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COOPERATIVE PLANNING BY COORDINATING THE SUPPLY CHANNEL

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Abstract. Cooperation between manufacturing enterprises has recently become widespread in order to cope with newly emerged challenges, such as growing customer expectations, increasing product variety and decreasing product lifecycles. Nowadays the response to these challenges seems to be the formation of tight relations in supply chains and networks, which enables joint handling of market risks and involves sharing benefits and mutual growth. Our current work studies this situation in case of high manufacturing setup costs, which inspire enterprises to produce in large sized lots, which could in turn, lead to obsolete inventories on unstable markets. We propose a method for coordinating supply channels on such markets and a framework for cooperative planning.

Keywords: Coordination, cooperation, supply chain management

1. Introduction and motivation

Today's mass customized production (typically of consumer goods like low-tech electronics, mobile phones, light bulbs, cosmetics, etc.) aims at providing large product diversity and relatively cheap and simple manufacturing—both in small and large quantities—from standard components. Unfortunately, this policy usually induces either longer throughput times, lower service levels or higher inventories. On the other hand, customer expectations are permanently growing (e.g., acceptable delivery times are shorter and shorter), therefore a trade-off has to be found between the conflicting objectives. Shorter product life-cycles also follow from customization, which causes further problems [13].

Such markets are typically served by competing *supply networks* which consist of autonomous entities, most of them being engaged in more network relations. In a particular network, hardly predictable customer demand must be anticipated and satisfied directly by a manufacturer of end-products that works in the focal point of the network, while other members supply the manufacturer with necessary components including packaging materials. In order to cope with the above mentioned challenges, standard, autonomous ways of improving competitiveness—such as reducing inventory levels and raising resource utilization—should be extended to the network level and enhanced by cooperation [11, 16].

Though the ultimate goal of production is to satisfy actual customer orders, all partners are forced to apply also make-to-stock strategies so that they can

1. meet demand in time,
2. satisfy some constraints of mass production technology, and
3. exploit economics of scale.

Hence, it is inevitable to produce even customized products on the basis of forecasts and to keep inventories both from products and components to hedge against uncertainties of demand. However, just due to the very nature of the market, from certain products or components obsolete inventories may easily remain, which cannot be sold or used any more. An alternative way is to sustain capacity buffers, but this certainly incurs extra equipment and labor costs, which in most cases exceed the cost of holding inventory.

The motivation of this work comes from a large-scale national industrial-academical R&D project aimed at realizing real-time, cooperative enterprises [12]. Our particular aim is to develop planning methods that improve the overall logistic and production performance of a supply network involved in mass production of customized consumer goods. Though, the solution should be generic: we focus on the problem of how a focal network as a whole can guarantee short delivery time and high service level while keeping its logistics costs as low as possible. We do not tackle the issue of making forecasts on the market of customized mass products. When modelling autonomous partners, details of how they organize their own production is not dealt with, either. We assume that each partner does its best when planning and scheduling its internal operations, and takes also responsibility for the quality and execution of its plans. Even so, there is an inevitable need to coordinate their logistics and production related decisions. For reasons discussed below, we prefer coordination models that facilitate and sustain *cooperation* among network members.

The proposed method is based not on the extension of local planning and control processes but rather on the extension of information access and decision rights of the partners. This is accompanied by extended responsibilities, too.

In general terms, the flow of information, commodity and currency between the partners is regulated by *contracts*. Our interest is in designing such protocols and decision models that are applicable under realistic conditions and help to find a common, acceptable performance trade-off for all members of focal supply networks.

In the sequel we give a short overview of related works, and then specify the requirements towards a cooperation mechanism. Section 4 presents an analytical model for coordinating the channel between the manufacturer and its suppliers. Next, this model is embedded into a cooperative planning mechanism. Section 6 discusses our industrial case study and summarizes simulation results on historical data sets. Finally, subsequent steps of our research program are presented and conclusions are drawn.

