InCoCo-S

Innovation, Coordination and Collaboration
in Service Driven Manufacturing Supply Chains

Deliverable Nr. 2.5

Recommendation for a Collaborative Planning Interface for Service SC at the Master Planning Level of an APS

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Abbreviations

3PL	Third Party Logistics
APO	Advanced Planning and Optimization
APS	Advanced Planning System
ASN	Advanced Shipping Notification
BOM	Bill-of-Material
BL	Base-Level
BW	Business Warehouse
CLSP	Capacitated Lot-Sizing Problem
CPFR	Collaborative Planning, Forecasting and Replenishment
CIF	Core Interface
CP	Collaborative Planning
CSNS	Computer Supported Negotiation Scheme
EDI	Electronic Data Interchange
EOQ	Economic Order Quantity
ERP	Enterprise Resource Planning
fos	Fairness of a solution
ICH	Inventory Collaboration Hub
JELS	Joint Economic Lot Size
KPI	Key Performance Indicator
LP	Linear Program
MILP	Mixed Integer Linear Program
MINLP	Mixed Integer Non-Linear Programming
MLCLSP	Multi-Level Capacitated Lot-Sizing Problem
MRP	Material Requirements Planning
OEM	Original Equipment Manufacturer
PP / DS	Production Planning, Detailed Scheduling
SC	Supply Chain
SCM	Supply Chain Management
SNP	Supply Network Planning
RCPSP	Resource-Constrained Project Scheduling Problem
RFC	Remote Function Call
TL	Top-Level
TP / VS	Transport Planning / Vehicle Scheduling
TSP	Transportation Service Provider
VICS	Voluntary Interindustry Commerce Standards
VMI	Vendor Managed Inventory
XI	eXchange Infrastructure

XML	Extensible Markup Language

List of Symbols

(j,k)	BOM-link from product j to k
α_t	Capacity utilisation rate
Δ_r	Value deviation of a system feasible solution from its facility-best solution
λ	Parameter
λ^r_{jkt}	Lagrange parameter (conflict pricing)
π	Fair solution point
$\pi_b(q)$	Profit function of the buyer
$\pi_e^{\min}$	Minimum profit requirements
$\pi_s(q)$	Profit function of the supplier
Φ	Share of the revenue
a_{mj}	Capacity consumption to produce one item of operation j at resource m
$a^{TL/BL}$	Decision
$A^{TL/BL}$	Decision space
A_i^g	Greedy acceptance criterion
$AF(IN)$	Anticipation function
b_{jt}	Large number, not limiting feasible production quantities of product j in period t
c	Element i.e. contract out of contract space C
c_0	Marginal production costs
$c^{\min}$	Minimum cost of supplier
ci	Anticipated average cost increase
co_m	Overtime cost at resource m
C	Contract space
$C^{TL/BL}$	Decision criteria
C_b	Costs of buyer (sum of holding costs and setup costs)
c_{mt}	Available capacity of resource m in period t
d	Demand per unit time
$d_j^{\max}$	Maximum deviation in supply units of j
d_{jt}	(External) demand for product j in period t
$ddem_{kt}$	Dependent demand for product j in period t
D	Market demand
D^+_{jt} / D^-_{jt}	Supply shift to next/previous period of j in t

E	Set of companies
f	Density function
f_l	Utility function of agent l
f_a^t	Cost function for activity a in bucket t
f_s^t	Cost function for stock level in location s in bucket t
F	Distribution function
h_b	Holding costs of the buyer
$\underline{h_b}$	Lower bound of the buyers holding costs
$\overline{h_b}$	Upper bound of the buyers holding costs
$h_b^{\max}$	Maximal amount of holding costs of buyer for which trade is profitable
h_j	Holding cost for one unit of product j in one period
i	Supply chain tier
$I(q)$	Salvage
I_{jt}	Inventory of item j at the end of period t
IN	Instruction
j	Operation
J	Set of operations
J_r	Set of products produced in facility r
JS	Set of supplied items
k_{ar}^t	Consumption function of activity a of resource r in bucket t
k_{as}^t	Consumption function of activity a of stock in spatial location s in bucket t
k_b	Order costs of the buyer
k_s	Order costs of the supplier
K	Penalty cost parameter (per unit)
K_r^t	Maximum Capacity of resource r in bucket t
K_s^t	Maximum stock of commodities s in spatial locations in bucket t
l	Agent l
L	Set of BOM-links
m	Resource
M	Set of resources
O_{mt}	Amount of overtime at resource m in period t
p	Price
$parx_{jkt}$	Production target associated with the BOM-link (j,k) in period t

P	Compensation payment
q	Order quantity
q_b^*	Optimal order quantity of the buyer
q_{SC}^*	Optimal order quantity for the supply chain
r	Facility
r^j	Facility where product j is produced
r_{jk}	Unit requirement of operation j by successor operation k [ME]
R	Set of facilities
s_t	Delivery quantity in period t
sc_b	Setup costs of the buyer
sc_j	Setup cost for product j
sc_s	Setup costs of the supplier
$S(q)$	Sold quantity to the external market
S_j	Set of direct successor operations of operation *j*
t	Period
tc^+	Reservation profit
tr_j	Setup time for product j
T	Set of periods
v	Salvage value
V_a^t	Level of abstract activity a in bucket t
V_s^t	Stock level of commodity s in spatial location in bucket t
w	Wholesale price
xo_{jt}	Quantity of product *j* in period *t* ordered by the buyer
$xo_{jt}^{cum.\min}$	Minimum cumulated supply quantity of *j*, in periods 1 through *t*
$xo_{jt}^{cum.\max}$	Maximum cumulated supply quantity of *j*, in periods 1 through *t*
X_{jt}	Production quantity of operation j in period t
X_{jkt}^r	production output (input) from (to) facility r associated with the BOM link (j,k) in period t
XO_{jt}	Order quantity of product *j* in period *t*
Y_{jt}	Setup variable

Executive Summary

Service providers and their customers are facing tremendous challenges in synchronizing their business processes and facilitating collaboration. In addition to the integration on a process level, the alignment of planned order quantities of goods and services, computed by Advanced Planning Systems is of crucial importance. From an *inter-organizational* perspective, planned production, distribution and service provision can be suboptimal coordinated, although plans have been optimized within each *intra-organizational* domain. Current approaches to integrate partners at the boundaries of a planning domain primary aim at the effective and efficient communication of demand and order commitment across the supply chain to ease administration, to allow lower safety-stock levels and to avoid out-of-stock situations. Nonetheless, there is no support of a supply-chain wide generation of optimal order quantities, since partners are closing their private information. With work package 7, InCoCo-S aims at the development of a prototype for enabling such kind of *collaborative planning*. In general, it is possible to decrease supply chain wide costs related to uncoordinated plans by allowing the supply chain partners to propose deviations from suboptimal order-quantities and times in a kind of negotiation process, without the need to disclose private data. In this regard, innovative academic approaches seem very promising but need further to be developed in more life-like settings. This deliverable provides an overview about these new concepts, evaluating and recommending those of substantial practical importance. In addition, an introduction to Advanced Planning Systems and related collaborative planning functionality currently implemented by software providers is given.

1 Introduction

The optimal planning and controlling of a supply chain (SC) can be hard tasks. There exist various software solutions providing a rich set of tools to support the management in this difficult job. So-called Enterprise Resource Planning (ERP) systems cover a broad range of functionality, such as material requirements planning, accounting, controlling, human resources, research and development etc. These systems are transactional-based and support all relevant business processes, seamlessly integrated across the SC to enable corporate-wide resource planning based upon a central data warehouse. One of the goals of InCoCo-S is to develop a reference model to capture the cross-functional dependencies between the manufacturing and service sector, along with specially suited performance indicators, mechanisms to price the value added by a service or coordination mechanisms for an optimal alignment on the process level.

In addition to process alignment and efficiency measurement related problems, however, complex material and resource related constraints in production, procurement and distribution lead to mathematical planning problems that are beyond the capabilities of an ERP system. These problems are addressing decisions such as, for instance the optimal sequence of orders to be produced on different machines having limited capacities with respect to material availability and customer demand. Other examples are the optimal location of distribution and production centres to reach a set of target customers or the optimal route to deliver items from a distribution centre to several retailers.

To solve such kind of problems, Advanced Planning Systems (APS) have been intensively researched by academia in the recent years and are continuously developed and improved by software providers such as SAP or Oracle. APS are based upon mathematical problem formulations including proper definitions of decision variables, constraints and objective functions and efficient approaches for solving such problems, starting with classic procedures from Operations Research, as for example the Simplex Algorithm for solving Linear Programs, over Constraint Programming to recent meta-heuristics approaches such as Evolutionary Algorithms.

Usually APS require a lot of input data describing all the complex relationships, as for example the bill-of-material (BOM) for every product, the structure of the company, available capacity, costs assigned to resource usage etc. Since this information is highly sensitive, Advanced Planning is only applied within an *intra-organizationa*l context today. It is hardly possible to optimally plan production and resource availability by setting up an *inter-organizational* model as SC partners are closing their data.

Thus, it is current practice to sequentially plan the production and distribution along the inter-organizational supply chain. For example, the original equipment manufacturer (OEM) is planning first, generating demand for his service providers, supplier of goods or subcontracting partners, who are again in turn optimizing locally, generating demand for their subsequent partners and so on. This approach, however, can leads to high redundant costs. For instance, a service provider shall provide preventive maintenance to all his customers in the same period, which causes costly overtime of a supplier of goods has additional setup times that would not be necessary if he could deliver the demanded item one day later or a carrier has high transportation costs as he has to move empty trucks.

In many cases, at the side of the subsequent partners, these redundant costs can be decreased drastically if the order quantities and times only changed slightly, whereas the leaders of the supply chain might not necessarily be aware of such circumstances. Of course, the leaders of the SC might encounter additional costs if the order cycle deviates from their optimal plan computed. However, if the sum of cost-savings exceeds the sum of cost-increases, the whole SC has gained a competitive advantage (partners with cost increases need to be compensated accordingly). Thus, by balancing costs from an inter-organizational perspective the situation of the supply chain as a whole can be improved, which is of substantial practical importance in today’s world of competitive global markets.

However, this form of coordination is a challenging task. On the one hand, as already mentioned, partners hide their private data. On the other hand, through local optimization, decision variables are already traded-off within each decision domain, i.e. it is hard to find proposals for order quantities that lead to win-win situations.

Within InCoCo-S, this deliverable is directly interconnected with the outcomes of deliverables 2.1 and 2.3. In these deliverables, requirements for coordination of service supply chains in practice have been derived.

Deliverable 2.1 has identified the state of the art and the main issues regarding coordination and collaboration in service supply chains. Here, it has been stated that manufacturer and service providers do not use sufficiently coordination mechanisms because for a lot of practical situations, suitable coordination mechanisms do not exist. Deliverable 2.3 analysed this issues further by analysing AS-IS and TO-BE scenarios of four business cases and deriving requirements for collaboration and coordination. One central result of this analysis is the evidence of a present lack of coordination mechanisms and IT solutions to support collaborative processes.

As a first step for developing suitable coordination mechanisms deliverable 2.5 examines software solutions and theoretical work in order to identify the existing ideas for coordination.

Another interface of this deliverable is work package 7 whose goal is to develop a coordination mechanism that effectively supports this kind of mutual balancing of plans. The basic idea is to use existing APS to enable the planner to issue, receive and evaluate proposals for alternative order quantities. This way the different parties of a SC would be provided with a set of tools to start a negotiation process in order to decreases SC-wide costs.

In addition to the promising coordination on a process level developed in other work packages, this *coordination on a planning level* has the potential of a highly effective synchronization of planning results, equally encompassing manufactures and service providers with the ultimate goal to increase the competitiveness of the whole SC.

This deliverable is mainly concerned with a requirement analysis for such an approach, evaluating and recommending coordination mechanisms for collaborative planning based upon existing literature and already available coordination mechanisms included in today’s software solutions.

In Chapter 2, a precise definition of coordination and collaborative planning will be given. Chapter 3 provides an introduction to the capabilities of Advanced Planning Systems. Moreover, existing approaches to include partners at the boundary of a decision domain into the planning procedure will presented and evaluated. Proposals from literature are comprehensively evaluated and presented in a structured way in Chapter 4. As a conclusion, in Chapter 5, based on the requirements derived in Chapter 3, the most promising collaboration schemes presented in literature are identified.

2 Definition of Coordination and Collaborative Planning

To have a consistent idea of the terms “coordination” and “collaborative planning”, the most important significations will be elaborated for “coordination”. For “collaborative planning”, the differences to the already existing concept “Collaborative Planning, Forecasting and Replenishment” (CPFR) will be clarified.

According to Horváth, the term “coordination” is one of the most “dazzling” ones in business economics (Horváth 2001). In the field of organization theory coordination plays a big role. There, coordination and division of labour are seen as the two basic issues (Horváth 2001). The need for coordination is the direct consequence of division of labour which leads to different single activities with interdependencies among them (Laux and Liermann 1993). Therefore, coordination can be seen as a task complimentary to division of labour: *the re-adjustment of these single activities in order to reach superordinate aim*s (see e.g. Frese 1975). The essence of this definition is mostly accepted in business economics literature (Horváth 2001, Kieser and Walgenbach 2004), although often more application-oriented definitions are given, too, as e.g. in (Horngren, Foster and Datar, (or similar Bhatnagar 1993): “Coordination is the meshing and balancing of all factors of production or service and of all the departments and business functions so that the company can meet its objectives.”

In principle, this definition of coordination can also be applied within the field of Supply Chain Management (SCM), which is concerned with “integrating organizational units along a supply chain and coordinating material, information and financial flows […]” (Stadtler 2005). When we go more into detail, however, and look at typical operational problems which are important for the collaborative planning concepts described below, we need a more precise definition of coordination than the ones provided above.

This can be seen by means of the following example: One supply chain (SC) partner (buyer) orders a product of his SC partner (supplier). Depending on the order cycle both partners face different costs. Furthermore, we assume that both the individually optimal order cycles and the SC optimal order cycle are of a different magnitude. In the “default solution”, each partner is optimizing his own margins without consideration of the margin of the SC. As a consequence of this, the individually optimal actions (here: the order cycle) of the more powerful SC partner are implemented. This phenomenon that usually leads to inefficient solutions is called *double marginalization* (Spengler 1950).

Now, under which circumstances is this SC said to be coordinated? There are various possibilities and each of them is supported by some authors from literature. According to the contract literature, a contract coordinates the SC if (and only if) “the set of supply chain optimal actions is a Nash equilibrium, i.e., no firm has a profitable unilateral deviation from the set of supply chain optimal actions” (Cachon 2003). For our example, that would mean that coordination is established only if the SC optimal order cycle has been implemented. A “softer” definition of coordination would be to call the SC coordinated if the implemented actions lead to an improvement for the SC compared to the default solution. Such a definition is implicitly supported by Corbett and de Groote, who compare their (suboptimal) coordination mechanism with the default solution (no coordination) (Corbett and de Groote 2000). The third alternative, finally, is to call even the default situation coordinated, which seems to be favoured by Schneeweiss (“worst-case” coordination, Schneeweiss 2003).

In the following we adopt the alternative mentioned second. We call a *SC coordinated if the situation for the SC as a whole has been improved with respect to a default situation, which suffers from the problem of double marginalization*.

The reasoning for this is that in realistic situations the optimal SC actions required for the alternative mentioned first can be implemented rather seldom. The consequence of this is, that approaches which only lead to an improvement (that can be a near-optimal solution) would have to be called non-coordinating, which seems misleading. Apart from that, in the literature of organization theory and controlling usually no emphasis is placed on the question if the readjustment of the single actions does lead to a global optimum or not. Therefore, we refer to the case that SC optimal actions have been implemented, as a special case of coordination ("optimal coordination"). Also the third alternative (the default solution is already coordinated) seems to be less appropriate in our context because usually coordination is associated with an improvement of a given situation. An improvement with this alternative, however, cannot be achieved with respect to our "default situation", but only with respect to a fictitious situation in which the supplier does not match the demand of the buyer without necessity.

After discussing the issue of coordination itself we will turn to the question how coordination at the master planning level of a SC can be established. In the remainder of this paper we will examine various ideas which can be subsumed under the topic "*Collaborative Planning"*.

The term "Collaborative Planning" is generally known as a part of the business practice "Collaborative Planning, Forecasting and Replenishment". As a formalized process, CPFR has been worked out by the standardization committee VICS (Voluntary Interindustry Commerce Standards) and implemented within over 300 companies (VICS 2004). The CPFR process model consists of eight planning tasks, which can be subsumed under four main activities: strategy & planning, demand & supply management, execution and analysis (VICS 2004). "Planning", in this context, does not refer to the alignment of operational plans, but to the identification and communication of events which may affect demand, such as promotional activities or product introductions.

Whereas in the original model collaboration is restricted to mere information exchange, some other authors extend the scope of CPFR to joint decision-making of the partners involved. Danese mentions a concept called "limited CPFR collaboration", where plans are synchronized jointly by the partners (e.g. replenishment plans between a central company and a distribution centre) and exceptions are managed (Danese 2005). Akkermans et al. describe a business process called collaborative planning, where companies "jointly take decisions regarding production and shipments for a large part of their collective supply chains" (Akkermans et. al 2004). Ragunathan extends the scope of CPFR (called CFAR in his paper) explicitly to the integration of production scheduling (Ragunathan 1999). A similar notion of collaboration can be found within other areas. E.g. for Bruner, one main element of collaboration is the joint decision on goals that cannot be reached singly by the partners (see Bruner 1991, cited by Krajewska and Kopfer 2006).

The task which has to be tackled by collaborative planning in this study is coordination of the master plans of SC partners. Here, mere exchange of information surely can bring improvements. In order to achieve a more effective coordination, however, changes in the supply plans have to be made, which have to be agreed on by all partners. In line with the above-mentioned authors we will consider the alignment of the plans as a key feature of collaborative planning. To sum up, we define *collaborative planning as a concept for the alignment of plans of (organizational independent) SC partners with the aim of achieving coordination.*

Finally it is important to note, that coordination in a supply chain cannot be reached by means other than collaboration. In some approaches for coordination of an (intra-organizational) SC it is proposed that a central instance sets incentives which coordinate the actions of the decentralized units (e.g. (Lee and Whang 1999), Pfeiffer (1999)). For SC consisting of legally separated and independent entities, however, coordination by unilateral targets, which in principle could worsen the situation of some SC partners compared to their default situation, does not seems possible.

3 State of the art in Collaborative Planning Modules

Complex planning tasks are more and more given to the responsibility of Advanced Planning Systems. These systems optimize product and resource availability while respecting capacity and material availability constraints.

Today, only the intra-organizational supply chain, i.e. the planning domain under the control of one legal entity is area of true optimization in the sense of operations research. Nonetheless, there are various efforts to integrate partners at the boundaries of a domain, e.g. suppliers, customers or subcontracting partners into the planning procedure to provide a seamless synchronization of global supply chain activities.

For this purpose, Advanced Planning Software providers, such as SAP or Oracle offer, next to their APS solutions, so-called collaborative planning modules. Primary goal of these modules is to simplify and enhance the communication of purchase orders, commits and forecasts of future demand between the different partners within a supply chain. Practical experience has shown that these approaches are able to significantly reduce costs by automating administrative processes, decreasing safety stock and avoiding down-time caused by material shortage. These modules are often denoted to support collaborative “planning” and to have “optimizing capabilities” to leverage integration as they are facilitating the communication.

Nonetheless, optimization in a close sense means to optimally trade-off different cost-factors of production while respecting given constraints, such as maximal capacity and material availability. This kind of (advanced) collaborative planning is – from an inter-organizational perspective - not supported by the solutions available on the market. Practically, collaborative planning in the sense of a central decision making unit is hardly possible due to the closure of sensitive information between the collaborating partners. In practice, the leader of a supply chain plans their production first – generating demand for their followers, i.e. suppliers of goods or services. However, it is very likely that this chain of sequential local optimization from partner to partner leads to high redundant costs that can be avoided by balancing, i.e. coordinating local plans from a global perspective. Innovative academic concepts try to solve this dilemma of global optimization while closing sensitive information by introducing a coordination process as will be explained in Chapter 4.

Here, the state of the art of existing collaborative “planning” approaches in practice shall be described. In addition, an introduction to Advanced Planning Systems will be provided.

3.1 Introduction to Advanced Planning Systems

The aim of Advanced Planning Systems is to plan the product and resource availability while respecting customers demand, available capacities and material availability constraints. For this purpose trade-offs in the objective definition and the tight temporal and capacitive constraints encountered in real world domains have to be considered. Advanced Planning Systems aim at the integral planning of the supply chain by using true optimization techniques. This requires proper definitions of alternatives, objectives and constraints for the various planning problems. Note that the traditional material requirements planning which is implemented in nearly all ERP systems does not have any of the above properties: It is restricted to the production and procurement area, does not optimize and in most cases not even consider an objective function, and it is a successive planning system, see Fleischmann et al. (2005).

To cope with the model’s complexity, the planning problem is typically split up into several, hierarchical levels that are solved sequentially by APS modules. On a long-term planning level, strategic decisions are encountered such as the planning of locations for production and distribution centres. On a mid-term level, cost-optimal plans are derived in a master planning procedure. Here, the structure of the supply network is regarded as constraint that can not be changed and it is tried to optimally load production resources and efficiently use available distribution channels, by taking demand forecasts as input.

As it will be further explained, master plans rely on aggregated data. These plans have to be disaggregated to detailed production / scheduling instructions and transportation plans. On the short-term level the focus is on finding feasible plans that fulfil the master instructions.

For each of these structural clusters, the planning horizon is different. For example the planning horizon for scheduling is usually shorter than within the master planning context. Commonly, a rolling horizon approach is followed at every level. That is, while having a long planning horizon to capture seasonal fluctuations, planning results are only executed at a much shorter time-period, the so-called frozen horizon. After a certain period, plans are re-optimized to include updated demand forecasts, while the results of the previous frozen horizon and the instructions of the superior decision level have to be respected.

Figure 1 shows the several software modules belonging to an Advanced Planning System in the so-called supply chain planning matrix. The modules are arranged according to a temporal and a functional dimension. Strategic Network Planning, Master Planning, Production Planning and Scheduling and Distribution and Transport Planning are optimization procedures in the true sense, i.e. an objective function has to be minimized or at least a feasible solution has to be found.

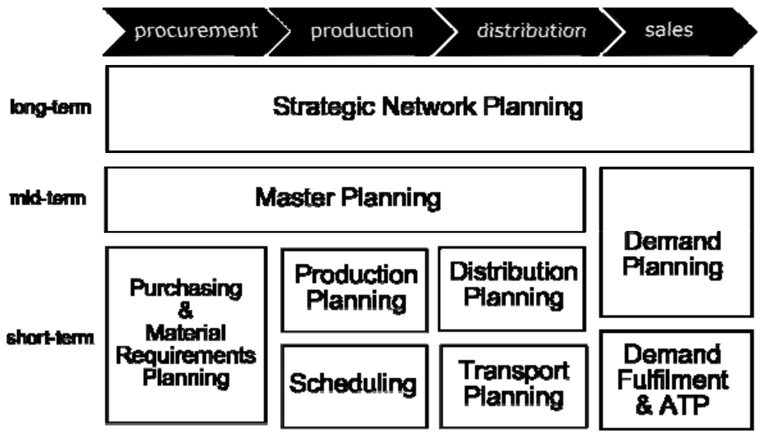

Figure 1: Software modules covering the SCP-Matrix. Taken Meyr et al: (2005), p. 109.

3.1.1 Master Planning

According to Rhode and Wagner, (2005) p. 159, Master Planning *"supports mid-term decisions on the efficient utilization of production, transportation and supply capacities, seasonal stock, as well as an balancing of supply and demand.[...] The results of Master Planning are targets / instructions for Production Planning and Scheduling, Distribution and Transport Planning as well as Purchasing and Material Requirements Planning".* The aim of Master Planning is to synchronize the flow of material by optimizing an aggregated model in order to link several short-term sub-planning domains. A master planning problem is defined at the mid-term planning level. The planning horizon, i.e. the time for which master plans shall be calculated is divided into several periods, so-called buckets. It is one of the major characteristics of master planning that not the detailed time of production activities, input requirements and output products is of interest. Instead it is searched for cost-optimal *quantities* of produced, transported, procured and delivered items for every bucket.

It is worth stressing that deterministic models serve for Master Planning. Thus, this modelling approach is only suitable for production processes with low input and output variance. This precondition is important when regarding the modelling of services. While deterministic services, such as preventive maintenance can be modelled at the Master Planning Level, the modelling of a service subsequent of a stochastic event, such as repairing a machine after an unforeseen breakdown is not supported by Master Planning (this is also true for other modules of an APS).

Decision Situation

The decision situation for Master Planning differs depending on the problem's characteristic. As a commonality, the objective of Master Planning is always to retrieve an optimal plan by balancing costs of several activities and inventories while respecting related capacities, material availability constraints and the goal of supply-demand matching, i.e. customer satisfaction.

Given the customer demand, the following options are evaluated if bottlenecks on production resources occur; see Rhode and Wagner (2005), p. 160 et seq.

- Produce in earlier periods while increasing seasonal stocks.
- Produce at alternative sites with higher production and / or transport costs.
- Produce in alternative production modes with higher production costs.
- Buy products from a vendor with higher costs than your own manufacturing costs.
- Work overtime to fulfil the given demand with increased production costs and possible additional fixed costs.

For transportation lines, the following alternatives have to be taken into consideration:

- Produce and ship earlier while increasing seasonal stock in a distribution centre.
- Distribute products using alternative transportation modes with different capacities and costs.
- Deliver to customers from another distribution centre.

Model Building

Master Planning problems are typically described as a mixed integer linear program (MILP). In this section we will give an introduction to linear programs (LP) and MILP. Furthermore we will explain how aggregation can decrease complexity and which possibilities exist to model real-world constraints.

With the development of the Simplex Algorithm by Dantzig in 1947, Linear Programs started to become one of the most used mathematical tools in optimization. Linear Programs can describe a huge variety of deterministic optimization problems while the computation of the solution is of polynomial order[1]. The different algorithms for computing the cost-optimal so-

[1] Algorithms, for which the time needed to find a solution is a polynomial function of the size of the input data are regarded as efficient. In some pathological cases the simplex is of exponential order. However, interior point methods to solve LPs have been proved to be always of polynomial order. The interested reader is referred to Neumann and Morlock (2002) p. 190 for a further discussion.

lution will not be covered in this paper. Here, only a classification of problems and their key characteristics shall be given.

