Improving Supply Chain Execution by an Integrated Optimization - Negotiation Approach

Tung Bui and
Hans – Jürgen Sebastian

University of Hawaii at Manoa
RWTH Aachen University

RWTH
RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

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Agenda:

1. Introduction: Supply Chain Execution and Available/Capable to Promise
2. A special Production-Distribution Supply Chain:
   Motivation and Outline of the integrated Optimization-Negotiation Approach
3. The Multi-Attribute Utility Approach for Negotiation Support
4. Implementation by a Multi-Agent System (MAS)
5. Conclusions and Future Work

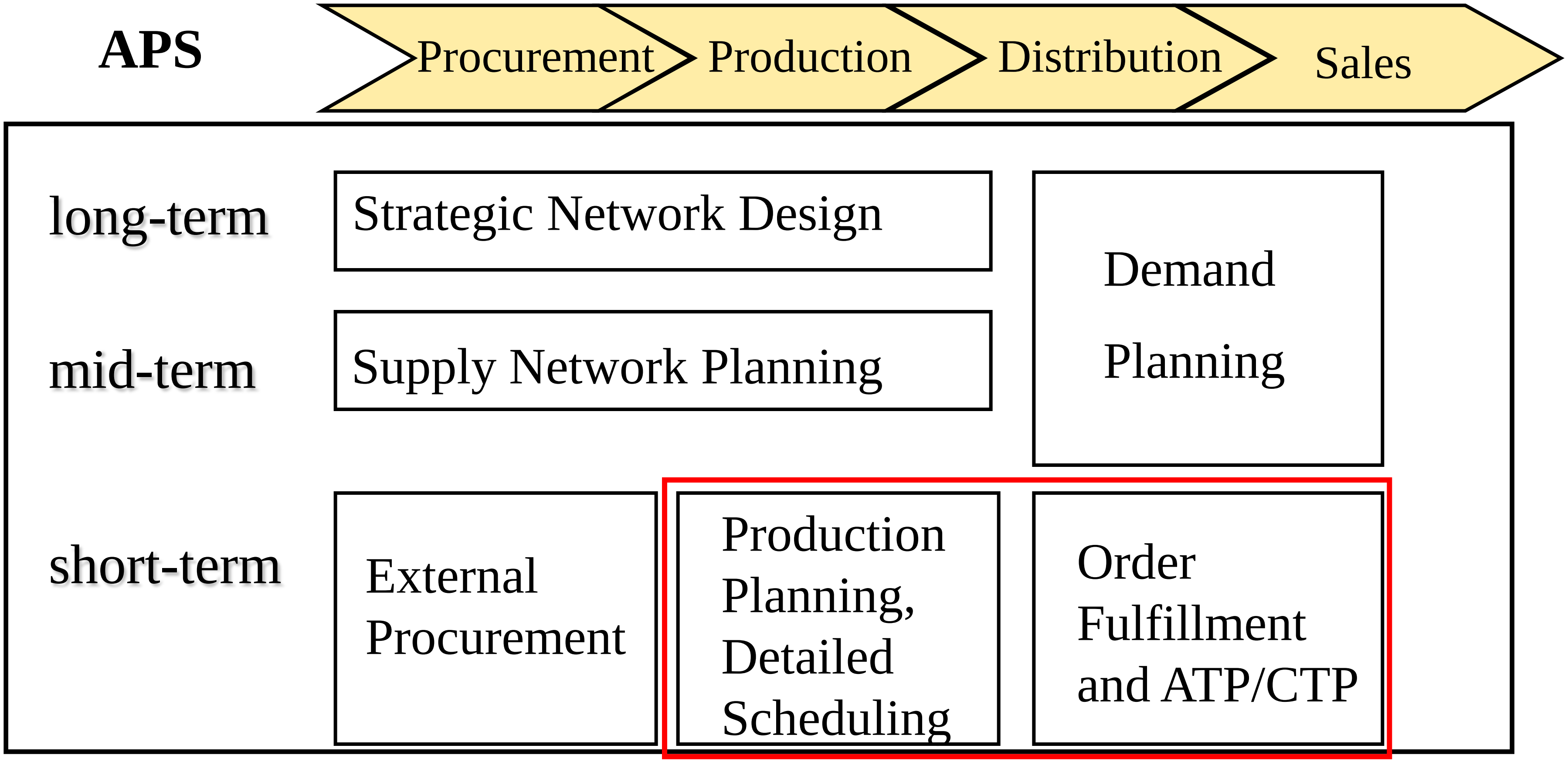
1. Supply Chain Execution and Available/Capable to Promise

Supply Chain Execution short-term (operational) planning focus (tactical decisions are regarded to be fixed)

- daily or weekly planning horizon
- control of the material flow within the network
- fulfilling individual customer orders

key issues:

- assigning of production, inventory, transportation orders or tasks to customer orders
- production or warehousing operations: order-picking, container or pallet loading
- freight handling, empty container balancing



Software Modules of Advanced Planning Systems

Example of an APS: SAP‘s Advanced Planner and Optimizer APO

Available-To-Promise / Capable-To-Promise

CTP is a planning function within the Supply Chain Execution

„It decides for a short term planning horizon whether or not a customer order can become accepted, and if yes, which date of delivery can be reliably assured to the customer“.