2. Related work

There exists a number of approaches that provide technology for information sharing in a supply network. However, these *supply chain management* (SCM) systems are mostly transactional and do not really support coordinated decision making [7, 14]. So-called *advanced planning systems* (APS) are already applicable to solve—even in a close-to optimal way—production planning and scheduling problems locally, at the nodes of a network [17], but still there is a lack of comprehension on how to coordinate local, distributed planning processes in case of firms whose primary objective is their own profit [14]. Since performance criteria are conflicting both at the individual partners and at the network level, local optimization may even adversely affect the system's performance—a phenomenon know for long as *double marginalization* [15].

When the manufacturer and its supplier make plans and decisions independently, the system can deviate from optimum and effect poor performance. So-called *channel coordination* is achieved when the manufacturer and its supplier make local decisions so that their joint profit is maximized. This is what could be produced by a centralized system (e.g., a so-called *virtual enterprise*), but it can be carried out also in case of autonomous enterprises that contract on the payment, if each firm's objective is aligned with the supply chain's overall objective [3]. Contracts that associate decision rights with appropriate incentives are just for accommodating different and disparate objectives. There is a variety of contracts both in the theory and practice of supply chains that strive to achieve good system performance while keeping the manufacturer-supplier relation flexible. While contracts in the practice are usually too complex for analytical modelling, most theoretical models work in a time-invariant, single-period setting. A general coordination framework based on *options* is presented in [1], where several contract types (e.g., quantity flexibility) are proved to be special cases of options. However, this model is applicable only for short-term coordination, because its horizon includes no more than two periods.

In any case, an integral part of coordination is to decide how much to produce from particular products and components at a given moment. The planning of *lot sizes* is well studied in the literature. Lot sizing problems (LSP) can be classified according to several criteria: granularity of time (continuous or discrete), number of production levels (single or hierarchical), length of production horizon (finite or infinite), capacity constraint (capacitated or uncapacitated), objective function (total or average cost), inventory limits, etc. For example, the widely used Economic Order Quantity (EOQ) model is continuous, uncapacitated, minimizes average cost and can be computed easily. On the other hand, the (improved) uncapacitated Wagner – Whitin method considers a finite and discrete horizon, minimizes the total cost and the optimal lot sizes can be computed in $\mathcal{O}(n \log n)$ time, where n is the length of the horizon. However, realistic variants of LSPs are usually NP-hard problems [2].

Stochastic inventory policies can handle uncertainty in case of demand volatility (such as the (R, Q) policy) and one-period uncertain demand (*newsvendor* model) [3], but the unexpected termination of the demand is still missing. In [4] a lot sizing model is introduced with imperfect demand forecasts, on a rolling horizon basis. In this situation, the decision is related only to the period right after the decision time, and then the horizon is rolled forward with the updated demand. It is shown, that this usually leads to "system nervousness": the altered demand in a later period could cause additional costs. This model includes multiple items, capacity limits and setup costs too. However, because of the generality of the model, even the approximate version has high computational complexity and works only on small-sized problems.

A common example of cooperation is *Vendor Managed Inventory* (VMI), which is a special *one-point-inventory* system, in which the supplier decides the appropriate inventory policies to manage the manufacturer's inventory, based on the manufacturer's forecasts. In a focal supply network, a manufacturer may not maintain inventory at all. Instead, it gives only forecasts and suppliers have to decide the production quantities and store the goods until the manufacturer needs and calls them off—this is the so-called *consignment VMI* [9]. In [5] a VMI implementation is described through a case study of a household electrical appliance manufacturer. As it was observed, VMI could operate much better than the traditional replenishment system, even if demand was highly unpredictable. However, it requires organizational changes, mighty trust and advanced information sharing between enterprises.

Relations between enterprises can be represented on a range of colors: from cold (competitive auctions, single business relations), through warm (cooperative planning), to hot (full integration). Although relations between manufacturers and end customers are usually "cold", the relationships with suppliers (*upstream firms*) are usually richer and more complex [15]. In a conventional, non-cooperative manufacturer-supplier relation, the manufacturer orders components and pays proportionally to the quantity delivered. It can be shown, that in such a situation, uncertainty is amplified due to safety stocks as we traverse upwards the chain (the so-called *bullwhip effect*) [10]. This deteriorates competitiveness of the net, therefore it is inadequate.