In general, a mathematical program is an optimization problem that can be described as:

$$\text{min or max} \quad f\left(x_1,\ldots,x_n\right)$$

$$\text{s.t.} \quad g_i\left(x_1,\ldots,x_n\right) \left\{ \begin{matrix} \le \\ = \\ \ge \end{matrix} \right\} b_i \qquad i=1,\ldots,m \quad ,$$

whereas f and g_1 … g_m are functions of the decision variables $x_1 \ldots x_n$. The function f is denoted as objective function and is to be minimized or maximized. The m functions g_1 … g_m and the right-hand sides b_1 … b_m define the constraints. A point in the search space is called feasible if it fulfils all the constraints, otherwise it is called infeasible. For infeasible problems no solution exists.

A (continuous) linear program is a mathematical program, where all the decision variables are continuous, where there is single linear objective function and the constraints are only defined by linear equations and inequalities.

If some of the decision variables are discrete (the rest of the definition stays the same) the problem becomes a mixed integer linear program (MILP). It should be mentioned that MILPs are usually harder to solve, since a polynomial run-time can not be guaranteed. This is caused by the combinatorial dimension introduced by integer variables, which usually have a huge influence on the problem's complexity and run time. In general, finding only a feasible solution in a considerable amount of time can already be impossible for MILPs, as these problems are commonly NP-complete[2].

For Master Planning problems the objective function usually describes the costs for a given vector of decision variables and has to be minimized. A decision variable is primary related to the quantitative output of an activity, for example the number of items of a certain product produced within a certain bucket on a distinct machine, whereas the constraints are related to the availability of input material and production capacity.

There are several possibilities for discrete decision variables:

1. The output of an activity is integer, e.g. products can only be produced, procured or distributed in batches.
2. The cost-function of an (continuous or discrete) activity is piecewise linear, as for example for setup costs.
3. The problem incorporates zero-one decisions or logical conditions.

In the second case, there exist several techniques, such as the big-M method to convert the problem to a MILP by introducing additional discrete variables. These techniques will not be discussed in this report.

[2] In computational complexity theory, NP ("Non-deterministic Polynomial time") is the set of decision problems solvable in polynomial time on a non-deterministic Turing machine (which is a theoretic computer model). Until now, for non NP-complete problem an algorithm has been found to decide the problem in polynomial time on a deterministic machine (as a real-world computer is), which is regarded as efficient.

Restrictions, for example given by maximum capacities of machines and limiting inventory sizes are defined by linear constraints. However, there also exists the possibility to model real-world constraints as soft constraints by introducing additional continuous or discrete decision variables. Soft constraints have no influence on the feasible region of a problem but on the objective function.

As an example, consider a worker of a production unit. Normally, such a worker is regarded as a resource that can be consumed at no costs, since a (fixed) wage is paid to him independent of the actual work done. Hence, the costs of the activities of the worker must not be incorporated as linear coefficient in the objective function (in contrast to full costing approaches in economics)[3]. Beyond this free available capacity there usually exists another mode of resource consumption that comes with a capacity increase entailed by additional costs. In case of the worker this mode is known as overtime: if work-time exceeds the regular time, additional wages need to be paid. Mathematically, the regular work time is a soft constraint: It is not the ultimate upper bound of a available capacity but can be exceeded for additional penalty costs. Nonetheless, there is still an ultimate upper bound of the work time (at least a maximum of 24 h / day) that has to be modelled as a hard constraint, otherwise planning results will become infeasible. Also for other resources like machines, transportation capacity, etc. there usually exist several capacity consumption modes, for instance by subcontracting additional resources if the own capacities are reached. The example of the worker also shows that soft constraints can incorporate discrete decisions, e.g. shall there be an extra-shift or not?

Alternatively, penalty costs are often used to explicitly influence the optimal solution. For example, lateness in delivery is regarded as something highly undesirable but can not always be quantified by real-world accountancy costs. However, if timeliness is modelled as hard constraint, the problem might be infeasible. One approach in practice to solve this dilemma is to principally allow lateness but to penalize it with severe hypothetical costs[4].

To reduce the models' complexity as well as to decrease the influence of uncertain mid-term forecasts, data is commonly aggregated at the master planning level. The aggregation of data is the grouping of, for example, production capacities, transport capacities, inventory capacities, purchasing bounds and demand data. Similar products and resources are consolidated to product and resource groups.

In addition, time-buckets can be grouped to larger buckets to further decrease the number of decision variables. Typically, the degree of aggregation gets larger with increasing time distance as shown in Figure 2. The reason is that data in the very future comes with a larger forecast error, such that a larger aggregation does not lead to a significant loss of planning quality.

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[3] On the other hand, an explicit modelling of free capacities as additional cost in order to achieve a higher load of the worker should be avoided, too. This approach can lead to worse planning results, since it might decrease the load of bottleneck resources.

[4] In this regard it should be stressed that, although there might not be an equivalent to real-world costs, the penalty costs must be in relation to real-world accountancy costs. By specifying penalty costs, the planner implicitly defines a trade-off, e.g. how much overtime he is willing to sacrifice for timeliness causing real-world setup-, inventory-, overtime costs and so on.? Hence, penalty costs must be adjusted very carefully to equilibrate the optimal solution to satisfy the customers and the companies needs.

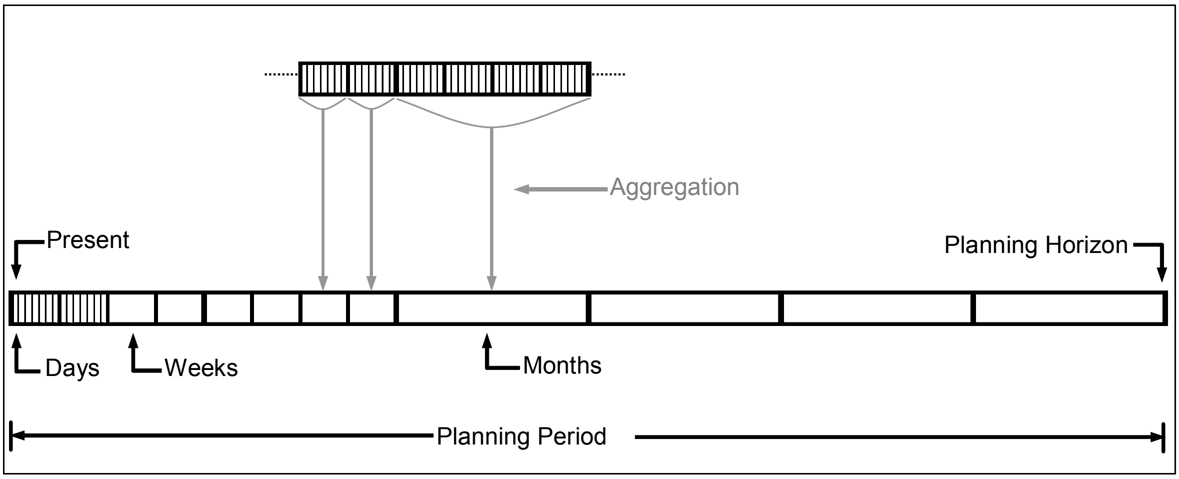

Figure 2: Typical distribution of buckets, cf. Sander (1998)

For a more detailed description confer to Rhode and Wagner, (2005), p. 170-172.

As already mentioned, discrete decision variables have a major influence on the models complexity and solution time. Therefore, the planner should carefully decide which discrete real-world decisions to model as such. For instance, discrete real-world production quantities usually come in huge numbers, such that the failure of a formulation as continuous variable is negligible small.

On the other hand, there exist decisions that entail a large non-continuous decrease or increase of costs. For example, increasing the capacity might require the introduction of an additional shift, regardless of how much overtime is actually needed. Modelling overtime as linear cost factor might lead to plans with large hidden costs if executed, since the problems fundamental properties are not considered in an adequate manner. In many cases, the planner has to trade-off accuracy of the solution that can be computed in available time against accuracy of modelling the complexity of real-world settings.

Modelling Approach

According to Rhode and Wagner (2005), p. 167, Master Planning models are generally set up using a top-down approach as shown in Figure 3.

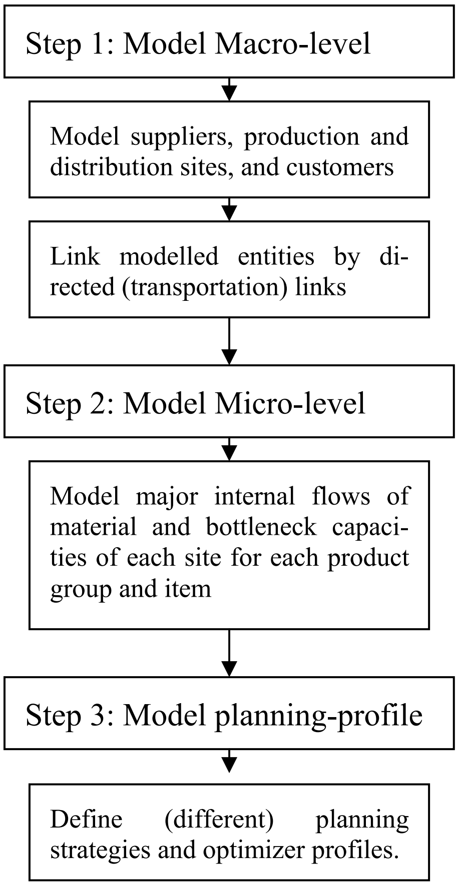

Figure 3: Building a supply chain model (taken from Rhode and Wagner (2005) p. 167.)

In Step 1, key-customers, key-suppliers as well as production and distribution centres are modelled. These entities are connected to a network by transportation lines. Each entity can be modelled in more detail in Step 2, if required. For instance, the material flow at a production centre with capacitated resources and inventories can be defined in more detail, whereas the dependence between input and output materials has to be specified for each (bottleneck) production activity. For transportation lines, means of transport such as trucks, planes and ships can be specified with related costs, transportation times and capacities. The last step is to define a planning profile. Planning strategies could include how a first feasible solution is generated and how improvements are obtained. Optimizer profiles could include different weights for parts of the objective function, the application of aggregation and decomposition techniques whether the MILP or the relaxed LP shall be solved.

For a detailed discussion of the general planning functionalities, supported by short-term production and transport planning modules, the interested reader is referred to Stadtler (2005). Here, these modules will be introduced exemplarily for SAP Advanced Planning and Optimization, presented in the next section.

3.1.2 Hierarchical Planning in SAP APO

With Advanced Planning and Optimization (APO), SAP offers a comprehensive Advanced Planning solution for the synchronization of activities along the (intra-organizational) supply chain.

SAP's APO supports mid-term supply-network planning, demand planning, short-term purchasing, production planning and detailed scheduling, deployment / transport load building, transport planning and vehicle routing and global available to promise calculations.

Figure 4 shows the arrangement of the modules within the SC matrix.

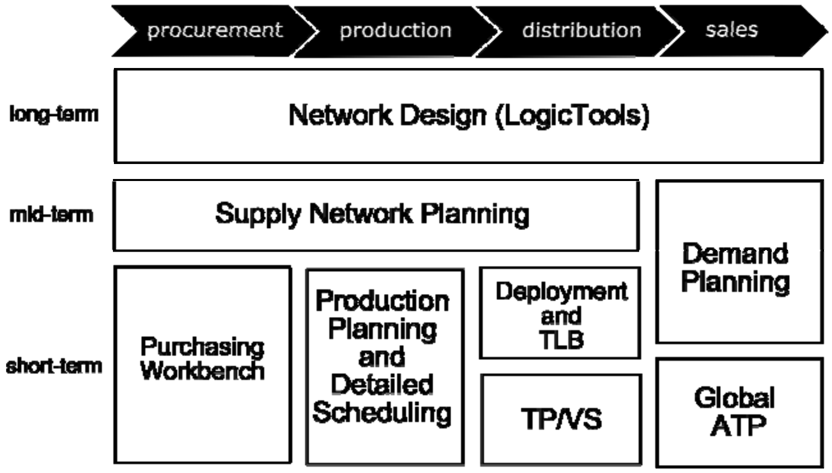

Figure 4: Modules of the Supply Chain Matrix covered by SAP software modules, adapted from Meyr et al. (2005b) p. 350.

The distinct modules are built upon the same persistent data-base, the so-called liveCache. Planning results can be seamlessly transferred as modules are highly integrated. The Supply Chain Cockpit is a graphical tool that allows the access to the modules and supports the modelling, visualization and planning of the supply chain. Demand planning offers statistical forecast functionality by using state-of-the-art forecasting algorithms for product life-cycle planning and trade promotion planning. Global Available-To-Promise (ATP) performs a multi-level component and capacity check based on current data. It provides product substitution methods, alternative site selection for production and purchasing, and methods for allocating scarce products and components to customer, markets, orders, etc. With Supply Network Planning (SNP) the material flow along the whole supply chain can be synchronized on a Master Planning level. Features of the underlying SNP model and related solving techniques will be explained in detail in Section 0. After production is complete, deployment determines which demands can be fulfilled by the existing supply. If there are insufficient quantities available to fulfil the demand or the quantities available exceed the demand, deployment makes adjustments to the plan created by the SNP run. The system then determines how the Available-To-Deploy quantity is to be distributed to destination locations, by using fair share and push rules. SNP provides targets for short-term production planning and detailed scheduling (PP / DS) and transportation and vehicle routing (TP / VS) procedures. The purchasing workbench is used to make automated decision on multiple supply sources and replenishment. The planner can administrate several models and versions for simulation purposes. Strategic long term decisions concerning the overall design of the SC, such as location of production centres and distribution hubs are supported by 3rd party providers, whereas SAP recommends LogicTools. In January 2004, LogicTools became an SAP software partner for supply chain network design. LogicTools network design solution, LogicNet Plus, is now offered as an extension to the mySAP SCM solution and has a certified integration with SAP APO.

<u>Integration over APO Core Interface (CIF)</u>

SAP APO is usually linked to an ERP system (SAP R/3, SAP R/3 Enterprise, or SAP ECC) which provides it with master data. The planning results are subsequently retransferred to the ERP system for further processing and execution.

The APO Core Interface (CIF) manages the data exchange between an SAP ERP and an APO system. For this purpose, via an additional program, certain functions in the ERP System are disabled and related, but more powerful functions in APO are enabled. The CIF provides a comprehensive integration, for example it allows the user to transfer the bill-of-materials between the two systems.

Over the Business Application Program Interface (BAPI), also non-SAP system can access certain functionality of SAP APO.

Overview of Supply Network Planning Module

The Supply Network Planning (SNP) module covers the master planning functionality within the SAP APO solution by combining a distribution requirements and a master production planning at a mid-term level. As it is typical for Master Planning, SNP is based upon a Mixed Integer Linear Program (MILP) formulation of the production and distribution network, that is a mathematical model with linear constraints and objective function and linear and discrete decision variables as discussed previously.

General aim of SNP is to maximize the service level, e.g. a timeliness delivery, by computing plans with a close match of supply and demand. Moreover, SNP allows to define costs to be minimized, whereas stock and resource capacity constraints have to be fulfilled.

SNP can be applied in several fields:

- Source determination: Here, the optimal sources of supply, dates and quantities of procurement can be determined.
- Lot sizing: Master plans with optimal lots can be computed. In addition, the modelling of long lasting campaigns is supported.
- Inventory control: Optimal inventory levels to fulfil upper and lower bounds, such as shelf-life of stored products, maximum stock size, safety stock or target days of supply are determined.
- Cost minimization of:
    - Production, procurement, storage and transportation costs.
    - Costs for increasing resource capacities for production, storage, transportation and handling
    - Penalties for violating service level requirements, such as late delivery, shelf life, a static safety stock or dynamic target days of supply in case of a machine breakdown.

As SNP offers a broad functionality covering various application fields, the underlying mathematical problem formulation is rather complex and would be beyond the scope of this paper. Here, the basic modelling approach will be made clear by presenting a generic problem formulation, confer to Sandner (1999). Thereafter, more specific features of the SNP model will be explained by graphical illustrations and additional textual information.

MP 1 is a generic multi-period, multi-commodity master planning problem. It consists basically of six components:

- Buckets that define the temporal dimension.
- Commodities *s*, i.e. input, output, intermediate or waste products.
- Abstract activities V_a^t per bucket t that transform these commodities into "other" commodities, i.e. succeeding products, products transported to another location or customer demand consuming these products. It is important to note that an activity can last and transfer commodities over several buckets. Activities can be continuous variables, semi-continuous or discrete decision variables.
- Resources with limited capacities K_r^t consumed by these activities.
- Dynamic stock levels V_s^t of commodities (in spatial locations) s that are subject to material flow.
- Functions f_a^t, f_s^t to calculate costs of activities and stock levels as well as capacity / commodity consumption functions k_{ar}^t, k_{as}^t of activities. The resulting cost objective functions favours or penalizes activities, whereas the resource consumption functions k_{ar}^t define hard constraints either capacity limiting or specifying activity appliance levels. The functions k_{as}^t define how products are transformed, and thus specify network flow and stock-levels constraints. The functions can be piecewise linear or discrete, such that the model can be transformed into a MILP model.

It is worth stressing that since there is no topographic restriction, the model defines a multi-level and / or a multi-item problem.

$$\min \sum_{\substack{t\in T\\ a\in A}} f_a\left(V_a^t\right) + \sum_{\substack{t\in T\\ s\in S}} f_s\left(V_s^t\right) \tag{1}$$

s.t.

$$\sum_{\substack{a\in A\cup S\\ t'\le t\le t''_{at'}}} k_{ar}^{t'}\left(V_a^{t'}, t\right) \le K_r^t \qquad \forall r \in R, \forall t \in T \tag{2}$$

$$V_s^t = V_s^{t-1} + \sum_{\substack{a\in A\cup S\\ t'\le t\le t''_{at'}}} k_{as}^{t'}\left(V_a^{t'}, t\right) \quad + K_s^t \qquad \forall s \in S, \forall t \in T \tag{3}$$

$$V_a^t \in \begin{cases} R^+ \\ R^+ \cap \left\{0, \left[\underline{V}_a^t, \overline{V}_a^t\right]\right\} \\ N \end{cases} \qquad \forall s \in S, \forall a \in A, \forall t \in T \tag{4}$$

$$V_s^t \in R^+ \qquad \forall s \in S, \forall t \in T \tag{5}$$

$$f_a^t, f_s^t, k_{ar}^t, k_{as}^t \ \textit{piecewise linear} \qquad \forall s \in S, \forall a \in A, \forall t \in T, \forall r \in R \tag{6}$$

MP 1: General Formulation of the Supply Network Problem.

The following list gives a description of sets used in the problem formulation:

- *A* is the set of possible activities.
- *R* is the set of resources.

- S is the set of stock-levels of commodities in specific spatial locations with respective fixed quantities from K, for example demand.
- T is the set of consecutive time period indices starting with 0.
- F is a vector of piecewise linear functions defining capacity coefficients and stock coefficients.
- $\underline{V}, \overline{V}$ are vectors of minimum and maximum bounds on the activities' application if they are applied..

The SNP Model specifies abstract activities of the generic MP 1 and provides further constraints for resource and inventory usage. The mathematical formulation covers several pages and will not be presented in this paper. Instead, the business logic of the SNP Model will be discussed, that is the interaction of model elements representing relationships on a business level. Using object oriented programming this business model is build-up in memory during each optimization run. The mathematical formulation is then derived automatically while iterating over the model elements and passed to a MILP solver.

As already mentioned, the SNP module combines production and distribution master planning: The network of distribution is modelled by production or distribution centres that are connected over transport lanes. A production centre is responsible for the production of materials, whereas the distribution centre is responsible to match supply and demand for a customer region. However, there is no strict distinction; even a production centre can directly cover demand.

Each location has stock, materials, resources capacities as well as production, demand, and procurement activities assigned. Production activities at a location are defined by so-called production (process) models. A production model defines a single production step by containing a recipe, how several input products are transferred to output products. In addition, a production model specifies the capacity consumptions of resources that are needed for this product transfer.

Transportation lanes define the material flow between locations. In a graph-theoretic sense, transportation lines are directed edges that allow the capacitated flow for a subset of the set of materials. In addition, transport lanes can be aggregated to fleets. Thus not only the material flow on an edge has a maximum capacity, but also the sum of material flows on several edges can be defined to have finite capacity.

Figure 5 shows an example of a distribution and the related production network. The rectangle on each location depicts which materials are produced / distributed and stored in inventories. For transportation lines, rectangles show the subset of materials that can be transported. Although not shown in the example, the distribution network can have several tiers of production and distribution centres.

Within the production network it is illustrated how several production models transform input to output materials. Moreover, the picture shows how models are dependent on resources. A production model might be defined on several resources, and vice-versa one resource may serve different production models.

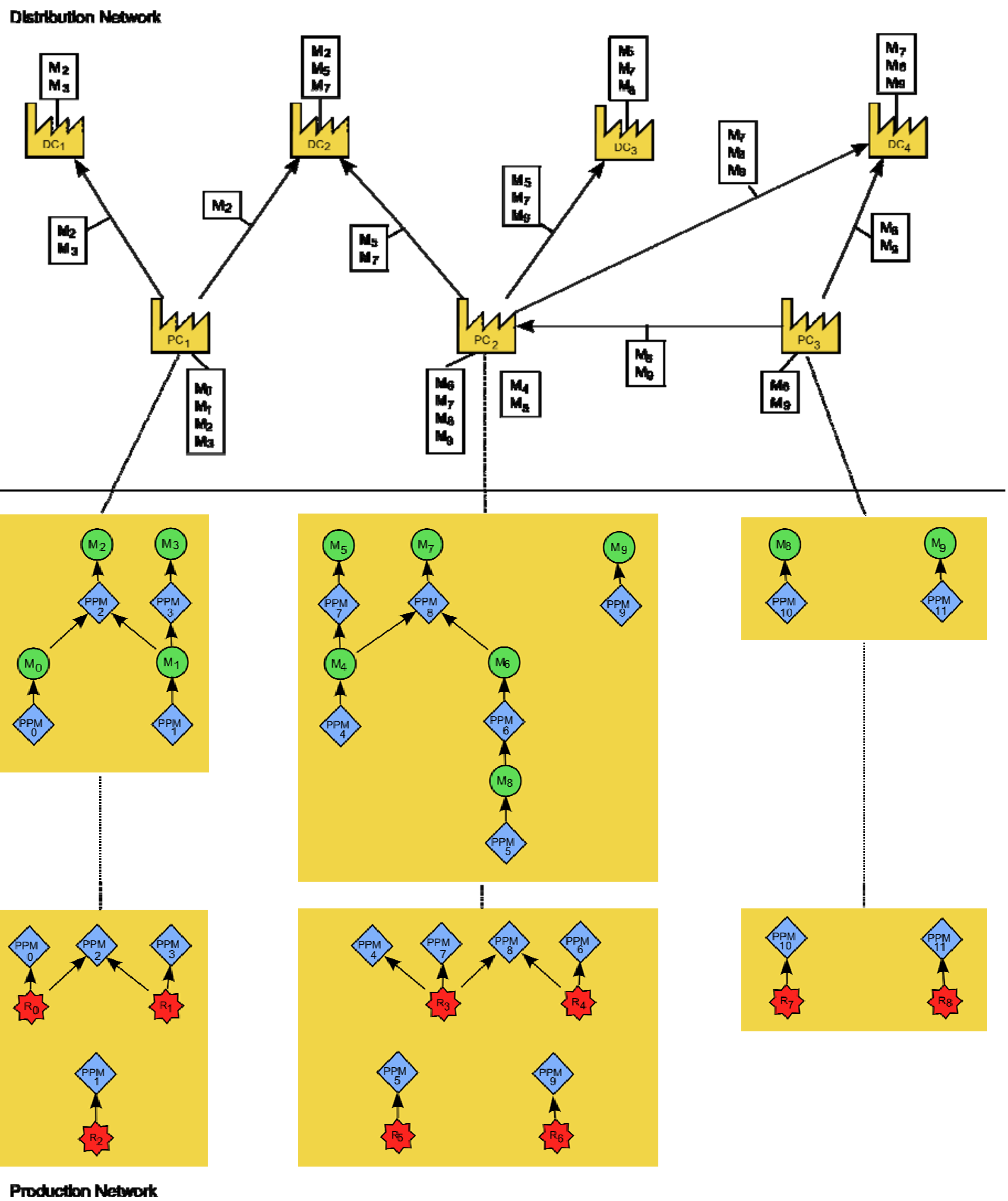

Figure 5: Graphical Example of a SNP Problem instance.

Figure 6 shows the material flow at a location. Material is either produced or consumed by a production model, it can be transported to other locations, delivered to customers or remains in stock until the next bucket. In addition, a fixed production can be modelled. Depending whether this term is positive or negative, it introduces an additional source or sink in the network. These elements are needed to connect several decomposed sub-models as will be explained later.

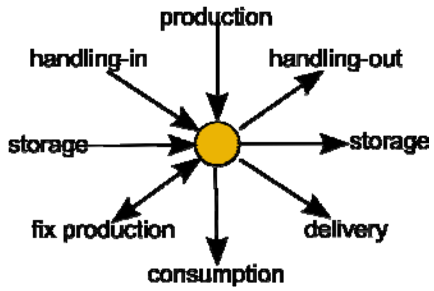

Figure 6: Flow of material at a location.

Figure 7 gives an overview about the various constraints and cost functions. For every location, an available transport capacity is defined by transport lanes to other locations and related fleets. Moreover, there is a maximum handling-in or handling-out capacity a location can provide. The model supports the transportation of discrete lots. Transport can also be defined to have a minimum required lot size. For a transport activity a piecewise linear cost function can be assigned.

The production of items can be defined to have a piecewise linear cost function, whereas only discrete lots or minimal lots might be allowed. Also for procurement piecewise linear costs can be defined. For supply-demand matching delay and non-delivery costs can be specified. Satisfaction of demand can also be handled for different priority classes of customers. For the inventory, static upper and lower bounds, the storage capacity and a safety stock to cover unexpected demand can be set. In addition, dynamic upper and lower bounds can be specified: As lower bound the inventory level to guarantee a certain amount of target days of supply can be computed; that is the number of days where there is enough material available to continue production, even if new supply of this material is cut-off, for instance due to a machine breakdown. In contrast shelf-life denotes the maximum number of days a material can be stored before it has to be discarded.

