zoomed in)



With respect to the research question (3) (*What policies can be implemented in order to reduce or eliminate the negative consequences of this demand amplification?),* multiple solutions are suggested by existing literature about the bullwhip effect. Among those potential improvement policies, two initiatives – namely using point-of-sale data and reducing lead-time – have been simulated by using system dynamics. Both policies are confirmed to be involved with bullwhip mitigation. Reducing lead-time proved to mitigate the bullwhip directly whereas focusing on the end-market increased the ability of NXP to deal with demand fluctuations.

Research question (4) (*What reasons can be identified for not implementing suggested solutions to the bullwhip effect?)* explores roadblocks for companies to diminish the bullwhip-effect. Organizational factors -such as short-termism and interest alignment- are provided little attention in existing literature. Beside the operational causes of the bullwhip effect and the behavioral cognitive limitations of decision-makers, a third perspective on the bullwhip effect can be chosen. This perspective takes the organizational hurdles into account for companies to implement bullwhip-reducing policies.

9.2. Limitations

The four research questions each have distinct limitations. With respect to research question (1) limited knowledge and familiarity with psychological and cognitive literature was present. These subjects belong to diverse departments within the social sciences. This limitation could have lead to an incomplete literature review, since valuable information may have been overlooked.

Research question (2) is limited with respect to its generalizability since it involves a snapshot of only one industry and supply chain. The persistence of the bullwhip effect is only observed in this specific case setting.

Research question (3) involves usual limitations of using system dynamics simulations. System dynamics always is a trade-off between aggregations and details. To be able to observe the big picture, the used model takes a highly aggregated view on the automotive industry. The input of the model is global cars sold in dollars. No distinction is made between sales regions, types of cars, and car brands. Between the semiconductor echelon and the car manufacturer echelon, generally, all types of module-makers are present. Because the model would become too complex if these different module-makers would be distinguished, the dollars of car sales just keep flowing through the model and are transformed into NXP sales by using the average chip content per car and NXPs market share. These assumptions and aggregations limit the accuracy of the study. However, by going further into detail, it would not be possible to give strategic or tactic recommendations. Furthermore, as stated earlier, the system dynamics model is limited with respect to its variable capacity.

Finally, the limitation for research question (4) is related to the exploratory nature of the question. In general, little attention has been paid to this perspective on the bullwhip effect. Only a few aspects of the broad array of organizational literature have been highlighted in this study. Follow up research is needed to confirm the hypothesis that organizational factors increase the knowledge about the persistence of the bullwhip effect.

9.3. Implications

On one hand, this thesis has implications for the case company. (1) Attention is drawn to the diverse causes of the bullwhip effect by distinguishing the different perspectives on the phenomenon. (2) Awareness of the bullwhip effect is enhanced within NXP by observing the persistence of demand amplification in the automotive supply chain. (3) NXP should persist in reducing lead-time to mitigate the bullwhip effect's operational causes. Order lead-time reduction is a powerful tool to mitigate the bullwhip effect since it does not only enhance agility but also positively influences the ordering pattern of direct customers. Besides reducing lead-time, end-market involvement is recommended. Really understanding what is behind the incoming direct demand is vitally important to mitigate the bullwhip effect. Focusing on the end-market instead of the direct distorted demand enhances the ability of the company to cope with the demand amplification. To deal with the cognitive causes of the bullwhip effect, training in stock-flow problems and system dynamics training can be recommended. (4) The company should be aware that their organizational structure might impede them from *doing what is right*. Organizational aspects, such as interest-alignment and short-termism, hinder the company to cope successfully with the bullwhip effect. NXP should make sure that long-term goals are not hindered by the short-term objectives.

On the other hand, this thesis has implications for research. Since, only a few aspects of the broad array of organizational literature have been highlighted in this study, the impact of organizational factors with respect to the occurrence of the bullwhip effect should be studied further to enhance the understanding of it.

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11. Appendices

11.1. Appendix A: Automotive Industry

- Decreasing lifecycles: The lifecycle of the European car models decreased significantly since 1980 (Juerging & Milling, 2006). From an average eleven years during the eighties, the average lifecycle of a car has decreased to six years in the current century. 'Rather than just a short time to market, the shortest time to volume must be the goal." Therefore, it is essential for first and second tier suppliers to be able to meet the high ramp up volumes during the introduction of new cars models. The decrease of the lifecycle has implications the volatility production. The shorter the lifecycle, the more the negative impact of schedule volatility (Childerhouse et al., 2008).
- Modularization: Within the automotive business the trend of modularization is clearly visible (Doran et al., 2007). Modularization is linked to a products architecture, components, and interface. The collaboration between Mercedes-Benz and Swatch with end product 'Smart' can be called a typical example of modularization (Doran et al., 2007). A typical car manufacturer would deal with 200-300 suppliers in order to produce such a product. The previously stated collaboration only used twenty to twenty-five suppliers. Complete body structure, breaking systems, dashboards were supplied and thereafter assembled. Value added activity is thus more and more outsourced upstream to first and also second tier suppliers.

  This modularization provides OEMS with several benefits, which will not be scrutinized further during this research. OEMs in the automotive industry modularize more and more. It certainly affects the role of different parties within the industry. Due to this trend, original equipment manufacturers add significantly less value to the entire process. In contrast to having hundreds of parties, which contribute minimally by supplying small parts, the value is shifted from the OEMS to manufacturers of modules such as complete dashboards. Dashboard manufacturers might choose to outsource the assembly of car radios in their produced dashboards. This trend does not lead to significant changes at every tier of the industry. Operations and business of upstream parties such as NXP are not influenced radically. However, modularization often leads to additional echelons within an industry (Doran et al. 2007). Being located one echelon more from the end customer results contributes to bullwhip effects. This could be an explanation of the automotive supply chain, experiencing more and more volatility.
- Environmental issues: Next to the modularization trend, importance of environment is more and more a recurring theme in the car industry. So far, ambiguity remains about trends such as hybrid and electric cars. Whether these trends continue or not, semiconductors will play important roles in this environmental focused industry. With their well-known FlexRay transceivers, NXP enables wireless in-vehicle networks instead of current heavy cabling, cars will lose weight and thus be

less environment polluting. Since the average semiconductor content per car keeps rising, this environmental focus creates huge opportunities for NXP.

11.2. Appendix B: Quotes interviews in Dutch

1. Je zegt in wijze dat je het beter weet dan alle lemmingen van NXP

2. Je bent dan Cassandra zoals in zoals in de Mythe. En het gaat veel verder. Alles wat de data analisten zeggen spreek je tegen. Alle Gartners en dergelijke. Beursanalisten. En als iedereen dat denkt, dan denkt mijn baas dat ook.

