Advanced planning and scheduling with collaboration processes in agile supply and demand networks

Yohanes Kristianto
Department of Production, University of Vaasa, Vaasa, Finland
Mian M. Ajmal
College of Business Administration, Abu Dhabi University, Abu Dhabi, United Arab Emirates, and
Petri Helo
Department of Production, University of Vaasa, Vaasa, Finland

Abstract

Purpose – The general purpose of the paper is to improve supply chain (SC) responsiveness and agility by developing advanced planning and scheduling (APS) with collaboration process into agile supply and demand networks (ASDN).

Design/methodology/approach – Some industrial examples are presented to extract the APS requirements, then business models that are supported by analytical models are developed into APS modules to respond to the requirements. At the end, the modules are attached into an ASDN simulator to measure the benefit of the APS with collaboration process.

Findings – The results show that the APS with collaboration process is superior to existing APS software in terms of promising lead times to customers at minimum inventory level.

Research limitations/implications – Since the APS with collaboration process cannot optimize transportation planning, SCs cannot therefore optimize networks by finding the optimum network configuration. Currently, the simulator needs to be tested in several possible network scenarios to find the optimal network configuration.

Practical implications – The APS with collaboration process makes it possible to give guaranteed lead times at minimum inventory level. Furthermore, it is possible to combine the APS with collaboration process with enterprise resources planning or MRP II by considering the criticality of the planning.

Originality/value – The attachment of APS with collaboration process business into ASDN represents the original aspect of this paper.

Keywords Value chain, Flexible labour, Supply chain management, Production scheduling, Market share

Paper type Conceptual paper

1. Introduction

The production planning and control procedures used in industry are subject to dramatic changes. Many companies have recognized that the currently used MRP II and enterprise resources planning (ERP) philosophy does not support planning in the sense that the capacities of the resources are adequately considered during the planning process. It is now commonly understood that ignorance with respect to capacity results

Business Process Management Journal
Vol. 17 No. 1, 2011
pp. 107-126
© Emerald Group Publishing Limited
1463-7154
DOI 10.1108/14637151111105607

in high work-in-process combined with decreasing service levels and long customer waiting times. In addition, in highly integrated supply networks with small "slack" insufficient planning procedures become more evident than in non-integrated logistic networks. Being considered as waste, safety stock and safety time are reduced to a minimum. Generating feasible plans under these conditions is a real challenge for a planning system. However, feasibility is only achievable if planning is based on a realistic modeling of the logistic processes that reflects the key factors having an impact on the system's performance.

The appeal of advanced planning and scheduling (APS) to integrated supply networks is that it enables a supply chain (SC) to distribute job orders and machine scheduling to meet the required due date, and at the same time to improve product margin by reducing costs and increasing manufacturing throughput (Lee *et al.*, 2002; Moon *et al.*, 2004; Chen and Ji, 2007). This makes the planning system of APS the first business model to deal with the gap between the requirements of the sales department and those of the manufacturing department. To satisfy a customer's requirements, the APS system usually makes a schedule and then changes it frequently (Nishioka, 2004).

Furthermore, APS is also useful for managing the SC, where multi-tier and multi-site production exists. This means the planning process has to be de-coupled (Wiers, 2002). A tier agent not only has the planning capability for its production planning but also needs to cooperate and to coordinate with other tier agents as well as site agents to meet the order (Chen *et al.*, 2009). This coordination makes multi-tier and multi-site production capable of promising delivery lead times to end customers.

However, today's APS has been developed in a way that partially ignores global optimization for the entire SC (Lockamy and McCormack, 2004). That causes upstream SCs to suffer from receiving orders that cannot be accomplished optimally by them. For instance, it is common in practice that the master production schedule (MPS) of a buyer, due to demand changes, produces an unrealistic and unconstrained order plan to suppliers such that when it is issued to purchase material then the suppliers find it very difficult to deploy the order into their operations scheduling to meet the delivery schedule because of capacity limitation. The purpose of our paper is to tackle this issue by developing a conceptual model of APS with collaboration process to coordinate supplier and buyer planning. The expected result of the model is to produce coordinated action between suppliers and buyers that will enable lead times to be guaranteed to the end customer.