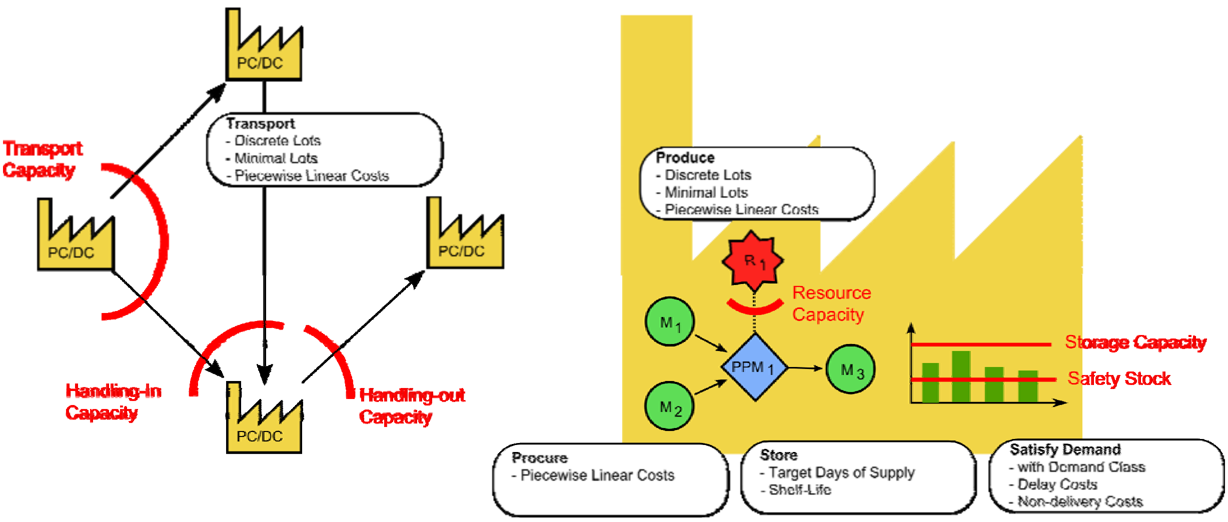

Figure 7: Constraints and cost functions between and within a location

Practical planning problems usually come in large sizes with several thousand continuous and discrete decision variables and constraints. For such kind MILPs the optimal solution can not be computed in a reasonable amount of time, as the problems are NP-complete. However, common solution techniques for solving MILPs, such as branch-and-bound or branch-and-cut algorithms are often able to find a feasible, non-optimal solution after a short amount of time which is then continuously improved.

To decrease the run-time until an acceptable solution has been found either the model can be simplified by aggregating data or the solution process can be speed up by introducing a divide-and-conquer approach, namely decomposition into several sub-models.

Aggregation reduces the amount of data by grouping similar entries. For instance, several adjacent time-buckets can be grouped to one large time-bucket. By ignoring country specific documentation in packaging a product, products can be grouped to product groups. Analogously, similar resources, i.e. machines of one production centre, can be summarized into one resource with cumulative capacity. Last but not least, several locations can be mapped to one transportation zone, for example to postal code areas.

Using the decomposition methods optimization runtime and memory requirements of SNP can be reduced. Decomposition may also represent the only way for the SNP optimizer to find a feasible solution in the event of large discrete problems.

Decomposition techniques split up the problem into a set of partial sub-problems that are then solved sequentially. This approach can be imagined as a window that glides over the space of decision variables and optimizes only its local view at a time. By solving (simple) sub-problems sequentially, it is tried to quasi-linearize the overall run-time. To maintain the global model consistent, the sub-models have to be sealed off appropriately. Locally optimizing a set of sub-models affects the global solution quality, of course. Assuming an infinite run-time, the solution found by a decomposition approach will be worse (have similar or higher costs) than the centrally computed solution. On the other hand, the solution process is much faster. Given a limited run-time the planner has to carefully trade-off between the approximate solution of an exact model and the exact solution of an approximate model, for both, decomposition and aggregation. The SNP optimizer currently supports time, product and resource decomposition.

- *Time decomposition* reduces the number of decision variables for each sub-problem by grouping several buckets to larger buckets. To maintain a global model consistence, for example to capture seasonal demand there are distinct rules which buckets shall be grouped and in which sequence.
- *Product decomposition* speeds up the solution process by forming product groups. The system solves the model for one product group at a time according to the window size selected.
- *Resource decomposition* speeds up the solution process by analyzing the material flow and basic optimizer decisions about production, procurement, and transportation to determine a resource sequence. The optimizer can then create sub-problems for the individual resources, which are solved in sequence. The optimizer makes decisions in every sub-problem that cause the resource to be loaded.

<u>Solution procedures and Architecture</u>

The SNP optimizer consists of several modules as shown in Figure 8. Depending on parameter settings, these modules are synchronized by scripts that define the order of execution. The modules can be categorized regarding their functionality to Controls, Basic Optimizers and Decomposition modules. All modules work on a core-model, where the SNP business logic is stored. For instance, a decomposition script calls several times the time decomposition, which splits up the initial model according to bucket-aggregation procedures and passes these sub-models to the SNP basic optimizer.

Besides the LP / MILP optimizer that calculates cost-optimal plans while respecting material and capacity constraints, other rule based heuristics such as Capable-To-Match[5] and a deployment optimizer or procedures can be applied on a core model.

The initial core model is constructed by a model generator that reads from tables of a relational LiveCache database and writes back the solution.

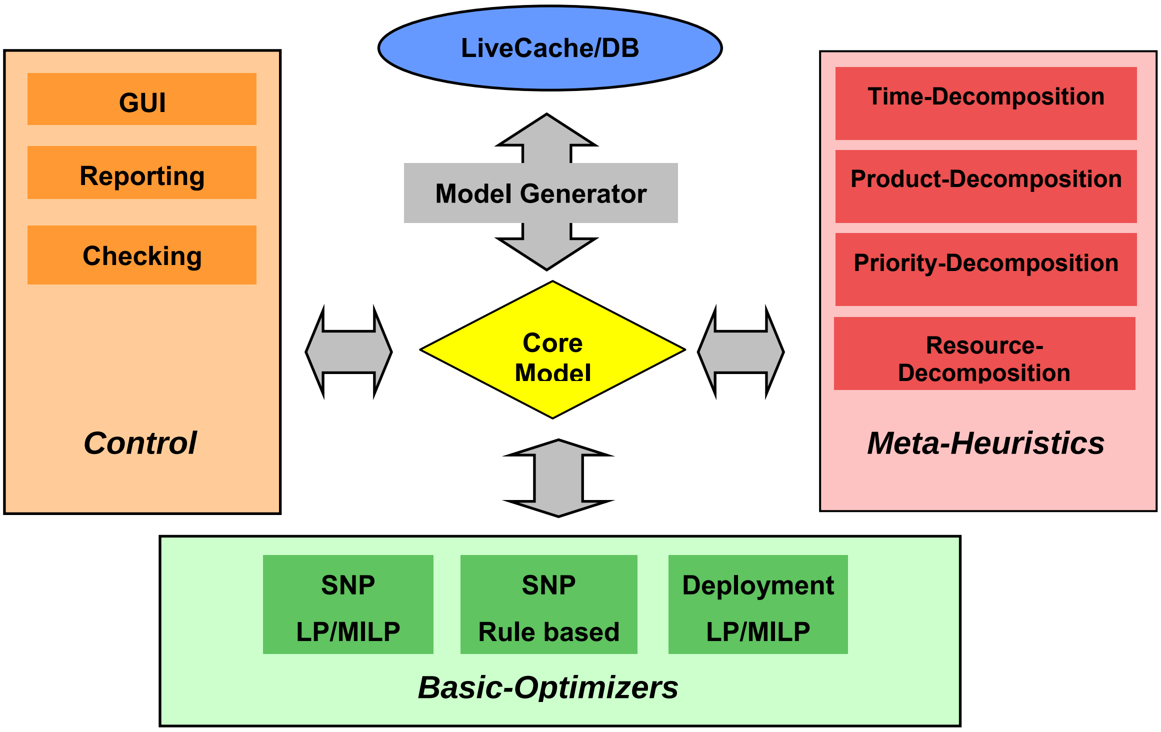

Figure 8: Modules of the SNP optimizer.

<u>Grid computing</u>

Grid computing is a computing model that provides the ability to perform higher throughput computing by taking advantage of many networked computers to model a virtual computer architecture that is able to distribute process execution across a parallel infrastructure. Grids use the resources of many separate computers connected by a network to solve large-scale computation problems. Computations on large data sets are usually performed by breaking them down into many smaller ones, or provide the ability to perform many more computations at once than would be possible on a single computer, by modelling a parallel division of labour between processes.

Also, SNP models can be solved in a grid. The communication is based upon SAP's Remote Function Call (RFC) technique – a standard that allows the execution of functions across different systems. With RFC, a (sub) model can be passed to a different machine, where it is solved and the solution is then sent back. In particular, when using decomposition techniques the solution time can be speed up significantly by a grid, since several decomposed parts of the problem can be solved in parallel. Within the grid, a master is responsible for controlling the process, i.e. sending input data to so-called slaves and collecting solution data. The slaves are connected to the master over a gateway, as shown in Figure 9.

[5] CTM planning uses a proprietary heuristic procedure, which does not optimize the costs. Instead, priorities can be used, for example, to influence the sequence of demands and the selection of the procurement alternatives. CTM planning does not consider the individual production and distribution levels one after the other, such as the classic MRP run, but considers them at the same time.

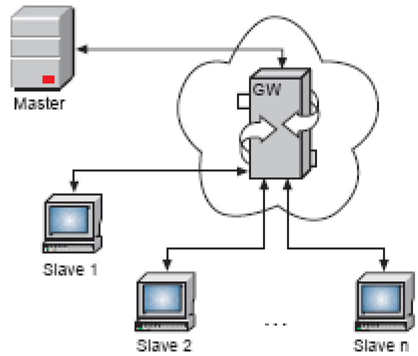

Figure 9: Master-Slave Architecture

The grid framework could also be adapted to support the development of a prototype, since communication between several planning domains can be easily emulated using existing functions.

Production Planning and Detailed Scheduling

According to Stadtler (2005), p. 197, "*Production Planning and Scheduling aims at generating detailed production schedules for the shop floor over a relatively short amount of time"*. Primary goal is to create feasible schedules that respect the instructions of the master planning level. However, data of Production Planning is not aggregated as it is for master planning. Here, detailed start and end dates of activities are of importance. Figure 10 gives a graphical example of a production schedule.

For some production types, like a job shop[6], sequencing and scheduling of activities on potential bottlenecks is required. The goal of the Production Planning and Detailed Scheduling is to find a schedule of activities with minimum lateness, setup and machine costs as well as mode and deallocation costs of activities. This way, it is possible to create procurement proposals for in-house production or external procurement to cover product requirements and to optimize and plan the resource schedule and the order dates/times in detail.

PP / DS allow the inclusion of various types of constraints as, for example, earliest starting times, due dates and delay costs for orders, minimum and maximum distances between activities, sequence dependent setup costs or multi-resources that allow several types of activities. The material flow is constrained by process production models, defining input and output product relations of an activity, storage resources with discrete or continuous product flow.

PP / DS allows also the planning of configurable products, e.g. steel of quality s 37 with density d, cutting-shape c, length l and so on.

[6] Job shops are typically small manufacturing operations that handle specialized manufacturing processes. The difficulty is introduced since several orders require different certain sequences of jobs / products to be performed on different machines with finite capacities.

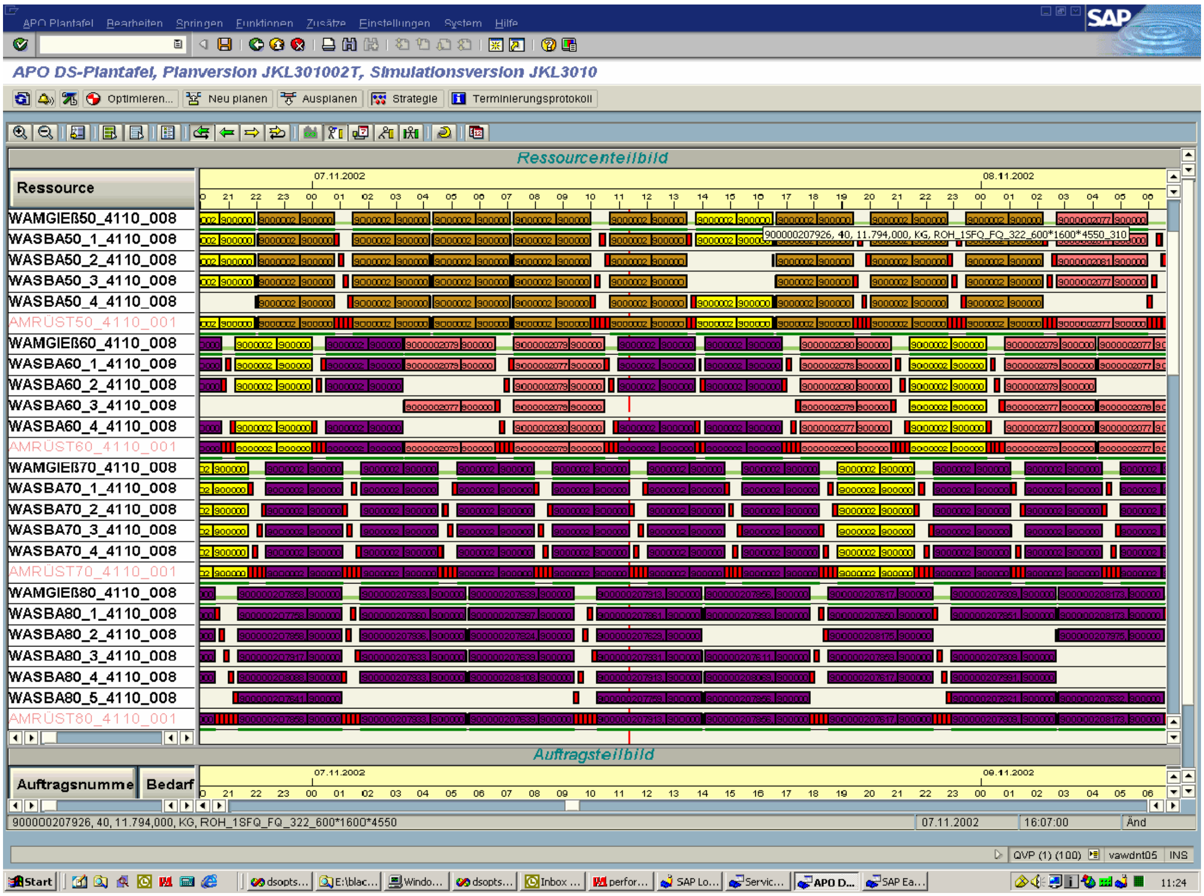

Figure 10: Example of a graphical visualization (Gantt Chart) of a sequence of jobs optimized by PP / DS.

The PP / DS optimizer bases on a genetic algorithm and constraint programming that support cost-based single-objective[7] optimization while respecting all constraints of the NP-complete scheduling problem. Moreover, priority-based planning heuristics that only respect material availability can be used or the proprietary capable to match procedure. As SNP, PP / DS supports the grid-framework and decomposition techniques. A time decomposition is achieved by moving a gliding window and only locally optimize its content. Using a shifting-bottleneck meta-heuristic it is tried to identify bottlenecks, to schedule the most urgent bottleneck first, fix the order and move to the next bottleneck.

Planning results from SNP can be integrated to PP / DS and vice versa. For this purpose, two horizons, the SNP and PP / DS horizon need to be defined. The SNP horizon denotes the period of time, in which activities can be planned with SNP. The PP / DS horizon is usually located earlier, whereas both horizons can overlap.

Within this overlapping range, SNP respects already fixed PP / DS orders as capacity reduction and material flow, i.e. the bucket-wise data is changed to capture the already planned PP / DS orders. In contrast PP / DS respects pegged SNP orders as due dates and tries to schedule the orders independently of SNP buckets as early as possible.

[7] The problem is transferred to a single-objective problem by building a weighted sum of the different costs for delay, setup, etc.

But not only planning results can be transferred between to two modules. APO also support san automated aggregation of PP / DS input data, for instance PPMs, to SNP data. Hence, data needs to be administrated only from one point.

Transport Planning and Vehicle Scheduling

The goal of the vehicle scheduling and routing problem (VSRP) is to schedule orders on vehicles such that total costs are minimized and certain constraints are met. From a central hub, optimal routes are searched to satisfy customer demands at different locations. The goods are delivered to the customer with m vehicles with limited capacity. In addition pickup and delivery activities have to be within predefined time windows as shown in Figure 11.

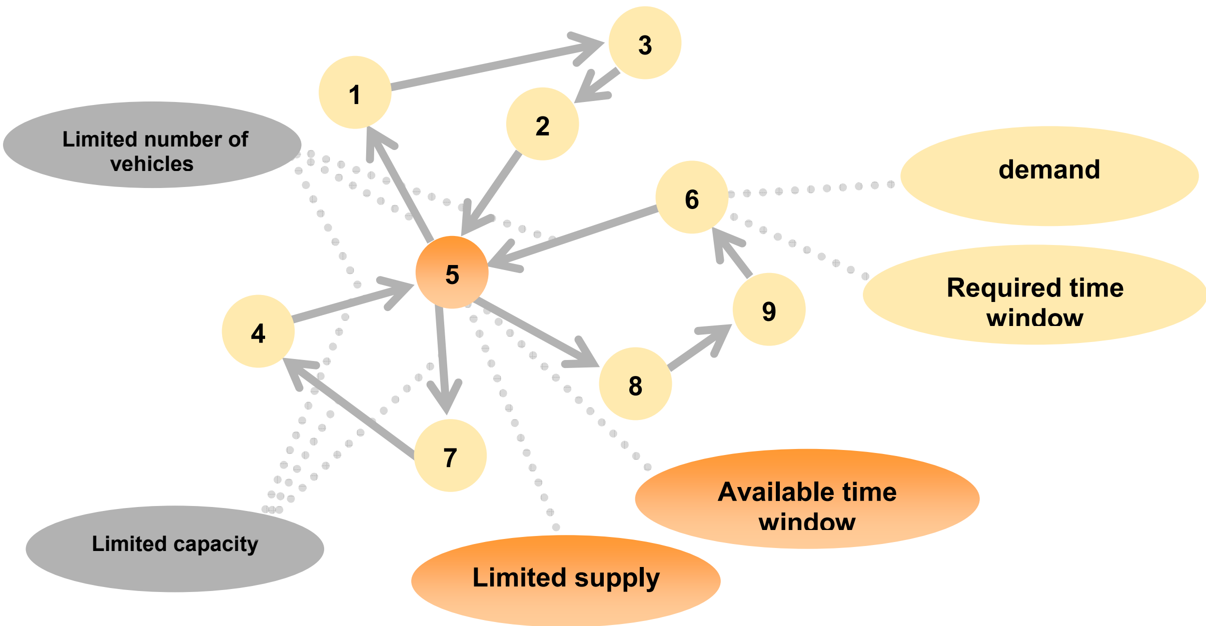

Figure 11: Graphical Representation of a Vehicle Routing Problem

These so-called Capacitated Vehicle Routing Problem (CVRP) and Capacitated Vehicle Routing Problem with Time Windows (CVRTPW) have been shown to be NP-hard.

In addition, in TP / VS the CVRTPW problem has been extended to allow hard and soft constraints for delivery / pickup time windows, whereas these activities can be modelled to have their own inbound and outbound activities and capacities. For each vehicle a comprehensive catalogue of costs and constraints can be defined, including travel characteristics, break times, capacities for several loading dimensions and several limits for time, distance, number of stops, etc. Moreover, incompatibility constraints can be introduced between order attributes, order attribute and vehicle type, order attribute and hub as well as vehicle type and hub. There is the possibility to fix route and schedules a priori for the modelling of ships and trains. Furthermore, for indirect shipment, i.e. shipment of intermediary hubs, a minimum and maximum waiting time can be defined at those locations.

Given all the above constraints, the goals of transport planning and vehicle scheduling is to reduce non-delivery, earliness, lateness, fixed vehicle costs, usage duration of vehicles, travelled distances and quantity costs.

The costs are combined to a weighted sum and the a solution of the NP-complete problem is calculated by an Evolutionary Algorithm.

Scheduling and transportation problems are of huge importance for the service sector and might be considered in further evaluations. Regarding the coordination scheme, however and exchange of data at the master planning level, i.e. demanded or committed quantities within certain time buckets seems to be sufficient.

3.2 Evaluation of existing Collaborative Planning Modules in Advanced Planning Systems

Following the introduction to Advanced Planning Systems and solutions provided by SAP, the different existing extensions to ease collaborative planning will be presented. We start by giving a classification of collaborative planning processes.

3.2.1 Classification and General Steps of Collaborative Planning Processes

According to Kilger and Reuter (Stadtler, Chap. 14), collaborative processes can be classified by means of leadership, object and structure of the network. Depending on the position within the network, a local planning domain has suppliers of goods or services as well as customers, whereas the ultimate customer denotes the most downstream entities to which the final products are sold.

In nearly all supply chains a leading partner can be identified who drives and initiates the collaborative planning process, whereas the followers support the process. In case the leadership is assigned to the supplier we have a supplier driven collaboration. If the customer is the leader, the collaboration process is called customer driven.

Moreover, collaboration relationships can be distinguished in material or service related depending on the type of object being delivered from supplier to customer.

Last but not least the structure of the network has a major impact on the complexity of the collaboration process. The number of suppliers for each customer and vice versa influences the density of the (inter-organizational) supply network. Another important factor is the number of tiers. A supply network is denoted to be n-tier if the maximum path length within in the network is n. The simplest structure of a supply network is single-tier, if a planning domain is directly delivering goods only to the ultimate customers. Thus, inter-organizational collaborative planning can only happen in a network that has at least two tiers. In such kind of network each planning domain is either supplier or customer, if we neglect the relationship to the ultimate customer, which is not a collaboration process that can be supported by an APS at both ends. In a network with more than two tiers a local planning domain can be customer and supplier at the same time, however.

According to Kilger and Reuter a collaborative process can be in general described by six steps:

1. Definition
2. Local domain planning
3. Plan exchange
4. Negotiation and Exception Handling
5. Execution
6. Performance Measurement

In the definition phase the collaborating partners establish a formal agreement how they intend to work together. This agreement addresses the gives and gets for each partner, the items to be collaborated upon, the time horizon of collaboration, the type of data exchanged and a dispute resolve mechanism in case of extraordinary events.

In the local domain planning phase each partner generates plans for production and distribution for his local domain. During or subsequent to planning plans are exchanged. It is worth stressing that only non-sensitive data is commonly exchanged such as forecasted demand replenishment orders or supply commitments. The sources of data might be transactional data of suppliers and customers, that is maintained in ERP-systems or their local domain plans generated by an APS. Depending on the kind of collaboration process partners might have the possibility to negotiate upon the exchanged plans. In case of a large deviation between the plans exception are commonly thrown to indicate that further action is required.

Most recently several authors proposed an iterative traversing of the local domain planning, plan exchange and negotiation phase in order to decrease inter-organizational supply chain costs, see chapter…

If the partners have agreed upon the plans, replenishment-, production- and procurement orders are executed. After execution the performance of the collaboration process can be analyzed using appropriate key performance indicators.

Kilger and Reuter identified several typical planning processes:

- In the demand collaboration, the customer provides additional information such as mid-term material requirements, promotion and marketing activities to the supplier. The supplier then in turn performs a consensus based forecasting of his demand by including his sales, marketing, product management and planning department. As a prerequisite harmonized planning and transactional data is needed. Moreover, every local planning domain needs to have the possibility of monitoring the planning process, to generate alerts if the deviations between plans are too large and to analyze historic sales data.
- As a special form of demand collaboration, inventory collaboration means that the supplier automatically plans the replenishment of the customer inventory driven by predefined service level agreements such as minimum or maximum stock levels. This process is also denoted as Vendor Managed Inventory (VMI).
- In the capacity collaboration supplier and customer exchange information about demand and availability of production services. For instance a manufacturer collaborates with a subcontractor on the usage of the subcontractor's production facilities. In many cases there is an agreement on minimum / maximum capacity levels. The supplier is typically interested to define a minimum capacity in order to ensure the load of his production capacity. In many contracts it is agreed that first this minimum capacity has to be loaded at the suppliers side, before the customer can load his own production facilities. In general, the customer is interested in knowing the maximum capacity available while pursuing his goal to generate upside flexibility for the case his own capacity is not sufficient to satisfy fluctuating demand.
- Transport Collaboration is a special form of capacity collaboration, whereas parts or the whole distribution is outsourced to third party logistics (3PL) providers.
- Last but not least collaboration based upon mutual reconciliation has gained increased importance in the recent years. As typical examples, Collaborative Planning, Forecasting and Replenishment (CPFR) in the consumer goods industry or Collaborative Development Chain Management (CDCM) should be mentioned in this context.

3.2.2 Collaborative Planning Processes Supported by SAP

SAP software solutions support various possibilities for interaction between supplier and customer for inventory and capacity collaboration. Special data exchange infrastructures allow the connection of SAP and non SAP systems as well as web based user interfaces. For example, SAP's supplier portal groups collaborative functionality from several solutions and presents it within a single interface to the supplier, as shown in Figure 12.

The vast amount of possibilities makes it hard not to loose the big picture and to classify the supported processes. Here, we try to give a classification by dividing provided tools and solutions into three categories:

- The first category of modules eases administrative effort in the coordination of the *handling* of key-suppliers. A typical example is the Supplier-Relationship Management (SRM) solution that aims at cutting down procurement expenses by providing automated support for standard procurement processes. Since this category is more concerned about managing the general interaction and integration rather than collaborative planning it will not be discussed further.
- The second category consists of predefined "out of the box" inventory collaboration processes. These processes are bundled in the so-called Inventory Collaboration Hub (ICH) that is basically a stand-alone, web-based solution that can, however be connected to existing ERP or APS systems.
- The third category consists of predefined collaborative business scenarios. Here, not stand-alone collaboration solutions are in the focus but rather recipes or recommendations how several modules can be connected, which systems shall be used and how data exchange can be automated to support business scenarios such as CPFR, VMI, etc. in both a general or a industry-specific way. Regarding APO, the so-called Collaboration Engine provides support of data-exchange, the management of alerts and web-based communication to enable these processes.

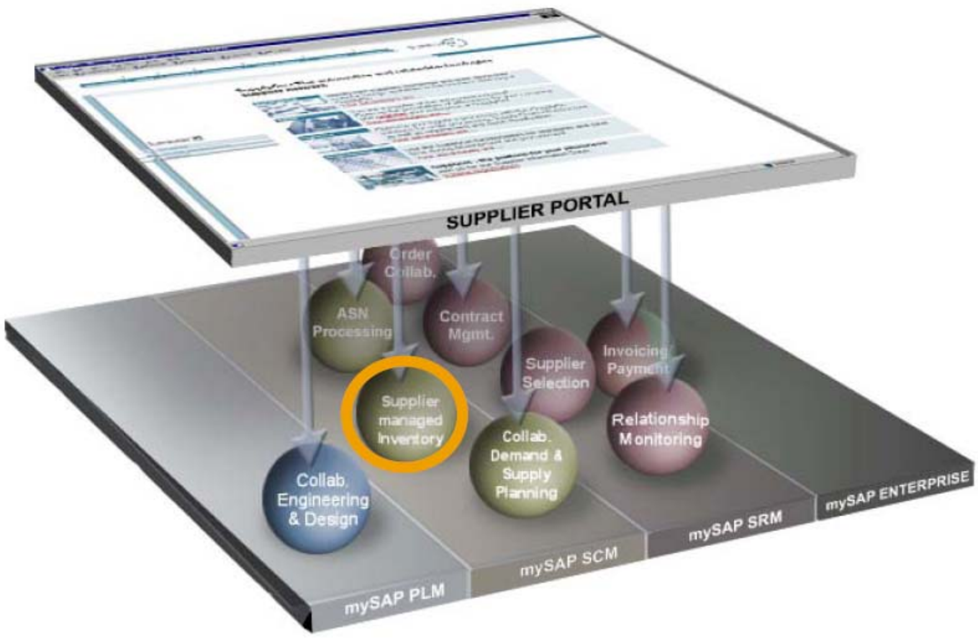

Figure 12: Processes of several SAP solutions that can be accessed over the supplier web portal.

