Collaborative Planning with Dynamic Supply Loops

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Abstract

The paper presents a generic collaboration scheme for supply networks that is based on practical assumptions motivated by the automotive industry. Primarily, it is decentralized, allows autonomous decision making at the partners, and requires a relatively simple information exchange between immediate partners in a supply chain. Within this scheme called Dynamic Supply Loops (DSL), it is possible to balance the benefit of coordination between the partners. Simulation results on a multi-echelon model show that the DSL approach outperforms traditional upstream planning and facilitates coordination.

Keywords:

Planning, Supply chain, Collaboration

1 INTRODUCTION

This paper investigates a general and recurrent issue of supply chain management: the contrast between collaborative and local planning. Specifically, it deals with collaborative planning of autonomous decision makers, where alone the Original Equipment Manufacturer (OEM) has information about market demands, while all the partners keep their own constraints, objectives and decision mechanisms private. In this asymmetric situation, the goal is to coordinate planning activities of the partners along all tiers of a chain by having as few assumptions towards the local planning processes and communication protocols as possible.

In the past decades several schemes were proposed to support collaborative planning in supply chains (see [1] for an overview). Recently, mathematical formulations have been developed for various versions of the core, decentralized planning problem [2]. It was also realized that cooperation of autonomous partners presupposes an incentive scheme that aligns distinct, in part even conflicting objectives [3]. E.g., this is a prerequisite of exchanging truthful information on demand forecasts and of minimizing system wide production and logistics costs [4]. Though, when it comes to coordinate a real supply chain, the theoretical approaches are typically prone to fail due to some of the following reasons: they are rooted in unrealistic assumptions; the decision problems are computationally prohibitive; industry is reluctant to apply complex automated negotiation protocols; it is hard to transform an incentive scheme into a business model that is acceptable for each partner; and, last but not least, they preclude the application of well-proven planning methods available in de facto standard Enterprise Resource Planning (ERP) systems.

The work presented here was strongly motivated by the above practical concerns. Within a project aimed at realizing the European concept of Customize-to-Order (CtO) car production, one of the main goals was to develop such a novel planning method that improves overall performance in terms of service as well as inventory levels even though decisions are made in a decentralized way [5]. The ACDC project answered this challenge by offering a new concept called **Dynamic Supply Loops** (DSL).

In the sequel the collaborative planning problem is exposed, together with requirements towards a generic planning scheme. Section 3 outlines the DSL approach, while Section 4 presents a benefit balancing method that can be realized within DSL. By embedding standard planning methods into this DSL scheme, computational test were also carried out on particular multi-echelon planning problem instances. The encouraging results lead also to the conclusion that DSL is a viable approach to decentralized collaborative planning.

2 PROBLEM STATEMENT

2.1 Planning in automotive supply networks

Actually the supply chain in the automotive industry is organized as a hierarchical **upstream** planning system, proceeding top-down from the OEM to its suppliers [6]. Thereby the planning process encodes restrictive planning conditions where the OEM forces the $tier_1$ suppliers to fulfil its specific demands without compromises and delivering the needed information to generate a robust and reliable plan for a longer time period at $tier_1$. The same pattern is repeated between $tier_n$ and $tier_{n+1}$. Hence, $tier_{n+1}$ supplier loses flexibility in its planning procedures while more often reacting $tier_n$ needs whether then controlling material flow and planning cycles.

Forced through the supply chain, this problem leads to several problems: loss of optimization potentials in local planning decisions because of restricted information policies, capacity overloads because of uncertainty according to future demand developments and the needs of an enhanced event handling system to react fast to uncertain demand changes and occurring material shortages. These circumstances lead to an unstable and nervous system wasting time and money for keeping it running, therefore increase the product price while reduce the accounts.

Summarizing these problems the actual automotive supply chain is operated in local optima according to the specific situation of each partner. E.g., the OEM can optimize his costs unilaterally by forcing the $tier_1$ suppliers to deliver only just in time.

2.2 Requirements towards collaborative planning methods

A new planning approach should be established that regards all the illustrated problems in the actual automotive supply chain driving the overall system towards a better performance in terms of lead time, reactivity and overall system costs. The new planning concept should meet the following requirements:

- It should guarantee **local planning autonomy** and the usage of local planning systems including multi-criteria decision making at each partner in the supply chain, and thereby regarding non-local planning pre-conditions and information about the $tier_{n+1}$ supply chain partner. Details of this problem have been analyzed by Döring [7].
- The concept should allow **competition** between partners in the supply network as well as support **cooperation** between them. By using principles for benefit sharing and incentives for system participation, the system as a whole should be driven from local minimum points towards global optima.
- More information should be shared to consider $tier_{n+1}$ suppliers' conditions when planning at $tier_n$ or the OEM while avoiding information overflow and unstructured information exchange. A simple protocol is needed for an efficient, bi-directional **communication process**, extending existing standards in automotive industry like ODETTE and enabling also smaller suppliers' a simple access to essential network-wide information.