ATP: based on a check of the available inventories within the SC

(Quantity of the considered good which has been not reserved yet, that means which is available to sell)

→ today: Integral part of many SCM software tools, such as of APS‘s (e.g. APO).

In contrast CTP function checks whether the ordered products might be transported or produced, if they are not on stock (when and where to produce within the SC?)

Critical Factors, which determine the quality of a CTP system

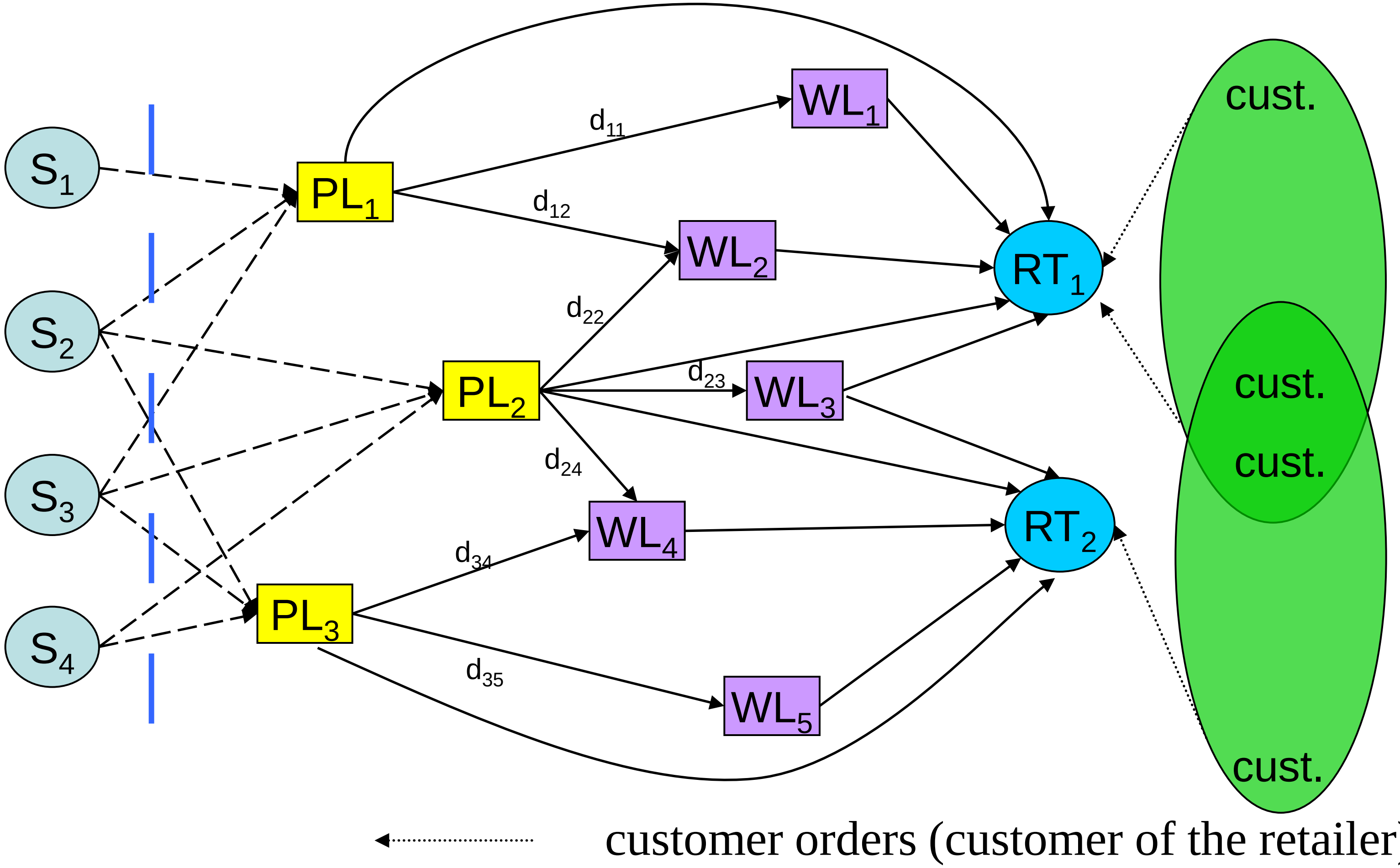
1. Reaction time of the CTP-system (duration of the decision making/ supporting process).
2. Reliability of the promised delivery date (reliability of the lead times).
3. Small number of not taken customer orders, selection of accepted orders on the basis of a profit maximization criterion.