<u>Inventory Collaboration Hub</u>

SAP ICH (Inventory Collaboration Hub) is a typical example for a web-based exchange platform for demand and supply plans to support replenishment processes. The main goals are to reduce costs through decreased inventory buffers and administration, to improve customer service through reducing risk of stock outs and to increase velocity and responsiveness through reduced variability and real-time shared inventory information.

SAP ICH sits within the firewall / network of the customer, allowing access via messages or the web for outside supplier companies and users. Depending on the process context the supplier can integrate via the web user interface or integrate his backend system via SAP XI (Exchange Infrastructure). However, this integration is not provided by SAP as a standard functionality. SAP XI allows an effective data exchange by coordinating the communication at the host's side to several partners. The Inventory Collaboration Hub is a standalone solution with the possibility to integrate the customers ERP, APO or BW (Business-Intelligence Warehouse) SAP system, as shown by Figure 13.

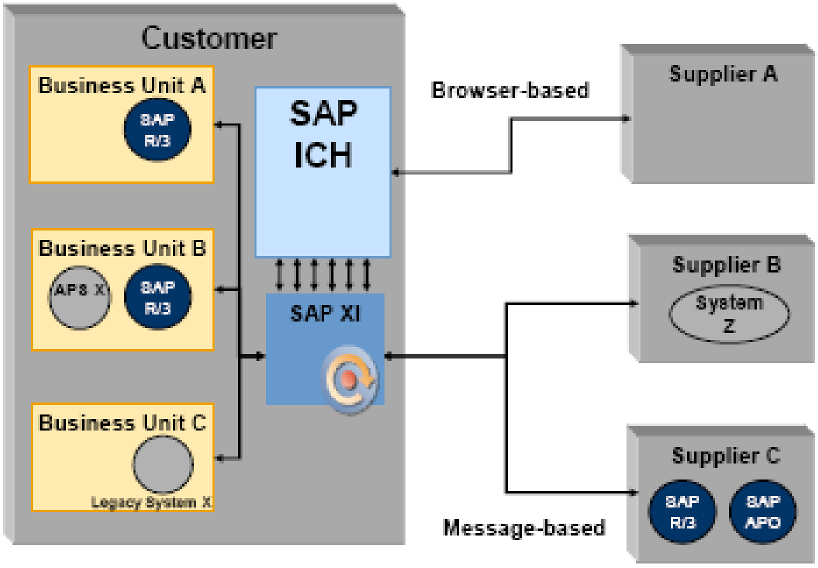

Figure 13: Supported SAP XI and ICH connections to planning systems.

To support distinct collaborative business processes, ICH enables collaboration by providing an alert monitor to show and specify various exceptions. The development of ICH was mainly influenced by automotive and high-tech industry, where usually a lot of suppliers have to be managed by the OEM.

Depending if the host of ICH intends to integrate suppliers or customers into his planning procedures, the collaborative processes can be distinguished into supplier and buyer collaboration.

Supplier collaboration

Figure 14 gives an overview of the benefits of ICH for supplier collaboration.

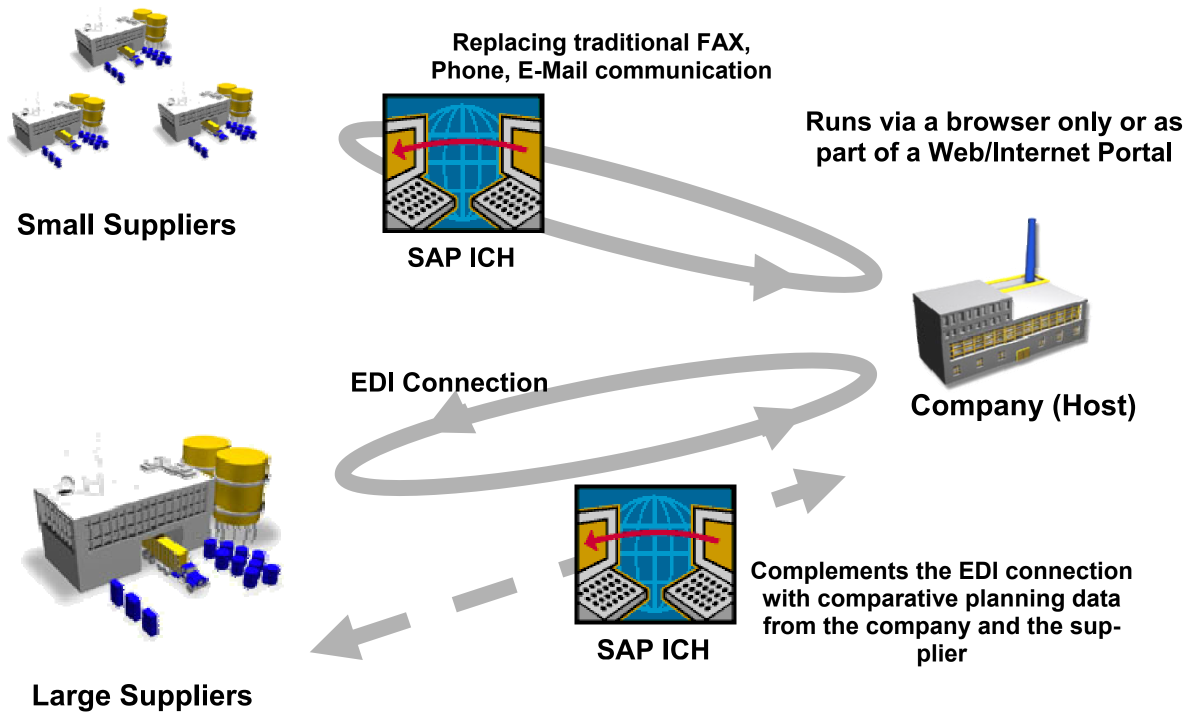

Figure 14: Goals of supplier collaboration of SAP ICH

The goal of SAP ICH is to replace traditional fax, phone and e-mail communication with small suppliers and to complement existing EDI connections with large suppliers

Several supported processes allow for a shift of the replenishment responsibility to the supplier, as well as comparison of the customer data with supplier's planning data. In the current version 5.0 the following collaboration processes are supported:

- Purchase Order
- Release
- Supplier Managed Inventory
- Dynamic Replenishment
- Contract Manufacturing Purchasing
- Supply Network Inventory
- Kanban
- Delivery Control Monitor

These processes shall be shortly explained in the following.

Purchase Order

Discrete customer net demand can be communicated to the supplier by transmitting purchase orders in ICH. A purchase order is basically a table with a header and several delivery items with respective dates, quantities and shipping locations. For every item so-called schedule lines can be added containing more detailed information. This way, a communication protocol between supplier and customer is established. The supplier has the possibility to confirm the order and to change date and quantity fields. A confirmation is automatically sent back to the host system. At the time of shipment an advanced shipping notification can be automatically created by the supplier to inform the customer. Only the customer is privileged to cancel a purchase order.

Release Process

In extension to purchase orders the release process allows the communication of delivery schedules from the customer to the supplier. Usually, delivery schedules consist of time-series with both an order and a forecast horizon. A release comparison monitor allows the supplier the calculation of the difference between several versions of delivery schedules.

Both, Purchase Order and Release Process allow a real time communication of requirements and confirmations with respective dates and quantities. This helps in easing administrative efforts and prevents process failures.

Supplier Managed Inventory

The Supplier Managed Inventory process supports a ‘light’ VMI at the short-term level, hosted by the customer. Stock balances, demand, minimum and maximum stock levels given by the customer serve the supplier as a basis for planning of stock replenishment.

The supplier can – according to his assigned rights and roles – view several KPI’s describing the situation of the customer inventory over the web-based user interface. Besides manual adjustment of planned replenishment the system can generate a proposal for planned receipts. In addition, purchase orders can be exchanged between supplier and buyer as an intermediate process step.

The goal of the Supplier Managed Inventory process is to support the supplier in optimizing his own capacities while also being responsible for customer replenishment planning. This frees planning resources at the customer’s side while increasing inventory turns and order fill rates.

Dynamic Replenishment

Dynamic Replenishment allows a comparison of customer orders and forecasts with supplier deliveries and forecasts. Deviations between ordered and planned items of customer and supplier are depicted in the so-called demand monitor. As for the other processes, the data can either be extracted from a backend-system or entered manually by using the web user interface.

Contract Manufacturing Purchasing

The contract manufacturing purchasing process allows the exchange of orders to subcontracting partners. In contrast to the standard purchase orders, these orders include the bill of material. As for the standard purchase order the supplier can confirm or change the purchase order. Additional the supplier can also announce changes in the bill of material to the customer. If the customer accepts the changes, the component updates can be automatically transmitted to the ERP systems.

Supply Network Inventory

The supply network inventory process allows the monitoring of inventories at several sites of customers and suppliers for unique or multiple products. Through a profile management system special views for customers for monitoring inventory at supplier plants and views for suppliers for monitoring inventory at customer plants are enabled.

Kanban

Customers who use the SAP ERP Kanban replenishment logic can extend this to external suppliers using SAP ICH. The suppliers can monitor the Kanbans over the web, and can set states of Kanbans from empty to in-work and in-transport. Moreover, ICH allows customers to create advanced shipping notifications directly from within the web user interface.

Delivery Control Monitor

With the delivery control, the replenishment responsibility is outsourced to the supplier whereas the planning responsibility remains with the customer. Via ICH, the suppliers can compare inventory level to pre-set signals (reorder points) as well as min and max limits set by the customer.

Customer Collaboration

To integrate customers into the planning procedures, ICH provides the Responsive Replenishment process, which is a VMI strategy from the supplier's perspective. This process allows the controlled data import of sales and short-term forecasts from the ERP System of the customer. Based on customer forecast and actual demand transport loads can be planned at the supplier (host) side. Using a web user interface current sales and forecast inventory data can be compared, such that planned sales pattern of promotion activities can be updated according, for instance, to the current sale situation.

Nonetheless, the replenishment process is driven by actual demand and not by forecast. The main goal of this process is to support and efficient management of promotions and to help manufacturers to enable store-specific replenishment processes like cross-docking.

Summary

To summarize, with ICH, SAP offers a stand-alone solution that does not require SAP APO or ERP but has the possibility to integrate with SAP and non-SAP systems. The major achievement of ICH is the provision of global visibility of inventory and demand across the partners of the supply chain. By enabling several out-of-the box collaboration processes, like SMI, Release and Purchase Order Process and Dynamic Replenishment ICH improves customer service and increases revenue while reducing inventory level and administrative costs on both supplier and customer side.

Nonetheless, ICH itself is not a planning tool in the sense of an Advanced Planning System. Instead it is primarily supporting the transmission of requests and signals from the customer to the supplier by providing the access to automated processes. It should be stressed that ICH does not provide any automated reconciliation of production plans or other coordination mechanisms as will be described in chapter 4, although there exist some heuristics to support coordination on the operational level. Moreover, ICH does not allow the integration of services.

Concluding, ICH can not be regarded as an alternative to mere upstream planning. In fact, the overall purpose of this tool is to allow a fast execution of upstream planning by providing out of the box collaboration processes, which is in practice already a quite challenging task.

Supply Chain Processes with APO

Besides ICH, SAP supports the exchange of planning data between partners by predefining so-called collaborative business scenarios, as for example, VMI or CPFR. These scenarios are not supported by a single solution, instead it is defined which systems can be used and how they need to be configured for a distinct planning scenario.

For example, the data required for VMI planning can be transmitted through Electronic Data Interchange (EDI) or eXtensible Markup Language (XML) messages and is then stored persistently in SAP APO. The following data can be processed here:

- Stock on hand
- Sales history
- Promotion sales
- Sales forecast
- Promotion sales forecast
- Open purchase order quantities
- Shortfall quantities

As another example, the SAP F&R Solution allows a planning domain to forecast and to derive demand out of current sales data, specially suited for retailers. However, CPFR is supported only in the way that point 3 of the VICS standard – creation of a joint forecast - is currently implemented. CPFR data can be requested from SAP F&R from an external system by calling a remote function call (RFC) function. For more details on the different collaborative business scenarios the interested reader is referred to the homepage of SAP, www.sap.com.

With the so-called Collaboration Engine, APO offers the opportunity that external partners change and provide planning data. This integrated APO-tool was designed to

- Enable exchange of required planning information with business partners
- Allow the use of browser to read and change data
- Restrict user access to authorized data and activities
- Support consensus planning process
- Support exception-based management

Data of the planning book can be exchanged directly between two APO, an APO and another APS system or can be visualized and changed over a web-based user interface. By specifying user profiles it can be regulated which of the data can be accessed and changed. Restricting access to authorized data and activities influences the web interface for performing certain activities by internal or external partners. Depending on predefined scenarios, alerts are automatically triggered and sent to the partners. A workflow template can be used to define and control steps the partners have to undertake during the collaborative process.

As depicted in Figure 15, an internal connecting to another SAP system is established over the Business Application Program Interface (BAPI) and RFCs. Non-SAP Systems can be connected over the SAP middleware technology Business Connector (BC), whereas the data is exchanged in XML format. In the logical system values can only be changed for figures that are stored in InfoCubes or in time series in the liveCache.

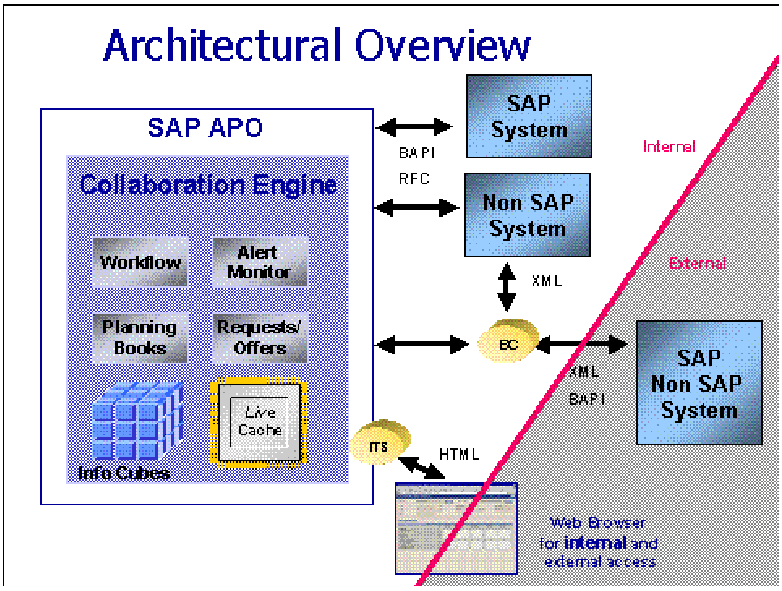

Figure 15: Architectural overview about the collaboration engine within APO

SAP defines several use cases where this data visibility and exchange can be used for collaborative planning. These scenarios are presented in the following and can be further specified to fit industry-specific needs.

Collaborative Demand Planning between manufacturers and their distributors allows both partners to streamline their work processes. As shown in Figure 16, the collaboration is based on the exchange of forecast data, whereas exceptions are triggered for predefined circumstances that need additional action. In a similar way, partners can establish a collaborative promotion planning process.

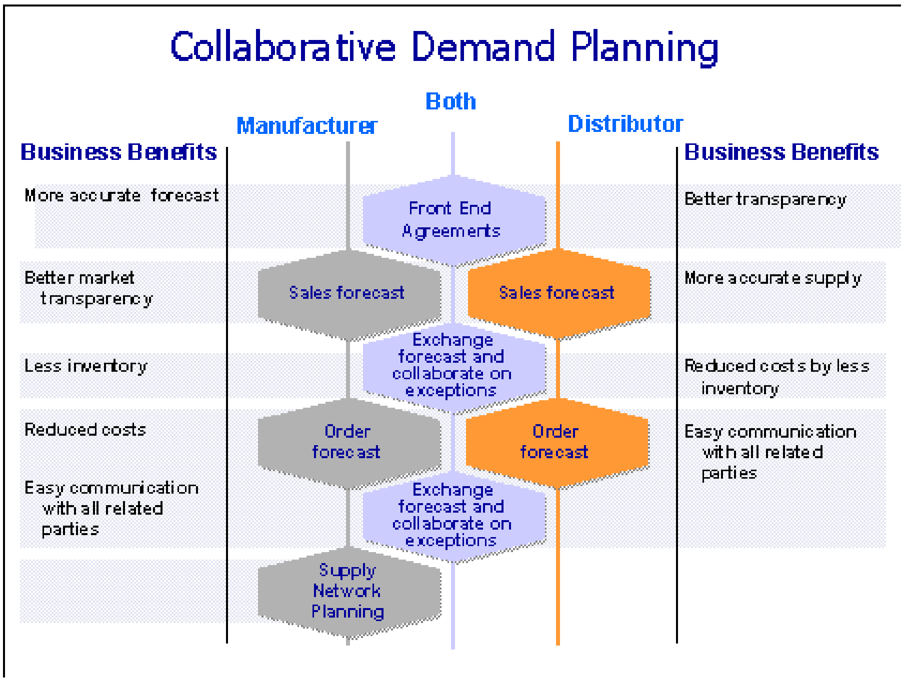

Figure 16: Collaborative Demand Planning Scenario

Collaborative supply planning involves the supply-network planning modules of the supplier and manufacturer. As for the collaborative demand planning, the collaboration is mainly based on a one-time submission of forecast data and component requirements.

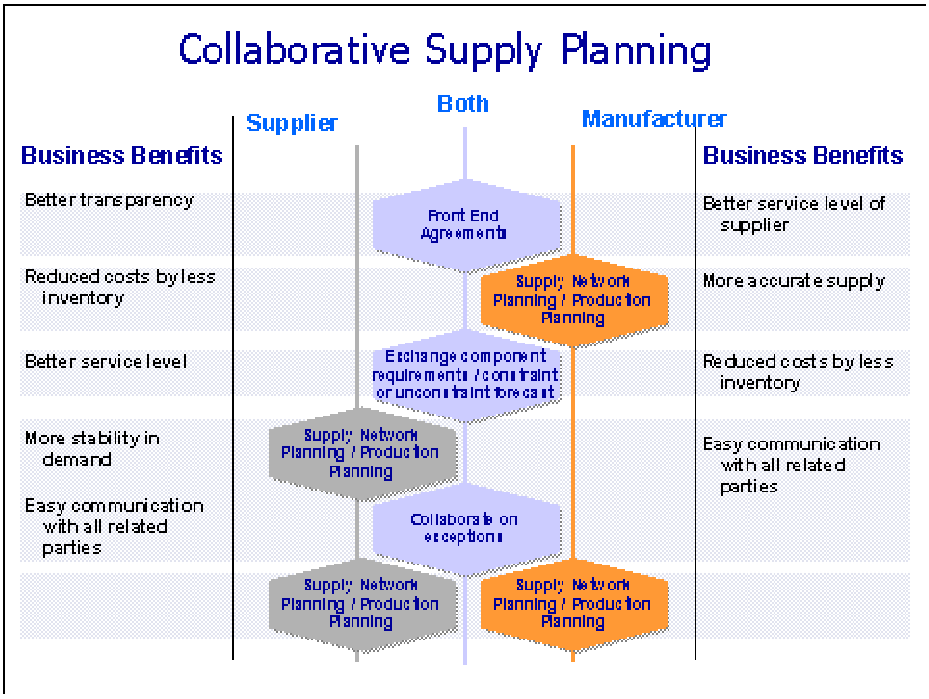

Figure 17: Collaborative Supply Planning Scenario

In collaborative transportation planning, manufacturers inform their transportation service providers about scheduling agreements. The transportation service provider (TSP) can accept, reject, or change the transportation Requests for Quotation (RFQ). For instance, the TSP can suggest an alternative pickup or delivery date.

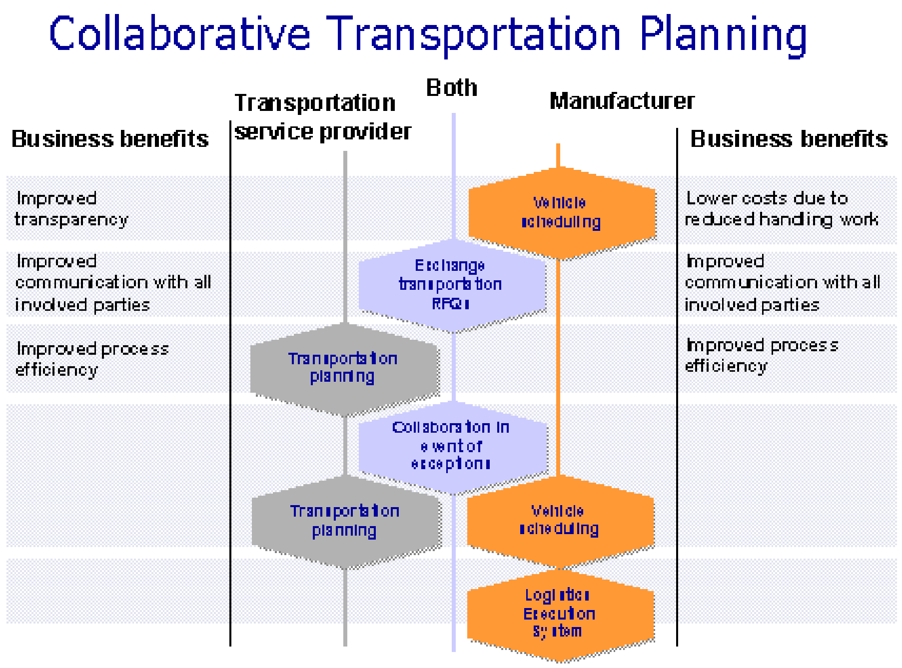

Figure 18: Collaborative Transportation Planning Scenario

Collaborative Planning in APO is currently supported by the exchange of data between two systems over BAPI, RFC or XML. Alternatively, partners can gain access to local planning data over a web-based user interface with predefined roles that restrict access to certain activities. At the current stage of development, the primary goal is the provision of views of the local the planning data to other partners while maintaining security. There is no kind of further automated reconciliation process that is based upon the data exchange.

Collaborative business scenarios are recommendations or recipes how to put collaborative strategies, such as VMI into practice. The APO collaboration engine can serve as a building-block for this purpose.

Without any form of collaboration, partners are commonly integrated into the local planning process by administrating and adjusting local planning data such as freight or subcontracting costs stored within the database of one decision making unit.

3.2.3 Collaborative Planning Processes supported by Oracle

Overview about Oracle's Advanced Supply Chain Planning Solution

The different modules of the APS solution provided by Oracle are shown in Figure 19. Strategic Network optimization allows the graphical design and evaluation of complex supply chains. Production and Distribution Planning focus on the mid-term Master Planning and the shorter term Distribution Planning. The Vehicle Loading module allows the optimization of storage space in vehicles, Production Scheduling allows the planning of production on a short term level. For a more detailed discussion, the interested reader is referred to Meyr et al. (2005b) or to the homepage of Oracle, www.oracle.com.

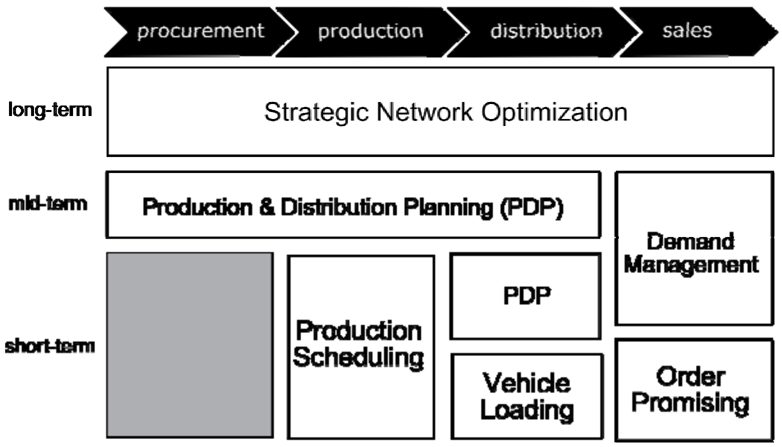

Figure 19: Software modules of Oracle's Supply Chain Planning, see Meyr et al. (2005b) p. 346.

Support of Collaborative Planning

With "collaborative planning" Oracle provides a set of planning processes that aim at an efficient communication of actual demand, commits and forecasts along the supply chain. For example, a VMI process is supported both in customer or supplier direction. These processes can be integrated into the Oracle purchasing system, the Advanced Supply Chain Planning System and also into other legacy systems. Partners can access this module over a web-based user interface. With several analysis functions, such as out-of-stock analysis, suppliers are provided with tools to compare order forecasts and supply commits, view exceptions and supply demand mismatches and to analyse their own commit performance. Parts of the workflow can be automated, e.g. messages can be automatically sent if exceptions are detected. PDP provides the infrastructure for collaboration of different users in several locations by automated data synchronization, including alert monitoring and messaging.

All efforts aim at enhancing the communication between supply chain partners in order to decrease administrative efforts, safety stock and costly out-of-stock situations. There is no support of an automated inter-organizational coordination of plans, i.e. the functionality represented by the prototype to be developed during InCoCo-S.

3.3 Requirements for coordination mechanisms for use within Advanced Planning Systems

From the local perspective of a manufacturer (or service provider) within the supply chain, collaboration partners can be divided into three different categories, namely customer, suppliers and outsourcing partners, as depicted in Figure 20. The interactions differ from group to group, which has to be taken into account when developing a coordination mechanism.