3 THE OVERALL DYNAMIC SUPPLY LOOPS CONCEPT

The DSL are structured in three layers according to classical supply chain management:

- The **strategic loop** generates the up to 5 years long frame plans for the whole supply network used as general planning agreements (e.g., expected demands, needed capacities and locations on product platform level) and valid as constraints for deriving tactical and operational plans. The generation of frame plans has been described by Timm [8] using a hierarchical optimization model.
- The **tactical loop** offers planning methods for generating demand and corresponding production and supply plans on a horizon of up to 18 months. Planning in this tactical loop is discussed in this paper.
- The **operational loop** processes occurring events based on operational plans and regarding shop-floor flexibilities.

Implementing the listed requirements the system should be very robust and less nervous because it is based on reliable long- and mid- term plans and can react to unexpected events by exploiting shop-floor flexibility.

By using the DSL the traditional hierarchical automotive supply chain planning concept will be broken to establish a one-step feedback planning loop between $tier_n$ and $tier_{n+1}$, between any immediate partners as shown in Figure 1. $Tier_n$ will propose several planning scenarios to its suppliers at $tier_{n+1}$ and ask them for the specific cost statements. The scenarios

include implicitly the knowledge about the plant locations, flexibility and delivery conditions of the suppliers. The idea is to propose only those scenarios which could be fulfilled by the supplier according to formerly defined delivery contracts. Tier_{n+1} will calculate scenario cost statements using its own planning facilities (e.g., an ERP system) and communicate those back to tier_n. This feedback will be used by tier_n when making a final decision on the distribution of demand figures to the tier_{n+1} supplier.
The resulting process is a strictly structured negotiation process which can be implemented easily and allows for fast reaction times. Because of using implicit information on tier_{n+1} during the scenario generation at tier_n, the accepted plans will be more focused to the actual situation at tier_{n+1}, in opposite to the traditional upstream planning procedures in today's automotive supply chains. This information includes e.g., the knowledge of capacity capabilities, flexibility agreements, quality issues or specializations as well as the frame plan at tier_{n+1}. This implicit information will be gained by collecting information about tier_{n+1} at tier_n and by using new protocols based on EDI standards.

The supplier is getting more flexibility, now being able to reduce its costs and stocks because of focused and reliable demand plans from its buyer. Further on, it can evaluate various alternatives and express its preference in terms of prices. Though, when choosing the final scenario not only prices but other factors like lead times or inventory levels may matter, too.

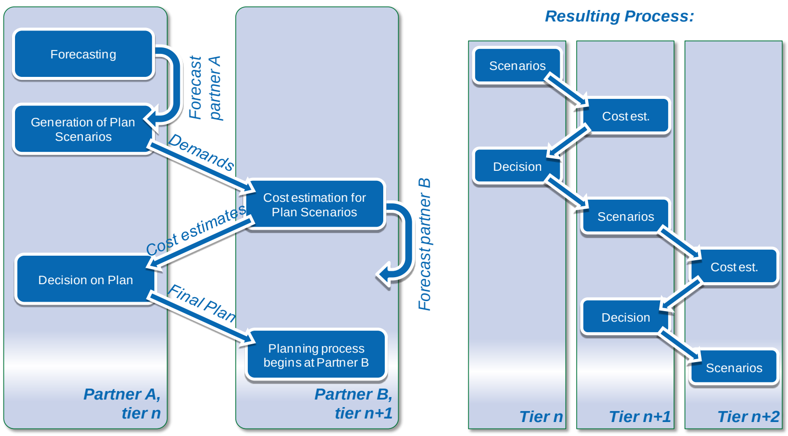

Figure 1: Planning protocol of the Dynamic Supply Loops.

To offer incentives for taking part in the DSL, tier_n and tier_{n+1} should agree on some regulations for balancing the saved system costs as benefits of cooperation. E.g., the supplier at tier_{n+1} offers its tier_n partner a well operated vendor managed inventory without including the costs into the products, and tier_n regards available inventory and capacity information on tier_{n+1} when generating the planning scenarios. Both have profit in this situation: the inventory level is on the needed level at sufficient costs and tier_{n+1} is able to operate a robust production system relying on expected buyer call-offs from $tier_n$. On the long term, costs as well as stock levels can be reduced due to increased reliability and less nervousness of the whole planning system. Finally, the DSL scheme does not impose any particular planning and performance evaluation method on the partners.