→ Combine negotiation and optimization in order to maximize revenue and to find good compromises between customer requests/expectations and a profitable SC-process design.

→ Use of Multi-Agent-Systems to implement such a CTP

→ Modeling the stochastic uncertainties of the SC in order to propose reliable lead times

2. An Illustrative Example of a Production-Distribution Supply Chain: Motivation and Outline of the proposed Approach



Supply Chain Configuration – The Stakeholders of the Example

- ***Producer P*** (focal enterprise of the SC, negotiates with the retailers)
  - has 3 manufacturing facilities PL_1, PL_2, PL_3 at different locations
  - produces one good (product) manufactured at all three locations (functional product such as e.g. washing machine, refrigerator, toaster etc.)
  - PL_i has a capacity C_i (number of items per time unit) and cost K_i (per item)
  - has an inventory at each location PL_i with an inventory level $I_t(PL_i)$ at time t (available for direct delivery to the warehouses or retailers as well)

- ***Warehouses*** WL_j, (5 regional warehouses, j=1, …, 5)
  - has an inventory level $I_t(WL_j)$ of the considered good at time t, j=1, …, 5 measured in number of items

- ***Retailers*** RT_1 and RT_2
  - predict the demand of their assigned customers and
  - generate „customer-orders“ for the Supply Chain

- *Transportation Links*

- (PL_i, WL_j) with assigned transportation times d_{ij} , (matrix $D_{P \to W}$)
- (WL_j, RT_k) with assigned transportation times d^*_{jk} , (matrix $D^*_{W \to R}$)
- (PL_i, RT_k) direct delivery option with transportation times d'_{ik} , (matrix $D'_{P \to R}$)

Customer Orders

- The retailer RT_1 (or RT_2) orders from the Supply Chain at time point t

→ one single order defined by $O_t^{(1)} = (Q_t^{(1)}, RLT_t^{(1)})$

where $Q_t^{(1)}$ - ordered quantity (e.g. number of items, if the good is discrete)

$RLT_t^{(1)}$ - requested lead time at time t

($O_t^{(1)}$ can be extended by additional attributes such as e.g. a requested price per item etc.)

→ a set of orders: $O_{t,k}^{(1)}$ of retailer RT_1 and $O_{t,l}^{(2)}$ of retailer RT_2 at time t;
$k = 1, 2, \ldots, k_0$; $l = 1, 2, \ldots, l_0$

The idea of a Capable-To-Promise with integrated Optimization-Negotiation functionality

- The retailers are considered to be the customers of the Supply Chain.
- The Supply Chain represented by the focal enterprise P (Supply Chain Agent SCA) negotiates with the retailers (Customer Agents – CA).

These agents are using a CTP system which is based on:

- Description of the input stream of customer orders (possible extension: uncertainty of demand)
- Description of the alternatives of the SCA when accepting an order;
  - delivery from stock (from which warehouse how many items)
  - direct delivery from the producers inventories (from which Pl_i how many items)
  - production-orders, if the customer orders can not be fulfilled by the available (not promised to other customer orders) stock (where to produce? – capacity constraints, cost)

  →Formulation of a set of MILP-models and if-then rules
- Description of the negotiation framework

Set of Models for different SC-situations

Instead of building one complex model using the decision variables, constraints, order sets and objectives (partly defined above), which is possibly not solvable in a reasonable computation time, we define a sequence of submodels (set of models) starting with the simplest case and getting more and more complex. These models get names describing the „Logistics Functionality of the CTP within the Supply Chain“.

The <u>overall strategy</u> is as follows:

If the ordered quantity is Q_t at time t

(I) start with fulfilling this request by the inventories of the warehouses (ATP function)

If there is not sufficient volume on stock

(II, III) consider the volume of the product which is in transport from the producers inventories to warehouses (CTP function)

If there is not sufficient volume on stock or in transport

(IV) start production at the different production sites at time t (full CTP function)

This creates a sequence of submodels using only subsets of the variables and constraints formulated above

(I) If $\sum_j I_t(WL_j) \geq Q_t$, then use submodel (I) } fulfilling order from warehouses

(II) If $\sum_j I_t(WL_j) < Q_t$

and $\sum_j I_t(WL_j) + Q_{P \to W}$ (In Transport) $\geq Q_t$

use submodel (II) } fulfilling order from warehouses + goods on the way to these warehouses

(III) If $\sum_j I_t(WL_j) + Q_{P\to W}$ (In Transport) $< Q_t$

and $\sum_j I_t(WL_j) + Q_{P\to W}$(In Transport) + Inventory (Prod)(t) $\geq Q_t$

use submodel (III)

} adding direct delivery from the producers to the retailer

(IV) If: $\sum_t = \sum_j I_t(WL_j) + Q_{P\to W}$(In Transport)(t)+ Inventory(Prod)(t) $< Q_t$

and $\sum_t + C_1 + C_2 \geq Q_t$

use submodel IV

} start production at time t

- Need to be continued: What if $\sum_t + C_1 + C_2 < Q_t$?, etc.