3. De reden dat NXP goed door de crisis is heen gekomen. Door interne oorzaken zijn we gaan herstructureren en verkochten we een divisie. We legden een gigantische voorraad aan producten neer terwijl de markt omlaag ging. We waren dus aan het investeren. We deden het niet omdat het bullwhip effect te bestrijden, maar omdat we wat wilden doen met onze fabrieken. Maar hoera dus want we hadden een jaar of 2 op voorraad liggen. We plukken de vruchten van het contracyclisch investeren.

4. In de downturn is dat makkelijker? Ja, dan weet iedereen ook dat anticyclisch werken een kern van waarheid heeft.

5. Het verhaal dat ik vertel, dat je cross organisatie moet werken, veel mensen kunnen dat niet. Of willen dat niet. Veel mensen zouden op bepaalde policies kunnen antwoorden: ja je hebt misschien wel gelijk, maar ik moet voor mijn site of afdeling ook punten halen, ook al is het goed voor NXP.

6. Je krijgt dit soort dingen gedaan met een betrouwbaar order patroon. Geen gekke onvoorspelbare dingen. Grote volumes, betrouwbare leverancier, betrouwbare afnemers, een hoop geld, alleen daarbij zou dit kunnen. In monopoliepositie bijvoorbeeld. Of althans, dat je elkaars belangrijkste klanten bent. Bij alle andere zaken dan geef ik het je te doen.

7. Beleggers -we zijn natuurlijk een beursgenoteerd bedrijf- die meten een bedrijf ook in hoeverre ze de business begrijpen. Oplopende voorraden worden gezien als dat je de business niet begrijpt. Als je het uitlegt dat je de voorraden opbouwt omdat je dan sneller kan reageren, is de vraag of ze je geloven. Meer voorraden betekent natuurlijk meer risico.

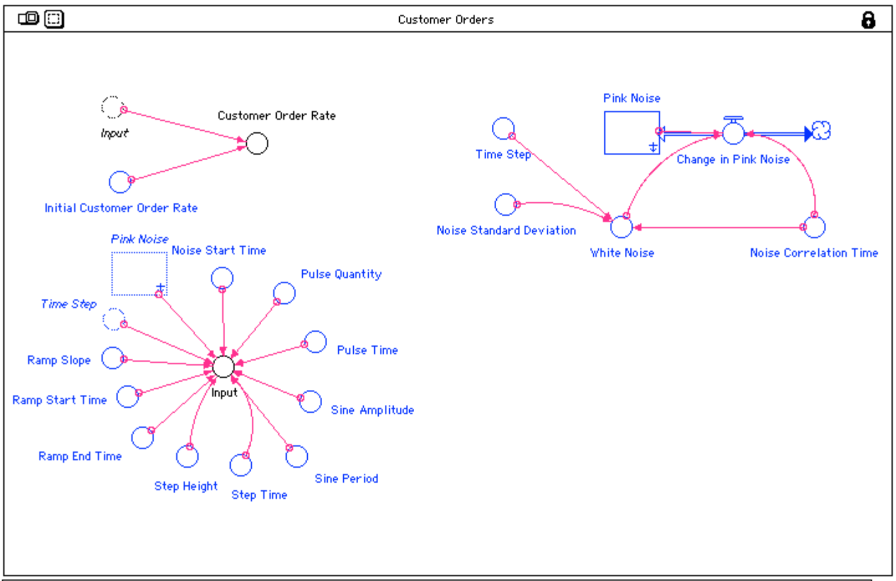
8. Tuurlijk spelen organisatie en politiek er een rol in. Ik kan je een artikel sturen van ST. Die hebben een aantal weken geleden geschreven dat het onbegrijpelijk is dat er zo weinig voorraad neergelegd wordt bij onze klanten. Ik ben bij Conti geweest. Die hebben zulke strikte cash flow regels. Er mag maar miniem aantal voorraad liggen. Er zijn hele strikte regels.

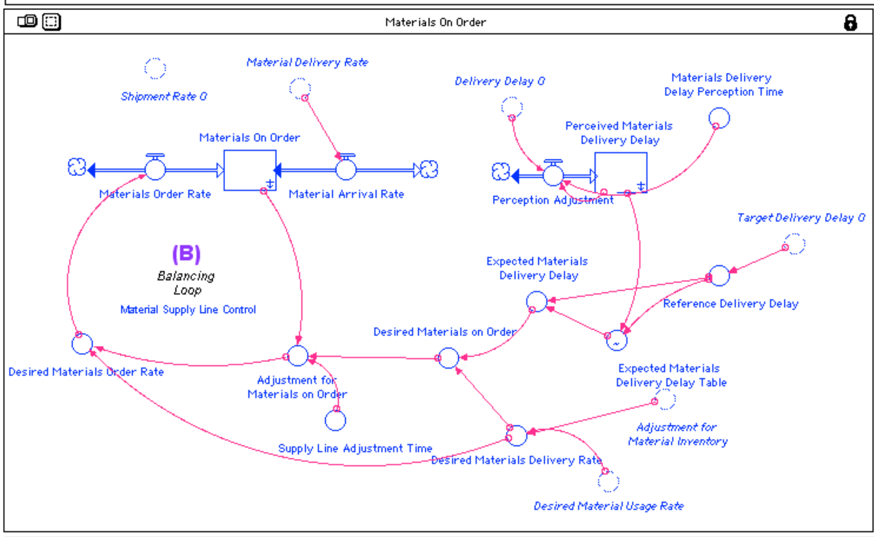
9. Er werd veel integraler gedacht. Nu zijn alle functies veel meer gefragmenteerd. Niet een iemand kan het besluit nemen. Je moet om de tafel.

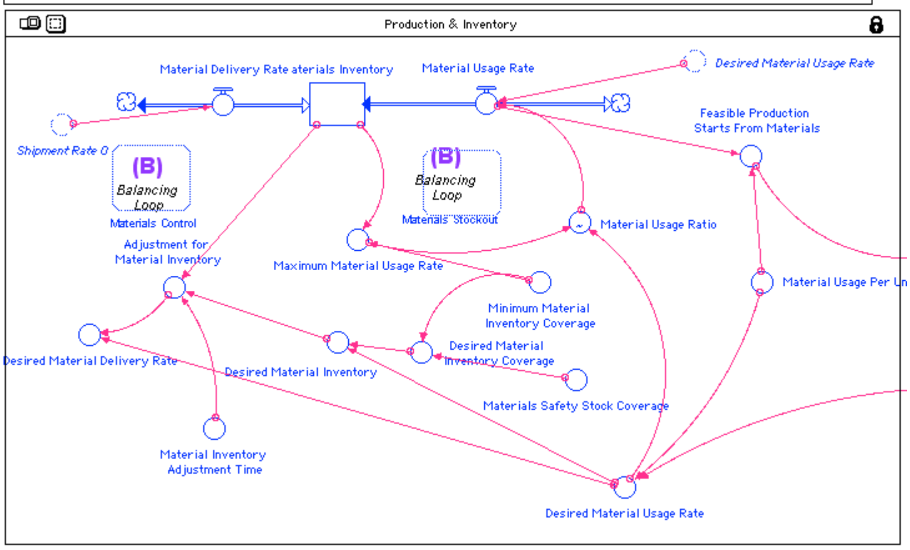
10. Ja er zijn natuurlijk verschillende belangen. De financiële man zal natuurlijk op het moment dat vraag achter blijft zeggen dat je geen voorraden aan moet leggen en de fabriek moet sluiten om