3. Requirements towards cooperative planning

We depart from a focal network, where market demand is transmitted to the manufacturer by distribution centers. All the partners are *autonomous.* The network is reconfigured time and again, but we consider the stable periods of its operation. In such periods, suppliers are contracted for producing particular components. There is no overlap between the channels—hence suppliers are not in a competitive situation. (They do compete at reconfiguration time, but this network design problem is out of the scope of the paper.) The suppliers may serve several manufacturers acting on different markets. In fact, a particular firm may fill in both manufacturer's and supplier's role in different nets. We allow also for lateral cooperation—when suppliers mutually help each other in critical shortage situations (see Figure 1).

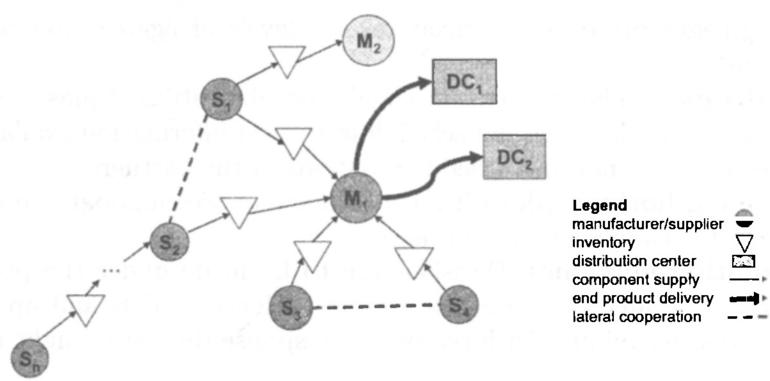


Figure 1. Typical elements and connections of the supply network.

The question all members of the network have to answer time and again can be put simply as how much and when to produce so that they can satisfy demand; neither more, nor less, neither earlier, nor later, just in the required quality.

A network-wide solution emerges from the interaction of local decisions. This is essentially a *distributed planning problem*: network members would like to exercise control over some future events based on information what they know at the moment for certain (about products, technologies, resource capabilities, sales histories) and only anticipate (demand, resource and material availability). Hence, partners—at least along the various supply channels—need to *coordinate*; i.e. to take into account some of the other's decisions. Further on, they can enhance even more their relations by *information exchange* and *cooperation*.

The basic requirements towards a cooperative planning mechanism are as follows:

- **Autonomy** of the network partners has to be respected. Partners are considered independent, rational entities, with their own resources, performance objectives and internal decision mechanisms. Though, together with the distribution of decisions rights, the mechanism has to align responsibilities too.
- **Service level** The mechanism has to guarantee that the overall network can operate at a predefined, arbitrarily high service level.
- **Channel coordination** The mechanism has to facilitate that on the long run, local decisions lead to the emergence of coordinated channels.
- **Profit and risk sharing** Acknowledging the opportunities and risks of the markets of customized mass products, the mechanism should allow the division of the profit and risk between the manufacturer and the suppliers.
- **Aggregation** Information at several levels of aggregation has to be handled.
- **Adequacy** The mechanism should be able utilize (quasi-) standard production planning and scheduling related information available from the local planner and scheduler systems of the partners.
- **Rolling horizon planning** is necessary to accommodate on a regular basis to changes and disturbances.
- **Solution efficiency** Decisions are to be made under the pressure of time, typically in interactive settings. Hence models and appropriate solution techniques with reasonable response time are sought for.

The above generic requirements are unequivocally reasonable for each member of a supply network, let it be either in the role of the manufacturer or the supplier. Note that channel coordination on the long run requires the sharing of medium-term production plans and risk-related information about the future of products. Solution efficiency, on the other hand, calls for *symmetric* information between the manufacturer and the suppliers (otherwise the decisions models would be too complex). Hence, *cooperation* and *trust* between the partners is a prerequisite for meeting the above requirements. In relatively stable focal networks, partners are willing to cooperate and to share such private business information.

We defined the following steps for designing, setting up and running a cooperation mechanism with the above properties:

1. Disregarding the borders between network members—i.e., handling them as a virtual enterprise—one has to determine coordinated channels.
2. Assuming autonomous, self-interested network members, interaction rules—so-called *mechanisms*—have to be designed that provide network members both with sufficient information and incentives to cooperate. Mechanism design involves also the sharing of risks and benefits.
3. Implementation and integration of information sharing protocols, existing databases and decision support systems, as well as legal instruments.