How do the submodels look like?

The most simple case is

Submodel I: Order Fulfillment from Warehouse-Stocks only

Because the ordered volume Q_t (for simplicity let‘s assume $Q_t = Q_t^{(1)}$, $Q_t^{(2)}=0$) is on stock of the involved warehouses ($\sum_j I_t(WL_j) \geq Q_t$) ,there are only simple constraints:

$\sum_j w_{j1}(t) = Q_t$, $w_{j1}(t) \geq 0$, $w_{j1}(t) \leq I_t(WL_j)$ for all j and for each t,

where $w_{j1}(t)$ denotes the quantity which is shipped from warehouse WL_j to the retailer RT_1.

Create Optimization models by defining objectives

1. Transportation Costs K_t

$$K_t = \sum_j k_{j1} \cdot w_{j1}(t) + \sum_j \overline{k_{j1}} \cdot \delta(w_{j1}(t))$$

where k_{j1} transportation cost per unit on link $WL_j \rightarrow RT_1$, $\overline{k}_{j1}$ fix cost for a vehicle travelling from WL_j to RT_1 and $\delta(w_{j1}(t))$ =1 for $w_{j1}(t) > 0$ and =0, otherwise.

We assume that each amount $w_{j1}(t)$ is shipped directly on the link from WL_j to RT_1, where the transportation time is d_{j1}^* and cost per unit is k_{j1}. There is no consolidation, no round trips etc.
Then,

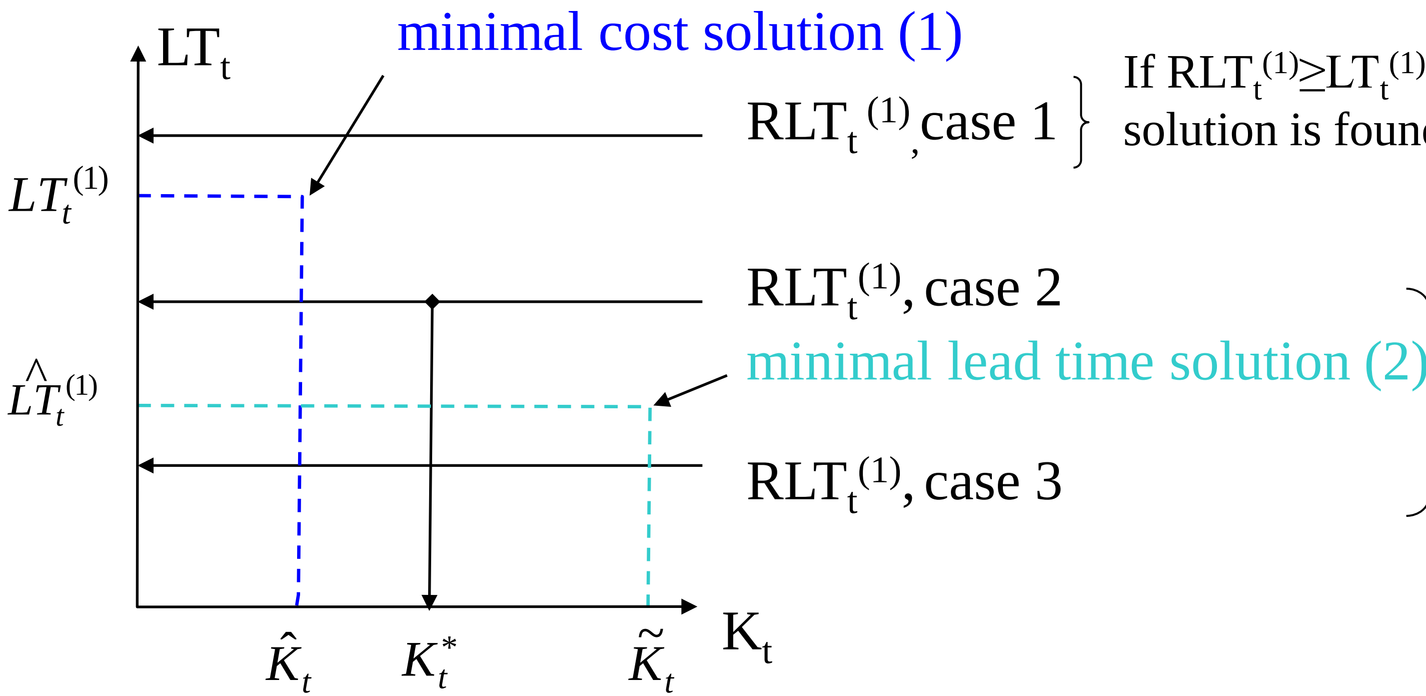
2. The lead time for the whole ordered quantity $Q_t^{(1)}$ is determined by