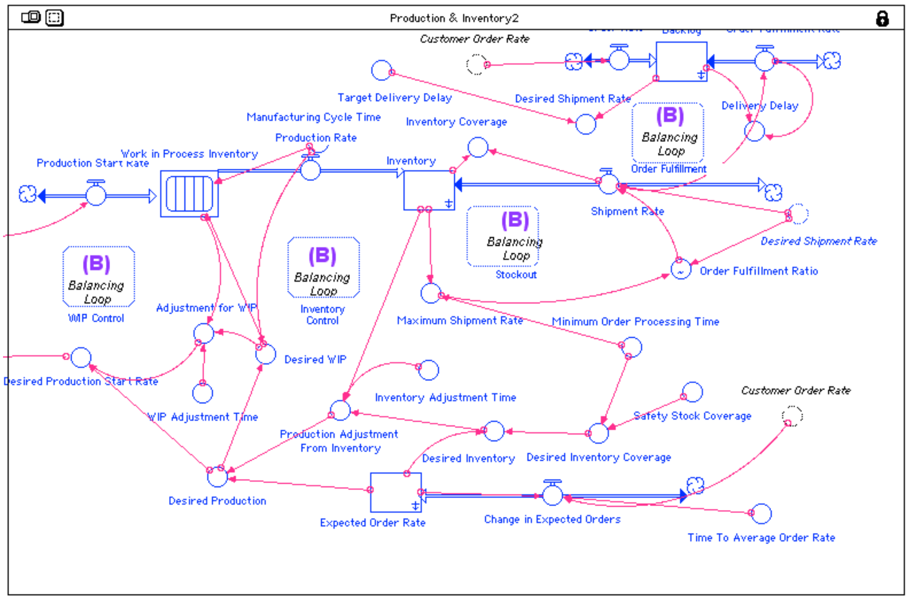
kosten te drukken. Zo zal die man redeneren. Misschien is het niet verstandig, omdat je dan mensen aan moet gaan nemen op het moment dat de vraag wel omhoog gaat. In principe zal zijn redenering vanuit financiën zijn dat als je vraag 100 is de capaciteit ook 100 moet zijn. Geen voorraad neerleggen want dat is een risico en doe de fabriek dicht want dat bespaart kosten. In een bedrijf heb je daarom dus verschillende functies die allemaal andere belangen hebben. De productie man zal zeggen dat een stabiele productie wenselijk is. Die wil natuurlijk rustig en gedegen ramp up en ramp down. Liever geen mensen ontslaan omdat dat onrust geeft. Dus die zal lekker over 3 jaar willen afbouwen zodat er minder gedwongen ontslagen dienen te komen. Dus de productie man zal zo redeneren. De financiële man zal vanuit de kosten redeneren. Maar dat heeft te maken met de definitie van organisatie. Waar functiescheidingen zijn, zijn ook conflicten. En dit kan leiden tot suboptimale beslissingen.