The reasons for developing coordinated actions among suppliers and buyers are twofold. Module tier collaboration in APS is managed to generate flexibility by providing the capability to promise in the SC, and at the same time to structure a streamline SC to improve efficiency. The aim of this collaboration process is to improving the competitiveness of the SC (Stadtler, 2005). Second, in order to introduce the APS model with collaboration process to practitioners, a business model had to be taught. Though generic in design, these business models did not result in industry standards.

The following section first introduces background for the research (Section 2). Then the methodology section is started by structuring the APS model with collaboration, which continues with analytical modeling to detail the operability of the APS (Section 3). Section 4 models the APS modules coordination that is analyzed further by comparing it with the existing APS software (Section 5). Managerial implications are then examined in Section 6 and finally the outcomes of this paper are concluded in Section 7 to summarize the analysis results and discuss some future research opportunities.

2. Literature review

In introducing the importance of APS with collaboration process, we will first give some examples of best practices that are using collaboration process in their SCs to improve their competitiveness: for instance, the business practices in Dell computers (Lee, 2004), Hewlett Packard (HP) desk jet printers (Feitzinger and Lee, 1997), Amazon (Kassmann and Allgor, 2006), and Phillips Personal Garment Care (Sanchez, 2002). One of them, HP, established the Strategic Planning and Modeling group to apply more radical approaches, namely the realignment of manufacturing and distribution strategies, improvement in forecasting techniques and methods, and product and process redesign for SC management.

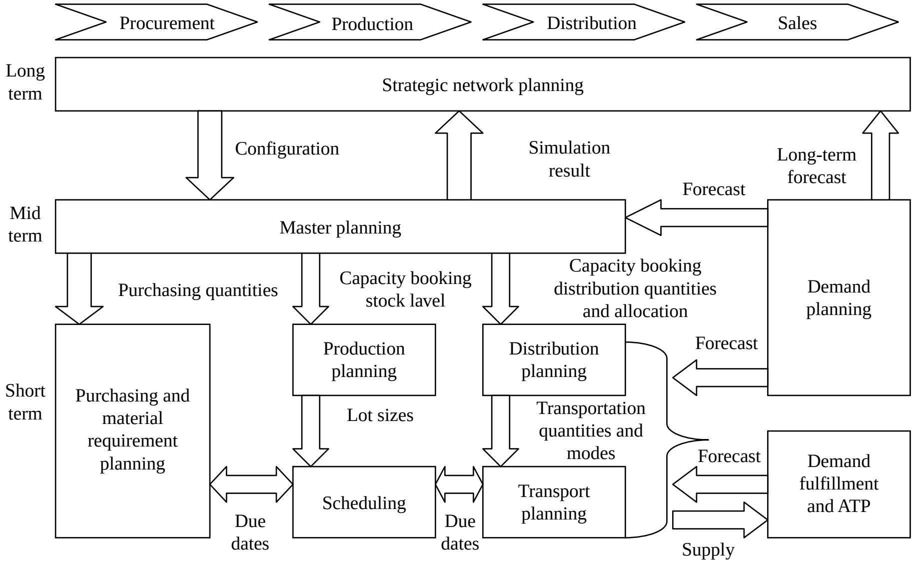
HP strategy has further investigated the application of logistics and manufacturing integration (Feitzinger and Lee, 1997).The important outcome of this research is how to optimize SC performance by building coordination among marketing, research and development, manufacturing and distribution and finance activities. However, the logistics and manufacturing integration seem to be confined to within an enterprise or factory.

Manufacturing and logistics integration beyond the enterprise is practiced by Dell Computers' virtual integration, which insists on the manufacturer specializing and integrating together the business with partners. One important piece of information from this example is that manufacturing also opens the possibility for outsourcing strategy. This outsourcing definition, however, is different to traditional thinking on outsourcing, where the buyer also outsources his or her problems. Indeed, risk sharing emerges as a form of SC collaboration. In this case, Dell Computers is not just cost-effective and fast, but also agile, adaptable and aligned (Lee, 2004).

From the examples, SC best practices can be categorized into three properties, namely agility, adaptability and alignment, where they supports the application of a collaboration process (alignment) in order to achieve a quick response to highly varied demands (Lee, 2004). Thus, it is important to look beyond the enterprise to create adaptability and agility in collaboration in material and capacity planning in order to give availability to promise (ATP) to customers.