4. Coordination of a supply channel

Planning tasks of enterprises are usually categorized according to their horizons into three levels: long term, medium term and short term [7, 14]. Consequently, a coordination model should cover all of these levels. The purchasing of raw materials can be planned on the long term, by exploiting economies of scale, forasmuch the bulk of them are standard materials and the demand of the end products can be aggregated. The production related decisions (plans, lot sizes) have to be made on medium term, by aligning the conflicting aims of flexibility and economic efficiency. On short term, the challenge is to organize smooth operation of the network, i.e., production should not stop anywhere due to material shortage. In this model we focus only on medium-term problems and assume, that raw material procurement is working effectively[1]

An acceptable coordination model should provide optimal or quasi-optimal trade-off between

1. inventory holding, obsolete inventory and setup cost on medium term, and
2. feasible, economical production and high service level on short term.

Our proposed model considers single components, discrete, finite (medium-term), rolling horizon component forecast and no inventory limits. We also assume uncapacitated production, and that throughput time of components (manufacturing plus shipment) fits into one time unit—a week in our case.

[1]We suggest also a protocol for short-term coordination, whose detailed elaboration and analysis is part of our future work.

Although the model is discrete, the proposed solution method is continuous, i.e., the lot size can cover arbitrary front fragment of the forecast horizon. The model does not assume the so-called Wagner – Whitin property, which says that within a time unit one can either satisfy demand from inventory or from production, but never from both. The partners are *risk neutral*: their objective is to minimize the expected average cost.

It is an exogenous property of the market, that the demand for a product can suddenly cease and this *run-out* produces obsolete inventory. It happens more frequently in case of the non-standardizable (customized) packaging materials, where *design changes* are also possible. This situation is different from the newsvendor problem, since we do not know anything about the length of the demand period. Run-out must be taken into account, because obsolete products cause significant loss in the network. All in all, we have identified two types of demand uncertainty:

1. quantity fluctuation, and
2. unexpected run-out.

To the best of our knowledge this latter one has not been studied yet, therefore it is a novelty in our model. To measure the loss in case of a run-out, the production cost of the obsolete inventory should be included into the total cost. The production cost may represent both material and labor costs and could be reduced with salvage value, etc.

We assume one-point-inventory between the manufacturer and the supplier. The manufacturer generates in each period a new *master plan* (MP), that determines on a medium-term horizon the output of finished goods in each time unit. The component forecast, which is derived from this MP, is the basic input for the supplier's lot sizing problem.

This forecast is uncertain, but must represent the best knowledge of the manufacturer. Concrete orders (*call-offs*) can be given only for one time unit ahead, therefore must be satisfied with *Just-In-Time delivery* from stock (with 100% service level—after similar considerations as for the "zero defects" principle of *Total Quality Management* [8]).

Since the component forecasts are derived from the MP, they do not provide valid statistical information (such as *standard deviation*), thus we cannot include it into our model. Nevertheless, the demand can neither be considered deterministic. Hence, we propose an easily implementable heuristic policy, which minimizes the expected average cost—either by the length of the expected consumption period or by the produced quantity. The model uses the *probability of run-out* that demand can cease in any time unit of the planning horizon with a specific probability.

This version of the model considers only one product. Thus there are no "speculative motives", i.e., it is always preferable to produce at a later period rather than producing earlier and holding stock. The model can be extended to more components, where setup cost depends on the set of manufactured products (changeover cost). In this case speculative motives can occur, which leads to a combinatorial optimization problem.

The basics of the model can be seen on Figure 2, whose parameters and variables are the following:

- n length of the horizon,
- F_i forecast for the ith week,
- h inventory holding cost per piece per time unit,
- c_s setup cost,
- c_p production cost per piece,
- p probability of run-out in an arbitrary time unit[2],
- x length of the period for which demand should be produced (decision variable).

