Supply Chain Responsiveness and Efficiency – Complementing or Contradicting Each Other?

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Abstract

Balancing responsiveness to market requirements with overall efficiency is an important issue in supply chain design and management. The objective of the system dynamics model introduced in this paper is to capture generic structures and the intrinsic dynamic behaviour modes of supply chains considering aspects of responsiveness and efficiency. The research strives for a better understanding of these aspects: what are the structural consequences of implementing strategies striving for efficiency or responsiveness in the real world, and how can they be represented in a System Dynamics model? Furthermore, simulations will be used to assess the dynamic consequences of these different strategic alternatives. Future research will then focus on identifying policies to balance responsiveness and efficiency in a specific industry and by that resolve the trade-off between the two.

Keywords: Supply Chain Management, Supply Chain Responsiveness, Supply Chain Efficiency, System Dynamics

1. Introduction

The responsiveness of supply chains to changing market requirements and their overall efficiency are important issues in supply chain design and management and therefore currently receive wide attention in the scientific community as well as in practice. Responsiveness can be defined as the "ability to react purposefully and within an appropriate time-scale to customer demand or changes in the marketplace, to bring about or maintain competitive advantage" (Holweg, 2005, p. 605). In contrast, a supply chain would be considered efficient if the focus is on cost reduction and no resources are wasted on non-value added activities (Naylor, Naim and Berry, 1999, p. 108).

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Companies have three principal means to buffer against changes in quantity demanded for specific products, namely inventory, capacity and time. Safety stocks, excess capacity and safety lead times all provide a time buffer to be able to react to demand variability (Hopp and Spearman, 2004, p. 145). One could argue that one sensible approach to increase responsiveness could be to raise the inventory levels of finished goods or components, which would allow more flexibility for reactions to changes in customer demand. Increased inventory levels do, however, reduce the efficiency of the supply chain since they are costly, both in terms of storage cost and cost of capital. This suggests that such an increase in inventory may not be the optimal approach to increase responsiveness – or, as Hopp and Spearman phrased it: "inventory is the flower of all evil, and variability is its root" (2004, p. 146), i.e. high inventory levels are a sign that something is suboptimal in the supply chain, and other strategies such as variability reductions may be more beneficial than inventory increases.

In an efficient supply chain, suppliers, manufacturers and retailers manage – implicitly through independent ordering processes between tiers or through explicit coordination of ordering decisions of the different supply chain elements – their activities in order to meet predictable demand at the lowest cost. A responsive supply chain, in contrast, requires an information flow and policies from the market place to supply chain members in order to hedge inventory and available production capacity against uncertain demand (Fisher, 1997, p. 108). Improving responsiveness in a supply chain, however, incurs costs for two primary reasons: (1) excess buffer capacity and inventories need to be maintained, (2) investments to reduce lead times need to be made. Boeing, for example, at the end of the 1990s failed to achieve sufficient buffer capacity or inventory levels by pursuing a lean manufacturing strategy without considering the variability of demand in the aerospace industry (Naylor, Naim and Berry, 1999, p. 108 and p. 112). Airplanes fulfil most of the criteria for functional products as identified by Fisher, except long-term demand predictability (1997, p. 106). If, as in this example, end-user demand is subject to sudden, unpredictable variations, it is not sensible to implement lean manufacturing at the interface with the end-user (Naylor, Naim and Berry, 1999, p. 112). In general, the cost resulting from investments in responsiveness needs to be compared to the opportunity cost of lost sales resulting from stockouts (Thonemann, Behrenbeck, Küpper and Magnus, 2005, p. 18). These stockouts are most likely to occur with products that are subject to demand fluctuations. Responsive supply chains aim to avoid such stockouts and therefore prioritise the ability to react to changing customer requirements (Alicke, 2003, p. 145).

Providing the right degree of responsiveness and having an efficient supply chain at the same time is a goal that is hard to achieve and that typically involves trade-off decisions by management, since increased responsiveness can be perceived to come at the expense of reduced efficiency, and vice versa. However, there may be strategies, such as revised planning approaches, that restructure supply chain processes to achieve both goals at the same time and enable a supply chain to be responsive and efficient simultaneously. Identifying strategies that achieve responsiveness and efficiency simultaneously is the goal of the research presented in this paper.

Many authors see responsiveness and efficiency as distinct strategies that are strongly linked to different types of products. Fisher, for example, distinguishes innovative products with short product life cycles and functional, more commodity-like products (1997, p. 106). It appears to be sensible to think of products as being positioned on a continuum between functionality and innovativeness. Functional products "satisfy basic needs, which don't change much over time…, have a stable, predictable demand and long life cycles" (p. 106). They are also characterised by relatively low contribution margins, low product variety and long order lead times (Childerhouse and Towill, 2000, p. 339). Innovative products, in contrast, are characterised by short product life cycles, high contribution margins, high product variety and unpredictable demand. Electronic products and fashion goods are examples for this category (p. 344). Linked to this Fisher then provides recommendations for the strategic alignment of supply chains and suggests that functional products require a focus on efficient processes, while innovative products require a focus on responsive processes (p. 109). The requirements for supply chain management are different for these distinguished types of products – for products that are innovative and reflect new trends, demand is less predictable than for products that fulfil basic needs, such as sugar[3] (Fisher, 1997, p. 106). The uncertainty of demand for innovative products makes supply chain responsiveness a critical capability, since stockouts should be avoided in particular if the products have high contribution margins. For functional products aspects of efficiency, i.e. focusing on the elimination of waste or non-value added activities across the chain, prevail management's attention (Huang, Uppal and Shi, 2002, p. 193). Some functional products may, however, also have quick response requirements of the supply chain – for example, milk and other dairy products are perishables with relatively stable demand patterns but limited shelf life. Also, companies often carry out promotions that can drastically change the otherwise stable and predictable demand patterns of products such as generic food. In such cases, pipeline stock is often "drained to no-one's real advantage" (Childerhouse and Towill, 2000, p. 338; Fuller, O'Conor and Rawlinson, 1993, p. 91).