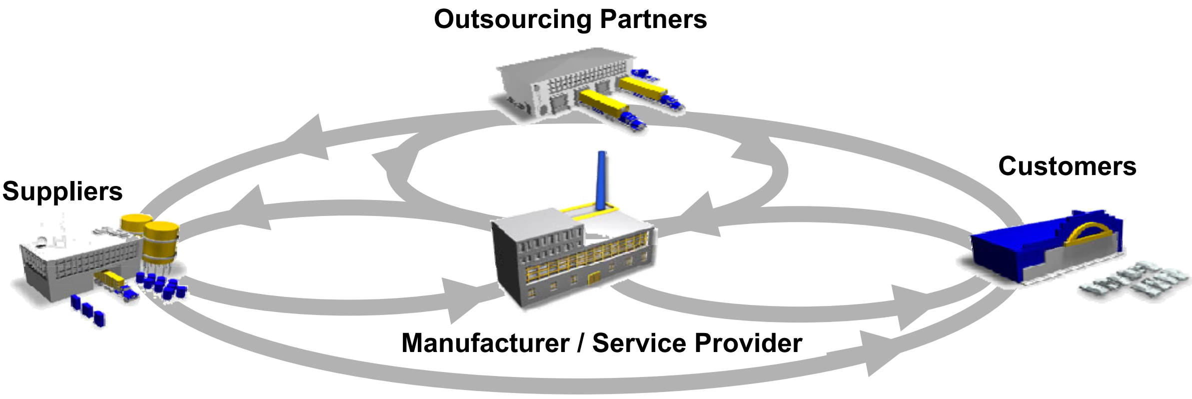

Figure 20: Collaboration Interfaces of a Manufacturer / Service Provider with other partners within the supply chain.

Concluding, the collaboration solutions currently supported by software providers try to enhance partner interaction by streamlining their business processes and to reduce inventory stocks and administrative costs by inventory or forecast collaboration. Inventory collaboration today basically means that there is a leading entity in the supply chain generating demand for its suppliers / customers, who take the responsibility for inventory replenishment. In addition, forecast of future demand is often coordinated among the partners in strategies such as, for example, Collaborative Planning, Forecasting and Replenishment (CPFR) in the retail business.

Till today there is no support of decentral collaborative planning in the sense that equal partners mutually adjust their production plans to decrease the costs of the entire supply chain. Usually, by locally optimizing his domain, a partner sets constraints by demanded items or services for his subsequent partners. From a broader point of view collaborative planning can be regarded as a decomposition technique: the inter-organizational supply chain is split into several pieces that are solved locally, whereas each local planning domain propagates constraints and costs functions such as demanded material and delay penalties to his neighbouring domains. Today’s collaborative strategies foster the communication of these constraints and costs; however, there is no levelling along the inter-organizational context.

A mutual reconciliation of plans is a real competitive advantage since it has a huge cost-saving potential by avoiding redundant costs of, for example, overtime shifts, setup costs and lateness penalty.

SAP intends to enhance the existing concepts for integration in Supply Chain Management by a collaborative planning functionality that supports a mutual decentral collaborative planning as described above. The challenges are here to develop a coordination mechanism for collaborative planning at the Master Planning Level that supports large-scale benchmark customer cases and meets real-world requirements such as solution quality, computation time, closure of sensitive information and practical acceptance of the mechanism: balancing the costs among the partners in order to reach the global, inter-organizational supply plan must always lead to win-win situations among the concerned partners.

Innovative models need a detailed proof of concept, which shall be elaborated during InCoCo-S. At the current stage of research, a direct development during the release cycle is considered as too risky. In a first step, a prototype shall be developed providing the basic functionality for such kind of computer-supported negotiations.

Coordination mechanisms to move towards the inter-organizational optimal delivery plan can be applied in the fields of mid-term master planning, but also on a short-term level, such as production planning, scheduling, distribution and transport planning. Some industries actually require the application of short-term detailed scheduling techniques, such as for example steel and paper mill as they need to plan configurable materials that cannot be captured in SNP.

However, for the items / services to be coordinated the transmission of delivery plans at the Master Planning level[8] seems to be sufficient. For instance, the arrival of a truck transporting input materials or a service team can not be guaranteed to arrive on second due to stochastic influences. However, an arrival per bucket, e.g. an availability of the material until 8 a.m. can be committed. Collaboration at the strategic level seems not promising.

Advanced Planning Systems as back-ends used by the parties collaborating at the Master Planning Level imply one central requirement for the coordination scheme: Since Advanced Planning System can only cope with deterministic / low-variance problems, the issue to be coordinated must be deterministic, too. This excludes the coordination of services with stochastic elements in the model, such as intensity-rate models where defaults are modelled as stochastic processes.

Nonetheless, services that can be modelled as a deterministic activity using or blocking resources or transferring commodities, such as preventive maintenance and transportation services can be considered by APS. From a mathematical point of view, a distinction between services and materials is not required, as long as both can be modelled as an abstract activity.

In this regard it should be stressed that usually only single objective problems are within the capabilities of APS, or at least problems, where the different objective are combined into a single function via a weighted sum.

To enable collaboration from a technical point of view, a collaboration protocol defining standard steps of negotiation activities including alert messages and data transmission is an important precondition. In general, it must be ensured that items exchanged between the partners are correctly mapped within each APS, which can be a hard task if different systems are used.

[8] Only requested / confirmed number of delivered materials in each bucket is transmitted, not the exact time of shipping.

Even in trusted relationships, partners will not disclose their critical data. This includes information such as detailed production and storage costs or machine load. This requires the APS of the collaborating partners to be linked by delivery / supply plans, whereas non-sensitive cost information and constraints of variables in the domains of supply / order proposals might be exchanged in addition. This could be detailed orders for the next days as well as a contractual defined delivery corridor with upper and lower bounds for the next years. In further steps, it will be agreed upon practical most relevant scenarios in close cooperation with Solution Management and SAP customers.

It is of utmost importance that the coordination mechanism sustains a lasting development of trust among the partners. The mechanisms to be developed should not lead to any incentive for opportunistic behaviour or fraudulent activities that would decrease practical acceptance.

It should be clear, that the alteration of plans must lead to a win-win situation for all involved partners; otherwise changes to the current plan will not be accepted. Only proposals which lead to a decrease of total costs are possible candidates, such that partners with a local cost increase can be compensated in an adequate manner.

In practice, Advanced Planning Problems are of considerable size and it is likely that a solution of acceptable quality needs long computation times. The coordination mechanism should not unproportionately further prolong the planning process and the amount of user interactions should not exceed an appropriate level. A kind of coordination cockpit – extending existing APS modules by providing an overview about most relevant performance indicators of the collaboration process – might ease user interaction. To increase the acceptance of coordinated results for the user, the collaborative planning process must not end up with a solution that has an obvious improvement potential. Negotiated results should not be virtual, intermediary proposals, but rather hard commitments, such that the negotiation scheme can be aborted at any time. In order to obtain a surveyable planning procedure, the coordination mechanism should focus on a small number of collaboration points, i.e. only the main partners should be involved in the collaboration process, whereas the focus should lie on the relevant costly products or services causing the bottlenecks in production and distribution.

A further difficulty is introduced by the use of virtual costs for planning purposes, e.g. huge penalties for lateness. Inter-organizational plans, coordinated on virtual costs can give a wrong picture of the real situation. Relating virtual costs to real cash-flows between the partners (if required) is a challenging task, however this is within the responsibility of the planner and can not be corrected by the coordination mechanism.

Although prototypes first have to be tested on considerable small inter-organizational supply networks the coordination mechanism for collaborative planning should be extensible to larger networks. Moreover, the quality of results of coordination should not depend on the underlying data, i.e. the coordination mechanism should also be extensible to further planning scenarios and use cases.

A common problem for real world-problems is that the solution quality is often bounded by the available computation time such that branch-and-cut techniques or Evolutionary Algorithmms can have an unpredictable solution quality. For example, even a slight, “unimportant” change in the constraints or objective function might lead to another search path of the algorithm that ends with a totally different solution for the same limited run-time. Such effects can hamper the convergence of a coordination mechanism and need closely to be watched: On the one hand, even a better solution might be considered as worse since the search space could not fully be evaluated. On the other hand, even for a solvable LP, a slight change within the delivery plan can lead to a totally different production plan, such that the planner might not be capable to evaluate the outcome of the coordination mechanism.

A built-in mechanism that prevents the search process to get stuck at local optima can increase the quality of negotiated solution. To speed up the coordination, an exploration and exploitation of possibilities during a fast evaluation by parallel computation of proposals, as well as the use of aggregation and decomposition techniques is deemed of substantial importance. In addition, a fixation of decision variables considered to be already globally optimal, might be a promising strategy to further decrease run-time.

The coordination mechanism should be as generic as possible and has to support complex NP-complete problems such as Mixed Integer Linear Programs for mid term production and distribution planning, Job-Shop scheduling for short term production planning and Vehicle Scheduling and Routing for short term transportation planning. In particular, for Job Shop Scheduling and Vehicle Scheduling and Routing problems in real world applications metaheuristics like Evolutionary Algorithms show much better performance than common MILP solvers. In these complex planning scenarios we cannot expect optimal solutions in the given run time (typically less than an hour) and we need robust coordination schemes with "graceful degradation" in case of suboptimal planning solutions of each partner.

To guarantee a high practical relevance, real world planning data should be used for the purpose of testing and verification. To be able to connect prototypes representing different planning domains and functionalities, a communication structure including a data transfer or “negotiation” protocol is necessary.

As already mentioned in the grid-framework could be adapted for the implementation of a prototype based upon SAP SNP, PP / DS or TP / VS. Here, the master would handle the data transfer between the slaves, each of them representing an own planning domain of the supply chain. This way, a mapping of products between the partners can be easily implemented within the prototype.

Summarizing and concluding the above, the following properties are of crucial importance for a coordination mechanism:

- Support of (deterministic) complex planning problems, such as Master Planning, Vehicle Routing or Detailed Scheduling.
- Closure of sensitive data between the partners.
- The scheme should be unassailable by opportunistic counteractions.
- A negotiation protocol defining standard alerts and messages is of practical importance.
- The mechanism should be tested on real-world planning data.
- For huge problems, a global solution is not guaranteed. However, negotiating on suboptimal solutions can hamper the convergence to the global SC-wide solution. To decrease the effect of extreme suboptimal outliers further means are required. For instance, a parallel generation and evaluation of several proposals at each iteration might stabilize the negotiation procedure leading to a more robust scheme.
- The process of proposal generation can be speed up by including aggregation and decomposition techniques or by a fixation of parts of the problem as well as using grid-computing.

- Convergence to the global SC optimum should be fast and extensive requiring only limited amount of user-interactions.

4 Analysis of Proposals from Literature for Coordination Mechanisms

Within this chapter several coordination mechanisms from literature will be analysed to get an overview about the status quo of research in this area. In section 4.1 a typology of CP will be developed that characterises the initial planning situation and the CP scheme separately. According to the outlined criteria a couple of approaches will be classified and documented in respective tables (see Tables 1, 2 and 3).

During an intensive literature research few articles on coordination schemes for services could be found. Since no substantial differences for the design of CP schemes of either handling deterministic services - which is the topic of work package 7 (cp. chapter 3) - or production processes have been identified our investigation will focus on all CP schemes in literature without regard whether they have been developed for services or not.

In section 4.2 the approaches are grouped according their basic ideas and the most important ones are described in more detail. Based on the findings of this section a recommendation for a CP interface for SC at the Master Planning level of an APS will be given in chapter 5.

4.1 Development of a Typology for Collaborative Planning

A first taxonomy in the area outlined above has been advocated by Whang (1995). He first discriminates organizational units according to coordination "within operations", "cross-functional" and "inter-organizational". The second criterion relates to the behaviour of the people in the organization, namely "single-person perspective", "team perspective" and "nexus-of-contract perspective". A single-person perspective incurs the advantage that there is a single decision making unit who has access to all relevant information. In the team perspective each party has limited information and action sets. This requires to communicate and to coordinate activities to achieve the global (team) objective. I.e. in the team perspective the organizational units act separately but share the same objective. This is in contrast to the "nexus-of-contract perspective" where there are separate decision making units with private information and individual goals (self-interest). For each of the resulting nine subcategories Whang presents examples from literature. One of his conclusions is that in 1995 the research in Operations and Information Management has heavily leaned towards the single-person perspective of organizations.

In this chapter we will further elaborate the two subcategories defined by "inter-organizational coordination" and "team-perspective" as well as "Nexus of-contract perspective". Since the latter involves multiple organizations and has no relevance to a single organizational perspective Whang (1995) renamed it into "inter-organizational interaction".

Although the taxonomy of Whang (1995) is a first attempt to categorize different types of coordination it does not span the large variety of characteristics necessary to describe CP schemes. Subsequently, we will present a framework (synonym "typology") of CP schemes intended to describe their main characteristics as observed in the literature in greater detail. Still, we do not claim to have extracted all possible characteristics in its totality as would be required for a classification (see Dyckhoff and Finke 1991, for a discussion of these terms).

Ideally, a CP scheme should contain a set of activities and rules applicable to a wide range of decision problems. However, CP schemes presented in the literature often are closely linked to a specific decision problem and are limited to a certain solution method (like analytical optimization). Hence, we will make a distinction between,

- the structure of the SC and the relationship among SC members (subsection 4.1.1),
- the decision situation facing each partner (subsection 4.1.2) and
- the characteristics of the CP scheme itself (subsection 4.1.3).

Separating these areas allows both to relate and to abstract the CP scheme from the application area and to cluster those application areas where CP schemes are already available.

4.1.1 SC Structure and Relationships Among SC Members

The structure of the SC constitutes a major factor for CP and the complexity of aligning plans. Furthermore, the behaviour of SC members will have an influence on the type and validity of the information exchanged. Thirdly, there maybe an objective to be followed by the supply chain as a whole including the notion of fairness. These issues will be described in the following (see Table 1):

Number of SC Members and SC Tiers

The easiest situation, where collaboration can be applied is a two party situation, usually termed a supplier and a buyer (depicted by “1-1”). In general one has to mention the number of tiers considered and the number of partners n_i (individual planning domains) on each tier i (where i=0 depicts the partner most downstream of the SC).

Assumptions about the partners’ behaviour

The assumptions about the partners´ behaviour comprise the following issues:

- the power of each partner in the SC,
- the extent of self-interest governing a partners´ behaviour,
- the consideration of learning effects and rolling schedules.

The power of a partner and its relative position in a SC may result from different sources, like

- product and (production) process know how,
- number of competitors,
- portion of the value creation with respect to the value of the final product,
- access to the customer base (market) and
- financial resources.

Listing and describing these attributes is rather simple, however, measuring power is much more difficult. Furthermore, the distribution of power may and usually will change over time, it may even change in the course of a single instance of collaboration.

In the literature on CP the notion of power is usually not discussed in detail explicitly. However, the premises and the CP schemes may reveal in which way a partner will make use of her power. Still, generalizations often are impossible: For instance a partner making the first offer may on the one hand fix her minimum profit while on the other the proposed (initial) plan will contain information which may be exploited by the other partner when making a counter proposal.

The extent of self-interest governing a partners’ behaviour has already been mentioned in the introduction when referencing the taxonomy of Whang (1995). Here, we will discriminate the three terms *team behaviour*, *self-interest* and *opportunism*. A definition of these terms will be based on Williamson (1979) but adapted to the context of CP. Consequently, a team behaviour exists if all actions (or decisions) required by the CP scheme are accepted, irrespective of the partners´ individual interests. Self-interest applies, if partners disclose truthfully the information requested by the CP scheme but only implement actions which are in their own interest. Finally, opportunism prevails, if partners only implement actions which are in their own interest (like self-interest) but may be cheating when passing information to others.

Looking at the literature it is not easy to state the extent of collaboration exactly. Obviously if a CP scheme works in the case of opportunism it will also do if there is self-interest (but not necessarily vice versa). According to a survey by Landeros and Monczka (1989) a supplier-buyer partnership rests (among other things) on a trustworthy commitment of future conduct. Hence, their findings can be attributed to self-interested partners, a setting which is assumed only by Dudek and Stadtler (2005) so far. All other proposals listed in Table 3 either assume a team perspective (Banerjee 1986, Ertogral and Wu 2000, Zimmer 2004, Gjedrum et al. 2001, 2002) or opportunism.

Rolling schedules play a role in the planning phase. It is most popular in industry in order to cope with uncertainty (e.g. of demand). In a SC setting this not only involves updating and extending an existing plan at one partner but to renegotiate all changes with all other partners affected by e.g. a change in demand. One question here is, who will bear the costs resulting from these changes if there is already a previously agreed upon plan in force? The majority of papers assumes that a plan once agreed upon will be executed unaltered up to the planning horizon (an exception is Dudek 2004).

Closely related to rolling schedules is the notion of learning effects. If the negotiation procedure is repeated, then a party may make use of information gained in previous negotiations. This is especially true if there is an overlap of decisions in two successive plans (like in rolling schedules). In the extreme this may lead to a totally different situation, like in Corbett and de Groote (2000): once the buyer has decided to choose a specific purchasing contract all data is revealed to the supplier. Thus there is no renegotiation and the conditions of the contracts must last “forever” (Corbett and de Groote 2000).

Objective(s) of the SC

The objective governing the generation of plans in the CP scheme should not be mixed with the partners’ individual objectives. Here, we are interested in the way the – often conflicting – objectives are handled. We discriminate three broad types of objectives:

- the search for the SC optimum,
- the search for a fair solution and
- the acceptance of a bias for some partner(s).

Aiming at the SC optimum often means maximizing profits for the SC as a whole. Such a solution may incur a loss for some partners and high profits for some others. In these cases side-payments or discounts may become an issue to yield a win-win situation for each partner.

Searching for a fair solution requires a definition of the term *fair*. As it turned out during the literature research there are different understandings about fairness (cp. Ertogral and Wu (2000) and Gjerdrum et al. (2001, 2002)) selective ideas will be presented in chapter 4.2.

Finally, if the distribution of power in a SC is uneven a bias regarding the allocation of savings or profits for some (powerful) partners may result. Still, this may coincide with finding a SC optimum, however, the efficiency gain rests solely by some powerful partners.

SC Structure and Relationships Among SC Members	Structure of the partners involved	Postulated behaviour of the partners (opportunism, self-interest, team)	Objective(s) of the SC (alignment of flows bias/SC optimum/ fair solution)	Consideration of rolling schedules?
Monahan (1984)	1_1	opportunism	SC optimum	no
Banerjee (1986)	1_1	team	SC optimum	no
Lu (1995)	1_n_0	opportunism	bias	no
Corbett/de Groote (2000)	1_1	opportunism	bias	no
Sucky (2004)	1_1	opportunism	bias	no
Barbarosoĝlu (2000)	1_n_0	opportunism/team	SC optimum/fair solution	yes
Ertogral/Wu (2000)	$n_2\_n_1\_n_0$	team	fair solution	no
Zimmer (2004)	1_1	team	SC optimum	no
Dudek/Stadtler	1_1, 1_n_0	self-interest	SC optimum	yes
Fink (2003/2005)	1_1, n_1_1	team	SC optimum	no
Fransoo et al. (2001)	1_n_0	opportunism	SC optimum	no
Gerchak/Wang (2004)	n_1_1	opportunism	SC optimum	no
Cachon/Larivière (2005)	1_1, 1_n_0	opportunism	SC optimum	no
Gjerdrum et al.	$...n_2\_n_1\_n_0$	team	fair solution	no
Jung et al. (2005)	1_1	opportunism	SC optimum	no

Explanation: n_i number of partners at SC tier i

Table 1: SC Structure and Relationships Among SC Members

4.1.2 Characteristics for Discriminating the Decision Situation

Characteristics for discriminating the decision situation considered in the literature fall into three broad categories which stem from answering the following questions for each partner: What is decided when, with which information and which objectives? Due to the fact that within the InCoCo-S project only coordination mechanisms at the operational planning level are of interest, the question "when" can be left out for further examination. The resulting three W´s of CP will be described in greater detail in the following (Table 2 lists these characteristics for the CP schemes considered here).

What Are the Decisions to Be Made?

Here the real world decision situation (planning tasks) of each SC partner should be described. However, for the sake of generalization, it seems more appropriate to consider the resultant decision model(s) as mentioned by the authors.

Often it is assumed that each partner in the SC faces the same type of decision model, e.g. both the supplier and the buyer deploy a static Economic Order Quantity (EOQ) model for a single product from which the buyer derives his order quantity while the supplier determines his production orders. But there are also examples where SC partners face different (basic) decision situations best described by the well-known models Resource-Constrained-Project Scheduling Problem (RCPSP) for the buyer and a Capacitated Lot-sizing Problem (CLSP) for the supplier (e.g. Zimmer 2004).

We would like to add that in the course of collaboration both the goal(s) as well as the action set of a partner may change. This may require additional constraints which often destroy the "typical" structure of a standard decision model. As a result the solution technique applicable for the standard decision model may no longer be applicable. As an example consider the EOQ model where the non-linear objective function can be minimized by taking the first derivative. In a situation where a supplier would like to generate a menu of supply proposals to be presented to the buyer additional constraints result. Now the constrained non-linear optimization model requires the application of the Karush-Kuhn-Tucker conditions (e.g. Sucky 2004).

The complexity of describing CP schemes becomes clear when dealing with the decision problem at hand. For each decision problem there may exist a classification or typology (e.g. for the RCPSP see Brucker et al. 1999, for lot-sizing see Drexl and Kimms 1997). Further typologies for decision problems in the area of production have been put forward which so far have not been addressed in conjunction with CP schemes (e.g. cutting and packing (Dyckhoff and Finke 1991) and assembly line balancing (Boysen et al. 2006)).

What Is the Information Status of Each SC Partner?

The information status in an inter-organizational collaboration normally will be asymmetric, i.e. a situation where the SC partners do not have the same state of knowledge (Schneeweiss 2003). The reasons for asymmetric information may be manifold. On the one hand there are practical reasons, like administering a decentralized database may be more economical and faster than a central database. Also, information gathered by employees may remain their expertise. On the other hand some information may be disclosed from the other SC partner(s) in order not to weaken the (future) bargaining power (e.g. disclosing large slack capacities at the suppliers side may inspire the buyer to ask for price reductions).

Another aspect regards the type of information to be exchanged. Here, one can discriminate three subcategories:

- quantities (like purchase orders or supplies for a product),
- monetary values (like cost data),
- key performance indicators (KPI´s).

As monetary data we may have data directly applicable for decision making (like a product’s holding cost coefficient or penalty costs for late delivery). Another type of monetary values are the total costs of a “plan” (which may also be regarded as a KPI) or a side-payment or compensation requested for accepting a SC partner’s proposal. Cost data usually are regarded as sensitive data, i.e. data that can do harm to the owner of the data if it is exploited by a third party.

The third sub-category, the KPI´s, form an important constituent of a SC partnership and are often agreed upon at the start of a SC partnership. KPI´s are calculated continuously or in certain intervals of time and serve to measure whether the SC is still operating as expected.

A final discrimination of the data is its degree of certainty. A decision model facing a SC partner may contain uncertain data due to the environment (like currency changes) or due to the behaviour of SC partners. The latter has been addressed in the SC literature very often and various ways to overcome this source of uncertainty have been proposed (e.g. the uncertainty of demand of a supplier can be reduced by transferring the buyer’s production plan in a VMI situation (see Holweg et al. 2005)).

Looking at Table 2 one can observe that CP schemes make use of nearly all subcategories except the exchange of KPI´s (which is addressed by Jammernegg and Kischka 2005). Obviously, a CP scheme will be more attractive to SC partners the less sensitive the data are exchanged.

What are the Objectives of the Decision Problem?

The last category concerns the objective(s) of the decision problem a SC partner is in. We distinguish either profit maximization (e.g. Cachon and Larivière 2005) or cost minimization (e.g. Dudek and Stadtler 2005) as the prevailing objective functions. If a standard decision problem (e.g. EOQ) is considered then the objective is also standard (e.g. minimization of the sum of setup and stock holding costs per unit time for the EOQ). A time-oriented objective function has only been observed in Fink (2003) where the objective of one partner is to minimize throughput times.

A multi-objective decision problem has not been tackled so far. However, when incorporating the decision models described in this section into a CP scheme then several objectives may be pursued (e.g. a goal programming approach is used by Dudek and Stadtler (2005)). But these extensions are the topic of Section 4.2 where we provide a detailed analysis of proposals from the literature for CP schemes.

Characteristics for Discriminating the Decision Situation

	Model(s) describing planning tasks of the partners	Which data are known?	Which data are uncertain?	Which data are unknown?
Monahan (1984)	EOQ	all data	-	-
Banerjee (1986)	EOQ	all data	-	-
Lu (1995)	EOQ	demand and order interval buyers	-	setup and holding costs buyers
Corbett/de Groote (2000)	EOQ	demand and setup costs buyer	holding costs buyer	-
Sucky (2004)	EOQ	demand buyer; setup and holding costs buyer types	probability of the buyer types	-
Barbarosoğlu (2000)	CLSP/ LP (production and inventory decisions)	all except for market demand	market demand the buyer is faced with	-
Ertogral/Wu (2000)	MLCLSP	-	-	all
Zimmer (2004)	RCPSP/CLSP	all except for the capacities of the supplier	capacities of the supplier	-
Dudek/Stadtler (2005/2006)	MLCLSP	primary and secondary material requirements buyer	-	all except of material requirements buyer
Fink (2003/2005)	MIP (sequence planning)	-	-	the explicit utility function
Fransoo et al. (2001)	inventory models ((R,S)-policy)	holding costs of one part of the buyers; required service levels of the other part	market demand the buyers are faced with	holding costs of one part of the buyers
Gerchak/Wang (2004)	newsvendor	all except for market demand	market demand the buyers are faced with	-
Cachon/Larivière (2005)	newsvendor	all except for demand buyer	market demand the buyer is faced with	-
Gjerdrum et al. (2001/2002)	MIP (production, inventory and transportation decisions (linear) and transfer prices (discrete))	all	-	-
Jung et al. (2005)	LP (production, inventory and transportation decisions)	-	-	all

Explanation: - none

Table 2: Characteristics for Discriminating the Decision Situation

4.1.3 Characteristics for Discriminating Collaborative Planning Schemes

When describing the characteristics of CP schemes we are interested in which way coordination takes place. There are a number of characteristics discriminating CP schemes (see Table 3), namely the

- incorporation of a mediator,
- number of offers to be exchanged (and the stopping criteria),
- number of parallel proposals,
- allocation of gains among SC partners and

- guarantee for finding an optimal solution.

Incorporation of a Mediator

A mediator is a third party controlling the rules of the game, e.g. by controlling the (timing of) interactions among partners. A mediator may have the capability of generating plans and presenting these to all SC partners for evaluation and even may be entitled to propose the allocation of efficiency gains among SC partners. An important issue is the proliferation of data to a mediator required for generating plans for the SC as a whole, i.e. a mediator must be a trusted entity. In industrial practice such a mediator in the area of planning has become known as an application service providing company (Knolmayer et al. 2002). So far, a mediator has rarely been considered in the literature on CP (with the exception of Ertogral and Wu 2000, Fink 2003).

Number of Offers (and stopping criteria)

The expected number of offers to be exchanged in the course of negotiations largely differs among CP schemes analyzed. There may be "none" if there is only one instruction by one partner the other partners have to follow. This is the case of "no coordination". Limited coordination exists if there is an offer or a menu of offers where the other party has the right to choose from - known as "take-it-or-leave-it" (see Corbett and de Groote 2000, Sucky 2004). The main distinction is between a small and a large number of offers expected in the course of CP. The number is regarded "small", if each offer (or plan) can be evaluated by a human decision maker before it is presented to the other partners in the SC. If this is the case then an interactive CP scheme can be designed, otherwise the CP scheme must be automated (like in the case of Fink 2003). One can assume that an interactive CP scheme with a small number of offers (e.g. at most ten) increases the chances of acceptance by the decision maker(s).