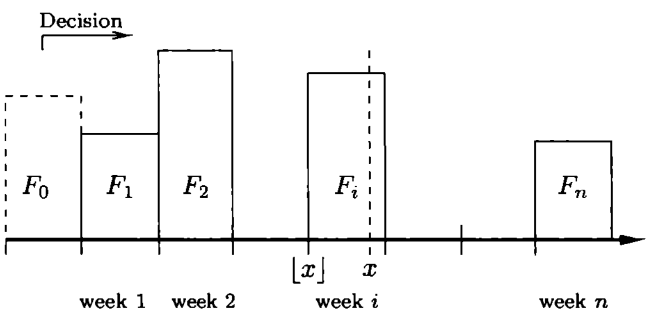


Figure 2. Planning horizon

Decision is made on week 0. In absence of speculative motives, at planning time the stock is below the safety stock level—practically considered to be zero. Since the lead time equals to the time unit, $x \geq 1$, (because later we will not have time to produce the next week's demand) and $F_1 > 0$ (no speculative motives). We also assume, that the call-off (F_0) can be satisfied from the stock (including safety stock).

We use some further notations: $S_k := \sum_{l=1}^{k} F_l$ is the accumulated forecast of the first k weeks and $q(x) := S_{i-1} + yF_i$ is the production quantity, where $i := \lfloor x \rfloor + 1$ and $y := \{x\}$ (here $\lfloor x \rfloor$ means the integer, and $\{x\}$ the fractional part of x). This expresses, that we produce all quantities of the first $(i-1)$

[2]For special cases, one can use a different p_i for every time unit.

weeks, and the y proportion of the ith week's demand. The expected decrease of the inventory level can be seen on Figure 3.

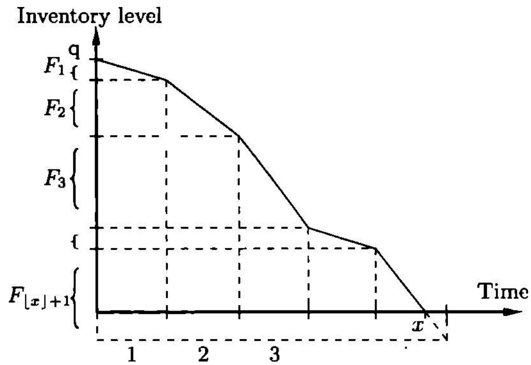


Figure 3. Expected inventory level

If we do not consider run-out, and assume linearly decreasing inventory within a time unit, then the expected storage cost in the first l ($l < i$) time unit is:

$$SC(l,x) = h \sum_{k=1}^{l} \left(q(x) - S_{k-1} - \frac{F_k}{2} \right), \tag{4.1}$$

where $q(x) - S_{k-1}$ is the opening inventory of the time unit k, and $\frac{F_k}{2}$ expresses the linearly consumption within the time unit. Hence, the expected storage cost with run-out can be expressed as:

$$\begin{aligned} SC(x) = & \sum_{k=1}^{i} \left(p(1-p)^{k-1} SC(k-1,x) \right) \\ & + (1-p)^i \left(SC(i-1,x) + h\frac{y^2 F_i}{2} \right) \end{aligned} \tag{4.2}$$

where $p(1-p)^{k-1}$ is the probability that the product runs out in the kth time unit, and with probability $(1-p)^i$ it is still saleable in the ith time unit. In this latter case, both the storage cost of the first $(i-1)$ time units and the storage cost of the remaining fraction[3] incur. The cost of the obsolete inventory can be computed in a similar manner:

$$OC(x) = c_p \sum_{k=1}^{i-1} \left(p(1-p)^{k-1} (q(x) - S_{k-1}) \right) + c_p p(1-p)^{i-1} y F_i. \tag{4.3}$$

[3]The quantity yF_i is consumed only during y time unit.

The model assumes, that if run-out happens at any time, the obsolete inventory is immediately thrown away—so no further storage cost must be paid. Thus we obtain piecewise continuously differentiable average cost functions $AC_x(x) = \frac{c_s+SC(x)+OC(x)}{x}$ and $AC_q(x) = \frac{c_s+SC(x)+OC(x)}{q(x)}$. They can be minimized by searching through the roots of the their derivative and the borders of the intervals.