Demand uncertainty is an important aspect that is linked to the classification of innovative or functional products. Innovative products are often characterized by a high degree of unpredictable demand uncertainty, whereas functional, commodity-like products face a high degree of demand stability. This point needs to be seen critically, since many commodities are confronted with the typical bullwhip effects – one of the major concerns in supply chain management – upstream in the supply chain, with order batching, speculative buying, delays and suboptimal planning being the major reasons. Therefore, upstream supply chain members can be confronted with rather unpredictable demand, even for commodities. Consequently, the required responsiveness in a supply chain depends on the anticipated uncertainty of demand. This means that the required responsiveness depends on both the inherent deviations in demand and on the planning capabilities of the company (Baiker, 2002, p. 64). This relates not only to estimating the quantities demanded of certain products, but more generally to using market knowledge to exploit profitable opportunities in a volatile market place (Naylor, Naim and Berry, 1999, p. 108). A company's ability to forecast and serve the demand for its products changes during a product's life cycle – during ramp-up and phase-out, demand is less predictable than during maturity (Alicke, 2003, p. 146). This means that the supply chain requirements also change over the product life cycle, which is a factor many companies do not consider.

A survey of consumer packaged goods companies in 2005 indicates that of the companies that tailor their supply chain approach to the product, those that consider changes in volatility of demand over time for the segmentation of their product portfolio are

[3] Note that every product initially is innovative – even sugar was at one point in time an innovation.

more successful – 50 percent of the best performing companies in supply chain management[4] used volatility as a segmentation criterion, compared to only 27 percent of the other companies, which use simpler criteria such as volume (Alldredge, Allen, Howe and Kelly, 2005, p. 21). This indicates that many companies do not realise the importance of tailoring the supply chain to the requirements a particular product has during the various stages of its life cycle.

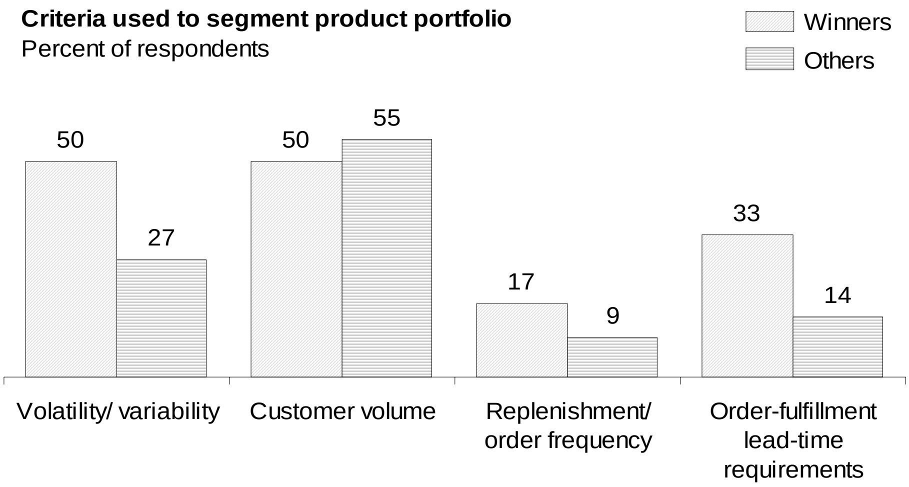

Figure 1 – Criteria used to segment product portfolio (adapted from Alldredge et al, 2005, p. 21)

Management of supply chain responsiveness is particularly important when operating in a competitive market where short lead times might be critical and inventory – which can allow fast response – is risky (e.g., due to product obsolescence), costly and therefore reduces efficiency. These aspects become even more important for innovative products with short product life cycles, where management of supply chain responsiveness is seen as a crucial capability. At the same time, more commodity-like, functional products generally require more efficient supply chains, combined with minimisation of the bullwhip effect. When supply chains are more able to react to changing market requirements than necessary – i.e., having achieved a higher than necessary degree of responsiveness – customers will have to carry the additional cost, which is also problematic (Fisher, 1997, p. 110). The goal is to design the supply chain such that the "products may flow as required by the customer throughout the life cycle" (Aitken, Childerhouse and Towill, 2003, p. 127). Clearly, there is no "one fits all" approach for successful management of the supply chain, but different strategies are appropriate for different products at different stages of their product life cycles.