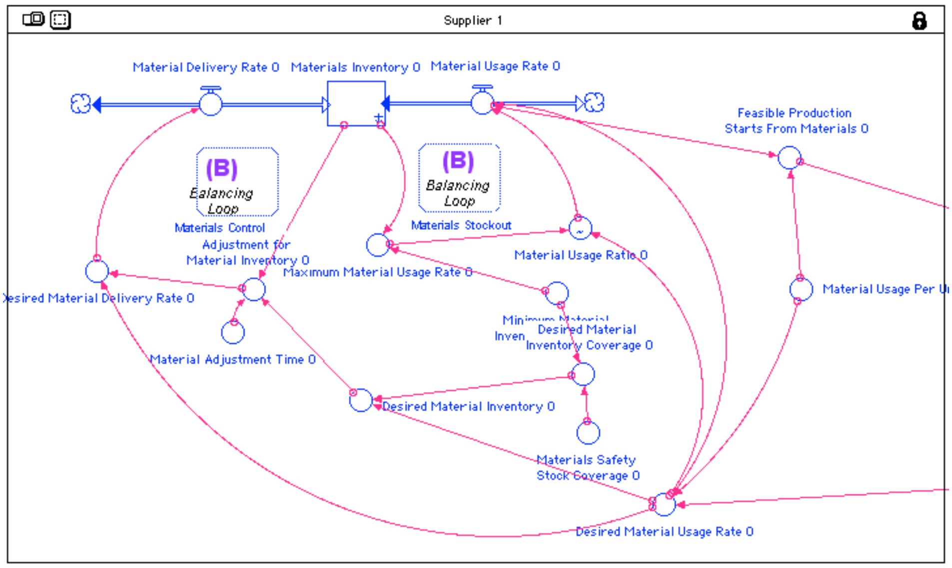
11.3. Appendix C: System dynamics model

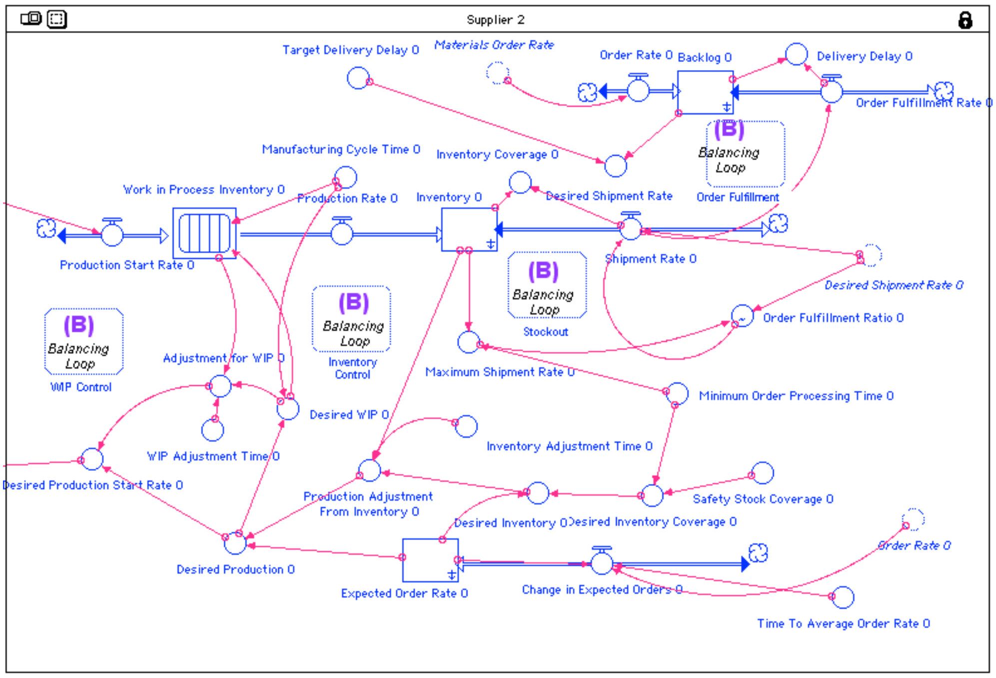







Production & Inventory2
Customer Order Rate
Target Delivery Delay
Desired Shipment Rate
Delivery Delay
Manufacturing Cycle Time
Inventory Coverage
(B) Balancing Loop
Order Fulfillment
Production Rate
Work in Process Inventory
Production Start Rate
Inventory
Shipment Rate
Desired Shipment Rate
(B) Balancing Loop
Stockout
Order Fulfillment Ratio
(B) Balancing Loop
WIP Control
(B) Balancing Loop
Inventory Control
Adjustment for WIP
Maximum Shipment Rate
Minimum Order Processing Time
Desired WIP
Desired Production Start Rate
Inventory Adjustment Time
Customer Order Rate
WIP Adjustment Time
Safety Stock Coverage
Production Adjustment From Inventory
Desired Inventory
Desired Inventory Coverage
Desired Production
Expected Order Rate
Change in Expected Orders
Time To Average Order Rate


Supplier 1
Material Delivery Rate 0
Materials Inventory 0
Material Usage Rate 0
Feasible Production Starts From Materials 0
(B) Balancing Loop
Materials Control
(B) Balancing Loop
Materials Stockout
Adjustment for Material Inventory 0
Maximum Material Usage Rate 0
Material Usage Ratio 0
Material Usage Per U
Desired Material Delivery Rate 0
Desired Material Inventory Coverage 0
Material Adjustment Time 0
Desired Material Inventory 0
Materials Safety Stock Coverage 0
Desired Material Usage Rate 0


Supplier 2
Target Delivery Delay 0
Materials Order Rate
Order Rate 0
Backlog 0
Delivery Delay 0
Order Fulfillment Rate 0
Manufacturing Cycle Time 0
Inventory Coverage 0
(B) Balancing Loop
Order Fulfillment
Work in Process Inventory 0
Production Rate 0
Inventory 0
Desired Shipment Rate
Production Start Rate 0
Shipment Rate 0
Desired Shipment Rate 0
(B) Balancing Loop
Stockout
Order Fulfillment Ratio 0
(B) Balancing Loop
Inventory Control
(B) Balancing Loop
WIP Control
Adjustment for WIP 0
Maximum Shipment Rate 0
Minimum Order Processing Time 0
Desired WIP 0
Inventory Adjustment Time 0
WIP Adjustment Time 0
Desired Production Start Rate 0
Production Adjustment From Inventory 0
Safety Stock Coverage 0
Desired Inventory 0
Desired Inventory Coverage 0
Order Rate 0
Desired Production 0
Expected Order Rate 0
Change in Expected Orders 0
Time To Average Order Rate 0

11.4. Appendix D: Equations of the model

Customer Orders

Actual_car_production = SMTH1(Average_car_production,12)
Actual_NXP_sales = SMTH1(Average_NXP_sales_544,12)
Automotive_Market = SMTH1(Global_average_car_sales_per_week,12,1395)
Blue = 0
Green = 0
Model_Order_Value_NXP = Materials_Order_Rate_MM*TAM_to_NXP
Model_Shipment_value_NXP = Shipment_Rate_NXP*TAM_to_NXP
NXP_Market_share = 0.037
Premium_chips_correction = 1.16
Red = 0
Smoothed_Sales_Quantity = SMTH1(NXP_Sales_Quantity,12)
TAM_to_NXP = NXP_Market_share*Value_of_chips_per_car*Premium_chips_correction
Average_car_production = GRAPH(TIME)
(0.00, 1395), (1.00, 1395), (2.00, 1395), (3.00, 1395), (4.00, 1420), (5.00, 1420), (6.00, 1420), (7.00, 1420), (8.00, 1655), (9.00, 1655), (10.0, 1655), (11.0, 1655), (12.0, 1467), (13.0, 1467), (14.0, 1467), (15.0, 1467), (16.0, 1526), (17.0, 1526), (18.0, 1526), (19.0, 1526), (20.0, 1567), (21.0, 1567), (22.0, 1567), (23.0, 1567), (24.0, 1323), (25.0, 1323), (26.0, 1323), (27.0, 1323), (28.0, 1282), (29.0, 1282), (30.0, 1282), (31.0, 1282), (32.0, 1514), (33.0, 1514), (34.0, 1514), (35.0, 1514), (36.0, 1658), (37.0, 1658), (38.0, 1658), (39.0, 1658), (40.0, 1638), (41.0, 1638), (42.0, 1638), (43.0, 1638), (44.0, 1311), (45.0, 1311), (46.0, 1311), (47.0, 1311), (48.0, 1525), (49.0, 1525), (50.0, 1525), (51.0, 1525), (52.0, 1547)...
Average_NXP_sales_544 = GRAPH(TIME)
(0.00, 15649), (1.00, 15649), (2.00, 15649), (3.00, 15649), (4.00, 16909), (5.00, 16909), (6.00, 16909), (7.00, 16909), (8.00, 17469), (9.00, 17469), (10.0, 17469), (11.0, 17469), (12.0, 17470), (13.0, 17470), (14.0, 17470), (15.0, 17470), (16.0, 18351), (17.0, 18351), (18.0, 18351), (19.0, 18351), (20.0, 18391), (21.0, 18391), (22.0, 18391), (23.0, 18391), (24.0, 17407), (25.0, 17407), (26.0, 17407), (27.0, 17407), (28.0, 16717), (29.0, 16717), (30.0, 16717), (31.0, 16717), (32.0, 19807), (33.0, 19807), (34.0, 19807), (35.0, 19807), (36.0, 19573), (37.0, 19573), (38.0, 19573), (39.0, 19573), (40.0, 18678), (41.0, 18678), (42.0, 18678), (43.0, 18678), (44.0, 17339), (45.0, 17339), (46.0, 17339), (47.0, 17339), (48.0, 17667), (49.0, 17667), (50.0, 17667), (51.0, 17667), (52.0, 18841)...
Global_average_car_sales_per_week = GRAPH(TIME)
(0.00, 1315), (1.00, 1315), (2.00, 1315), (3.00, 1315), (4.00, 1389), (5.00, 1389), (6.00, 1389), (7.00, 1389), (8.00, 1628), (9.00, 1628), (10.0, 1628), (11.0, 1628), (12.0, 1406), (13.0, 1406), (14.0, 1406), (15.0, 1406), (16.0, 1509), (17.0, 1509), (18.0, 1509), (19.0, 1509), (20.0, 1537), (21.0, 1537), (22.0, 1537), (23.0, 1537), (24.0, 1419), (25.0, 1419), (26.0, 1419), (27.0, 1419), (28.0, 1355), (29.0, 1355), (30.0, 1355), (31.0, 1355), (32.0, 1487), (33.0, 1487), (34.0, 1487), (35.0, 1487), (36.0, 1425), (37.0, 1425), (38.0, 1425), (39.0, 1425), (40.0, 1427), (41.0, 1427), (42.0, 1427), (43.0, 1427), (44.0, 1478), (45.0, 1478), (46.0, 1478), (47.0, 1478), (48.0, 1368), (49.0, 1368), (50.0, 1368), (51.0, 1368), (52.0, 1364)...
NXP_Sales_Quantity = GRAPH(TIME)
(0.00, 15.8), (1.00, 15.8), (2.00, 15.8), (3.00, 15.8), (4.00, 18.7), (5.00, 18.7), (6.00, 18.7), (7.00, 18.7), (8.00, 22.3), (9.00, 22.3), (10.0, 22.3), (11.0, 22.3), (12.0, 16.4), (13.0, 16.4), (14.0, 16.4), (15.0, 16.4), (16.0, 22.7), (17.0, 22.7), (18.0, 22.7), (19.0, 22.7), (20.0, 22.9), (21.0, 22.9), (22.0, 22.9), (23.0, 22.9), (24.0, 17.1), (25.0, 17.1), (26.0, 17.1), (27.0, 17.1), (28.0, 21.9), (29.0, 21.9), (30.0, 21.9), (31.0, 21.9), (32.0, 21.8), (33.0, 21.8), (34.0, 21.8), (35.0, 21.8), (36.0, 19.5), (37.0, 19.5), (38.0, 19.5), (39.0, 19.5), (40.0, 22.2), (41.0, 22.2), (42.0, 22.2), (43.0, 22.2), (44.0, 18.8), (45.0, 18.8), (46.0, 18.8), (47.0, 18.8), (48.0, 18.5), (49.0, 18.5), (50.0, 18.5), (51.0, 18.5), (52.0, 22.2)...
Value_of_chips_per_car = GRAPH(TIME)
(0.00, 271), (1.00, 271), (2.00, 271), (3.00, 271), (4.00, 271), (5.00, 271), (6.00, 271), (7.00, 271), (8.00, 271), (9.00, 271), (10.0, 271), (11.0, 271), (12.0, 273), (13.0, 273), (14.0, 273), (15.0, 273), (16.0, 273), (17.0, 273), (18.0, 273), (19.0, 273), (20.0, 273), (21.0, 273), (22.0, 273), (23.0, 273), (24.0, 276), (25.0, 276), (26.0, 276), (27.0, 276), (28.0, 276), (29.0, 276), (30.0, 276), (31.0, 276), (32.0, 276), (33.0, 276), (34.0, 276), (35.0, 276), (36.0, 280), (37.0, 280), (38.0, 280), (39.0, 280), (40.0, 280), (41.0, 280), (42.0, 280), (43.0, 280), (44.0, 280), (45.0, 280), (46.0, 280), (47.0, 280), (48.0, 279), (49.0, 279), (50.0, 279), (51.0, 279), (52.0, 279)...