Note that the above model is *hybrid*: continuous material flow (x, q) is controlled in discrete time unit, by discrete forecasts and actions. This property greatly reduces the computational complexity of the solution and makes the method practically applicable.

5. Cooperative planning in the network

The above channel coordination model gives the core for cooperative planning between the manufacturer and the supplier. Volatile markets call for flexible supply nets—hence suppliers provide not only components but also flexibility as part of their *service*. We suggest the following main rules for regulating this service (see also Figure 4):

The manufacturer is responsible for anticipating market demand, doing its local production planning and scheduling activities as well as for producing the end-products and delivering them to the customers. Planning and scheduling are performed on different horizons and with different time units (e.g., on weekly vs. daily basis). Specifically, the manufacturer:

- Generates master plans periodically, that determine its output on the medium term. Departing from the MP, it makes the F_i component forecasts (e.g., by using traditional Material Requirement Planning (MRP) methods).
- Schedules in detail its production on the short term. It generates component requests based on the schedules in form of daily call-offs towards the supplier.
- Provides and updates information about the probability of run-out.

The supplier's main responsibility is to satisfy the call-offs requested by the manufacturer. Consequently, it has to handle the one-point-inventory. In particular, the supplier:

- Acknowledges and guarantees the instant delivery of call-offs.
- Maintains the inventory: in each time unit it determines whether to produce or not to produce, as well as determines the lot size.
- Plans and schedules its own production according to its own objectives and additional demand.

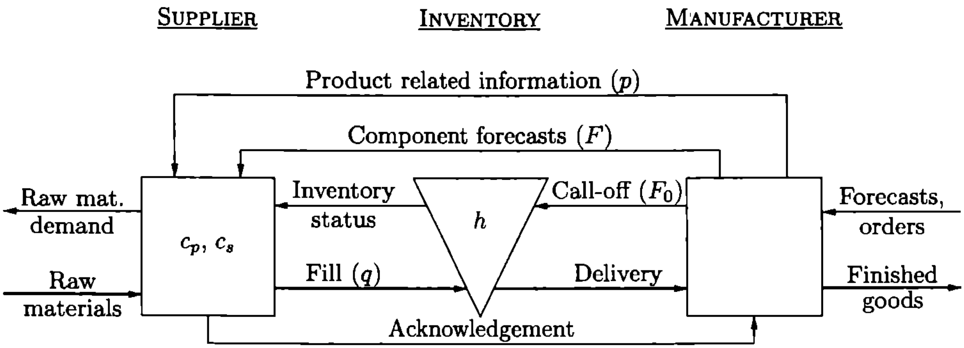


Figure 4. Information and material flow of cooperative planning

Bottom of the service is that production of end-products at the manufacturer must not be stalled by material shortage. Short-term production schedules may change frequently, and the total of call-offs for the actual planning period (F_0) may be more or less than the amount forecasted before. Hence, as part of the inventory, *safety stock* is needed to avoid short-term stock-outs of components. In fact, the safety stock de-couples the medium-term planning and short-term scheduling aspects of the cooperation problem. The safety stock level can be adjusted by at least three strategies:

1. Looking backward, based on the length of throughput time of components and the standard deviation of historical forecasts.
2. Looking backward, considering the forecasted demand of the next few time units.
3. Using the combination of the previous two methods.

The protocol and conditions of the above service are to be laid down by a contract that regulates the flow of information and material between the partners. As for the monetary terms, we suggest to introduce the *cost of flexibility* that has two components:

- The cost of operating on a risky market can be measured by the difference between the optimal expected average cost in risky and risk-free (i.e., where $p = 0$) markets (see also Section 6). This extra cost must be shared by the manufacturer and the supplier.
- Uncertainty in demand quantity can be measured by the variability of the series of component forecasts generated at subsequent planning times. As advancing in time, the effects of differences should be discounted.