APS improves the integration of materials and capacity planning by using constraint-based planning and optimization modules (Van Eck, 2003; Chen and Ji, 2007). This integration can be seen in Figure 1, which details the coordination of the APS modules. Different modules can interact via sending messages and exchanging data. This gives benefit to SCs by using all APS modules from the same vendor thus avoiding redundancies and inconsistencies in the planning data caused by multiple databases (Rohde, 2002).

The functionalities of each module can be described as follows: the demand-planning module necessitates forecasting, and what-if analysis is conducted to make the optimal calculation of required inventory and safety stock level (Meyr *et al.*, 2002). The master-planning module is used to balance supply and demand by synchronizing the flow of materials within an enterprise or factory (Meyr *et al.*, 2002). The ATP module is used to guarantee that customer orders are fulfilled on time and in certain cases, even faster. The production planning and scheduling module is intended for short-term



Source: Rohde (2002)

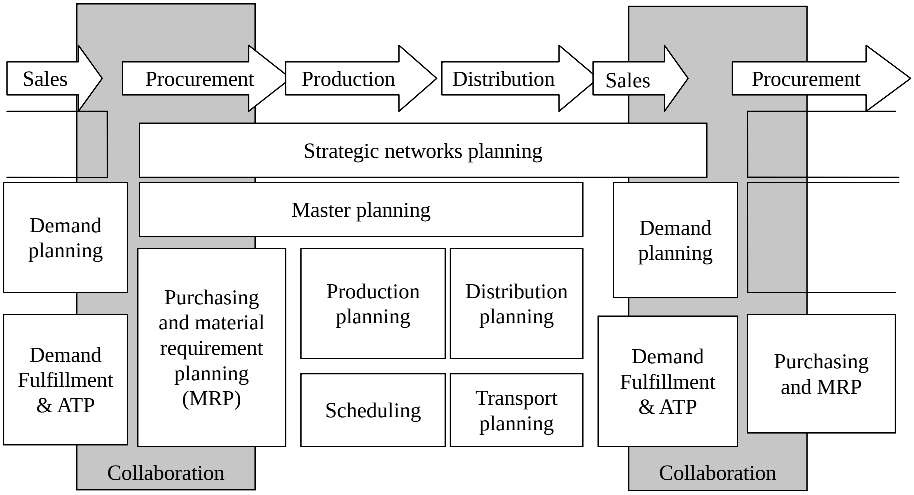
Figure 1.
Coordination and data flows of APS modules

planning within APS so that it sequences the production activities in order to minimize production time (Stadtler, 2002a, b). The material requirement follows a top-down hierarchical approach, where it starts with MPS. The schedule is then detailed into material requirement planning (MRP) by ignoring capacity constraint and assuming fixed lead times. The distribution-planning module is very much correlated with transport agreements for shipping consumer goods from manufacturers to customers (Fleischman *et al.*, 2002).

2.1 Insight from the literature

Figure 1 shows that APS deals with the planning process within one planning domain (an enterprise or a factory) by managing lead times (due dates), lot size, production capacity (committed supply) and production rates (capacity booking) to generate ATP. However, since the modules are designed for one enterprise or factory (Rohde, 2002), some of the decisions that are beyond the scope of the individual planning domain are not covered. For instance, if the buyer issues a purchasing and MRP decision, without having collaboration with the suppliers, then the buyer will loose the capability to promise lead times. The reason is that the buyer lacks supply capability because the buyer cannot access the suppliers' master planning. This master planning information is important since it describes the suppliers' production plans and inventory levels (Kilger, 2002). Thus, collaboration amongst different APS modules amongst different enterprises is required for tackling this discrepancy.

The difference between Figures 1 and 2 is that Figure 1 is single APS operated by one enterprise or factory, while Figure 2 links the APS to make them connected. Figure 2 shows the collaboration interfaces of an APS where it is divided into two opposite directions: divergent collaboration with customers (sales collaboration) and convergent collaboration with suppliers (procurement collaboration) (Rohde, 2002).



Source: From Meyr (2002)

Figure 2.
Collaboration between APS

Sales collaboration is mainly about the sharing of information on demand patterns, lead times, prices and product configurations. Procurement collaboration is mainly about sharing information on suppliers' inventory levels and production capacities. If the collaborations are managed appropriately then the downstream SC will not loose its capability to promise lead times to customers and at the same time minimize the total costs of the SCs. Thus, each of the two shaded blocks in Figure 2 represents both sales and procurement collaboration to create a common and mutual agreed-upon plan (Chen *et al.*, 2009). Furthermore, sales and procurement collaboration should also be supported by using, for instance, vendor managed inventory (VMI) by sharing demand and inventory information amongst enterprises or factories such that it creates demand collaboration, inventory collaboration, capacity collaboration, and transport collaboration, as shown in Figure 2 (Kilger and Reuter, 2002).