2. Feedback Structure Linking Responsiveness and Efficiency

In this paper, responsiveness and efficiency are seen as interrelated, which is visualised in Figure 2. Responsiveness and efficiency are directly and indirectly linked and even involve feedback. In supply chains, the interrelationships between key parts of the

[4] Winners for the Supply Chain Management area of the survey are defined based on a combination of ACNielsen data and P&L results (Alldredge, Allen, Howe and Kelly, 2005, p. 5).

system are complex. There are various players in the supply chain, and each of them addresses aspects of demand, production, and supply management, distribution, planning etc. Each of these aspects also interacts with the others. These interrelationships form feedback loops that either amplify or cancel out management initiatives in unintuitive ways. This is the case both when such initiatives are carried out by individual supply chain players in an un-coordinated fashion as well as when supply chain members coordinate their initiatives and attempt to align policies in the supply chain. These feedback loops make problem solving and decision making difficult because it is not at all obvious which combination of strategic or operational levers will have the desired effect in the short or long term.

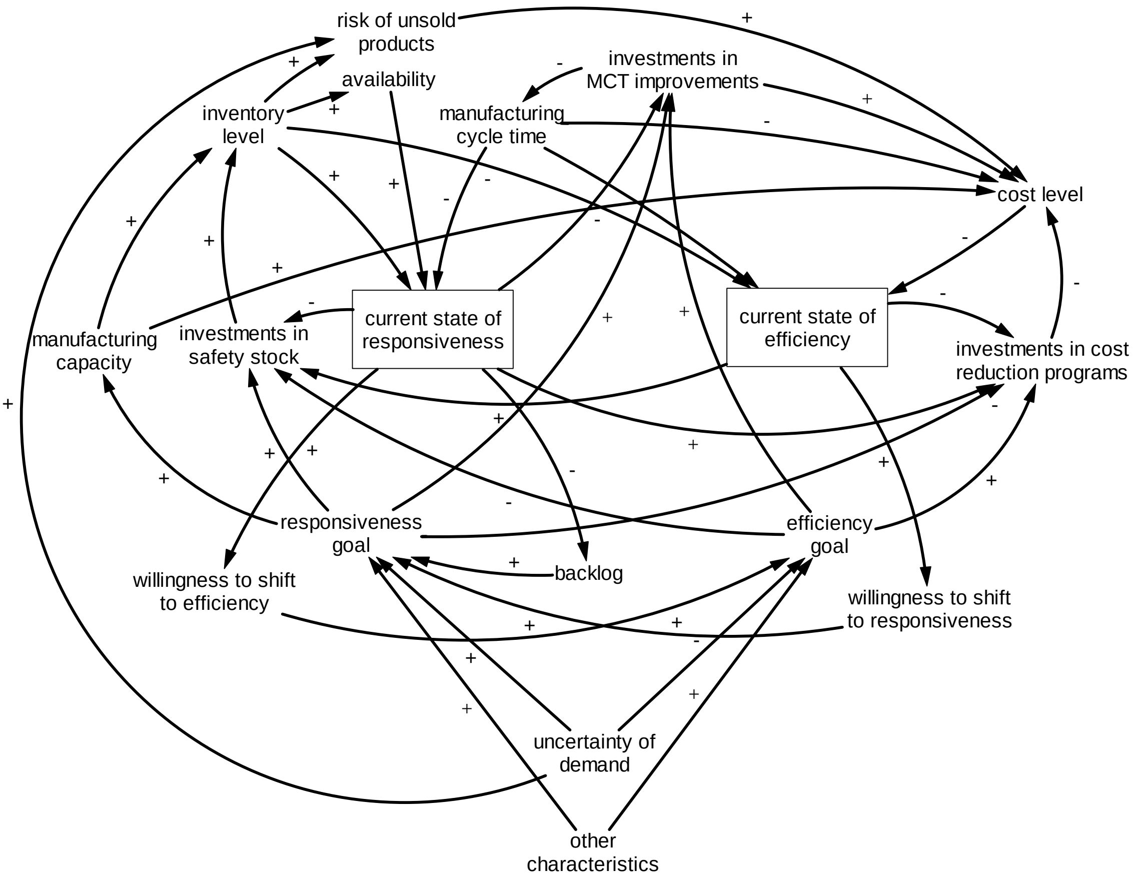

Figure 2 - Responsiveness and Efficiency: Inter-Relatedness at a Glance

For example, as noted earlier, a deliberate increase in safety stock may raise responsiveness through increased product availability when customer needs change unexpectedly. At the same time, however, such an increase in inventory levels raises the cost level both directly, i.e. through increased cost of capital and storage costs, as well as indirectly, since the products on stock might not sell and eventually become obsolete. This increased cost level reduces the degree of efficiency. This is an example for a trade-off between efficiency and responsiveness, which is visualised in Figure 3 below. Specifically, it can be seen that increasing safety stock is a trade-off decision because the responsiveness goal increases the willingness to accept higher safety stock, while the efficiency goal reduces the willingness to accept higher safety stock. The two goals balance each other, causing the system to finally adjust to a specific level of safety stock.