Number of parallel proposals

In a standard CP scheme *one* offer at a time is exchanged among two neighbouring SC members. Then the number of offers generated in the course of collaboration is twice the number of *iterations*. In order to reach a compromise solution among SC members more quickly one could also generate and present several (n) proposals in each iteration to the other members.

Whether the number of parallel proposals reduces the number of totally generated plans depends on the CP scheme and type of decision situation. However, in some cases not only the effort of generating plans may be important but also the decision situation itself: e.g. in Sucky (2004) the supplier may only propose the conditions for collaboration at one point in time. Now, the number of parallel proposals resembles the different types of cost structures assumed possible for the buyer.

Allocation of gains among SC partners

Gains achieved via engaging in CP may accrue by reduced costs or increased profits – if monetary objectives are considered. Additionally, one may look for an increase in product or service quality (e.g. on-time delivery). Subsequently we will concentrate on monetary objectives. Two broad types of CP schemes can be identified: one where there are no compensations at all and one where compensations between SC members are expected.

If there are no compensations then each SC member has to bear its own costs resulting from the SC plan agreed to. This may result in an unequal distribution of gains among SC members. Some members may even face losses by collaborating – thus violating the win-win paradigm of collaboration. In order to prevent this from happening the generation of proposals must take into account some kind of fairness (as has been proposed by Ertogral and Wu 2001). However, this results in a multi-objective decision problem, where a pure SC optimum generally does not exist. Even more important, numerical experiments by Ertogral and Wu (2001) have shown that incorporating fairness may increase SC costs significantly thus jeopardising competitiveness of the SC.

Hence, compensations or side-payments seem to be a much better way for CP. Here one can aim at reaching the SC optimum (either costs or profits) and subsequently to achieve fairness by providing side-payments to some members. Still the issue of what is regarded a fair solution remains. CP schemes can be further distinguished with respect to the determination of the extent of compensations to be paid to a partner: Some approaches (like Banerjee 1986 or Sucky 2004) explicitly calculate a proposal for compensations as part of the CP scheme while others postpone negotiations about actual compensations to a subsequent step. E.g. in the CP scheme of Dudek and Stadtler (2005, 2006) minimum compensations are exchanged between partners. However, as these will only preserve the status quo of one partner there may be subsequent negotiations about the ultimate allocation of the gains of collaboration (which is not part of their paper).

<u>Guarantee for finding an optimal solution</u>

The general aim of a SC is to improve competitiveness which may have several dimensions (criteria). If there is one prevailing objective to be optimized, like profits or costs, then an optimal solution may be looked for. The optimal solution is often regarded as a “central” solution for the SC as a whole. I.e. the central solution serves as a benchmark for the solutions generated by a CP scheme.

Proving optimality of a CP scheme often is only possible in a restricted decision situation (like in Monahan 1984 or Cachon and Larivière 2005). Although “securing optimality of solutions” is a nice characteristic of a CP scheme, one might argue that this will not exist in practice due to the unavailability of the data required for generating a central solution. Even more, it might be possible that the alignment of decentrally generated plans may result in a better solution than an “optimal” central plan, namely in case the decentral decision making units dispose of more accurate data.

In summary, it is appealing to prove optimality of an CP scheme. However, in practice it should suffice that a CP scheme improves the initial, uncoordinated solution significantly while requiring acceptable (computational) efforts.

Finally, the reader may be interested in the exact method used for deriving a solution for the SC (e.g. a meta-heuristic, mathematical programming). Therefore the reader is referred to the following section in which selected approaches are presented in more detail or to the papers listed in the references.

Characteristics for Discriminating CP Schemes	Mediator (yes/no)	Number of offers (0,1, n_{small}, n_{big})	Number of parallel proposals (0, 1, n)	Existence of compensation payments?	Determination of partners' final profits (utilities) by the scheme?	Guarantee to reach the SC optimum?
Monahan (1984)	no	1	1	yes	yes	yes
Banerjee (1986)	no	0	0	yes	no	yes
Lu (1995)	no	1	1	yes	yes	no
Corbett/de Groote (2000)	no	1	n	yes	yes	no
Sucky (2004)	no	1	n	yes	yes	no
Barbarosoĝlu (2000)	no	1	1	yes	yes	no
Ertogral/Wu (2000)	yes	$n_?$	1	no	yes	no
Zimmer (2004)	no	1	1	yes	yes	no
Dudek/Stadtler (2005/2006)	no	n_{small}	1	yes	no	no
Fink (2003/2005)	yes	n_{big}	1	no	yes	no
Fransoo et al. (2001)	no	0	0	yes	no	no
Gerchak/Wang (2004)	no	1	1	yes	no	yes
Cachon/Larivière (2005)	no	1	1	yes	no	yes
Gjerdrum et al. (2001/2002)	no	0	0	no	yes	yes
Jung et al. (2005)	no	n_{small}	1	no	yes	no

Table 3: Characteristics for Discriminating CP schemes

4.2 Detailed Description of Most Important Ideas for Coordination

As a basis for the recommendations in chapter 5, the most important ideas for a coordination scheme are examined. For each one of them, the description is structured as follows: at the beginning, the default situation is characterised, in which the problem of double marginalization leads to a suboptimal outcome for the SC. After that, the concepts for establishing coordination are explained. At the end, the most important advantages and disadvantages will be highlighted.

4.2.1 Coordination by Centrally Imposed Solutions

In the first category of this chapter coordination by centrally imposed solutions is addressed. The significant criterion of approaches of this type is that the solutions are generated by one central decision maker and understood as an instruction i.e. there is no possibility to reject the result of the centre. Collaboration here consists in the revelation of all necessary information and the acceptance of the generated solution. A means for improving the acceptance of the solution is the generation of a solution that can be regarded as "fair" for all SC partners. As an example for this, the approach of Gjerdrum et al. (2001, 2002) will be described in more detail, where coordination with respect to fairness is achieved by solving one central mathematical programming (MP) model.

Other approaches, which focus primarily on establishing coordination and leave open the question of the sharing of the savings, however, also have been proposed (e.g. Banerjee 1986, Fransoo et al. 2001). As an example, we want to describe shortly the idea of Fransoo et al. (2001), which considers the interesting situation of asymmetric information and the existence of both cooperative and non cooperative groups in a SC.

<u>Coordination with Asymmetric Information and the Existence of Both Cooperative and Non-Cooperative Groups in a SC</u>

As their *initial situation,* Fransoo et al. (2001) consider a divergent SC. Retailers' demand is stochastic and both the suppliers and all buyers are assumed to use an order-up-to policy for their inventory management. All SC members incur inventory holding costs. The buyers have to fulfil pre-specified service levels, otherwise they have to bear shortage costs. The supplier has to obey long-run service levels imposed by the retailers. If shortages occur, a linear allocation function is used by the supplier. Furthermore, different lead times for the delivery from the manufacturer to each of the retailers are assumed. Besides that, customer demand information is not known by the supplier. Only the required service levels are transmitted by the buyers.

An obvious *coordination scheme* in this setting is information sharing and integrated planning between the units. Fransoo et al. (2001) propose to do this and they consider the situation that the buyers are split into two different groups: on the one hand, there are some non-cooperative buyers, which only transmit their required service levels to the supplier. On the other hand, the cooperative buyers do not only share their data with the supplier, but also allow for an integrated planning of their inventory and the inventory of the supplier.

By means of an example, Fransoo et al. (2001) show that this seemingly simple scheme has to be applied carefully. For their analysis, they have developed an algorithm for decentralized planning in the setting with asymmetric demand information, but target service levels imposed by the suppliers (Fransoo et al. 2001). The details of this algorithm are omitted here.

First, they consider the case that planning is done in two separate models. That means, on the one hand, a central model for the cooperative buyers and the supplier is solved, and on the other hand, for the supplier and the non cooperative buyers, the above-mentioned algorithm is applied. A result of this analysis is that an improvement for the SC as a whole isn't necessarily achieved. Rather, in several scenarios, this procedure leads to a degradation compared to the default situation without collaboration. As a remedy, Fransoo et al. (2001) propose the following alteration: First, the central model for supplier and the cooperative group is solved. Then, the service levels resulting from this model are read out and used as input data for the above-mentioned algorithm, which is now applied for the whole SC. For their example, this alteration leads to considerably more favourable results.

An important *drawback* of the approach of Fransoo et al. (2001) is that the good performance of the proposed coordination scheme has not been proven for general settings. The results are only shown for one example, which cannot be seen as representative. What this analysis shows is that in quite complicated settings the coordination scheme employed has to be designed very carefully.

Central Coordination with Fairness as Objective

Concerning the approach of Gjerdrum et al. (2001, 2002), the underlying *initial situation* is the following: A general multi-tier SC is considered with multiple enterprises at each tier. To cover the inter-company price mechanism Gjerdrum et al. translate the terminology transfer price, commonly used for intra-organisational transactions, into an inter-company context: The prices for the products shipped from one company to another are called transfer prices and each company has a predefined number of transfer price levels to choose from. These prices are to be optimised (amongst others) and it is assumed that the companies accept them even if they do not match the current market prices.

The decisions about the production and transportation plans, the inventory and the transfer price levels are simultaneously determined by one central mixed integer programming (MIP) model. Thereby the objective is to fulfil deterministic customer demands in all periods and to maximise the total profit of the SC (i.e. the sum of the individual profits) whereas given minimum profit requirements of the companies have to be considered. These lower bounds can for example result from the given power structure. Gjerdrum et al. call this approach naive as the resulting profit distribution is normally not satisfying for all SC partners. The ex-post distribution of profits would always lead to discussions and is therefore not realisable. Because of the centralised decision making in a simultaneous model common information is required.

The aim of the *coordination mechanism* now is to reach a fair, implementable profit distribution and additionally to achieve a solution that is not significantly worse than the naive one. Regarding the definition of coordination given in chapter 2, the improvement should not be achieved with regard to profits (like in some other approaches specified next) but to fairness, thus assuming an underlying team situation.

But what is the supposed idea of fairness? Gjerdrum et al. adopt the definition of Nash (1950) who states that a fair solution, which will be accepted by rational partners, is characterised by the following four axioms: Pareto optimality, symmetry, scale invariance and independence of irrelevant alternatives. In the next chapters it will appear that there are different understandings about fairness (cp. Ertogral and Wu 2000, Fink 2003, 2005).

The Nash bargaining solution fulfils the postulated requirements: Given for each company $e \in E$ (with E the set of companies) the minimum profit requirements $\pi_e^{\min}$ as the status quo point, the fair solution point is $\pi \in \Re^{|E|}$ with:

$$\pi_e \geq \pi_e^{\min} \quad \forall e \in E \tag{7}$$

and maximising the Nash product:

$$\prod_{e \in E} (\pi_e - \pi_e^{\min}) \,. \tag{8}$$

Consequently the objective function of the naive approach is replaced by the Nash product resulting in a mixed integer non-linear programming (MINLP) model. This model is solved via a spatial branch and bound procedure (Gjerdrum et al. 2002) or alternatively by a separable programming approach (Gjerdrum et al. 2001).

Additionally Gjerdrum et al. (2002) introduce an improvement phase: First the fair solution is generated as described above. Subsequent the naive model is solved, but this time using the fair distributed profits as lower profit bounds in the model.

Computational tests for different SC settings show that a much more equally distribution of profits can be achieved. For a two enterprise example Gjerdrum et al. (2002) compare the SC profit of the naive and the fair solution and find out that in the latter case there is only a profit reduction of 3.36%. By performing the improvement phase the gap reduces to 1.58%.

Of course the fair profit distribution right from the start is one *advantage* of this approach. But there are also several *drawbacks* making this approach not realisable in practise: The acceptance of the inter-company transfer prices and especially the disclosure of all information have to be regarded critically. Gjerdrum et al. justify these assumptions in that way that they postulate a partnership but even in a partnership the partners are reluctant to make all information available for the partners. Alternatively it is proposed to commit all information to a mediator to avoid information sharing among the SC partners (Gjerdrum et al. 2002), but also then it is rather questionable whether companies are willing to do so.

4.2.2 Coordination by a Single Contract Offer

Now, we will consider the case that the SC partners explicitly take decisions on the actions they will implement. Here, contracts have to be applied in order to incentive the SC partner(s) (usually the leader) not to implement their individually optimal solution, but another one which establishes coordination of the SC. The partners that accept the contract receive a type of compensation, which assures that the profit obtained in the default situation, does at least not decrease. This compensation usually is given in monetary terms. Often, the contracts are established by a "take-it-or-leave-it offer", which means that the partners get one single possibility to accept the offered contract. In case of refusal, another pre-specified situation (often the default situation) is implemented.

In the following, we will describe three of the main ideas for coordination by contracts based on a one-time offer: ideas for coordination in a newsvendor-type setting, self-selection and hierarchical anticipation.

<u>Coordination in a Newsvendor-Type Setting</u>

The coordination schemes applied in a newsvendor-type setting aim to establish the SC optimal solution by offering additional incentives in form of compensation payments. Their particularity, in contrast to the ideas described further below, is that the concrete outcome is not fixed by the contract parameters, but only the incentives which should lead to the implementation of the SC optimal solution.

As the *initial situation* of a newsvendor-type setting a SC consisting of one supplier and one buyer will be considered. The supplier produces one good (with marginal production costs c_0) and sells it to the buyer for a wholesale price w. The buyer retails this product to an external market for a fixed price p.

In the uncoordinated case, planning is carried out as follows ("upstream planning", see e.g. Bhatnagar 1993, Dudek and Stadtler 2005 or also called "top-down planning" (Schneeweiss 2003)):

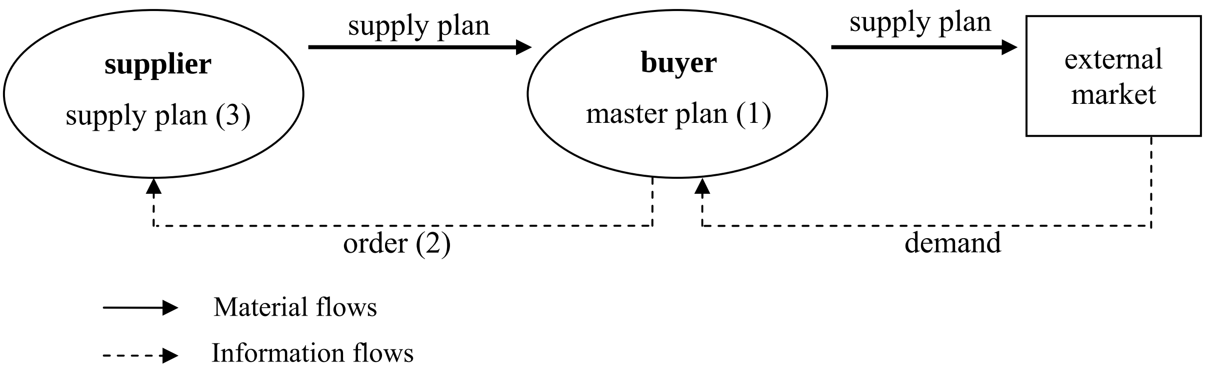

Figure 21: Upstream Planning

Within upstream planning, first, the buyer generates a supply plan which is optimal for his decision situation (1). For each planning period, he determines the amount of raw material necessary for carrying out this plan and submits a corresponding order to the supplier (2). The supplier uses this information for the generation of a supply plan optimal for his planning domain (3).

More specifically, in the setting analyzed here, the buyer faces a newsvendor problem (see e.g. Silver, Pyke and Peterson 1998): There is one single selling season and market demand *D* is stochastic with its distribution function *F* and its density function *f*. The quantity ordered by the buyer is denoted by *q* and the quantity sold to the external market by *S(q)*. Neither the demand of the buyer, nor the one of the external market, have to be fulfilled completely. Furthermore, the buyer has the possibility to sell leftover inventory for a salvage value *v*. The material and financial flows that result after the selling period can been seen in Figure 22.

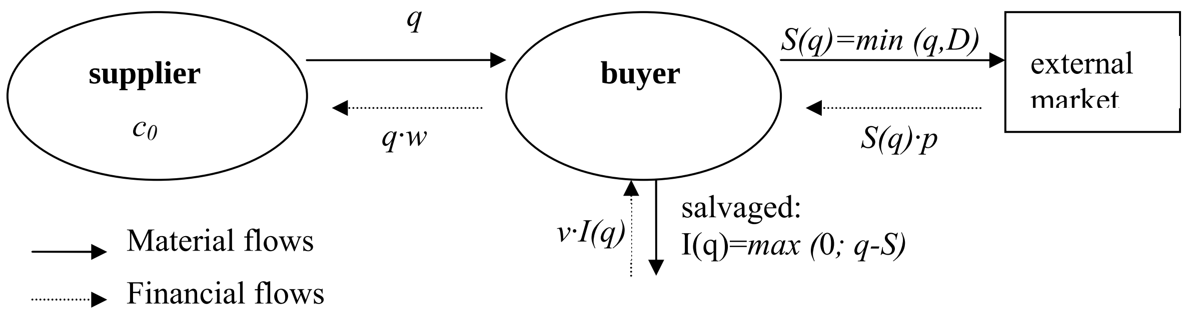

Figure 22: Coordination in the Newsvendor Model: Initial Situation

The suboptimality the SC is affected with in this default situation can be shown by analysing the optimization problems the partners are faced with. For the further, we assume that all data are known by both buyer and supplier. The problem of the buyer as the “newsvendor” is the determination of the order quantity *q*, which has to be decided on before the selling season begins and market demand is known. We assume that the objectives of the buyer and the supplier are the maximization of their own profits $\pi_b(q)$ and $\pi_s(q)$. The problem for determining the optimal order quantity of the buyer q_b^* can be formalized as follows (see e.g. Larivière 1999):

$$\max \pi_b(q) \tag{9}$$

$$\pi_b(q) = (p-w)q - (p-v)\int_0^q F(D)dt \tag{10}$$

$\pi_b(q)$ is made up by the profit in the case that all ordered units can be sold on the external market less the difference of selling price and salvage value for the salvaged units.

As this profit function is strictly concave, q_b^* can be obtained by means of differentiation of the profit function (for a mathematical derivation see Thonemann 2005):

$$q_b^* = F^{-1}\left(\frac{p-w}{p-v}\right) \tag{11}$$

A rational supplier, in this situation, would act as a Stackelberg leader (e.g. Holler and Illing 2003) and choose his profit-maximizing wholesale price with anticipation of the buyer’s behaviour. His optimization problem can be stated as follows:

$$\max \pi_s(w) \tag{12}$$

$$\pi_s(w) = (w - c_0)q(w) = \tag{13}$$
$$= (w\text{-}c_0)F^{-1}\left(\frac{p-w}{p-v}\right)$$

The question that now arises is whether a rational supplier would choose the wholesale price such that the profit of the whole SC, that means the sum of the profits of buyer and supplier, is maximized. For answering this, a simpler way than differentiating (13) is a comparison of q_b^* with the order quantity optimal for the SC q_{SC}^*. In analogy to q_b^* for the buyer, q_{SC}^* can be derived as:

$$\pi_{SC}(q) = (p - c_0)q - (p - v)\int_0^q F(D)dt \tag{14}$$

$$q_{SC}^* = F^{-1}\left(\frac{p-c_0}{p-v}\right) \tag{15}$$

When comparing (15) to (11), it can easily be seen that the only wholesale price which would induce the supplier to choose a SC optimal solution, is c_0. Such a choice, however, would lead to a profit of zero for the supplier and therefore would never be chosen by a rational supplier.

In order to improve this default situation, *coordination scheme*s in form of one-time contract offers have been designed. It could be shown that there exist various types of contracts (e.g. buy-back (Pasternack 1985), quantity flexibility (Tsay 1999), revenue-sharing (Cachon and Larivière 2005)), which lead to an optimal coordination of the SC. Here, as an example, we will describe revenue-sharing contracts which currently are used in the video retail industry (Cachon and Larivière 2005).

The idea which is common to all of these contracts is that the supplier offers to the buyer an incentive for choosing the SC optimal order quantity. Here, we consider that the supplier offers a lower wholesale price, but claims for compensation a share $(1\text{-}\Phi)$ of the revenue of the buyer. These contract parameters (w, Φ) have to be determined before the start of the selling season. As a result, the financial flows after the selling season are modified (Figure 23).

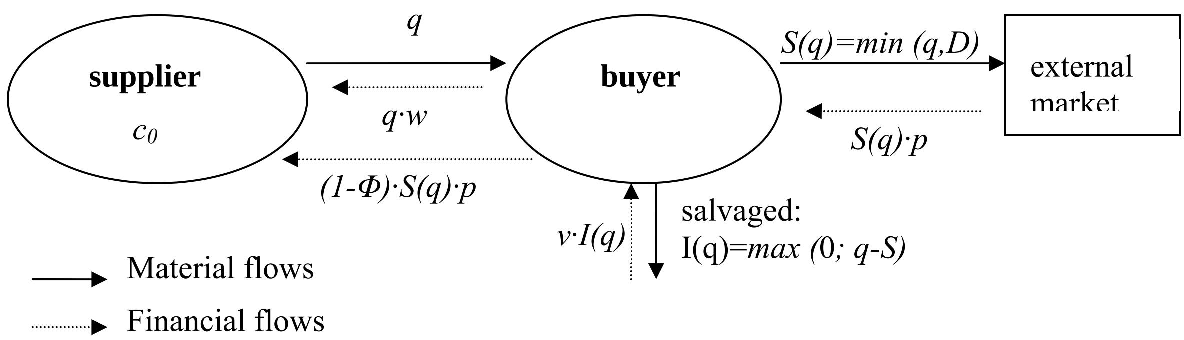

Figure 23: Coordination with a Revenue-Sharing Contract

It can be mathematically shown that a properly designed revenue-sharing contract leads to an optimal coordination of the SC independently from all other parameter as market demand etc. To demonstrate this, once again, the buyer's optimization problem has to be regarded. Now, the profit function of the buyer becomes:

$$\pi_b(q) = (\phi p - w)q - (\phi p - v)\int_0^q F(D)dt \tag{16}$$

q_b^* results now in:

$$q_b^* = F^{-1}\left(\frac{\phi p - w}{\phi p - v}\right) \tag{17}$$

A comparison of (17) with (15) leads to the following relationship of the contract parameters *Φ* and *w*:

$$\phi = -\frac{v \cdot (p - c_0)}{c_0 - v} + \frac{p - v}{p \cdot (c_0 - v)} \cdot w \tag{18}$$

Is it now possible that a rational, profit-maximizing supplier chooses the contract parameters as defined by (18))? It is, because, depending on the choice of the parameters *Φ* and *w* the profit of the supplier becomes a fraction λ (0≤ λ ≤1) of the profit of the SC (see e.g. Cachon 2003). As a consequence, a situation always can be encountered in which both supplier and buyer obtain higher profits than in the default situation. How this additional profit is distributed depends on the respective choice of *Φ* and *w* and can be determined by additional negotiations between the parties (Cachon 2003).

Now, what are the *advantages* and *potential drawbacks* of this collaboration scheme? A huge advantage is that for the basic situation here analysed and also a couple of extensions (e.g. several competing buyers (Bernstein and Federgruen 2005, Cachon and Larivière 2005) and several suppliers in an assembly system (Gerchak and Wang 2004)) an optimal coordination of the SC can be reached. It is important to note that this result holds independently from other assumptions concerning the probability distribution of demand or compliance regimes. Finally, these contracts exhibit a high degree of flexibility because the order and supply quantities are not fixed in the contract, but can be chosen freely in the selling period.

Drawbacks of this collaboration scheme are mainly the two following ones: At first, when applying these contracts as proposed, there is a considerable administrative burden, because the revenues of the buyer have to be monitored by the supplier. The hereby additionally incurred costs, however, do not always cover the gains from coordination (Cachon and Larivière 2005). Second, the field of application of these contracts is limited. On the one hand, this is due to the assumption, that for the partner proposing the contract, all relevant information (e.g. production costs) has to be available. This assumption may be valid for some SCs consisting of one producer and one retailer, but seems to be less likely for a buyer who himself adds significant value to the product sold. On the other hand, these approaches are primarily designed to cope with uncertainty of demand. Other extensions relevant for most planning problems, such as the trade of several products sharing constraint (production) resources, have not been covered.

Self-Selection

While the above presented coordination scheme aims to establish an optimal coordination of the SC, the intention of self-selection is different. In a situation of imperfect information, one partner offers a menu of contracts in order to establish a solution as best as possible for him-self, but without regard of potential improvements for the other SC partner.

Recently, some authors (Schenk-Mathes 1999, Corbett and de Groote 2000, Sucky 2004, Ca-chon 2006) have transferred self-selection, which has been first applied in the principal-agent literature (Salop/Salop 1976), to SC management. In the following, we will present this ap-proach on the basis of the paper of Corbett and de Groote (2000).

In the *initial situation* here, a SC is considered which consists of one buyer and one supplier. Note, that for ease of exposition, we drive the additional assumption that in each case trade is done between buyer and supplier (Corbett and de Groote (2000) consider the extension that the partners also can choose not to trade with each other). Demand is deterministic and con-stant and has to be fulfilled without shortages. In order to produce optimally, each partner has to solve an economic order quantity problem. Furthermore, a lot-for-lot production of the supplier and infinite production rates for both partners are assumed. The SC is driven by up-stream planning. The buyer as the leader determines the order quantity *q,* which minimizes his setup and inventory holding costs. The relevant data for this decision situation are dis-played in Figure 4.

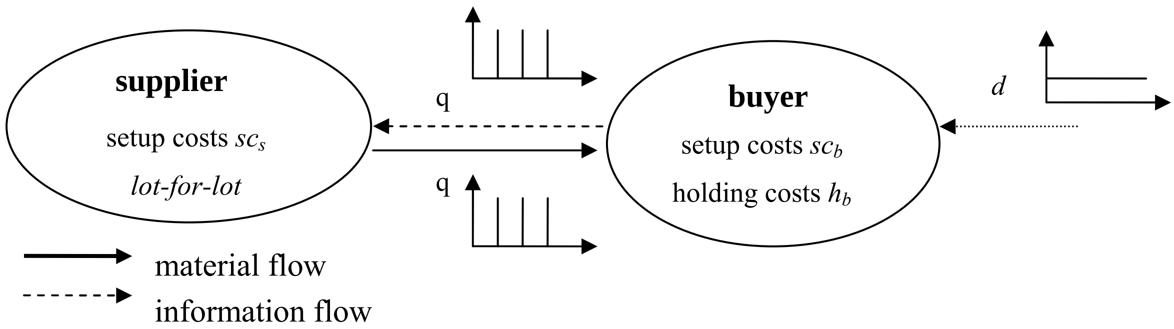

Figure 24: Default Situation of Self-Selection

Here, the problem of double marginalization becomes manifest in the discrepancy of the in-dividual optimal order lot sizes and the SC optimal lot size. The optimal lot size of the buyer can be calculated by the well-known EOQ-Formula:

$$q = q_b^* = \sqrt{\frac{2k_b d}{h_b}} \tag{19}$$

For the supplier, the optimal order lot size would only depend on his setup costs. This is be-cause the lot-for-lot policy doesn’t allow any inventory at the supplier. Therefore, the optimal lot size of the supplier would be infinitely high.