In detail, Figure 2 shows the results of collaboration amongst three APS modules, namely purchasing and MRP (procurement collaboration), demand fulfillment and ATP (demand planning), and demand planning (sales collaboration). ATP is the result of synchronized supply and capacity plan and represents the actual and future availability of supply and capacity that can be used to accept new customer orders (Kilger and Scheeweiss, 2002).

In addition to the benefit of collaboration between APS, it is also possible to measure its effectiveness in terms of SC network agility by attaching it into agile supply and demand networks (ASDN) simulator. This agility is reflected by using lead times and total inventory value of the SCs, where it reflects integral and comprehensive planning of the entire SC from supplier to end customer (Fleischman *et al.*, 2002). Thus, embedding APS into ASDN will improve the competitiveness of SCs significantly by revealing the close relationship between procurement and sales collaboration, which will support operation and supply flexibility (Coronado *et al.*, 2007).

In conclusion, to make APS with collaboration process possible, it is necessary first to establish information links and interfaces between sales (supplier APS) and purchasing and MRP (customer/buyer) modules (Meyr *et al.*, 2002). These information links and interfaces are important to enable at least procurement and sales collaboration. Then, as the next step, it is necessary also to link inventory and demand information to obtain the whole picture of APS with collaboration.

3. Methodology

This section starts with methodology as the focal point and only addresses the background for the readers in order to understand the motivation of this research, how and why the research methods and techniques were chosen in answering the research questions. Thus, this section presents a comprehensive framework within which this research operates.

Business and analytical models are used in this research since these approaches are predominant in science and assumes that science quantitatively measures independent facts about a single apprehensible reality (Healy and Perry, 2000). In terms of the ontology element, this research uses naïve realism because the reality that is considered in this research is real and apprehensible (Guba and Lincoln, 1994). Furthermore, this research aims to understand the operability of collaboration within APS that requiring the kind of measurement rather than changing collaboration concept in APS. In other words, we can conclude that our research area is closer to theory testing research (Healy and Perry, 2000).

3.1 Research design

The purpose of the research is to build APS with collaboration process into ASDN. We started with illustrating some examples from industry to emphasize the importance of collaboration ("Literature review" section). From the example, the main problems and expectations are summarized to develop business and analytical models of APS with collaboration process ("Modeling" section) and the result will be used for developing ASDN. Finally, the developed APS with collaboration processes model is benchmarked against other APS software to validate the results (Figure 3).

The Section 4 details the methodology into APS modeling.

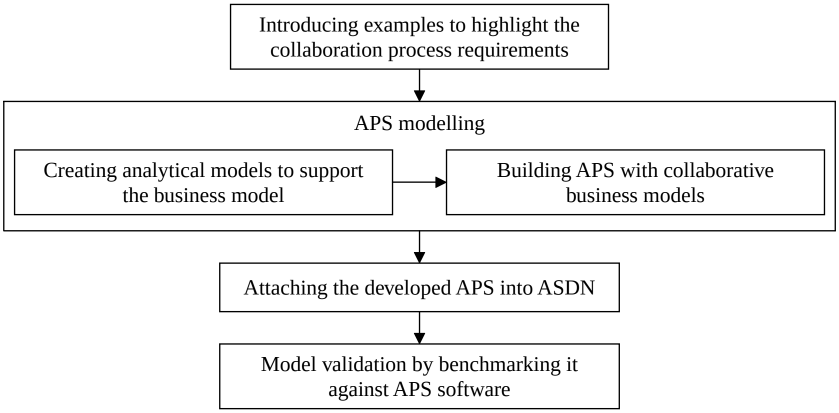


Figure 3.
Research flows for developing APS with collaboration process in the ASDN

4. APS modelling

APS modelling is intended to build tools for APS with collaboration process. When we are discussing APS in the SC domain, we refer to the Supply Chain Operations Reference (SCOR) model as a reference for performance metrics within the SC that should be analysed (Meyr *et al.*, 2002). In this paper, we will not discuss the SCOR model further since the metrics have, in fact, been included into ASDN software. The main task of this section is to build the new concept of APS with collaboration through business process model development. The reason is that the model will be used to analyse the potential of the SC to improve business performance (Kilger, 2002). Thus, the business model is created in the first phase of APS implementation.