$$LT_t^{(1)} = \underset{j}{Max}(d_{j1}^* \mid w_{j1}(t) > 0)$$

The ordered quantity $Q_t^{(1)}$ at time t, will be comletely delivered at time $t+LT_t^{(1)}$.

→ We have generated – solving Submodel I – two extreme solutions

- the minimal cost solution and
- the minimal lead time solution



If $RLT_t^{(1)} \geq LT_t^{(1)}$, then a perfect solution is found

If $RLT_t^{(1)} < LT_t^{(1)}$, then consider a different submodel or start negotiation

$RLT_t^{(1)}$ – requested lead time of the order $Q_t^{(1)}$

3. The Multi-Attribute Utility Approach for Negotiation Support

The negotiation approach by Bui and Shakun (NEGOTIATOR)

3.1 Values, Goal Variables and Control Variables for the Production-Distribution Network from 2.

- General Values: high performance, reliability in delivery, safety
- Goal Variables are the operational expressions of the general values :

  delivered quantity, lead time, cost, price
- Notations:

Q_t	– ordered quantity by the retailer (Party A of negotiation)
OQ_t	– offered quantity by the SC in response of the order SC-agent is Party B of negotiation
K_t	– cost of quantity Q_t
P_t	– price of quantity Q_t
LT_t	– lead time of quantity Q_t
t	– time index (t=0,1,2,…)

- Control Variables (CV) and their weights:

CV for Party A (Retailer): Ordered Quantity (number of items), Price (e.g. in EURO), lead time (e.g. in days)

CV for Party B (Supply Chain): Offered Quantity, Price, Lead-Time

First round of negotiation:

Starts with initial offers of each party

Special scenario: The SC-agent offers the ordered quantity $OQ_t = Q_t$. The negotiation focuses on price and lead-time only. Their values are related to the quantity Q_t. Then, each agent simultaneously starts the negotiation with an initial offer for lead-time and price.

The buyer (Party A) starts with a requested-lead-time RLT_t, but does not propose a price

The SC-agent (Party B) has to deliver the whole ordered quantity Q_t or to reject the order. Therefore he/she solves submodel I first and selects a solution closest to the RLT_t of Party A.

Weights for Price and Lead-Time: $w_A(P_t)$, $w_B(P_t)$
$w_A(LT_t)$, $w_B(LT_t)$

The solution of submodel I (slide 18) delivers ranges(intervals) for the control variables (under the condition that the ordered quantity Q_t can be delivered from warehouses (submodel I)).

$$\hat{K}_t \leq K_t \leq K_t(Max) \quad \text{and} \quad L\hat{T}_t \leq LT_t \leq LT_t(Max)$$

$$(\rightarrow \hat{P}_t \leq P_t \leq P_t(Max))$$

For more general cases (the SC-agent offers a fraction of Q_t only or the whole quantity Q_t has to be delivered from the whole distribution network-full CTP), we get the ranges:

$$P_t(Min) \leq P_t \leq P_t(Max) \quad \text{and} \quad LT_t(Min) \leq LT_t \leq LT_t(Max)$$

as a basis for negotiation.

3.2. Utility Functions

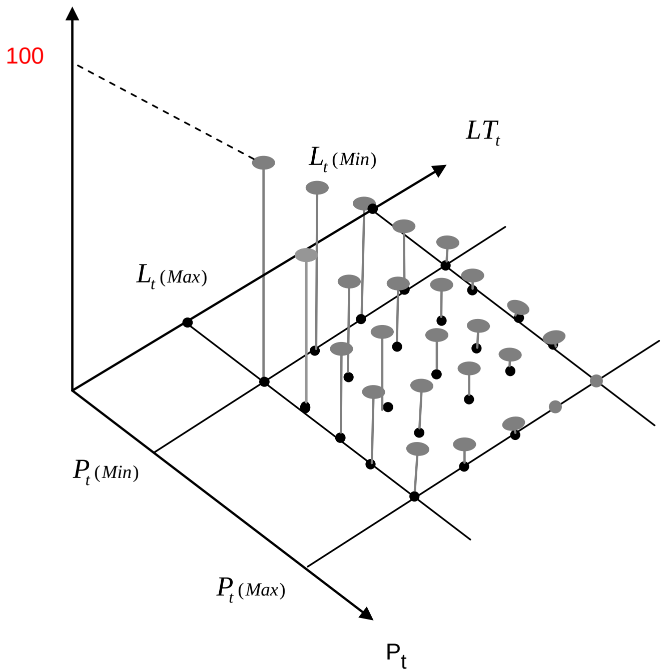
The method is based on each party's utility functions