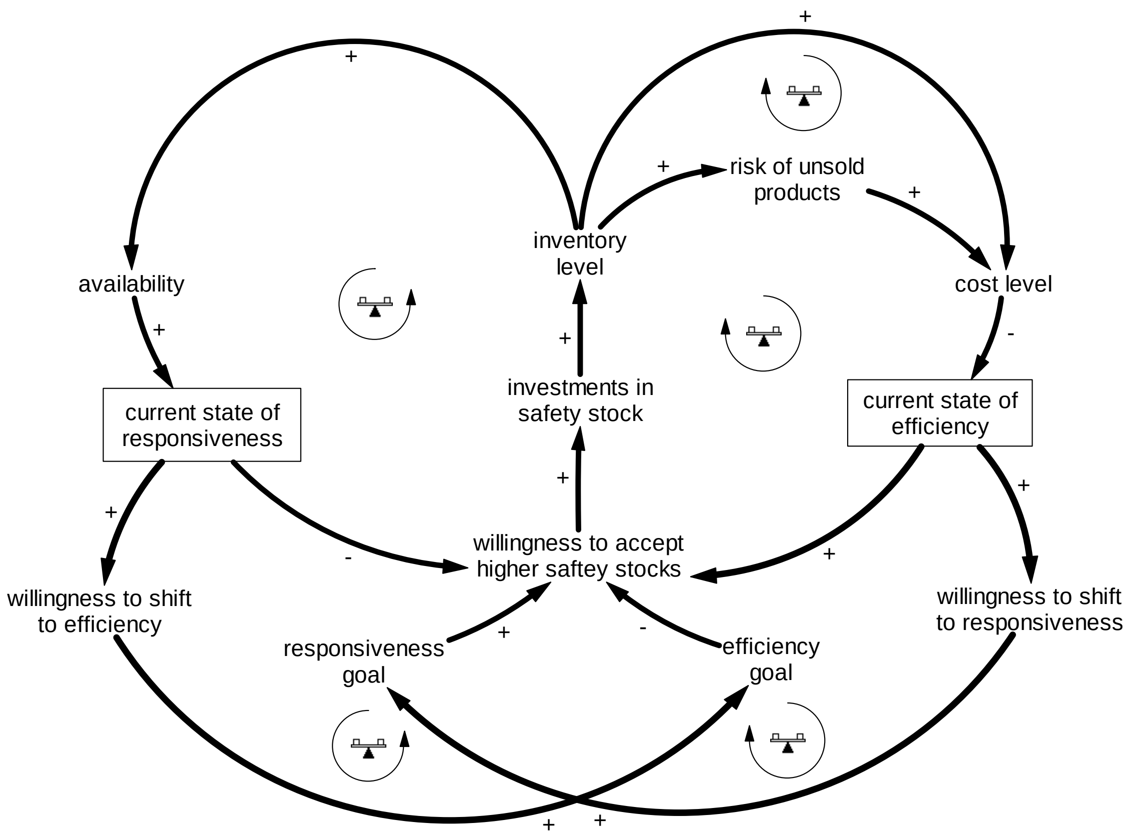

Figure 3 – Inventory Loops: Limits to Success[5]

As was outlined previously, there may be investment opportunities that increase both the degree of efficiency and the degree of responsiveness of the supply chain. Hopp and Spearman describe the example of Moog, Inc., a producer of precision servo valves (2004, p. 146). This company used lean methods to eliminate waste, thus increasing efficiency. At the same time, they increased selected inventory buffers using sophisticated models to segregate certain problems in production, which were addressed later. All other inventory buffers were reduced, again increasing efficiency. The result "has been much greater responsiveness to the customer with improved service. The improved flow also resulted in an unexpected (for management) benefit – a greater than 5% improvement in productivity" (p. 146). One other possibility for such an improvement of supply chain performance on both of these dimensions is to consider the structural conditions of both demand and supply in the (re-)design of the planning system. Depending on product characteristics, forecast quality etc., certain options may outperform others on both dimensions, responsiveness and efficiency. This could mean, for example, that such a move leads both to improvements in the time it takes for the supply chain to adjust to changes in demand, as well as to reductions in safety inventory because of im-

[5] The scale symbol and the snowball symbol in Figure 3 represent the loop polarities, indicating balancing and reinforcing feedback loops, respectively. The definitions of link and loop polarity, related time behaviour and many examples can be found in Sterman (2000, p. 135ff.).

provements such as lead time reductions. This is visualized in Figure 4 below. Here, it can be seen that planning improvements are not a trade-off decision because both the responsiveness goal and the efficiency goal increase the willingness to invest in planning improvements. When either efficiency or responsiveness are improved through an improved planning system, willingness to invest shifts to the other goal. This behaviour causes a reinforcing feedback loop, since the investment aimed at achieving the respective other goal will again have a positive impact on the former. There is no boundary for investments in planning systems, while there is one in the case of safety stock.