This business model includes strategic alignment of the planning processes, the structuring and interaction of the processes, the internal relationships and cooperation mode between modules involved in the planning tasks, and finally the collaboration mode between purchasing and sales. The result will be synchronizing the purchasing decision and order promising based on forecast (ATP) (Kilger, 2002). Afterwards, analytical models are developed (Section 4.2) to transform the business model into application.

4.1 Building APS with collaboration process business model

With regard to requirements in the business model, we are looking to find a framework for focusing the model in terms of collaboration building within the SC. Thus, we have summarized the required conditions as follows:

- The issue for developing APS with collaboration is that how to minimize customer losses (time and options) and at the same time manufacturer losses (overhead costs, for instance extra administration cost, order cost, etc.) (Kristianto and Helo, 2009). Problem example addresses this problem by showing that building commitments in terms of meeting the demand forecast by downstream and supply by upstream SCs to create adaptability and alignment. In tactical level, inventory allocation and replenishment must be aligned to create agility by giving guaranteed lead times at minimum total costs.
- Strategic inventory and replenishment alignment give significant contribution to SC network planning in terms of inventory value and lead times reduction as well as profit maximization. Thus, attaching APS to ASDN can be used by SCs to measure their APS performance through some indicator such as inventory value, profit and lead times.

This, this paper proposes the APS with collaboration process business model as Figure 4.

Figure 4 shows that the outcome of master planning should be the planned inflow of components where it can be used to synchronize the purchasing (by means the aggregate inflow) and ATP and the outputs should be mid-term demand forecast and guaranteed lead times to customer. Thus, the task of master planning is to link the planned component inflow with final item demand. This task is rather loose limitation with respect to varying long lead times and small procurement lot sizes. The objective should be to balance inventory-holding cost for the components against profit.

Purchasing need to know about the aggregate component inflow master planning calculates in for instance weekly basis for giving the least different between supply

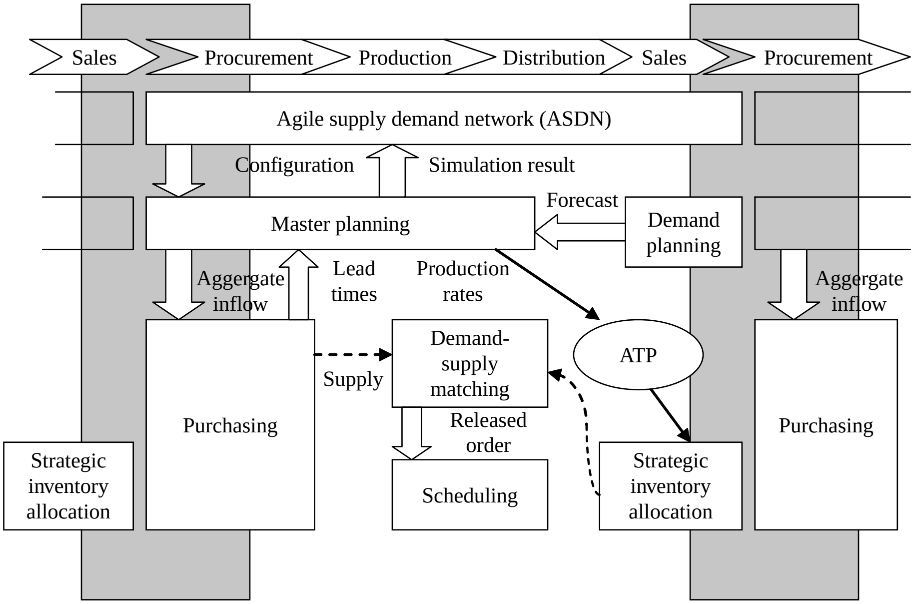


Figure 4.
The proposed APS with collaboration business model

and demand. With the result, those sourcing strategy, inventory allocation and lot sizing strategy should be considered. Thus, the output of purchasing module should be lead times and procurement lot sizes. On the other hand, ATP needs to know for instances inbound service time and demand rates that will be used to allocate safety stock for different components and products.

In supporting this business process model, we develop analytical models into Excel file and attach them with ASDN software. ASDN software is open source software that can be downloaded free. Next phase of this research would be developing a collaborative APS so that users can simulate their applicability into one software package.