Since a component forecast is created in every time unit, at the moment of the call-off we have an n dimensional, non-negative, real-valued *forecast history vector* for the actual week: $H_0 \in \left(\mathbb{R}_0^+\right)^n$, where $H_{0,j}$ $(j \in \{1,\ldots,n\})$ was made j weeks before. The difference between call-off and a forecasted quantity measures the fluctuation in the demand. An average fluctuation can be computed as a convex combination for the forecast history:

$$\sum_{j=1}^{n} \alpha_j \left|F_0 - H_{0,j}\right| \tag{5.1}$$

such that $\alpha_j \geq 0$ $(j \in \{1,\ldots,n\})$ and $\sum_{j=1}^{n} \alpha_j = 1$. It might be constant ($\alpha_j = \frac{1}{n}$), linearly decreasing discount ($\alpha_j = \frac{2}{n+1} - (j-1)\frac{2}{n^2+n}$), exponentially decreasing discount or even more complex functions. The proper approach may differ according to various product classes and needs further research.

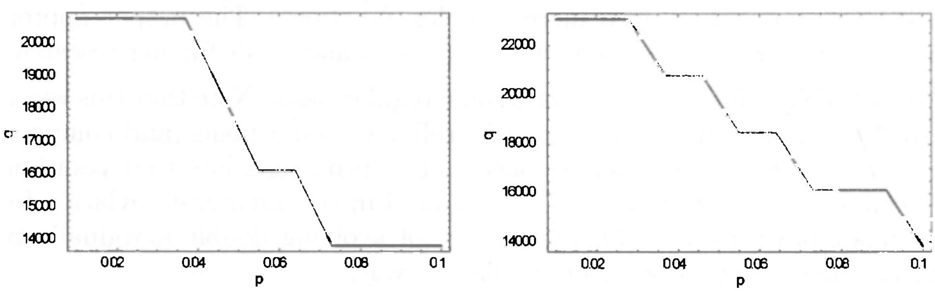
The cost of flexibility must be shared on a regular basis. Note that this way the manufacturer has an incentive to make reliable master plans (and component forecasts) while the supplier is concerned in producing lots that coordinate the channel. No partner should be interested in the unilateral deviation from this mode of operation. This is the key of avoiding double marginalization and running the network in a cost-efficient way.

6. Case study and simulation experiments

The coordination model has been developed together with industrial partners, who form a complete focal network. Some typical characteristics of the focal manufacturer in the studied network are as follows: it produces altogether several million units/week from a mix of thousands of products. The ratio of the customization follows the *80/20 Pareto-principle*: they give 80% of the product spectrum, but only 20% of the volume. The setup costs are significant: 10-20% of the total costs, depending on the lot sizes. Since customized products are consumed slower, their smaller lot sizes involve higher average setup costs. Service level requirements are extremely high: some retailers suddenly demand products in large quantities even within 24 hours, and if it is not fulfilled on time, they cancel the order (i.e., backorders are not possible). This causes not only lost sales, but also of goodwill. All in all, making larger lots and maintaining inventories is a must, but it incurs not only the usual inventory handling costs, but the risk of obsolete inventory.

Since many product differences are only due to packaging, furthermore it is just the design of packaging that changes most often, the coordination of production and packaging material supply is of crucial importance. Hence, we started the simulation experiments with coordinating various channels of packaging material supply. For solving the model and running simulations we have used the *Mathematica 5.2* system.

While forecasts and most of the parameters are easily accessible in the databases of the partners (so-called enterprise data warehouses), the probabilities of run-out are hard to estimate in general. Fortunately, on typical MP forecasts—where planned manufacturing of a product is sparse and involves large volumes—quantity is almost everywhere zero and the formula seems to be not too sensible to the uncertainty. According to our observations, optimal lot size will be a (decreasing) step function of the run-out probability (see Figure 5. for some representative results).



(a) (b)

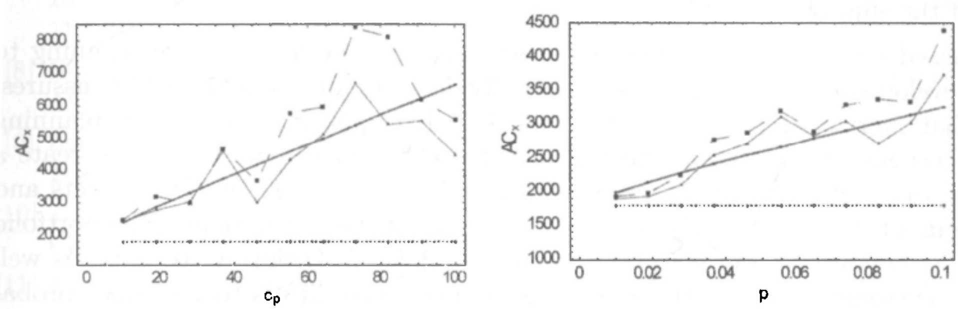
Figure 5. Example lot sizes, which minimize average costs (a) by the expected consumption period and (b) by quantity