4 COORDINATION WITH BENEFIT BALANCING

In traditional upstream planning the $tier_n$ enterprise optimizes its production without considering the consequences at the subsequent tiers. The DSL process changes this practice by involving the supplier into the decision making. But why would an enterprise choose collaborative planning instead of focusing exclusively on its own interests? The reason is the long-term sustainability: inefficient production anywhere in the process entails higher prices, which causes poor competitiveness of the whole supply chain. If for this reason the prices are kept artificially low, it becomes the source of financial, and eventually of supply problems.

In order to formally analyze the DSL approach, it is assumed that the supplier estimates the costs of the given scenarios and offers price discounts for its preferred plans. This can be interpreted as a combination of the **menu of contracts** and the **price discrimination** approaches of the classical microeconomic theory [9]. The **tactical planning loop** then works in the following steps:

1. Instead of generating only one optimized plan (S_0), the $tier_n$ enterprise generates several alternative scenarios ($S_0,\dots,S_m$). Let c_i^n denote the cost in $tier_n$ of executing the *i*th scenario, where S_0 is the default upstream plan, i.e., c_0^n is the lowest cost for the buyer.
2. The $tier_{n+1}$ enterprise does not know the buyer's costs for the scenarios, but only its own estimated costs: c_i^{n+1}. Then it calculates how much benefit can be realized in $tier_{n+1}$ executing S_i instead of S_0: $b_i^{n+1} = c_0^{n+1} - c_i^{n+1}$. If b_i^{n+1} is positive, the supplier prefers the *i*th alternative compared to S_0, and therefore is willing to share its benefit in order to inspire the buyer deviating from the default upstream scenario. The ratio of the benefit sharing is up to the supplier, considering both its own interest and the sufficient inspiration to $tier_n$.
3. Let t_i^{n+1} denote the compensation offered as price discount for choosing *i*th scenario, then the compensated cost for $tier_n$ is $c_i^n - t_i^{n+1}$.

It is easy to see that the total cost of the two tiers—not explicitly known by either of the partners—can only decrease by applying DSL instead of upstream planning. The loop is **coordinated**, if the $tier_n$ chooses the scenario that results in the lowest total cost. Since guaranteeing this requires unrealistic assumptions, a workable objective is to improve the performance compared to upstream planning (see also [1,2]).

The above process can be illustrated by the example in Table 1. Accordingly, the buyer prefers S_0, the supplier S_4, while S_1 is the optimal scenario. In this case, offering half of the benefit results in a coordinated solution (S_1), and price reductions from 13 to 12 in $tier_n$, and from 30 to 28 in tier$_{n+1}$. The example also shows that coordination—or even improvement—does not necessarily happen: if tier$_n$ offers only scenarios S_0 and S_2-S_5, the result will not be the optimal one (in this case S_4), but the same as in the upstream case.

Scenario	**S$_0$**	**S$_1$**	**S$_2$**	**S$_3$**	**S$_4$**	**S$_5$**
Tier$_n$ cost (c_i^n)	**13**	14	15	16	17	18
Tier$_{n+1}$ cost (c_i^{n+1})	30	26	28	28	**24**	32
Total cost ($c_i^n + c_i^{n+1}$)	43	**40**	43	44	41	50
Benefit ($b_i^{n+1} = c_0^{n+1} - c_i^{n+1}$)	0	4	2	2	6	-2
Compensation ($t_i^{n+1} = 50\% \times b_i^{n+1}$)	0	2	1	1	3	0
Tier$_n$ compensated ($c_i^n - t_i^{n+1}$)	13	**12**	14	15	14	18
Tier$_{n+1}$ compensated ($c_i^{n+1} + t_i^{n+1}$)	30	28	29	29	27	32

Table 1: Example of benefit sharing.

Although DSL cannot worsen performance in a two-echelon chain compared to upstream planning, this is not guaranteed in longer chains. Therefore, the behavior of DSL in multi-echelon cases is studied next.