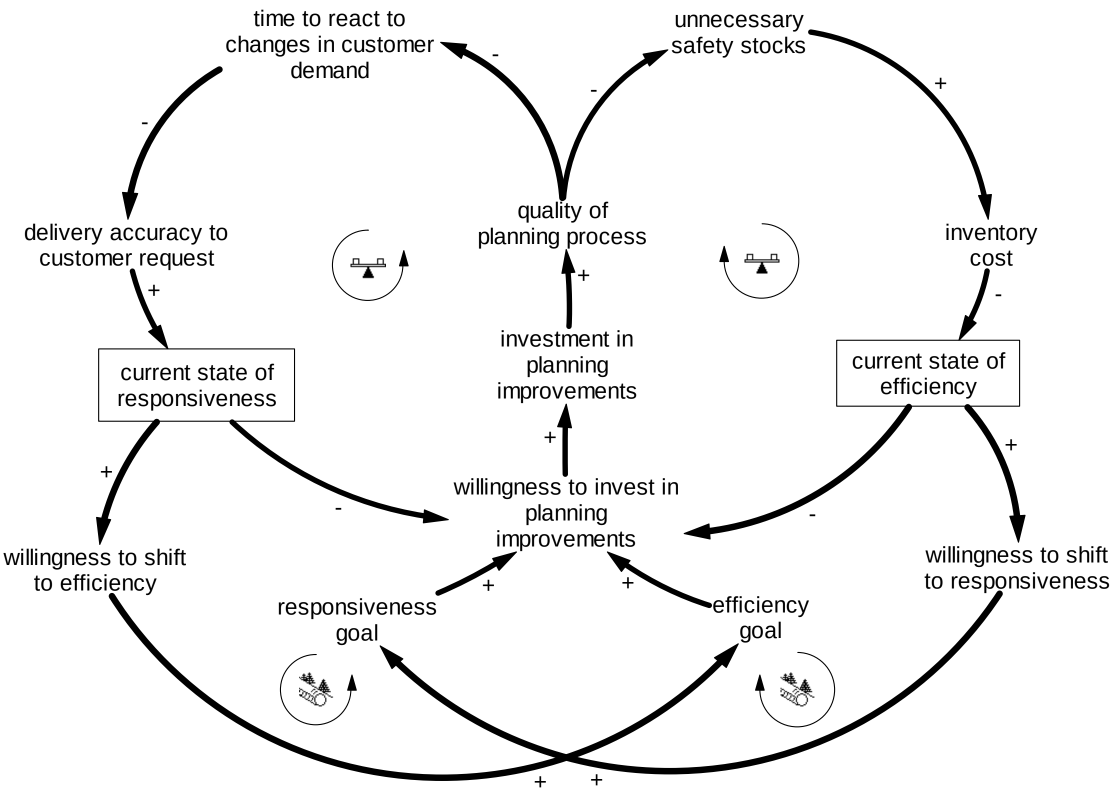

Figure 4 – Planning Loops: Improvements for Growth

There may also be performance measurement problems caused by time delays in the system, leading to suboptimal future decisions. In supply chains, time delays are prevalent at various points, for example there may be long order lead times, or information about demand takes some time until it passes through the supply chain – and might even be distorted on the way. As an example of a performance measurement problem leading to wrong future decisions, consider an investment in a manufacturing cycle time reduction. This investment may only show a measurable change in relevant performance measures after a certain time period, leading the company to believe that the investment did not cause the desired effects and actually introducing a typical worse-before-better behaviour. This, in turn, may lead them to discontinue these or similar investments, which would have a negative effect on responsiveness.

In addition to such internal policy issues, supply chains also typically face a number of external challenges that can reduce the responsiveness of the system. Examples include long component lead times, erroneous components, capacity constraints and missing information about true end customer demand. Information flows, in general, are a major concern in complex supply chains. A responsive supply chain, which Fisher suggests for innovative products such as many high tech products, requires an information flow and policies from the market place to supply chain members in order to hedge inventory and available production capacity against uncertain demand (1997, p. 108). In the high tech industry, for example, the trend to outsource production stretched supply chains across the globe. As a consequence, access to critical data about the supply chain became difficult or impossible, as details about quality, inventory levels or manufacturing capacity are no longer available. “For example, a computer hardware company’s supply planner, trying to meet a spike in demand for certain products, needs capacity and inventory information from several components suppliers and several contract manufacturers, but the data may be locked up in the IT systems or spreadsheets of a dozen or more companies” (Pande, Raman and Srivatsan, 2006, p. 16). In this industry and elsewhere, supply chain planning and control policies are often suboptimal, which results in inefficient systems that cannot satisfy customer demand appropriately, or only at very high cost.

Although Fisher’s principal ideas of the alignment of the supply chain strategies to the type of product are plausible, the interrelatedness also suggests that actions taken to improve efficiency, such as investments in manufacturing cycle time reductions, or different policies such as modified planning systems, could simultaneously lead to improvements in responsiveness. On the other hand, having achieved a high degree of responsiveness allows management to direct its attention more towards efficiency and cost considerations. In view of this interrelatedness, a focus on responsiveness or efficiency does not necessarily involve trade-off decisions. Actually, actions taken by supply chain members to improve efficiency might even increase their ability to be responsive, and vice versa. In this context several questions need to be answered.

- Are there specific conditions under which trade-offs are likely to occur and/or under which trade-offs can be avoided?
- If trade-offs can be avoided, should a supply chain focus first on efficiency and then build responsiveness, or should responsiveness come first?
- Can supply chains “automatically” build responsiveness when focussing on efficiency and vice-versa?

These are aspects being investigated in the context of the research this paper is based on. The objective of the model presented in this paper is to capture generic structures and the intrinsic dynamics of supply chains and to understand the linkages and dynamics between responsiveness and efficiency in supply chains. Since supply chain behaviour is strongly influenced by feedback and delays, system dynamics is the appropriate tool to model supply chain structures (Forrester, 1961; Sterman, 2000). System dynamics provides a systematic approach to linking cause and effect in complex, dynamic situations. Furthermore, simulation is a sophisticated means to understand the often highly counter-intuitive dynamics of the complex interrelations found in supply chains.