We have computed lot sizes with both heuristics and some representative p values from the $[0.00005, 0.15]$ interval. They have been usually similar to each other and not far from those created by simple *rules-of-thumb* by human experts. Then we have simulated the run-outs and computed the average of accumulated costs. This second series of experiments have shown that our methods did not conflict with inventory handling rationale. So as to present the simulation results in a concise way, we have characterized products by two aspects: average forecasted volume and production frequency. After having classified products by deviation from the mean, we had altogether four clusters: high volume-high frequency (HVHF), high volume-low frequency (HVLF), low volume-high frequency (LVHF) and low volume-low frequency (LVLF) products. In Table 1. the minimum and maximum improvements on average costs can be seen in case of 1% probability of run-out as well as the cardinalities of clusters. The proposed lot sizes have effected lower average costs in 99.4% of the simulations (the table also contains the minimal negative value).

Table 1. Percental improvement on average costs

Improvement		on AC_x		on AC_q	
Category	#	min	max	min	max
HVHF	5	0	11	9	23
HVLF	2	2	4	12	18
LVHF	2	1	4	12	28
LVLF	21	-3	35	15	61

For the sake of generality, we have also tested the coordination model with large series of random forecasts and made sensitivity analysis by all its parameters. Two example diagrams can be seen on Figure 6, where each point represents a mean made on 1000 simulation runs on 1000 forecasts on a 12 weeks horizon.



(a) (b)

Figure 6. Change in average costs in function of (a) production cost and (b) probability of run-out

The constant dotted (blue) lines express, that on a risk-free market (i.e., $p = 0$) the average logistic cost would be independent from the production cost. The almost-linear thick (red) lines mean the expected average cost on risky markets. Thin (purple) curves, which oscillate around the thick (red) ones, are the costs that arose in simulations. If the probability of run-out had been disregarded, then the cost would have been usually higher, as indicated by the dashed (green) curve. The diagrams can be interpreted in the following way: the gap between the dotted (blue) and the thick (red) lines is the theoretical difference of the costs of operating in a risk-free and a risky market, while the gap between the thin (purple) and the dashed (green) curves expresses the cost of inconvenient lot sizing.

7. Conclusions and future work

Our model couples basic factors of supply chain performance like service level as well as production, setup, inventory and expected obsolete inventory costs. The proposed channel coordination model can be solved efficiently, and comparative simulation experiments on historic data sets have led to decreased expected average costs. At the same time, simulation has shown that the results are sensitive to some model parameters, in particular to the cost of setups, as well as to the probability of run-out. Controlling these costs parameter are the responsibilities of local planning and scheduling, just as the provision of component forecasts that are directly generated from the MP of the manufacturer. Certainly, adjustment of the main model parameters needs an *adaptive* control approach.

Operating on a market of customized mass products, inventory—and even obsolete inventory—is inevitable, but with coordination and cooperation their amount and incurred costs can be decreased without violating the service level of the supply network.

Based on our coordination model and solution method, we are planning to develop cooperation mechanisms to divide costs and benefits, which assures, that every enterprise (or decision maker) is responsible for its own planning decisions. Since there is no "one-size-fits-all" solution, we intend to create a *portfolio* of cooperation mechanisms. It is essential to classify products and components, e.g., by risk levels or by inter-enterprise relations. The portfolio may contain several standard protocols (Make-To-Order, VMI, etc.) as well as customized ones. An interesting further possibility is to introduce probability of run-out into the discrete Wagner – Whitin model and compare it with the approach presented in this paper. Finally, we are going to validate the suggested cooperative planning mechanism by multiagent simulation tailored to the actual focal supply network of our industrial partners [6].

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