(1) Conditional Two-dimensioned Utility Functions

Each party defines a conditioned utility function (condition: the ordered quantity is Q_t):

$u_A (P_t, LT_t \ I \ Q_t)$, $u_B (P_t, LT_t \ I \ Q_t)$

utility of party A,B of a price P_t and a lead-time LT_t under the condition of an order Q_t (defined over the ranges for P_t, LT_t)



In case of n-dimensioned utility-functions, (here n=2), weights are not needed.

(2) Weighted Utility Functions

We define one-dimensioned utility functions
u_A (P_t I Q_t), u_A (LT_t I Q_t) for Party A and
u_B (P_tIQ_t), u_B (LT_tIQ_t) for Party B
and use normalized weights $w_A(P_t)$, $w_A(LT_t)$, $w_B(P_t)$, $w_B(LT_t)$ to combine them into weighted utilities u_A^w and u_B^w respectively.

$$u_A^w(P_t, LT_t|Q_t) = w_A(P_t) \cdot u_A(P_t|Q_t) + w_A(LT_t) \cdot u_A(LT_t|Q_t)$$

$$u_B^w(P_t, LT_t|Q_t) = w_B(P_t) \cdot u_B(P_t|Q_t) + w_B(LT_t) \cdot u_B(LT_t|Q_t)$$

Of course u_A^w and u_B^w are not equal to the two-dimensioned conditional utility functions.

(3) Joint Utility Functions

Multiplication of the one-dimensional utility function u_A and u_B with normalized weights and adding the A and B part results in:

$$u_{Joint}^{Price}(P_t|Q_t) = w_A(P_t) \cdot u_A(P_t|Q_t) + w_B(P_t) \cdot u_B(P_t|Q_t)$$

(Joint utility with respect to price)

$$u_{Joint}^{Lead-Time}(LT_t|Q_t) = w_A(LT_t) \cdot u_A(LT_t|Q_t) + w_B(LT_t) \cdot u_B(LT_t|Q_t)$$

(Joint utility with respect to lead-time)

These joint utility functions are used to determine which price and which lead-time maximes the joint utilities of both negotiating parties.

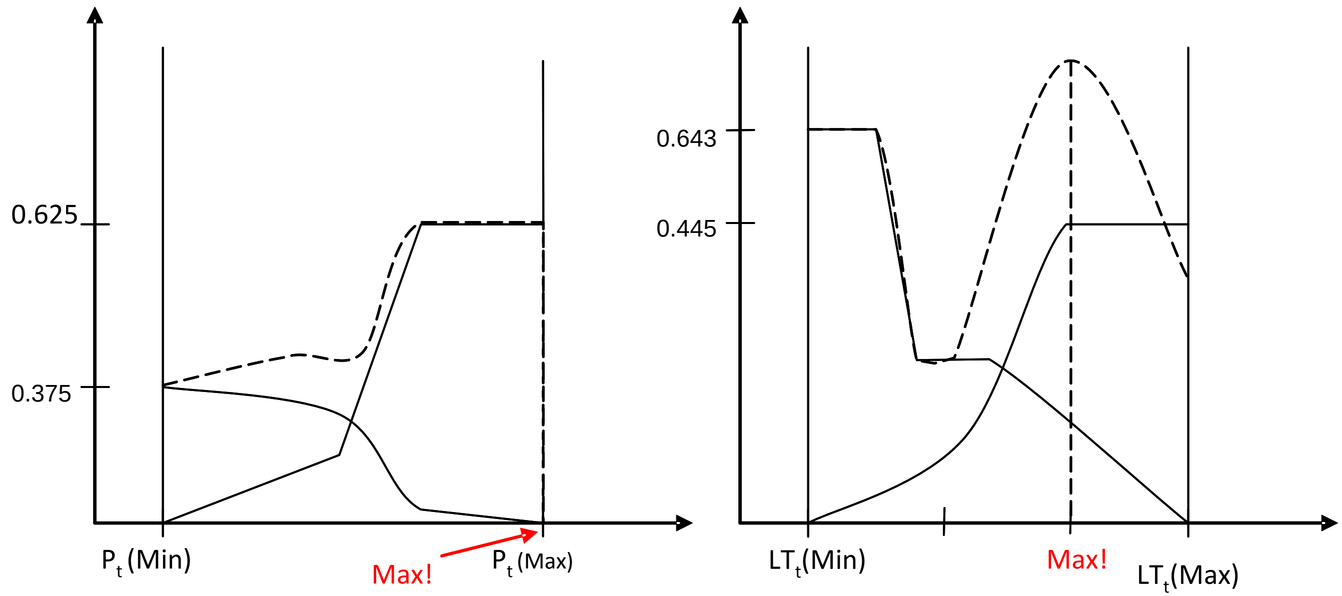
→ Compromise solutions for further negotiation (Bui and Shakuns approach)