3. Overview of Model Structure and Material Flows

The system dynamics model is intended to support decision makers in managing supply chains according to the goals of responsiveness and efficiency. The underlying supply chain structure, as depicted in Figure 5, has three layers plus the customer. It thus consists of a customer, a retailer, a manufacturer and its supplier. In its current version, the model represents the structure of a typical supply chain in the high tech industry. For each echelon, the model represents detailed production, inventory management and ordering policies as well as the order fulfilment process. It covers both product and information flows. At each stage of the supply chain delays in forming expectations about the order rates are explicitly considered as a starting point for production planning. The model is supposed to primarily serve as a basis for research, however, research findings are expected to be of high practical relevance. This goal shall be achieved by combining a generic structure of supply chains as previously described by Sterman (2000, p. 709ff.) and case-based input from practice.

To assess the quality of policies and structural changes to the model, several performance measures have to be used. Performance measures used to track the efficiency and responsiveness of the modelled supply chain include the total inventory cost, distribution and manufacturing cost incurred in the system and the achievement of defined targets such as availability, order fulfilment and delivery performance. These performance measures are strongly influenced by a company's business processes and are important determinants for customer satisfaction. Therefore, customer satisfaction is a central measure of performance (Reiner, 2004, p. 5). The input parameters of the system dynamics model will be determined both through analysis of data provided by sample companies and through expert estimations. This approach is also taken by Reiner (2004, p. 5).

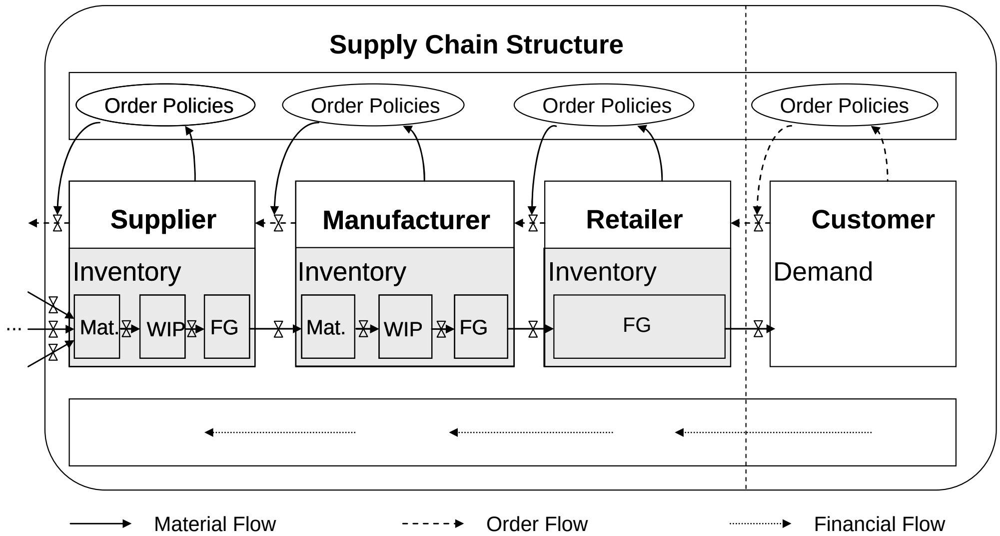

Figure 5 - Overview of the Structure of the System Dynamics Model

For products at different positions on the continuum between innovative and functional products, distinct demand patterns are represented in the model as well as structural differences in supply chain policies. With more functional products, the policies in the supply chain are designed primarily to supply at the lowest possible cost. Innovative products require processes that respond quickly to changes in demand in order to minimize stockouts and obsolete inventory (Huang, Uppal and Shi, 2002, p. 194). Using simulation, the impact of external effects, such as demand shocks, is analysed as well as the consequences of structural internal changes in the supply chain structures and policies. Various demand scenarios to reflect different types of products are currently represented in the model as a deterministic input (see Figure 6), and will at a later stage be included into the feedback system and thus be influenced by measures such as service level (see also Gonçalves, Hines and Sterman, 2005).

Figure 6 - Demand Patterns

4. Impact of Policy Making on Responsiveness and Efficiency

The primary goal of the model presented in this paper is to help identify the consequences of changes in process and product design policies for responsiveness and efficiency. Policies shall be identified that achieve the best efficiency level for a required degree of responsiveness. Operating the supply chain in a robust manner implies competitive cost levels as well as the reduction of the bullwhip effect. The latter refers to amplification of orders in supply chains. This bullwhip effect is visualised in Figure 7 below. It shows the system's reaction to a once-off 20 percent pulse input on day 5 for the finished goods inventory levels for each of the three echelons in the supply chain. The test input in form of a pulse has been chosen because it represents a stable and therefore predictable demand scenario at the end customer. Even in this scenario, however, the supplier's inventory level is subject to significantly more variation than those of the manufacturer and the retailer.