OEM Production & Inventory

Materials_Inventory_OEM(t) = Materials_Inventory_OEM(t - dt) + (Material_Delivery_Rate_OEM - Material_Usage_Rate_OEM) * dt
INIT Materials_Inventory_OEM = Desired_Material_Inventory_OEM
INFLOWS:
Material_Delivery_Rate_OEM = Shipment_Rate_MM
OUTFLOWS:
Material_Usage_Rate_OEM = Desired_Material_Usage_Rate_OEM*Material_Usage_Ratio_OEM
Adjustment_for_Material_Inventory_OEM = (Desired_Material_Inventory_OEM - Materials_Inventory_OEM)/ Material_Inventory_Adjustment_Time_OEM
Desired_Material_Delivery_Rate_OEM = Adjustment_for_Material_Inventory_OEM+Desired_Material_Usage_Rate_OEM
Desired_Material_Inventory_Coverage_OEM = Minimum_Material_Inventory_Coverage_OEM+ Materials_Safety_Stock_Coverage_OEM
Desired_Material_Inventory_OEM = Desired_Material_Inventory_Coverage_OEM*Desired_Material_Usage_Rate_OEM
Desired_Material_Usage_Rate_OEM = MAX(0,Desired_Production_Start_Rate_OEM)
Materials_Safety_Stock_Coverage_OEM = 2
Material_Inventory_Adjustment_Time_OEM = 2
Maximum_Material_Usage_Rate_OEM = Materials_Inventory_OEM/Minimum_Material_Inventory_Coverage_OEM
Minimum_Material_Inventory_Coverage_OEM = 1
Material_Usage_Ratio_OEM = GRAPH(Maximum_Material_Usage_Rate_OEM/Desired_Material_Usage_Rate_OEM)
(0.((0.00, 0.00), (0.2, 0.2), (0.4, 0.4), (0.6, 0.58), (0.8, 0.73), (1.00, 0.85), (1.20, 0.93), (1.40, 0.97), (1.60, 0.99), (1.80, 1.00), (2.00, 1.00)

OEM Continued

Backlog_OEM(t) = Backlog_OEM(t - dt) + (Order_Rate_OEM - Order_Fulfillment_Rate_OEM) * dt
INIT Backlog_OEM = Order_Rate_OEM*Target_Delivery_Delay_OEM
INFLOWS:
Order_Rate_OEM = Automotive_Market
OUTFLOWS:
Order_Fulfillment_Rate_OEM = Shipment_Rate_OEM
Expected_Order_Rate_OEM(t) = Expected_Order_Rate_OEM(t - dt) + (Change_in_Expected_Orders_OEM) * dt
INIT Expected_Order_Rate_OEM = Automotive_Market
INFLOWS:
Change_in_Expected_Orders_OEM = (Automotive_Market-Expected_Order_Rate_OEM)/
Time_To_Average_Order_Rate_OEM
Inventory_OEM(t) = Inventory_OEM(t - dt) + (Model:_Production_OEM - Shipment_Rate_OEM) * dt
INIT Inventory_OEM = Desired_Inventory_OEM
INFLOWS:
Model:_Production_OEM = Model:_Production_OEM'
OUTFLOWS:
Shipment_Rate_OEM = Desired_Shipment_Rate_OEM*Order_Fulfillment_Ratio_OEM
Adjustment_for_WIP_OEM = (Desired_WIP_OEM - Work_in_Process_Inventory_OEM)/WIP_Adjustment_Time_OEM
Delivery_Delay_OEM = Backlog_OEM/Order_Fulfillment_Rate_OEM
Desired_Inventory_Coverage_OEM = Minimum_Order_Processing_Time_OEM+Safety_Stock_Coverage_OEM
Desired_Inventory_OEM = Expected_Order_Rate_OEM*Desired_Inventory_Coverage_OEM
Desired_Production_OEM = MAX(0,Expected_Order_Rate_OEM+Production_Adjustment_From_Inventory_OEM)
Desired_Production_Start_Rate_OEM = MAX(0,Desired_Production_OEM + Adjustment_for_WIP_OEM)
Desired_Shipment_Rate_OEM = Backlog_OEM/Target_Delivery_Delay_OEM
Desired_WIP_OEM = Desired_Production_OEM*Manufacturing_Cycle_Time_OEM
Inventory_Adjustment_Time_OEM = 15
Inventory_Coverage_OEM = (Inventory_OEM/Shipment_Rate_OEM)
Manufacturing_Cycle_Time_OEM = 6
Maximum_Shipment_Rate_OEM = Inventory_OEM/Minimum_Order_Processing_Time_OEM
Minimum_Order_Processing_Time_OEM = 6
Production_Adjustment_From_Inventory_OEM = (Desired_Inventory_OEM -Inventory_OEM)/Inventory_Adjustment_Time_OEM
Safety_Stock_Coverage_OEM = 2
Target_Delivery_Delay_OEM = 6
Time_To_Average_Order_Rate_OEM = 12
WIP_Adjustment_Time_OEM = 2
Order_Fulfillment_Ratio_OEM = GRAPH(Maximum_Shipment_Rate_OEM/Desired_Shipment_Rate_OEM)
(0.00, 0.00), (0.2, 0.2), (0.4, 0.4), (0.6, 0.58), (0.8, 0.73), (1.00, 0.85), (1.20, 0.93), (1.40, 0.97), (1.60, 0.99), (1.80, 1.00), (2.00, 1.00)