Easy to calculate is also the optimal order lot size for the whole SC (JELS, see Goyal 1976)

$$JELS = \sqrt{\frac{2(k_s + k_b)d}{h_b}} \tag{20}$$

With these relationships it can be seen that for $k_s > 0$ the optimal lot size of the buyer is al-ways smaller than the JELS. Therefore, the cost optimal solution for this SC cannot be reached without the help of any *coordination scheme.*

The coordination schemes described in literature mainly aim to improve the situation of the supplier as much as possible. With the assumption that all data is known by the supplier, Monahan (1984) proposed a coordination scheme based on a quantity discount. More specifically, the supplier offers a compensation payment *P* to the buyer for implementing the order lot size specified by the supplier. Later on, Banerjee (1986b) showed that Monahan's coordination scheme in each case leads to the SC optimal order lot size.

A more challenging problem for the design of a coordination mechanism comes up if some information is unknown to the supplier. One of the first approaches which covers this is the one of Lu (1995). It starts from the assumption that only the order cycle of the buyer and the maximum cost deviation from the buyer's optimal solution (the buyer is assumed not to accept a greater deviation) are known. Then, an optimization problem can be stated which intends to minimize the costs of the supplier with the restriction of this maximal buyer cost deviation. Here, however, when the accepted cost deviation is small, only small improvements can be reached because compensation payments are not considered.

The approach of self-selection, which we will describe in the following, seems to be more effective in a situation of imperfect information. Corbett and de Groote (2000) investigate the case that the supplier makes a take-it-or-leave-it offer to the buyer. If the buyer rejects, no trade between buyer and supplier takes place. They further assume that only the setup costs of the buyer and the demand are known. Concerning the holding costs of the buyer, only the probability distribution together with the lower bound $\underline{h_b}$ and the upper bound $\overline{h_b}$ (which can be deducted by the reservation profit tc^+ of no trade between buyer and supplier) are known.

This can be regarded as a principal-agent setting with adverse selection (Corbett and de Groote 2000). The supplier takes the role of the principal and the buyer the one of the agent. One possibility for the supplier to increase his profit in such a setting is *self-selection*. The supplier offers a menu of contracts $\left[q(h_b), P(h_b)\right]$, which is characterised by the fact that from the buyer's point of view each contract is optimal for a specific amount of h_b. Choosing the contract optimal for his decision problem, the agent reveals his true cost parameters (here: h_b). For the proper design of such a contract menu, Corbett and de Groote adapt a model elaborated within the principal-agent theory (Sappington (1983)) to their specific decision problem:

$$\min \; E_{h_b \le h_b^{\max}}\left[\frac{sc_s \cdot d}{Q(h_b)} + P(h_b)\right] + E_{h_b > h_b^{\max}}\left[tc_s^+\right] \tag{21}$$

s.t.

$$\dot{P}(h_b) = \left(\frac{h_b}{2} - \frac{sc_b \cdot d}{Q(h_b)^2}\right) \cdot \dot{Q}(h_b) \tag{22}$$

$$tc_b^+ \ge C_b\left(Q(h_b)\right) - P(h_b), \quad \forall h_b \in \left[\underline{h_b}; h_b^{\max}\right] \tag{23}$$

<u>Data:</u>

$h_b^{\max}$ Maximal amount of holding costs of buyer for which trade is profitable

<u>Variables:</u>

C_b Costs of buyer (sum of holding costs and setup costs)

The aim of this model is to find a contract menu minimizing the sum of the expected costs of the supplier in case of acceptance of one of the contracts and the reservation costs of no trade taking place (21). Constraints (22) are called incentive-compatibility constraints. They assure that in each case it is optimal for the buyer to choose the contract which is designed for his actual holding cost parameter. These constraints can be deduced by the derivation of the objective function of the buyer's decision problem. $\dot{P}(h_b)$ stands for the derivative of $P(h_b)$. Participation of the buyer is guaranteed by (23), which keeps the costs of the buyer below the reservation cost level for holding cost parameters smaller than h_b^*.

With the solution of this model, which will not be stated here, the optimal contract menu can be derived. Although this contract menu never leads to outcomes worse than in the default situation, the implementation of the JELS cannot be guaranteed (Corbett and de Groote 2000).

Other self-selection approaches which have been applied in the context of SC management propose contract menus based on discrete buyer types (and not on continuous ones as in Corbett and de Groote 2000). Such a contract menu has been developed by Schenk-Mathes (1999) for the determination of the selling price under imperfect information about the contribution margin of the SC partners. Sucky (2004) transferred this idea to the question of choosing the optimal order lot size in a SC. There are mainly two differences of the settings analysed by Sucky (2004) and Corbett and de Groote (2000). First, in the setting of Sucky (2004), the buyer already has made an order to the supplier. Second, the buyer knows setup and holding costs of some possible buyer types, but is uncertain regarding the real type of the buyer.

When looking at the assumptions of Corbett and de Groote (2000) (a similar reasoning is valid for Sucky 2004), the postulated knowledge about one of the cost parameters seems to be a very strong restriction for an application in practice. Furthermore, the holding costs of the buyer are mainly built up by the costs of capital. The costs of capital, however, can be deducted from the selling price of the supplied product and are therefore known. If, as a consequence, the holding costs of the buyer can be estimated with sufficient precision, the approaches of Corbett and de Groote (2000) and Sucky (2004) become unnecessary.

In spite of that, self-selection also has some remarkable *advantages*. First of all, this concept is valid for all possible assumptions concerning the behaviour of the buyer including opportunism. Second, the process of collaboration is very easy to implement, no complicated negotiation rounds are necessary. Third, in principle, the application of this concept isn't restricted to a specific decision situation. The possibility of a transfer to a more complex decision situation, however, has not been shown yet. One severe *drawback*, however, which one has to bear in mind, is that this concept does not aim at all to improve the situation of the whole SC. One consequence of this is that rather seldom a solution that is optimal for the SC as a whole is reached. And even worse, the thereby resulting "unfairness" could be an impediment for the acceptance of a contract menu derived with this approach by the other SC partners.

Hierarchical Anticipation

To achieve coordination Zimmer (2001, 2004) developed an approach to determine contract parameters with the help of hierarchical anticipation.

The *initial situation* Zimmer studies is a SC consisting of one buyer and one supplier in a hierarchical relationship: the buyer representing the top-level (TL) and the supplier the base level (BL). In this setting the buyer is faced with a deterministic market demand for multiple products over multiple periods and to fulfil these requests he places orders for the necessary components with the supplier. The amount delivered does not always match the orders but for a long horizon the total amount is contractually fixed. The supplier's external demand of components is supposed to be stochastic. This is resulting from the assumption that the supplier has several unspecified customers apart from the buyer explicitly considered.

There is private information, in particular the buyer does not know about the supplier's capacities and other conditions when placing the orders. Thus to control the behaviour of the supplier a penalty cost parameter K per unit is contractually established for not delivering the correct amount in time. An overview of the situation is given in Figure 25.

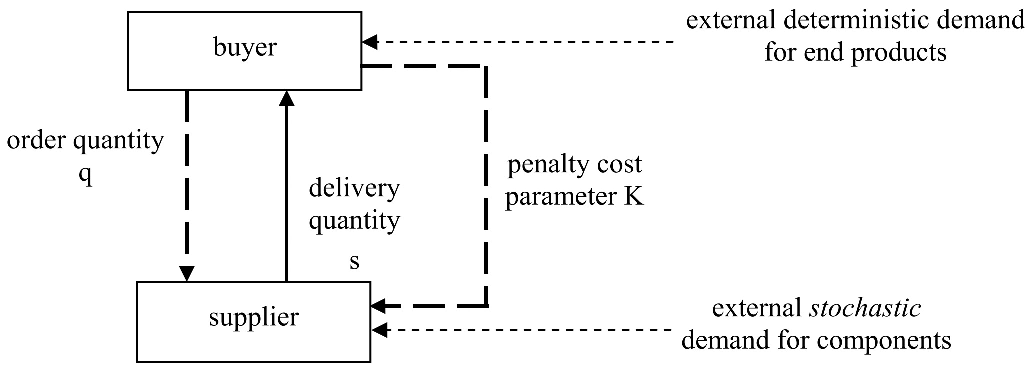

Figure 25: Buyer-Supplier Hierarchy, cp. Zimmer (2004)

Within this scenario both partners use mathematical programming models to plan their production, in particular the buyer is faced with a RCPSP, the supplier with a CLSP.

Summarizing the sequence of decisions is as follows (cp. Figure 26: Before the planning horizon the buyer decides about the ordering vector q and the penalty cost parameter K. Later in time but still before the start of the first period the supplier plans the production of the received orders. By now he got all requests from his customers and consequently the external demand (and following his capacity utilisation rate α_t in each period t=1..T) is known by him. With the beginning of the planning the buyer receives the supplies s_t in each period t and updates his optimal production plan also periodically in case of deviations. This default situation is a variation of the upstream planning presented in chapter 4.2.2. The supplier does not need to fulfil the order request. In case of a capacity bottleneck the he has the following possibilities to react: expand his capacity and/or build up inventories to secure timely delivery or accept penalties for delays.

In this initial situation the problem of double marginalization arises and leads to a suboptimal outcome.

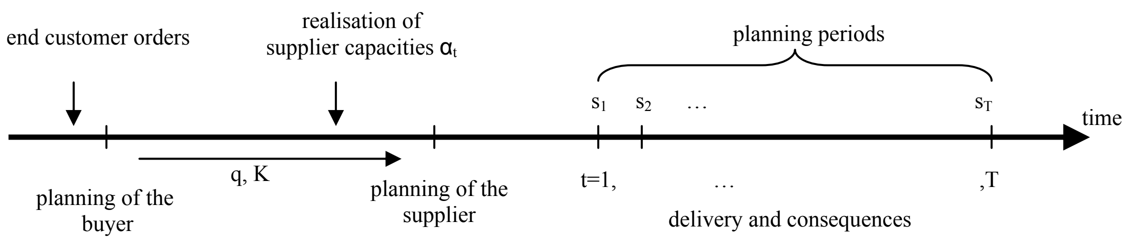

Figure 26: Upstream Planning: Sequence of Decisions, cp. Zimmer (2001)

The *coordination mechanism* developed by Zimmer is based on the theory of hierarchical planning (Schneeweiss 2003). Within this theory each level of the hierarchy is described by a decision model depending on a decision criterion $C^{TL/BL}$ and a decision space $A^{TL/BL}$ (with decision $a^{TL/BL} \in A^{TL/BL}$ of the top/base-level). Both levels are connected by a top-down and a bottom-up influence. The former one is the instruction IN i.e. in the given situation the penalty costs in combination with the order quantity vector. The bottom-up influence is the anticipation of the base-level behaviour taken into account by the top-level. If the anticipation is independent of IN it is called non-reactive. Otherwise it is represented through the anticipation function AF(IN), describing the possible reaction of the base-level to the instruction IN. This type of anticipation is called reactive and the associated function can also influence the decision criterion and space of the top-level. The concept is summarised in the upper half of Figure 27 (anticipations are marked by: ^, optimal values by: *).

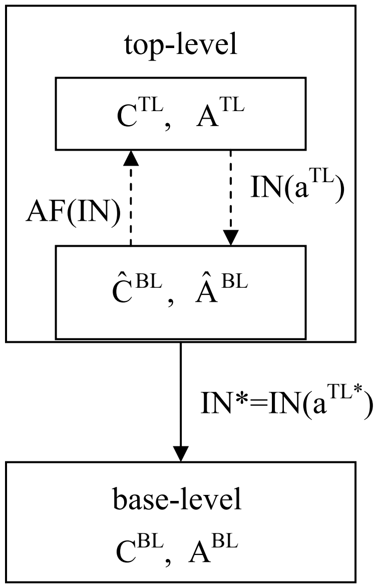

Figure 27: Hierarchical Planning, cp. Schneeweiss (2003)

For achieving coordination Zimmer considers both concepts of anticipation: non-reactive and reactive anticipation. Using non-reactive anticipation in the given situation the model of the top-level accounts for most important features of the base-level (in particular the capacity restrictions and an upper limit on the costs of capacity extensions the supplier will be willing to accept to ensure timely delivery); but no reaction to the instruction is taken into account. Contrary in the case of reactive anticipation: here the top level i.e. the buyer anticipates the complete model of the base-level and optimises it. Unknown parameters are estimated and the value of the anticipation function is the optimal result of the estimated base-level model. Here it is possible to analyse the impact of the control parameter K and the order schedule and further to choose them in such a way that the objective of the top-level is considered in the model of the base-level. The (near) optimal combination of K and s (IN*) is achieved by an iterative process in which various combinations are evaluated with regard to the common goal: the minimization of SC costs.

Subsequent to this anticipation process the resulting contract parameters are communicated to the supplier. Zimmer argues that an important feature of a SC is a long-term trusting relationship and consequently it is reasonable to take a common goal for granted implying team-like behaviour of the buyer. For the supplier the same assumption of behaviour has to be made as he accepts the ordering vector and the penalty cost parameter given by the buyer irrespective of the amount.

To evaluate the performance of the mechanism Zimmer carried out computational tests using the solution of a central model (best case) and the upstream solution (worst case) as benchmarks. In a first step she states a gap between the central solution and the upstream solution of in average 190%. The solution of the reactive anticipation is in average nearly as good as of the ideal model (average gap of 8%). For this type of coordination the optimum can be achieved compared to the non-reactive anticipation and the upstream solution, where the parameters K and s cannot be chosen optimal. But in comparison to the upstream solution the non-reactive anticipation induces only an average reduction in costs about 20%.

Further the author evaluates the impact of parameter uncertainty. Up till now it was presumed that the buyer can estimate the buyer's conditions correctly and the stochastic external demand is the only uncertainty, but now the effect of over- and underestimations of individual parameters are regarded. It arises that the reactive anticipation performs in average still better than the non-reactive anticipation (and is of course still better than the upstream solution), but depending on the uncertain parameter major deteriorations in solution quality can appear. For a detailed description see Zimmer (2001).

Coming to the *advantages and potential drawbacks* of this coordination scheme: In contrast to some other approaches a complex description of the planning situation with the underlying models is possible, an important condition for the application within APS.

The tests show that the solution quality of this approach is quite promising in case of reactive anticipation and parameter certainty. But therefore a high level of information is necessary. In particular the entire planning model of the supplier must be available for the buyer. Most of this information is regarded as critical and consequently treated confidential. For the tests including over- and underestimations of individual parameters a decrease in solution quality was observed.

Moreover, regarding the applicability it is questionable if contract parameters can be adjusted in every planning cycle and set alone by the buyer and besides whether the supposed team-behaviour can be really found in practice.

Besides the approach of Zimmer, Barbarasoglu (2000) has elaborated a coordination scheme based on hierarchical anticipation. In difference to Zimmer (2001), she examines a SC consisting of one supplier and several buyers and assumes that costs and capacities are deterministic and known, but the buyers' demand is uncertain. In the proposed coordination scheme, the supplier anticipates the reaction of the buyers to demand changes under a flexibility quantity contract. As a result of this anticipation, the supplier derives a contract which he offers to the buyers. As Barbarosoglu (2000) assumes a team situation, this contract not only benefits the supplier, but it is designed to establish a fair solution.

The advantages and drawbacks of the approach of Barbarosoglu are similar to the ones of Zimmer (2001) that have been discussed above.

4.2.3 Coordination by Negotiations

Another way to achieve coordination between two or more autonomous decision making units of a SC are negotiations. Proposals are passed between the partners in an iterative manner (possibly including compensation payments) to align the respective plans of the partners. During this negotiation process it is possible to make use of information gained in previous iterations (e.g. Jung et al. 2005).

Negotiations can be deducted by a mediator meaning that no direct communication between the SC members takes place (e.g. Ertogral and Wu 2000) or directly among the SC members (e.g. Dudek and Stadtler 2005). The number of proposals to be exchanged in the course of negotiations can strongly differ among the mechanisms and accordingly negotiations can also be automated (e.g. Fink 2003, 2005).

Within this chapter several coordination mechanisms based on negotiations will be introduced classified in two groups: Bilateral, model-supported negotiations and mediated negotiations.

Bilateral, Model-Supported Negotiations

The idea of this collaboration scheme is to establish by the help of bilateral, model-supported negotiations a (near-)optimal solution for the whole SC.

The *initial situation* resembles the one of Zimmer (2001). The SC members (for ease of presentation, a SC with two members, a buyer and a supplier, is considered) are doing their master planning. By the help of mathematical models, they derive their cost-optimal production schedules taking into account restricted capacities and scale effects by lot-sizing. The underlying procedure is upstream planning. In difference to Zimmer (2001), however, forced compliance, which means complete fulfilment of the buyer's demand, is assumed.

Analogously to Corbett and de Groote (2000) the default situation here is often suboptimal because the order schedules of the buyer are not aligned with the production schedules of the supplier. The degree of suboptimality cannot be calculated analytically. However, there have been computational studies quantifying the gap between upstream planning and centralized planning. In the case that there are only scale effects due to lot-sizing, but no capacity restrictions, average gaps of 1.8% to 31.5% from centralized planning have been identified (Simpson and Erenguc 2001). If capacities are restricted, these gaps become significantly higher because now unfavourable order schedule can cause shortages or significant overtime costs at the supplier.

In order to overcome the disadvantages of "upstream planning" in this context, Dudek and Stadtler (2005) have proposed a *coordination scheme* based on negotiations between the SC partners. The central idea of this coordination scheme is that the SC partners try to find out modified supply and order proposals which lead to substantive cost savings for themselves and to low cost increases for the partner. A numeric example for such a negotiation is provided in the table below:

Data exchange	Period item	1	2	3	4	Δcost B	Δcost S	Δcost total
		[product units (cumulated)]						
B → S	1	168	230	363	397	-	-	-
	2	77	239	239	375			
	3	247	347	548	650			
S → B	1	122	363	397	397	+4060	**-9452**	**-5392**
	2	239	239	239	431			
	3	247	299	548	650			
B → S	1	95	363	363	426	-2048	+337	-1711
	2	77	239	239	404			
	3	247	347	548	650			
S → B	1	95	397	397	397	+4772	-14231	-9459
	2	77	404	404	404			
	3	347	442	442	869			

Table 4: Negotiation Process Example (adapted from Dudek and Stadtler 2005, p.675)

For initialization, the buyer (B) transmits his orders per period and product to the supplier (S). The supplier generates a plan based on these quantities and calculates the thereby incurred cost. Next, the supplier generates a compromise proposal and transmits it to the buyer together with the cost effects of this proposal (here: a cost decrease of the supplier of 9452). The buyer checks whether this proposal leads to an overall improvement for the SC (here it does: 5392). After that, it is the turn of the buyer to generate a counter proposal and to transmit this with its cost effects to the supplier. After an evaluation of this counterproposal the supplier will generate another proposal and so on. This procedure can be stopped e.g. after a fixed number of negotiation rounds or – as proposed by Dudek and Stadtler (2005) – by means of a stochastic acceptance criterion. At the end of the negotiation the gains resulting from the cost improvements have to be distributed among the partners, which e.g. can be done by a simple 50%-50% split of this saving or by other pre-negotiated rules.

Furthermore, it has to be noted that the supplier needs to know the secondary demand forecast of the buyer. If the supplier does not produce less than this forecast requires, the required satisfaction of the buyer's demand is assured. This and the order/supply schedule together with their respective cost effects are the only information exchanged throughout the negotiation.

Crucial for the functioning of this negotiation scheme is the proper design of the planning models of the partners. Dudek and Stadtler (2005) have designed their models for the assumption that each SC partner faces a multi-level capacitated lot-sizing problem (MLCLSP). As an example, we will present the optimization models used by the supplier for evaluating the buyer's proposal and for the generation of the own counter proposal.

Model for Evaluation the Buyer's Proposal:

$$\min \sum_{t \in T} \sum_{j \in J} \left(h_j \cdot I_{jt} + sc_i \cdot Y_{jt} \right) + \sum_{t \in T} \sum_{m \in M} co_m \cdot O_{mt} \tag{24}$$

s.t.

$$I_{j,t-1} + X_{jt} = d_{jt} + xo_{jt} + \sum_{k \in S_j} r_{jk} \cdot X_{kt} + I_{jt} \qquad \forall j \in J, t \in T \tag{25}$$

$$\sum_{j=1}^{J} a_{mj} \cdot X_{jt} \leq c_{mt} + O_{mt} \qquad \forall m \in M, t \in T \tag{26}$$

$$X_{jt} \leq b_{jt} \cdot Y_{jt} \qquad \forall j \in J, t \in T \tag{27}$$

$$X_{jt} \geq 0, \; I_{jt} \geq 0 \qquad \forall j \in J, t \in T \tag{28}$$

$$Y_{jt} \in \{0,1\} \qquad \forall j \in J, t \in T \tag{29}$$

Indices and index sets:

j	Operation
m	Resource
t	Periods
J	Set of Operations
M	Set of resources
S_j	Set of direct successor operations of j
T	Set of periods

Data:

a_{mj}	Capacity consumption to produce one item of operation j at resource m
b_{jt}	Large number, not limiting feasible production quantities of product j in period t
c_{mt}	Available capacity of resource m in period t
co_m	Overtime cost at resource m
d_{jt}	(External) demand for product j in period t
h_j	Holding cost for one unit of product j in one period
r_{jk}	Unit requirement of operation j by successor operation k [ME]
sc_j	Setup cost for product j
xo_{jt}	Quantity of product j in period t ordered by the buyer

Variables:

I_{jt}	Inventory of item j at the end of period t
O_{mt}	Amount of overtime at resource m in period t
X_{jt}	Production quantity of operation j in period t
Y_{jt}	Setup variable (=1, if a setup operation for item j is performed in period t, 0 otherwise)

The aim of this model is to minimize the sum of inventory holding, setup, and overtime costs of the supplier (24). Constraints (25) are inventory balance constraints and ensure that external demand, the orders of the SC partners and secondary requirements can be fulfilled. In each period, the available capacity is built up by normal capacity and overtime (26). Constraints (27) allow production only if a setup has been done in the respective period. Finally, constraints (28) and (29) impose non-negativity and binary conditions, respectively.

Next, the model for the generation of the compromise will be presented. The idea behind this model is the reasoning that the probability of acceptance of a compromise increases if there are smaller modifications to the original buyer order. Therefore, this model has got two aims: low costs for the supplier and as few modifications as possible. Dudek and Stadtler (2005) solve this problem by the help of two more optimization models. The first one determines the optimal outcome for the supplier. The second one, which we will present here, determines the compromise proposal along the lines of goal programming.

Model for Generating the Compromise Proposal:

$$\min \sum_{t=1}^{T}\sum_{j\in J}\left(h_j \cdot I_{jt} + sc_i \cdot Y_{jt}\right) + \sum_{t=1}^{T}\sum_{m\in M} co_m \cdot O_{mt} - c^{\min} + ci \cdot \frac{\sum_{j\in JS}\sum_{t\in T}\left(D_{jt}^{+} + D_{jt}^{-}\right)}{\sum_{j\in JS}\sum_{t\in T} d_j^{\max}} \qquad (30)$$

s.t. 3-6

$$I_{j,t-1} + X_{jt} = d_{jt} + XO_{jt} + \sum_{k\in S_j} r_{jk} \cdot X_{kt} + I_{jt} \qquad \forall j \in J, t \in T \qquad (31)$$

$$XO_{jt} + D_{jt}^{+} + D_{jt}^{-} = xo_{jt} + D_{j,t-1}^{+} + D_{j,t+1}^{-} \qquad \forall j \in JS, t \in T \qquad (32)$$

$$\sum_{s=1}^{t} XO_{js} \ge xo_{jt}^{cum,\min} \qquad \forall j \in JS, t \in T \qquad (33)$$

$$\sum_{s=1}^{t} XO_{js} \le xo_{jt}^{cum,\max} \qquad \forall j \in JS, t \in T \qquad (34)$$

<u>Indices and index sets:</u>

JS Set of supplied items

<u>Data:</u>

$c^{\min}$ Minimum cost of supplier (solution of the model for determining the optimal outcome)

ci Anticipated average cost increase

$d_j^{\max}$ Maximum deviation in supply units of j (result of the model for determining the optimal outcome)

$xo_{jt}^{cum.\min}$ Minimum cumulated supply quantity of j, in periods 1 through t

$xo_{jt}^{cum.\max}$ Maximum cumulated supply quantity of j, in periods 1 through t

<u>Variables:</u>

D_{jt}^{+} / D_{jt}^{-} Supply shift to next/previous period of j in t

XO_{jt} Order quantity of product j in period t

The aim of this model is the minimization of the cost (deviation) and the partner cost increase, whose extent can roughly be estimated by the reaction of the buyer to former proposals (ci). For weighting in the goal program, the quantity shifts of the compromise proposal to the former respectively next periods are normalized by the maximum shift quantities the supplier would choose. Constraints (31) and (32) replace constraints (25) to allow these shifts of supply quantities. Constraints (33) and (34) ensure that the shifts keep within certain limits. In (Dudek and Stadtler 2005) these limits are defined by a shift of the entire period quantity to the next or previous periods with a supply greater than zero.

The evaluation and the compromise model for the buyer can be formulated analogously (see Dudek 2004). It has to be noted, that the above model not always encounters a compromise solution which differs substantially from the proposals made before. Therefore, Dudek proposes further models for the generation of additional compromises (see Dudek 2004).

In their computational tests, Dudek and Stadtler (2005) show that, for their test instances, pretty good result can be achieved with this collaborative planning scheme. In average, an initial gap from central planning of 22.4% (upstream planning) could be improved to 1.6% after negotiation. All in all, 69.8% of the gap resulting from upstream planning could be closed in average. The number of iterations (one iteration consists of one evaluation and one compromise of the buyer plus one evaluation and one compromise of the supplier) needed to achieve these results is 4.6 on average.

Another *positive aspect* of this coordination scheme is the already mentioned limited exchange of information. Some information which could be regarded as critical, e.g. capacities (e.g. Kersten 2002), have not to be exchanged, but only (non-critical) demand and order data and partner cost increases. Furthermore, it has to be pointed out that complex models as the ones modelled within an APS can in principle be coordinated with such a negotiation scheme.