4.2 Building analytical models for APS with collaboration process

APS analytical models details the operationalization of APS modules according to Figure 4. Section 4.2.1 models master planning module. Section 4.2.2 models purchasing module that comprises promised lead times and lot sizing strategy optimization. Section 4.2.3 models strategic inventory allocation module. Section 4.2.4 models demand and supply matching module and Section 4.2.5 models scheduling module. Attaching the APS module into ASDN is elaborated into Section 4.3 to illustrate the operability of the models. Each sub-section in this section represents module in Figure 4.

4.2.1 Master planning module. The focus of master planning is in converting demand forecast information into aggregate inflow and production rates. Master planning decomposes the multi-stage SC strategic inventory location model into J-stages. J is the number of workstations in the SC and there is one stage for each node. Suppose we have I components where each of these components supports directly at least one product family 1 to J in a different manner Φ_{ij}. For each node $-j$ we define μ_j to be the optimum production rates and W_j to be the promised lead times. W_j is received from purchasing and transferred to strategic inventory allocation to make ATP. Beforehand, μ_j and W_j

need to be optimized against system parameters such as demand rate at stage $-j$ λ_j, demand inter-arrival times and service times standard deviation at stage $-j$ σ_{A-j} and σ_j, respectively, and utilization factor ρ_j to inform us whether in our order there is a delay/backorder at stage $-j$, or not. In addition, penalty (i.e. delivery lateness) cost C_{W-j} and service costs (i.e. transportation, production and distribution) C_{T-j} are also measured as well as customer demand and its standard deviation for each product variant for allocating stocks. Thus, cost function is developed in order to determine our optimum decision, as follows:

$$E(C)_j = C_{T-j} \cdot \mu_j + C_{W-j} \cdot N_j \tag{1}$$

Equation (1) can be generalized into:

$$E(C) = C_{T-j} \cdot \mu_j + C_{W-j} \cdot \left(\frac{\lambda_j^2 \cdot \mu_j \cdot \left(\sigma_{A-j}^2 + \sigma_j^2\right)}{2 \cdot (\mu_j - \lambda_j)} + \rho_j \right) \tag{2}$$

In considering that the demand inter-arrival rate λ_j and processing rate μ_j are not stationary and are just barely less than one $(1 - \varepsilon) < \rho < 1$ or are equal to or greater than one $(\rho \geq 1)$. $0 \leq \rho_j \leq 1$, we simplify equation (2) by excluding $C_{w-j} \cdot \rho_j$ since it is not significant to $E(C)$ as compared to:

$$C_{W-j} \cdot \frac{\lambda_j^2 \cdot \mu_j \cdot \left(\sigma_{A-j}^2 + \sigma_j^2\right)}{2 \cdot (\mu_j - \lambda_j)}.$$

Thus, equation (2) can be optimized according to μ_j so that we have:

$$C_{T-j} + \frac{\lambda_j^2\left(\sigma_{A-j}^2 + \sigma_j^2\right) \cdot C_{W-j}}{2 \cdot (\mu_j - \lambda_j)} - \frac{\lambda_j^2\left(\sigma_{A-j}^2 + \sigma_j^2\right) \cdot C_{W-j} \cdot \mu_j}{2 \cdot (\mu_j - \lambda_j)^2} = 0 \tag{3}$$

$$\mu_j = \frac{\lambda_j\left(4C_T \pm \sqrt{4C_T\left(1 + 4C_T + \left(\sigma_{A-j}^2 + \sigma_j^2\right)C_{W-j}\lambda_j\right)}\right)}{4 \cdot C_T}. \tag{4}$$

Equation (4) shows that the processing rate is determined by demand and process uncertainty as well as penalty and service costs. More service cost induces lower μ_j and more penalty cost induces higher μ_j. This result will be used for determining lot size in the purchasing module.

4.2.2 Purchasing module. The focus of purchasing is finding the promised lead times and procurement lot sizes. The objective of this module is giving the promised lead times to the customer with a 100 percent guarantee. Strategic replenishment covers the promised lead times for ATP for finding optimum lot sizes. Purchasing receives predicted demand from master planning (Figure 4).