Work_in_Process_Inventory_OEM = OPP_10 + OPP_11 + OPP_12
INFLOWS:
Model:_Production_Start_OEM = Material_Usage_Rate_OEM
OUTFLOWS:
Model:_Production_OEM = Model:_Production_OEM'
OPP_10(t) = OPP_10(t - dt) + (Model:_Production_Start_OEM' - Noname_6) * dt
INIT OPP_10 = total_initial_4/3
INFLOWS:
Model:_Production_Start_OEM' = Model:_Production_Start_OEM
OUTFLOWS:
Noname_6 = OPP_10/rt_4
OPP_11(t) = OPP_11(t - dt) + (Noname_6 - Noname_9) * dt
INIT OPP_11 = total_initial_4/3
INFLOWS:
Noname_6 = OPP_10/rt_4
OUTFLOWS:
Noname_9 = OPP_11/rt_4
OPP_12(t) = OPP_12(t - dt) + (Noname_9 - Model:_Production_OEM') * dt
INIT OPP_12 = total_initial_4/3
INFLOWS:
Noname_9 = OPP_11/rt_4
OUTFLOWS:
Model:_Production_OEM' = OPP_12/rt_4
rt_4 = Manufacturing_Cycle_Time_OEM/3
total_initial_4 = Desired_WIP_OEM

Ordering OEM to Modulemaker

Materials_On_Order_OEM(t) = Materials_On_Order_OEM(t - dt) + (Materials_Order_Rate_OEM - Material_Arrival_Rate_OEM) * dt
INIT Materials_On_Order_OEM = Desired_Materials_on_Order_OEM
INFLOWS:
Materials_Order_Rate_OEM = MAX(0,Desired_Materials_Order_Rate_OEM)
OUTFLOWS:
Material_Arrival_Rate_OEM = Material_Delivery_Rate_OEM

Perceived_Materials_Delivery_Delay_OEM(t) = Perceived_Materials_Delivery_Delay_OEM(t - dt) + (Perception_Adjustment_OEM) * dt
INIT Perceived_Materials_Delivery_Delay_OEM = 2
INFLOWS:
Perception_Adjustment_OEM = (Delivery_Delay_MM-Perceived_Materials_Delivery_Delay_OEM)/ Materials_Delivery_Delay_Perception_Time_OEM

Adjustment_for_Materials_on_Order_OEM = (Desired_Materials_on_Order_OEM-Materials_On_Order_OEM)/ Supply_Line_Adjustment_Time_OEM
Desired_Materials_on_Order_OEM = Desired_Material_Delivery_Rate_OEM*Expected_Materials_Delivery_Delay_OEM
Desired_Materials_Order_Rate_OEM = MAX(0,Adjustment_for_Materials_on_Order_OEM+Desired_Material_Delivery_Rate_OEM)
Expected_Materials_Delivery_Delay_OEM = Target_Delivery_Delay_MM*Expected_Materials_Delivery_Delay_Table_OEM
Materials_Delivery_Delay_Perception_Time_OEM = 4
Supply_Line_Adjustment_Time_OEM = 2
Expected_Materials_Delivery_Delay_Table_OEM = GRAPH(Perceived_Materials_Delivery_Delay_OEM/Target_Delivery_Delay_MM)
(0.00, 0.00), (0.5, 0.5), (1.00, 1.00), (1.50, 1.50), (2.00, 2.10), (2.50, 2.80), (3.00, 3.30), (3.50, 3.60), (4.00, 3.80), (4.50, 3.90), (5.00, 3.95), (5.50, 3.98), (6.00, 4.00)

Modulemaker Production & Inventory

Materials_Inventory_MM(t) = Materials_Inventory_MM(t - dt) + (Material_Delivery_Rate_MM - Material_Usage_Rate_MM) * dt
INIT Materials_Inventory_MM = Desired_Material_Inventory_MM
INFLOWS:
Material_Delivery_Rate_MM = Shipment_Rate_NXP
OUTFLOWS:
Material_Usage_Rate_MM = Desired_Material_Usage_Rate_MM*Material_Usage_Ratio_MM

Adjustment_for_Material_Inventory_MM = (Desired_Material_Inventory_MM - Materials_Inventory_MM)/ Material_Inventory_Adjustment_Time_MM
Desired_Material_Delivery_Rate_MM = Adjustment_for_Material_Inventory_MM+Desired_Material_Usage_Rate_MM
Desired_Material_Inventory_Coverage_MM = Minimum_Material_Inventory_Coverage_MM+Materials_Safety_Stock_Coverage_MM
Desired_Material_Inventory_MM = Desired_Material_Inventory_Coverage_MM*Desired_Material_Usage_Rate_MM
Desired_Material_Usage_Rate_MM = MAX(0,Desired_Production_Start_Rate_MM)
Materials_Safety_Stock_Coverage_MM = 2
Material_Inventory_Adjustment_Time_MM = 2
Maximum_Material_Usage_Rate_MM = Materials_Inventory_MM/Minimum_Material_Inventory_Coverage_MM
Minimum_Material_Inventory_Coverage_MM = 1
Material_Usage_Ratio_MM = GRAPH(Maximum_Material_Usage_Rate_MM/Desired_Material_Usage_Rate_MM)
(0.00, 0.00), (0.2, 0.2), (0.4, 0.4), (0.6, 0.58), (0.8, 0.73), (1.00, 0.85), (1.20, 0.93), (1.40, 0.97), (1.60, 0.99), (1.80, 1.00), (2.00, 1.00)