However, convergence is only shown empirically, which could be a problem for bigger problem instances, which have to be solved for some practical problems. Another *potential drawback* is that the scheme is only designed for an MLCLSP and has not been transferred to other planning problems yet. Furthermore, the underlying assumption concerning the behaviour of the SC partners could be questioned. If the partners do not communicate the cost effects of the proposals honestly, the sharing of the savings and possibly the performance of the negotiation could be affected. Therefore, Dudek and Stadtler (2006) propose a modification to this negotiation scheme, whose impacts on opportunistic behaviour, however, have not been analysed completely yet.

Another example for a coordination mechanism based on bilateral negotiations is proposed by Jung and Jeong (2005). In this approach coordination takes place between a production and a distribution unit of a SC and is further expanded for a third party logistics (3PL) (Jung, Chen and Jeong 2005). In the underlying *setting* of the latter multiple products over multiple periods are produced by one manufacturer in several facilities to satisfy the deterministic customer demand. A 3PL distributes the products to the customer zones, whereas inventory can be held in the distribution centres owned by the 3PL. Information is private, consequently a decentralised production-distribution coordination mechanism is developed.

The *mechanism* starts with the transfer of the customer demand data from the manufacturer to the 3PL, which should be fulfilled as good as possible over the planning horizon. By solving a linear programming (LP) model considering transportation and inventory decisions, the 3PL determines the minimum-cost supply quantities needed to deliver the customers in time. These requested supply quantities are given over to the manufacturer who decides (also with the help of an LP model) which fraction of them he has to fulfil in order to minimise setup, inventory holding and penalty costs for not delivering the requested amount. He submits the possible supply quantities to the 3PL, who generates based on these data a new distribution plan minimising his transportation, inventory holding and penalty costs for lost sales volume.

The resulting desired supply quantities are again transmitted to the manufacturer. If the manufacturer matches the requested quantities without shortages, the negotiations stop. Otherwise the manufacturer regenerates the production plan and possible supply quantities that will be transferred to the 3PL. These negotiations go on until the above-named stopping criterion is complied with.

In the initial iteration, the 3PL assumes infinite capacities of the manufacturer. Subsequent in each iteration the 3PL evaluates the possible supply quantities submitted from the manufacturer. This value is the minimum information exchanged and updated (i.e. a new upper supply limit is set for the specific product in period t produced in facility r) if the manufacturer cannot fulfil the request of the 3PL.

In the computational tests conducted by the authors the mechanism performed quite well: In comparison to the solution of one central model, deteriorations of in average under 1.0% occurred and it took up to 22 iterations until the negotiations stopped.

As already specified above the main *advantage* of this mechanism is the limited information exchange. Besides the assumption of opportunistic partners is quite reasonable for the application in practise, but it is not examined if the mechanism really works if the partners behave that way. The mechanism achieved rather good results in the test, but this could be dependent of the test instance and models, that do not represent the planning situation adequately (especially the choice of the penalty costs should be reconsidered). Moreover as no default situation is given the ability of the mechanism cannot really be assessed.

This approach by Jung, Chen and Jeong (2005) was presented here as it is the only one (found by the authors of this deliverable) about coordination among a production company and a service provider i.e. 3PL. The mechanism was first developed to coordinate production and distribution decisions and subsequent extended for service providers. This shows promise that coordination concepts or at least ideas developed for coordination among manufacturers can be conferred to (deterministic) service scenarios.

Coordination by Mediated Negotiations

Within this section coordination by mediated negotiations is addressed. The first approach described in more detail is developed by Fink (2003, 2005) and is based on completely automated negotiations in which the SC partners are represented by software agents. According to Fox et al. (2000 p.166) "an agent is an autonomous, goal oriented software process that operates asynchronously, communicating and coordinating with other agents as needed."

The *initial situation* Fink regards is as follows: He considers a 2-tier SC with the problem of determining delivery schedules regularly whereas a just-in-time policy is supposed. He analyses two scenarios, with one/two supplier/s and one buyer for which the job sequence at the coupling point between the production stages should be scheduled. The buyer is faced with a continuous flow-shop scheduling problem with the objective to minimize average completion time of the jobs, whereas the supplier/s aim(s) for cost efficient production schedules by minimizing the sequence-dependent setup costs.

The decisions of the SC members can be represented completely on the basis of formal contracts, thus the coordination problem can be modelled as a concurrent search problem in a contract space C. The elements of the contract space (i.e. feasible production plans) are assumed as common knowledge but the individual preferences (represented by the utility function $f_l : C \to \Re$ of agent l) are private.

The basic idea of the *coordination scheme* is that the SC members try to reach a consensus about a contract regulating the described situation with the help of automated negotiations in which the agents communicate via a mediator that is conducting the negotiations.

A fundamental criterion for the acceptance of the coordination mechanism is fairness. According to Fink a fair solution meets the following requirements (cp. the similar definition in Gjerdrum et al. 2001, 2002): Invariance to equivalent utility representations, symmetry and Pareto optimality (cp. Nash 1950, 1953 and French 1988). Hence the maximisation of the overall social welfare is not the objective of this approach since social welfare could be distributed odd among the agents and moreover because monetary evaluations of the decisions may not always be available.

The generic negotiation protocol is as follows: Starting from an initial (first active) contract, on which all agents agreed, the mediator generates alternative contracts in each round. The opportunistic agents either accept or reject this proposal; if all agents accept it, the candidate contract becomes the new active contract. The contract agreed on after a predefined number of rounds becomes the final outcome of the negotiation process.

The main variation points of this generic process are the contract space C and correspondingly the generation of candidate contracts and the acceptance criterion.

The mediator has no special trust relationship with one of the agents or any knowledge about their preferences and supports the negotiations without having self-interest. In consequence the candidate contracts are generated by chance, either by a random selection out of the contract space according to a uniform probability distribution or by generating neighbourhood solutions randomly. More intelligent options for the generation of proposals could be possible: For example by observing the negotiations the mediator may learn from former reactions and try to derive certain regularities to focus the process. Within his computational tests Fink employs the neighbourhood move definition by shifting one job to another position in the sequence.

Regarding the acceptance criterion Fink distinguishes between two types of behaviour: greedy and cooperative. An agent l with a greedy acceptance criterion A_l^g will only accept a candidate contract c' if it is not worse (or equal) than the current active contract c:

$$A_l^g(c,c') := \begin{cases} \text{yes} & \text{if } f_l(c') \geq f_l(c) \\ \text{no} & \text{otherwise} \end{cases} . \tag{35}$$

It is well known from local search methods that such search processes run the risk of sticking quite soon in a local optimum if no deteriorations are possible. In order to avoid this Klein et al. (2003) propose to adopt the Metropolis criterion of simulated annealing (Metropolis et al. 1953) resulting in the cooperative acceptance criterion:

$$P(A_l^k(c,c') = yes) := \begin{cases} 1 & \text{if } f_l(c') \geq f_l(c) \\ e^{(f_l(c')-f_l(c))/Temp} & \text{otherwise} \end{cases} . \tag{36}$$

Now the probability to accept deteriorations depends on the amount of deterioration and the positive control parameter Temp (temperature). During the negotiation rounds Temp might be gradually reduced and following the probability to accept deteriorations converges also towards zero.

But the question arises how to induce the agents to use the cooperative acceptance criterion as information is private and no one can control the behaviour of the agents. As an answer

Fink proposes to define mandatory acceptance ratios within specific phases of the negotiation process (decreasing in the course of the process). A general mechanism how to determine temperature values that conform to given mandatory acceptance ratios is described by Fink (2003, 2005).

To evaluate the scheme the author carried out computational tests with 100,000 and 1,000,000 respectively negotiation rounds in which he faces the four possible combinations of greedy and cooperative agents. Within this study the individual agents access the out coming contract on the basis of the deviation from an optimal contract resulting out of the assumption that their firm could decide independently.

The results show that the outcome due to just cooperative agents is Pareto efficient and additionally Pareto superior compared to all greedy agents. Regarding the outcome due to the combination of agents behaving differently, the agent(s) with a greedy acceptance criterion can clearly profit from the behaviour of the cooperative one(s); these outcomes are Pareto efficient. Underlying the non-cooperative game theory in the case of two agents, the outcome resembles the classic prisoner's dilemma (Axelrod 1984). The combination of two greedy agents represents the only Nash equilibrium. As one agent does not know about the other agent's behaviour, he will always choose greedy (although both agents are worse of when they both behave greedily instead of both cooperatively). To overcome this unfortunate situation Fink proposes to use given acceptance ratios for the candidate contracts as described above.

The quality of the overall solution is measured by the deviation of the result from the Pareto frontier (i.e. the set of Pareto optimal contracts determined (approximately) by applying a multi-objective simulated annealing heuristic (Ulungu et al. 1999) based on global optimization with no private information). Fink found out that if both agents follow a cooperative acceptance strategy this leads to a high-quality outcome very close to the Pareto frontier.

So what are the *advantages and potential drawbacks* of this coordination scheme? Of course the computational tractability and solution quality is promising as improvements from about 5 up to 54 percent were observed within a few seconds during the experiments. Moreover, the assumptions of private information and opportunistic agents seem to be suitable for the adoption in practice. But going into more detail these advantages weaken: It is assumed that the mediator has knowledge about the contract space C. But to identify the feasible contracts (i.e. feasible production plans) knowledge about the restrictions of the agents is necessary. Consequently the individual utility functions are the only private information. Moreover, it is questionable if an opportunistic agent is willing to behave cooperatively and consequently to accept deteriorations. The situation of the prisoner's dilemma arises and to overcome it acceptance ratios could be imposed to the agents. To secure the acceptance of these ratios Fink implies that at the end of the negotiations an agent would have the possibility to return to the initial situation. But there would still be the problem of screening the behaviour.

In the initial situation described by Fink there is no power relationship and consequently there is no default situation, a quite unusual situation in practice.

Besides this automated approach seems to be more applicable for short-term planning as for the Master Planning level manual interactions are commonly desired.

Another approach relying on mediated negotiations is developed by Ertogral and Wu (2000). They develop a Lagrangean Relaxation based mechanism for the distributed coordination of production plans among SC partners.

The *initial situation* considered by the authors is a multi-tier SC with several facilities on each tier whereas each facility plans their production based on a MLCLSP (in contrast to the MLCLSP underlying at Dudek (2005, 2006) no overtime is possible). No default situation is given, consequently there is a need to coordinate the order and delivery plans among the partners. The only alternative described is a centrally imposed solution but for reasons of private information and no willingness of self-interested enterprises to implement these solutions, this attempt is rejected but used to assess the solution quality of the mechanism proposed below.

An important issue Ertogral and Wu also address with their *coordination scheme* is fairness. Based on the definition of the facility-best solution that is resulting from a facility sub-model that satisfies its own dependent demand (i.e. the demand for item k corresponding to the demands for end items in period t assuming no initial inventory in the system) constraints without taking into consideration the plans of the other SC members, they characterise the fairness of a solution. It is defined as "how evenly the facilities share the burden of comprising their respective facility-best solutions for the system-feasible solution" (p. 934), meaning that each facility should have (approximately) the same absolute additional costs.

The idea of the coordination mechanism is described next: Starting with one central MLCLSP for the whole SC, this model is reformulated in a coordination problem in which the bill-of-material (BOM) links are regarded as a supplier-buyer pair who negotiate via a mediator mutually agreeable production plans. A facility-separable formulation is achieved as follows: The variable X^r_{jkt} is introduced as the production output (input) from (to) facility r associated with the BOM link (j,k) in period t (see Figure 28).

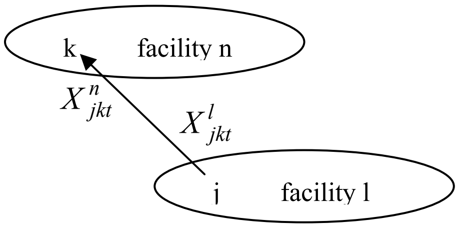

Figure 28: Variable X^r_{jkt} (Ertogral and Wu (2000), p.934)

Moreover a-priori determined production target parameters $parx_{jkt}$ for the inter-domain flow variables are defined resulting in the following reformulation of the MLCLSP:

$$Min \sum_{t \in T} \sum_{j \in J} (h_j \cdot I_{jt} + sc_j \cdot Y_{jt}) \tag{37}$$

s.t.
$$I_{j,t-1} + X_{jt} - \sum_{k \in S_j} r_{jk} \cdot X^{rj}_{jkt} - I_{jt} = d_{jt} \qquad \forall j \in J, t \in T \tag{38}$$

$$\sum_{j=1}^{J} (t_{rj} \cdot Y_{jt} + a_{mj} \cdot X_{jt}) \le c_{mt} \qquad \forall m \in M, t \in T \tag{39}$$

$$X_{jt} \le b_{jt} \cdot Y_{jt} \qquad \forall j \in J, t \in T \tag{40}$$

$$X^{rk}_{jkt} = q_{kt} \qquad \forall (j,k) \in L; t \in T \tag{41}$$

$$X^{rj}_{jkt} = parx_{jkt} \qquad \forall (j,k) \in L; t \in T \tag{42}$$

$$X_{jkt}^{rk} = parx_{jkt} \qquad \forall (j,k) \in L; t \in T \tag{43}$$

$$X_{jt} \geq 0,\ I_{jt} \geq 0,\ Y_{jt} \in \{0,1\} \qquad \forall j \in J, t \in T \tag{44}$$

Indices and index sets:

r Facility

r^j Facility where product j is produced

L Set of BOM-links

R Set of facilities

(j,k) BOM-link from product j to k

Data:

$parx_{jkt}$ Production target associated with the BOM-link (j,k) in period t

t_{rj} Setup time for product j in facility r

The model plans output and inventory levels for all operations considered with the objective to minimize the sum of inventory holding and setup costs. Constraints (38) and (41) together capture the mass-balance relationships between item inventories in the system over time. Constraints (39) represent capacity restrictions, while lot-sizing relationships are expressed in (40). The parameters $parx_{jkt}$ in (42) and (43) stand for the to-be-agreed on flow on product link (j,k) in t by the associated facilities and are therefore called target parameters. Constraints set (41) represents a just-in-time policy and constraints (44) specify domains of variable values.

Thereafter Lagrange relaxation is applied to the flow balance equations (42) and (43) to decompose the model described above into facility sub-models:

$$f'_r = \sum_{t \in T} \left[\begin{array}{l} \sum\limits_{j \in J_r} (h_j I_{jt} + sc_j Y_{jt}) + \sum\limits_{\{(j,k) \in L | r^j = r\}} \lambda_{jkt}^{rj} \mid X_{jkt}^{rj} - parx_{jkt} \mid \\ + \sum\limits_{\{(j,k) \in L | r^k = r\}} \lambda_{jkt}^{rk} \mid X_{jkt}^{rk} - parx_{jkt} \mid \end{array} \right] \tag{45}$$

s.t. (38)-(40), (44)

$$\left.\begin{array}{ll} \sum\limits_{t=1}^{t_h} \sum\limits_{(j,k) \in L} X_{jkt}^{rj} \geq \sum\limits_{t=1}^{t_0} ddem_{jt} \qquad \forall r \in R, \forall j \in J_r,\ t_0 = 1,\ldots,T & (46) \\ (with\ ddem_{jt} = \sum\limits_{k \in S_j} r_{jk} ddem_{kt}) & (47) \end{array}\right\} C'_r$$

Indices and index sets:

J_r Set of products produced in facility r

Data:

λ_{jkt}^{r} Lagrange parameter (conflict pricing)

$ddem_{kt}$ Dependent demand for product j in period t

The additional constraints (46) postulate that the total amount that a facility sends out by period t has to be greater than or equal to the total dependent demand by period t.

Ertogral and Wu state the corresponding problem (AD), which they call auction-theoretic decomposition, as follows:

$$(AD): \qquad \underset{\lambda, parx}{Min}\{\sum_r f'_r \mid C'_r\,,\;\; r \in R\} \tag{48}$$

In this formulation each facility plans its own production but is relying on or supplying to other facilities according to the BOM structure. The problem is facility-separable and any solution with zero inconsistency (i.e. the mismatch between the solutions of the sub-models) is feasible for the original problem. To eliminate the inconsistencies resulting from decentralized planning Ertogral and Wu develop a pricing mechanism using the Lagrange multipliers as penalty cost rates for deviations from the target values.

The starting point of the mechanism is the facility-best solution of each facility. A neutral mediator updates the conflict pricing λ^{r}_{jkt} and target parameters $parx_{jkt}$ in each iteration and forces the facility solutions to reduce overall inconsistency. The amount of increment in prices is proportional to total current inconsistency and individual derivations from target parameters. Within this mechanism fairness, as defined above, is an important aspect. By updating the target parameters the facilities which "suffer" more (i.e. whose fraction of the deviation of a system feasible solution from the facility-best solution and the average deviation across all facilities) have more influence on the new parameters. For this mechanism convergence was shown.

To evaluate the scheme computational tests were conducted by the authors. Two benchmarks are used to measure the performance: The deviation from the optimal solution (i.e. the solution of the centralized planning) and the fairness of a solution (fos):

$$fos = \sum_r \left| \alpha_r - \frac{1}{|R|} \right| \tag{49}$$

with $\alpha_r = \Delta_r / \sum_r \Delta_r$ and Δ_r as the value deviation of a system feasible solution from its facility-best solution.

The authors found out that the costs of the coordinated solution exceed the optimal solution on average about 9.95%, the fos takes in average the value 0.5699. With regard to the optimal solution where the fos takes 0.7446, the additional costs of each agent compared to the facility-best solutions are more evenly spread. In around 75% of the test cases the coordinated solution outperformed the optimal solution with regard to fairness (in average 28.09% more fair).

But some aspects of this mechanism should be regarded critically: one *drawback* for sure is the fairness criterion. According to this the SC members share the additional costs equally regardless of their individual contribution to the value added. This assumption will not be respected in practice and is not really impartially fair. Ertogral and Wu presume self-interested agents but for the realization of this approach team behaviour is a prerequisite. Besides the fos-value is still quite high and it is questionable whether the achieved reduction compared to the centrally imposed solution would already lead to acceptance in practice (assuming that the fairness criterion is approved).

Another point to criticise is that no default situation is given. In consequence the deteriorations are only assessed by unrealistic benchmarks as one facility has always more power than another one.

Moreover Ertogral and Wu underline the decentralized decision making because of private information, but for updating the price scale the total costs of the facilities have to be disclosed towards the mediator although this information could be regarded as sensitive.

By confronting the approaches of Fink and Ertogral and Wu, the latter one seems not suitable for application in practise and consequently also not for our purpose due to the fairness criterion, the assumption of altruistic behaviour and the kind of information exchanged

5 Recommendation of an Interface for Collaborative Planning at the Master Planning Level of an APS

In this chapter, we will mesh our findings from chapters 3 and 4 in order to give a recommendation of an interface for Collaborative Planning at the Master Planning level of an APS. In chapter 3 it has been shown that in actual APS, there aren't any modules for supporting collaborative planning. However, as could be seen in chapter 4, several approaches for collaborative planning have been proposed in literature. Now, the question is which of these approaches could be applied for a collaborative planning interface of an APS.

As a basis for this, we will analyse how the requirements from chapter 3 are covered by the most important approaches described in chapter 4. In chapter 3, three substantial requirements for the application of such a scheme in an APS could be identified:

- The scheme should work on a deterministic data basis.
- The scheme should be able to tackle LP/MIP models which are used in APS.
- The solution time for models used in an APS is significantly high. Given that the models of the partners have to be solved at least once within a negotiation round, the number of negotiation rounds has to be limited.

Apart from that, further requirements from the point of view of common sense seem necessary for the application of such a scheme in APS:

- The risk of degradations of solutions if the partners act opportunistically should be as small as possible for not affecting the performance and the acceptance of the scheme.
- In SC consisting of legally independent partners, the partners often are reluctant to disclose freely all their information. Therefore, few and only uncritical information should be exchanged (as a prerequisite for or during the coordination process) (see also Kersten 2002).

When regarding these criteria, some of the approaches described in chapter 4 can be discarded at the outset for use within an APS. The ideas concerning "centrally imposed solutions" and "hierarchical anticipation" have to be discarded because they are based on excessive exchange of information and on the assumption of altruistic behaving SC partners, which does not seem realistic for real situations. The approaches proposed for coordination in a newsvendor-type setting only consider stochastic data and very simple models and therefore cannot be applied within an APS either.

A similar problem exhibits "self-selection", because here, although deterministic data are used, the applications of this idea have been restricted to simple planning situations. Generally, the applicability of self-selection seems less probable with an increase of the number of uncertain parameters. Reasons for this are that with an increase of uncertain parameters the effort for estimating them increases and the quality of solution could degrade. Therefore, a transfer of this idea to LP/MIP models with a huge number of decision variables as required by APS seems to be problematic.

The approach "mediated negotiations", in principle, could be applied more directly in APS because MIP models are covered. Its main drawback, however, is the extensive number of iterations required. For practical problems with lots of decisions variables, this can lead to excessive efforts in computational time and supervision of the negotiation process.

The approach that seems apt best is ”bilateral negotiations”. Here, apart from the question of extensibility to different planning situations, the main problem seems to consist in potential opportunistic counteractions within the negotiation process. There have been proposals how to cope with this, but their performance has not been properly assessed yet.

As a result, in our further work within this project we will primarily focus on approaches based on bilateral, model-based negotiations. The ideas of self-selection and mediated negotiations, which also showed to have some advantages, will be kept in mind when working out the proposal for the CSNS in work package 7.

The prerequisite of a deterministic data basis restricts the application of collaborative planning for the service sector. The modelling of non-deterministic services such as repairing a machine after a sudden breakdown is – per definition – not supported by APS.

Despite this limitation, the incorporation of deterministic services, such as preventive maintenance or logistics follows the logic of the pure manufacturing related models found in literature as pointed out in Chapter 4. From a mathematical point of view, quantity units and delivery times of both, material and services provided from one to another partner form part of the continuous or discrete decision variables. For both, manufacturing and service domain, these decision variables influence the available capacities and/or stock levels, which form part of the constraints at both sides. If a decision relates to costs, the outcome of a negotiation process can always be measured via the objective functions, whereas the ultimate goal is to minimize the SC-wide costs. Hence, once a generic, practical applicable coordination mechanism has been developed it can easily be adapted to the needs of a more specific manufacturing or service scenario that relies on deterministic data.

Although complex planning problems can be formulated as MILP, the optimization algorithms should not be restricted to MILP-solvers, as discussed in chapter 3. Typical examples are vehicle scheduling and routing for short-term transportation planning or job-shop scheduling for short term production planning, currently solved by Evolutionary Algorithms as leading edge algorithms, which show a much better performance than standard MILP solvers. For these kinds of short-term planning problems, Collaborative planning at the Master Planning Level denotes the exchange of data in form of quantities per buckets but does not restrict the planning problem itself to be on the Master Planning Level of an APS.

From the view of real-world application, we can conclude further requirements and suggestions for an interface:

- A negotiation protocol defining standard alerts and messages is of practical importance.
- The mechanism should be tested on real-world planning data.
- For complex problems, an optimal solution is not guaranteed. However, negotiating on suboptimal solutions can hamper the convergence to the global SC-wide solution. To decrease the effect of extreme suboptimal outliers, further means might be required. For instance, a parallel generation and evaluation of several proposals at every iteration might stabilize the negotiation procedure leading to a more robust scheme with "graceful degradation" in case of suboptimal planning solutions of each partner.
- The process of proposal generation can be speed up by including aggregation and decomposition techniques or by a fixation of parts of the problem as well as using grid-computing.

6 Conclusions and Impact on InCoCo-S

This deliverable was concerned with giving an overall picture of the current situation of coordination on a planning level, summarizing innovative academic approaches and practical requirements for a collaborative planning mechanism based on computer-supported negotiation.

Chapter 1 gave a general introduction to the challenging task of collaborative planning and the problem of unaligned plans and order quantities leading to redundant costs. Besides existing efforts to integrate planning across the entire supply chain (SC), the disclosure of information between the partners of a SC currently leads to a chain of sequential intra-domain planning activities in practice, which is likely to create redundant costs, also referred to as the problem of *double marginalization.*

In Chapter 2, the meaning of terms coordination and collaborative planning was further discussed and several definitions were given.

An introduction to Advanced Planning Systems (APS) and an evaluation of existing approaches in practice to include partners at the boundary of a planning domain were provided in Chapter 3. It was argued that current collaborative planning approaches are focusing primarily on enhancing the communication of demand and order commitments across the supply chain. Plans can already be safely transmitted, compared and improved manually (or by heuristics on an operational level) to support strategies such as VMI or CPFR.

However, automated negotiation procedures using APS as back-ends coordinating plans within an inter-organizational context to decrease the total costs of the SC are currently not supported. Such computer supported negotiation schemes (CSNS) have just recently gained increased attention in academia. In Chapter 4, several academic proposals for coordination mechanisms have been evaluated and classified.

Finally, in Chapter 5, general requirements for a CSNS have been derived. It was argued that a CSNS must work on a deterministic data basis and has to support complex NP-complete problems such as Mixed Integer Linear Programs for mid-term production planning, Job-Shop scheduling for short term production planning or vehicle scheduling and routing for short term transportation planning problems whereas the iterative negotiation procedure must improve the uncoordinated solution in a reasonable amount of time. Moreover, private information must remain disclosed between the partners and the scheme should only give minimum opportunity for opportunistic behaviour, or such kind of behaviour should at least have minimum impact on the quality of the coordinated solution. These requirements strongly recommend a scheme based upon bilateral negotiations, whereas the ideas of self-selection and mediated coordination are kept in mind for further evaluation. As for real-world problems finding the optimal solution can not be guaranteed, further suggestions as the incorporation of decomposition techniques or parallel evaluation and generation of proposals using grid-computing have been derived. In complex planning scenarios we cannot expect optimal solutions of MILP solvers or Evolutionary Algorithms in the given run time (typically less than an hour) and we need robust coordination schemes with "graceful degradation" in case of suboptimal planning solutions of each partner.

All in all, the results of this analysis fit with the insights obtained within InCoCo-S so far. The analysis of existing APS for supporting collaborative processes confirm the results of Deliverables 2.1 and 2.3. Although there are some tools within APS for supporting mere information exchange, there is a present lack for coordination mechanisms that can be applied within supply chains consisting of legally separated partners with partly competing aims. For general situations, this lack has already been identified within Deliverable 2.1 and re-encountered in the business cases of Task 2.3.

Within this deliverable several theoretical approaches for coordination in literature were presented, which actually exist for coordination in planning. Although most of them are not specifically designed for service supply chains the underlying ideas can be quite useful for developing suitable coordination mechanisms. Of particular importance for InCoCo-S seems the missing transfer of these ideas for practical settings.

Among others, such a transfer is intended to be done in work package 7. Here, the partners of InCoCo-S are proceeding to further evaluate most relevant business scenarios, where such a scheme is of practical importance with the ultimate goal to present a working prototype at the end of the project.

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