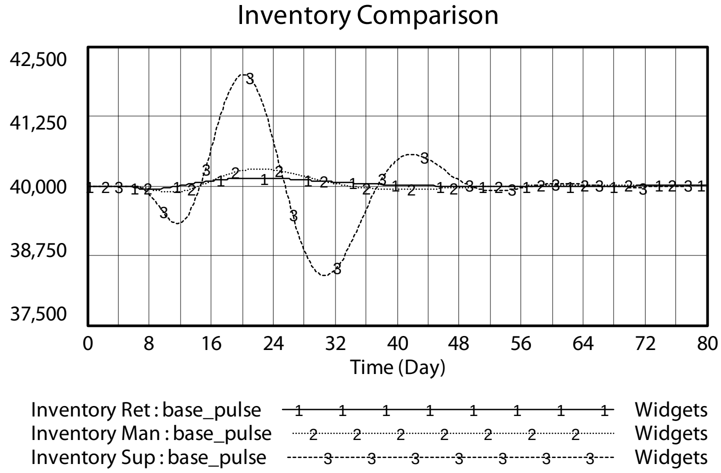

Figure 7 - Bullwhip Effect[6]

When judging the effect of policy changes, Reiner suggests that the impact of a process improvement on performance measures such as inventory cost or service level for the overall supply chain needs to be equal to or larger than the improvements achieved by the manufacturing company (2004, p. 4). This ensures that the manufacturer does not improve its performance at the expense of the other supply chain members. Several policy and scenario modifications have been simulated in order to test expectations and confront them with the outcome of the simulation runs. This ignites a learning process since the complex dynamics influencing supply chain responsiveness and efficiency are understood better. Several of these are briefly discussed subsequently.

The base case assumes a constant demand at 10,000 units/day and a once-off pulse increase in period 5, to 12,000 units/day (see also Figure 6). Afterwards demand is again stable at 10,000 units per day. Figure 8 shows the time behaviour of total inventory costs, which is one of the performance measures, for the following simulation runs. Total inventory costs are calculated by adding the costs for raw materials, work in progress and finished goods inventories across all supply chain echelons. The model is initialised to be in perfect equilibrium. The pulse input serves as the demand scenario for all subsequently discussed simulations. In the base case, the manufacturer, which is the focal company of the analyses, bases its order planning on the retailer orders. In a modified version of the model the manufacturer gets direct access to information about the customer orders. This is supposed to improve the planning capabilities of the manufacturer. Figure 8 below shows the consequences of this change for inventory costs over the aggregate supply chain (simulation run base_pulse_alternativeplanning). Communication between manufacturer and retailer, as in this example, is critical to allow the members of the supply chain to jointly react to changes in the demand pattern. Informing the manufacturer about customer orders leads to improvements in production planning, reductions in peak inventory levels and less demand amplification. A further modification to the model reduces the manufacturing cycle time for both manufacturer and supplier from 8 days to 6 days in period 5 (simulation run base_pulse_-lowmancycletime). The significant reduction in the inventory level can primarily be

[6] Since the bullwhip effect in this simulation run is rather weak, the scale of the y-axis was adjusted for increased clarity.

explained by a reduction in work in progress inventory. In addition, amplification is also reduced compared to the base_pulse simulation run.

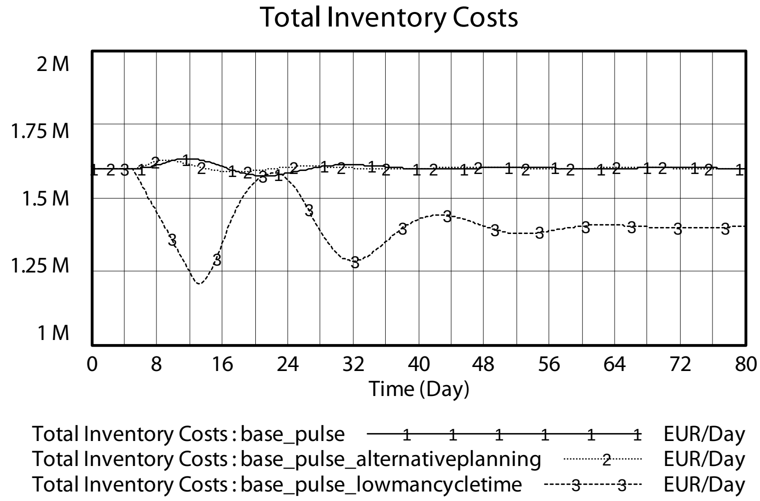

Figure 8 - Change in Inventory Costs in Different Scenarios

Since demand uncertainty is linked to the classification into functional or innovative products, the model also calculates several measures of forecast errors. The retailer experiences only a small forecast error in the pulse input run since end customer demand is stable over the simulation time, except for the pulse input in period 5 (see Figure 6). Therefore, from the demand pattern, the product could be characterized as a functional product and thus the supply chain should strive for efficiency according to Fisher's suggestions. Downstream in the supply chain, however, demands starts fluctuating and in consequence the model shows an increasing forecast error for downstream supply chain layers. This questions whether certainty of demand is sufficient to categorize a product as a functional product and to use this categorisation as the basis for strategic recommendations across the supply chain. Here, for example, the recommendation would be to strive for efficiency.