Modulemaker Continued

Backlog_MM(t) = Backlog_MM(t - dt) + (Order_Rate_MM - Order_Fulfillment_Rate_MM) * dt
INIT Backlog_MM = Order_Rate_MM*Target_Delivery_Delay_MM
INFLOWS:
Order_Rate_MM = Materials_Order_Rate_OEM
OUTFLOWS:
Order_Fulfillment_Rate_MM = Shipment_Rate_MM
Expected_Order_Rate_MM(t) = Expected_Order_Rate_MM(t - dt) + (Change_in_Expected_Orders_MM) * dt
INIT Expected_Order_Rate_MM = Automotive_Market
INFLOWS:
Change_in_Expected_Orders_MM = (Materials_Order_Rate_OEM-Expected_Order_Rate_MM)/
Time_To_Average_Order_Rate_MM
Inventory_MM(t) = Inventory_MM(t - dt) + (Production_Rate_MM - Shipment_Rate_MM) * dt
INIT Inventory_MM = Desired_Inventory_MM
INFLOWS:
Production_Rate_MM = Production_Rate_MM'
OUTFLOWS:
Shipment_Rate_MM = Desired_Shipment_Rate_MM*Order_Fulfillment_Ratio_MM
Adjustment_for_WIP_MM = (Desired_WIP_MM - Work_in_Process_Inventory_MM)/WIP_Adjustment_Time_MM
Delivery_Delay_MM = Backlog_MM/Order_Fulfillment_Rate_MM
Desired_Inventory_Coverage_MM = Minimum_Order_Processing_Time_MM+Safety_Stock_Coverage_MM
Desired_Inventory_MM = Expected_Order_Rate_MM*Desired_Inventory_Coverage_MM
Desired_Production_MM = MAX(0,Expected_Order_Rate_MM+Production_Adjustment_From_Inventory_MM)
Desired_Production_Start_Rate_MM = MAX(0,Desired_Production_MM + Adjustment_for_WIP_MM)
Desired_Shipment_Rate_MM = Backlog_MM/Target_Delivery_Delay_MM
Desired_WIP_MM = Desired_Production_MM*Manufacturing_Cycle_Time_MM
Inventory_Adjustment_Time_MM = 15
Inventory_Coverage_MM = (Inventory_MM/Shipment_Rate_MM)
Manufacturing_Cycle_Time_MM = 2
Maximum_Shipment_Rate_MM = Inventory_MM/Minimum_Order_Processing_Time_MM
Minimum_Order_Processing_Time_MM = 2
Production_Adjustment_From_Inventory_MM = (Desired_Inventory_MM -Inventory_MM)/Inventory_Adjustment_Time_MM
Safety_Stock_Coverage_MM = 2
Target_Delivery_Delay_MM = 2
Time_To_Average_Order_Rate_MM = 12
WIP_Adjustment_Time_MM = 2
Order_Fulfillment_Ratio_MM = GRAPH(Maximum_Shipment_Rate_MM/Desired_Shipment_Rate_MM)
(0.00, 0.00), (0.2, 0.2), (0.4, 0.4), (0.6, 0.58), (0.8, 0.73), (1.00, 0.85), (1.20, 0.93), (1.40, 0.97), (1.60, 0.99), (1.80, 1.00), (2.00, 1.00)

Work_in_Process_Inventory_MM = OPP_16 + OPP_17 + OPP_18
INFLOWS:
Production_Start_Rate_MM = Material_Usage_Rate_MM
OUTFLOWS:
Production_Rate_MM = Production_Rate_MM'
OPP_16(t) = OPP_16(t - dt) + (Production_Start_Rate_MM' - Noname_8) * dt
INIT OPP_16 = total_initial_6/3
INFLOWS:
Production_Start_Rate_MM' = Production_Start_Rate_MM
OUTFLOWS:
Noname_8 = OPP_16/rt_6
OPP_17(t) = OPP_17(t - dt) + (Noname_8 - Noname_11) * dt
INIT OPP_17 = total_initial_6/3
INFLOWS:
Noname_8 = OPP_16/rt_6
OUTFLOWS:
Noname_11 = OPP_17/rt_6
OPP_18(t) = OPP_18(t - dt) + (Noname_11 - Production_Rate_MM') * dt
INIT OPP_18 = total_initial_6/3
INFLOWS:
Noname_11 = OPP_17/rt_6
OUTFLOWS:
Production_Rate_MM' = OPP_18/rt_6
rt_6 = Manufacturing_Cycle_Time_MM/3
total_initial_6 = Desired_WIP_MM

Ordering Modulemaker to NXP

Materials_On_Order_MM(t) = Materials_On_Order_MM(t - dt) + (Materials_Order_Rate_MM - Material_Arrival_Rate_MM) * dt
INIT Materials_On_Order_MM = Desired_Materials_on_Order_MM
INFLOWS:
Materials_Order_Rate_MM = MAX(0,Desired_Materials_Order_Rate_MM)
OUTFLOWS:
Material_Arrival_Rate_MM = Material_Delivery_Rate_MM

Perceived_Materials_Delivery_Delay_MM(t) = Perceived_Materials_Delivery_Delay_MM(t - dt) + (Perception_Adjustment_MM) * dt
INIT Perceived_Materials_Delivery_Delay_MM = 2
INFLOWS:
Perception_Adjustment_MM = (Delivery_Delay_NXP-Perceived_Materials_Delivery_Delay_MM)/Materials_Delivery_Delay_Perception_Time_MM

Adjustment_for_Materials_on_Order_MM = (Desired_Materials_on_Order_MM-Materials_On_Order_MM)/Supply_Line_Adjustment_Time_MM
Desired_Materials_on_Order_MM = Desired_Material_Delivery_Rate_MM*Expected_Materials_Delivery_Delay_MM
Desired_Materials_Order_Rate_MM = MAX(0,Adjustment_for_Materials_on_Order_MM+Desired_Material_Delivery_Rate_MM)
Expected_Materials_Delivery_Delay_MM = Target_Delivery_Delay_NXP*Expected_Materials_Delivery_Delay_Table_MM
Materials_Delivery_Delay_Perception_Time_MM = 4
Supply_Line_Adjustment_Time_MM = 2
Expected_Materials_Delivery_Delay_Table_MM = GRAPH(Perceived_Materials_Delivery_Delay_MM/Target_Delivery_Delay_NXP)
(0.00, 0.00), (0.5, 0.5), (1.00, 1.00), (1.50, 1.50), (2.00, 2.10), (2.50, 2.80), (3.00, 3.30), (3.50, 3.60), (4.00, 3.80), (4.50, 3.90), (5.00, 3.95), (5.50, 3.98), (6.00, 4.00)