→ Simple example next slide

Example of Joint utility functions (Q_t=500, given weights)

$u_{Joint}^{Price} = 0.357 \cdot u_A(P_t \mid 500) + 0.555 \cdot u_B(P_t \mid 500)$

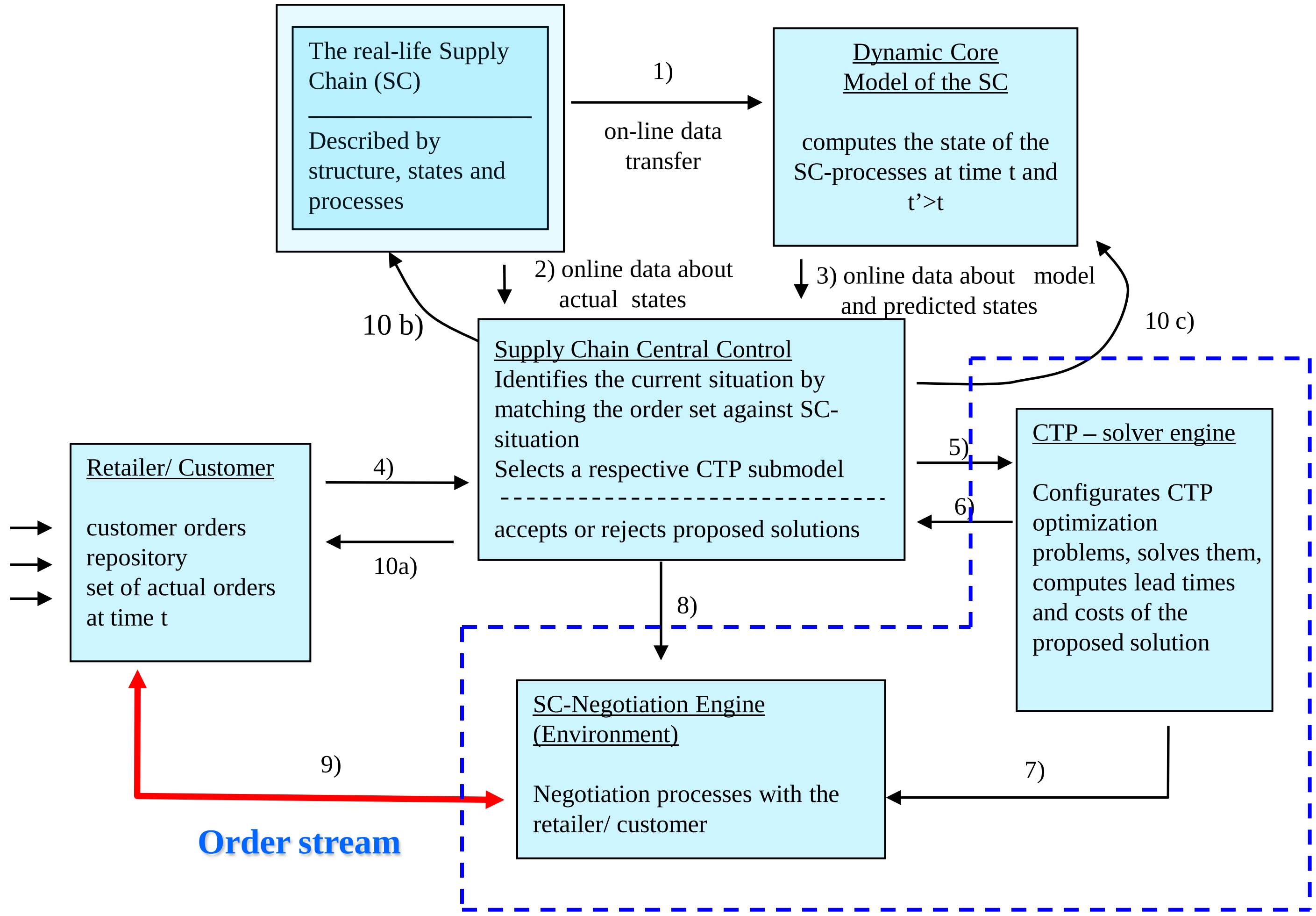
$u_{Joint}^{lead-time} = 0.643 \cdot u_A(LT_t \mid 500) + 0.445 \cdot u_B(LT_t \mid 500)$