This goal of more efficiency and reduced bullwhip effects could be achieved, for example, by taking measures such as using customer data for production planning at all levels of the supply chain and simultaneously reducing the inventory levels across the chain. Therefore, the model was modified by reducing desired safety stock coverage for the three supply chain echelons from 2 to 1 from day 5 on. Simultaneously, customer order data are made available to the manufacturer and to the supplier, which then are used for their production planning. The resulting adjustments in the finished goods inventory levels across the supply chain echelons are visualised in Figure 9 below. Finished goods inventory levels for the manufacturer and the retailer begin to adjust to the new, lower level, and both retailer and manufacturer reduce their order rates. During the transition, the supplier experiences increasing finished goods inventories, which represent the materials for the manufacturer. The reason for this development is that the shipments to the manufacturer are reduced more quickly than the production process at the supplier can adjust. Nevertheless, Figure 10 shows that aggregate inventory costs, including work in process and raw materials inventory as well as finished goods, begin to decline as soon as the actions to increase efficiency are taken. Striving for increased efficiency reduces total inventory cost by 9.4 percent at the expense of only a negligible decrease in responsiveness. The total delivery delay, for example, which can serve as a measure for responsiveness, increased by 2.4 percent.

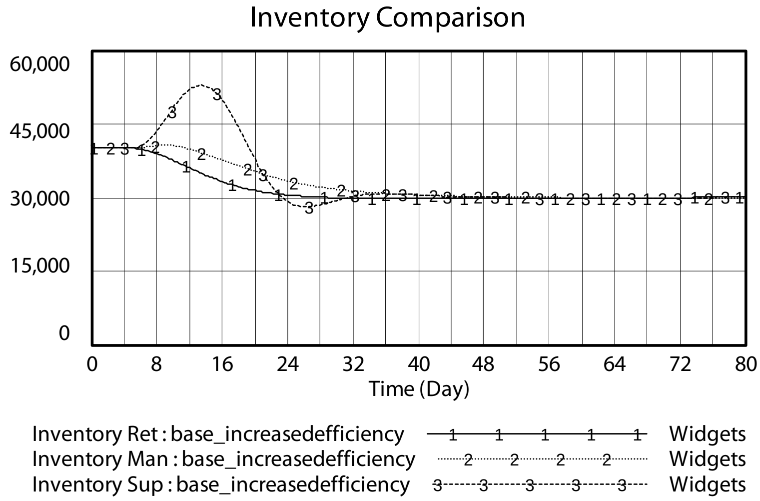

Figure 9 - Comparison of Inventory Levels across Supply Chain Echelons

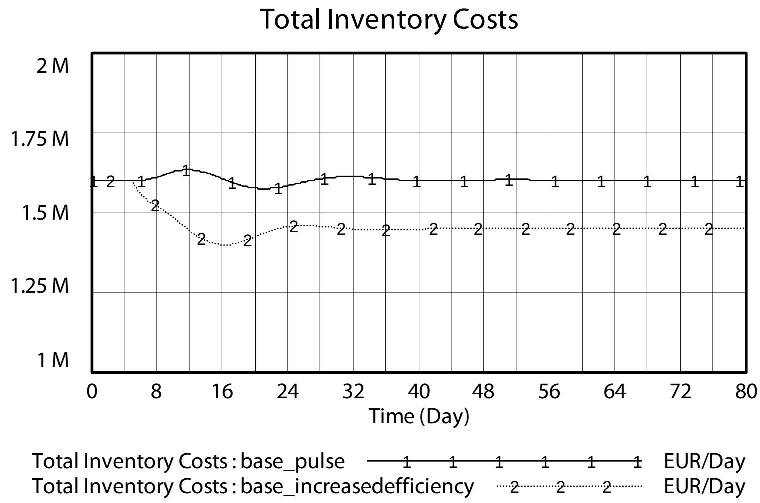

Figure 10 - Change in Inventory Costs

In conclusion, the behaviour simulated using the supply chain model is in line with expected behaviour and shows the traditionally expected trade-off between responsiveness and efficiency. Nevertheless, a sensible combination of measures taken to increase efficiency can at least reduce the negative impact on responsiveness. Among other aspects, further research intends to find out whether investments to increase efficiency can have a positive impact on responsiveness at the same time. For example, a reduction of inventory levels could be accompanied by measures to reduce manufacturing cycle time as well as alternative planning methods. The model can now be further fine-tuned and also be fed with data to show which supply chain set-up is optimal under different circumstances.

5. Future Research

The model adds value for both decision makers in companies as well as researchers focusing on supply chain management. The results of the research will allow decision makers to identify and test policies for an efficiently and responsive supply chain strategy. It will allow them to set up supply chain structures that provide optimal levels of efficiency and responsiveness. Future research will focus on identifying policies to balance responsiveness and efficiency in a specific industry. For example, a further modification to the model integrates the retailer into the manufacturing company. This implies a reduction of echelons in the supply chain. The central question to be analysed is how the supply chain costs and responsiveness change when such an integration is executed. These concrete insights based on a specific example should be of great interest, as adapting the supply chain to the requirements of new product launches is a common theme in many industries. This will allow a link between the theoretical considerations and the experience that exists in companies, which will be linked and analysed systematically through the system dynamics model. The policies to be found in this research aim to improve both efficiency and responsiveness – and by that resolve the trade-off between the two.

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