NXP Production & Inventory

Materials_Inventory_NXP(t) = Materials_Inventory_NXP(t - dt) + (Material_Delivery_Rate_NXP - Material_Usage_Rate_NXP) * dt
INIT Materials_Inventory_NXP = Desired_Material_Inventory_NXP
INFLOWS:
Material_Delivery_Rate_NXP = MAX(0,Desired_Material_Delivery_Rate_NXP)
OUTFLOWS:
Material_Usage_Rate_NXP = Desired_Material_Usage_Rate_NXP*Material_Usage_Ratio_NXP

Adjustment_for_Material_Inventory_NXP = (Desired_Material_Inventory_NXP - Materials_Inventory_NXP)/Material_Adjustment_Time_NXP
Desired_Material_Delivery_Rate_NXP = Adjustment_for_Material_Inventory_NXP+Desired_Material_Usage_Rate_NXP
Desired_Material_Inventory_Coverage_NXP = Minimum_Material_Inventory_Coverage_NXP+Materials_Safety_Stock_Coverage_NXP
Desired_Material_Inventory_NXP = Desired_Material_Inventory_Coverage_NXP*Desired_Material_Usage_Rate_NXP
Desired_Material_Usage_Rate_NXP = MAX(0.01,Desired_Production_Start_Rate_NXP)
Materials_Safety_Stock_Coverage_NXP = 2
Material_Adjustment_Time_NXP = 2
Maximum_Material_Usage_Rate_NXP = Materials_Inventory_NXP/Minimum_Material_Inventory_Coverage_NXP
Minimum_Material_Inventory_Coverage_NXP = 1
Material_Usage_Ratio_NXP = GRAPH(Maximum_Material_Usage_Rate_NXP/Desired_Material_Usage_Rate_NXP)
(0.00, 0.00), (0.2, 0.2), (0.4, 0.4), (0.6, 0.58), (0.8, 0.73), (1.00, 0.85), (1.20, 0.93), (1.40, 0.97), (1.60, 0.99), (1.80, 1.00), (2.00, 1.00)

NXP continued

Backlog_NXP(t) = Backlog_NXP(t - dt) + (Order_Rate_NXP - Order_Fulfillment_Rate_NXP) * dt
INIT Backlog_NXP = Order_Rate_NXP*Target_Delivery_Delay_NXP
INFLOWS:
Order_Rate_NXP = Materials_Order_Rate_MM
OUTFLOWS:
Order_Fulfillment_Rate_NXP = Shipment_Rate_NXP

Expected_Order_Rate_NXP(t) = Expected_Order_Rate_NXP(t - dt) + (Change_in_Expected_Orders_NXP) * dt
INIT Expected_Order_Rate_NXP = Automotive_Market
INFLOWS:
Change_in_Expected_Orders_NXP = (Orders_used_for_forecasting-Expected_Order_Rate_NXP)/Time_To_Average_Order_Rate_NXP

Inventory_NXP(t) = Inventory_NXP(t - dt) + (Production_Rate_NXP - Shipment_Rate_NXP) * dt
INIT Inventory_NXP = Desired_Inventory_NXP
INFLOWS:
Production_Rate_NXP = Production_Rate_NXP'
OUTFLOWS:
Shipment_Rate_NXP = Desired_Shipment_Rate_NXP*Order_Fulfillment_Ratio_NXP

Adjustment_for_WIP_NXP = (Desired_WIP_NXP - Work_in_Process_Inventory_NXP)/WIP_Adjustment_Time_NXP
Alpha = 0
Capacity = 1600
Delivery_Delay_NXP = Backlog_NXP/Order_Fulfillment_Rate_NXP
Desired_Inventory_Coverage_NXP = Minimum_Order_Processing_Time_NXP+Safety_Stock_Coverage_NXP
Desired_Inventory_NXP = Expected_Order_Rate_NXP*Desired_Inventory_Coverage_NXP
Desired_Production_NXP = MAX(0,(Expected_Order_Rate_NXP+Production_Adjustment_From_Inventory_NXP)*(1-Alpha)+Capacity*Alpha)
Desired_Production_Start_Rate_NXP = Max(0,Adjustment_for_WIP_NXP+Desired_Production_NXP)
Desired_Shipment_Rate_NXP = Backlog_NXP/Target_Delivery_Delay_NXP
Desired_WIP_NXP = Desired_Production_NXP*Manufacturing_Cycle_Time_NXP
Inventory_Adjustment_Time_NXP = 15
Inventory_Coverage_NXP = (Inventory_NXP/Shipment_Rate_NXP)
Manufacturing_Cycle_Time_NXP = 5
Maximum_Shipment_Rate_NXP = Inventory_NXP/Minimum_Order_Processing_Time_NXP
Minimum_Order_Processing_Time_NXP = 7
Orders_used_for_forecasting = Materials_Order_Rate_MM*(1-Switch_for_POS)+Automotive_Market*Switch_for_POS
Production_Adjustment_From_Inventory_NXP = (Desired_Inventory_NXP -Inventory_NXP)/Inventory_Adjustment_Time_NXP
Safety_Stock_Coverage_NXP = 4
Target_Delivery_Delay_NXP = 7
Time_To_Average_Order_Rate_NXP = 12
WIP_Adjustment_Time_NXP = 2
Order_Fulfillment_Ratio_NXP = GRAPH(Maximum_Shipment_Rate_NXP/Desired_Shipment_Rate_NXP)
(0.00, 0.00), (0.2, 0.2), (0.4, 0.4), (0.6, 0.58), (0.8, 0.73), (1.00, 0.85), (1.20, 0.93), (1.40, 0.97), (1.60, 0.99), (1.80, 1.00), (2.00, 1.00)

Work_in_Process_Inventory_NXP = OPP_13 + OPP_14 + OPP_15
INFLOWS:
Production_Start_Rate_NXP = Material_Usage_Rate_NXP
OUTFLOWS:
Production_Rate_NXP = Production_Rate_NXP'

OPP_13(t) = OPP_13(t - dt) + (Production_Start_Rate_NXP' - Noname_7) * dt
INIT OPP_13 = total_initial_5/3
INFLOWS:
Production_Start_Rate_NXP' = Production_Start_Rate_NXP
OUTFLOWS:
Noname_7 = OPP_13/rt_5

OPP_14(t) = OPP_14(t - dt) + (Noname_7 - Noname_10) * dt
INIT OPP_14 = total_initial_5/3
INFLOWS:
Noname_7 = OPP_13/rt_5
OUTFLOWS:
Noname_10 = OPP_14/rt_5

OPP_15(t) = OPP_15(t - dt) + (Noname_10 - Production_Rate_NXP') * dt
INIT OPP_15 = total_initial_5/3
INFLOWS:
Noname_10 = OPP_14/rt_5
OUTFLOWS:
Production_Rate_NXP' = OPP_15/rt_5

rt_5 = Manufacturing_Cycle_Time_NXP/3
total_initial_5 = Desired_WIP_NXP