5 COMPUTATIONAL STUDY

This section illustrates the behavior of the DSL planning concept based on some numerical experiments. Since the realistic planning algorithms are very complex (see [8]), here the simpler **multi-echelon dynamic uncapacitated lot-sizing problem** had been analyzed. In this problem the end-product demand is given on a finite horizon that should be fulfilled by a chain of manufacturers. At each echelon, all demand is satisfied without backordering. Production incurs a fixed setup cost as well as inventory holding costs. The total cost in the whole supply chain can be minimized by applying Zangwill's centralized model and algorithm [10].

For generating alternative DSL scenarios, the following standard single-echelon lot-sizing methods had been applied: Wagner-Whitin, Lot-for-Lot, Economic Order Quantity, Periodic Order Quantity and Silver-Meal (see e.g., [11]). These methods are also available in most commercial ERP systems [12]. For upstream planning, the Wagner-Whitin method was used at each tier, which provided the optimal solution for the single-echelon problem. The simulations were made with four different methods:

- Zangwill's algorithm provides a theoretical lower bound on the achievable cost.
- Upstream planning provides the AS-IS default solution.
- DSL approach with fair benefit sharing, i.e., the suppliers offer half of their benefit as compensation.
- Coordinated DSL is also a theoretical solution, where tier$_n$ chooses the scenario which minimizes the total cost of tier$_n$ and tier$_{n+1}$.

Compelling questions are as follows: Is it worth applying DSL instead of upstream planning? How far is the decentralized DSL solution from the theoretical optimum? These are real issues also in longer chains where bilateral collaboration of DSL cannot guarantee overall improvement.

Simulation runs were made with various parameter settings, showing here one promising example only. In this case, a 5-echelon chain was modeled on a 12-period long horizon. In each period demand was uniformly distributed between 0 and 200. Since storing end-products is typically costlier than holding parts and raw materials, inventory costs were assumed decreasing upwards in the chain. Various planning cycles were modeled by varying the average time between orders (TBO): at $tier_0$ (OEM) the production is continuous (TBO=1), while upstream the TBO increases. This also reflects that next to the market a pull principle is applied (Customize-to-Order), while the other end of the chain is rather operated in a push manner (Build-to-Stock) [5]. The setup costs were calculated back from the TBO values, assuming optimal order quantities.

The X axis of Figure 2 denotes the TBO increasing in the chain, i.e., when it is 0, there is no increase (in each tier TBO=1), while at the other end it equals to 2, thus the TBOs are 1,3,5,7 and 9. The Y axis shows the relative cost surplus of each planning method in comparison to the theoretical optimum. Averages were calculated from 100 simulation runs.

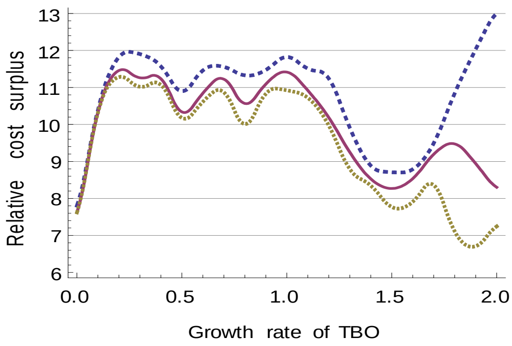

Figure 2: Inefficiency of the supply chain.

Figure 2 shows that each DSL approach performs better in average than upstream planning (blue dashed), especially if the TBOs increase significantly. Performance resulting from a fair 50% benefit sharing between $tier_n$ and $tier_{n+1}$ (purple solid curve) is dominated by a fully coordinated DSL (yellow dotted curve) when $tier_{n+1}$ offers all its benefits.

One should note that in a two-echelon case the costs of the upstream and coordinated DSL are tight upper and lower bounds for the DSL approach. This is however not guaranteed in longer chains; indeed, the simulation showed that in 2-3% of the cases the DSL resulted in larger costs than upstream planning (note that Figure 2 depicts average performance). All in all, simulations confirmed that applying DSL is promising and cost-efficient on the long term. At the same time, it is necessary to study extensively the potential planning models, cost structures and TBOs before implementing any particular protocol of the DSL collaboration scheme.

6 CONCLUSIONS

Although the need for collaborative planning in supply chains is generally recognized, there is still a gap between theoretical proposals and practical requirements. This paper discussed the generic DSL planning scheme that offers a viable compromise: it opens space for other partners' options, while keeps communication and decision complexity at bay through a relatively simple information exchange and decision protocol confined to immediate partners in a chain. DSL is open to embed standard planning techniques and novel incentive schemes alike. Simulation results on a multi-echelon model showed that DSL outperforms traditional upstream planning and facilitates channel coordination.

7 ACKNOWLEDGEMENT

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