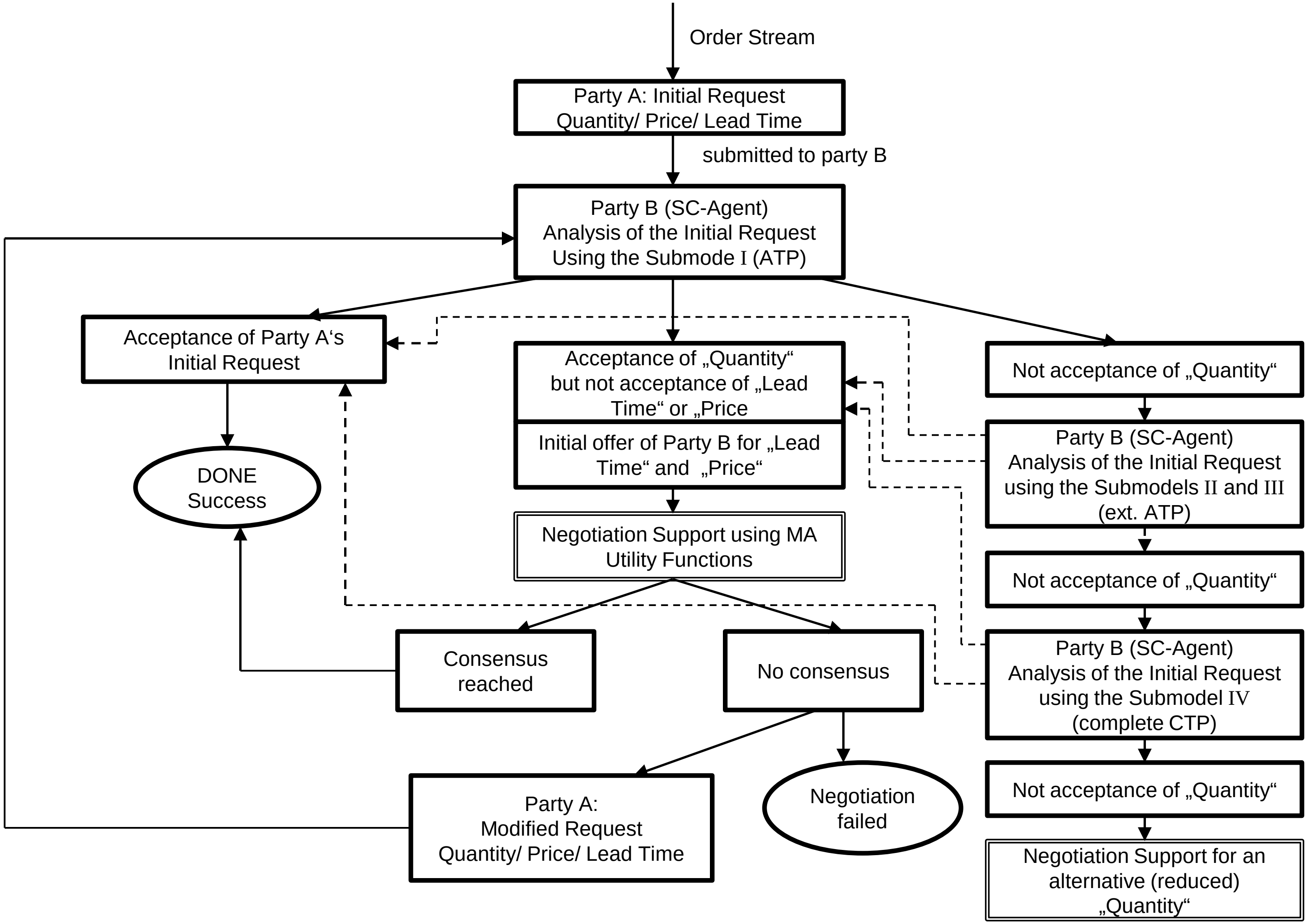


Joint utility for price **Joint utility for lead-time**

4. Implementation by a Multi Agent System (MAS) – The Architecture

The Supply Chain Central Control (SCCC) unit uses the measured actual states and the (by the Dynamic Core Model of the SC) predicted future model states to identify the current SC-situation. Then, it matches the actual order set against this SC-situation and identifies a respective CTP submodel from its model-base.





An integrated optimization – negotiation algorithmic approach

5. Conclusions and Future Work

- The approach proposed combines
  - Optimization and MCDA based on a MILP model of a production-distribution network with
  - Negotiation Theory, in particular with negotiation based on multiple attribute utility approach

- This conceptual framework needs both an implementation and an experiment in practice by case studies (next work)

-We will use our implemented multi-agent simulation framework for automated negotiation in order promising (AMCIS, SFO August 2009)