A. Promised lead time. We model the manufacturing process according to the GI/G/1 queue model. The reason is that the demand inter-arrival and processing rates are not stationary and are just barely less than one $(1 - \varepsilon) < \rho < 1$ or are equal to or greater than one $(\rho \geq 1)$. This model closely represents the real situation in job order operations where common product platform increases process flexibility and the number of possible product configurations. Thus, a common product platform makes manufacturing facility busier and has higher utilization.

By using this model, and following Little's formula (Gross and Harris, 1974), the total customers in the system at stage $-j$ N_j can be interpreted as:

$$N_j = \frac{\lambda_j^2 \cdot \left(\sigma_{A-j}^2 + \sigma_j^2\right)}{2 \cdot (1 - \rho_j)} + \rho_j \tag{5}$$

σ_{A-j} and σ_j in equation (5) denote the demand inter-arrival rate standard deviation and service rate standard deviation at stage $-j$. σ_{A-j} can be found as maximum difference between average inter-arrival time $1/\lambda_j$ and maximum inter-arrival time at maximum demand during net replenishment time $1/(D_j(\tau))$ or $\sigma_{A-j} = (1/\lambda_j) - (1/(D_j(\tau)))$. Demand during net replenishment time $D_j(\tau)$ is obtained by considering that safety stock should be covered only in this period, because after production is finalized the customer can get the product immediately.

In finding service rate standard deviation σ_j, we assumed that between inbound service time standard deviation σ_{ij} and production process time standard deviation σ_{T-j} are independent. The reason is that σ_{T-j} depends on the number of customer orders and σ_{ij} depends on the upstream stage $-i$ service rate standard deviation. These two processes are independent since they are two different firms. Finally, we formulate service rate standard deviation σ_j as:

$$\sigma_j = \sigma_{(m+p)-j} = \sqrt{\sigma_{ij}^2 + \sigma_{T-j}^2}.$$

Production process time standard deviation σ_{T-j} can be assumed to equal σ_{A-j} by considering that each stage will produce to order. Inbound service time standard deviation σ_{ij} can be obtained from the service rate variance at its upstream stage $-i$ or σ_{B-i} for $i = 1, 2, ..., j-1$ where stage $-i$ is an adjacent node to stage $-j$ We define inbound service time standard deviation σ_{ij} as,$\sigma_{ij} = \max\{\sigma_{ij}, \max\{\sigma_i | i : (i \cdot j) \in A\}\}$. Exceptionally, σ_{ij} for most upstream are known parameters since this standard deviation is caused by external factors of the SC, e.g. suppliers of most upstream.

On average, stage $-j$ places an order equal to $\Phi_{ij}\lambda_j$ where Φ_{ij} denotes arc $(i,j) \in A$ from downstream stage $-j$ to upstream stage $-i$ for which $\Phi_{ij} > 0$. Stage $-j$ cannot start production to replenish λ_j until all inputs have been received; thus, we have promised lead times ATP $W_j = \max\{W_i | i : (i \cdot j) \in A\}$where W_j and W_i for $i = 1,2, \ldots j-1$ denotes service time and optimum inbound service time for stage $-j$.

We do not permit $W_j > \max\{W_i | i : (i \cdot j) \in A\}$ to avoid excess inventory and/or delay of the orders to the suppliers so that idle capacity can be eliminated. Thus, we define inbound service time W_i, i.e. $W_i + T_j = W_j$ as:

$$W_i = \max\{W_j - T_j, \max\{W_i i : (i \cdot j) \in A\}|\}.$$

T_j is production time at stage $-j$ and with regard to the G/GI/1 queue system, W_i is equal to waiting time in a queue:

$$W_{q-j} \leq \frac{\lambda_j \left(\sigma_{A-j}^2 + \sigma_j^2\right)}{2(1 - \rho_j)}.$$

Since W_{q-j} is the maximum waiting time in a queue, then the following condition is applied to decide on W_i:

$$W_i \leq W_{q-j} \leq \frac{\lambda_j\left(\sigma^2_{A-j}+\sigma^2_j\right)}{2(1-\rho_j)} \tag{6}$$

Thus, finally ATP for stage $-j$ is equal to W_j and we can formulate it as follows:

$$W_j = W_i + T_j \tag{7}$$

Promised lead times, together with production rates, are useful information for developing lot sizing strategy.

B. Lot sizing strategy. To optimize lot size, first we consider the variable and fixed costs of product portfolios that consist of J product family. Suppose we have I components, where each of those components supports directly at least one product family 1 to J in a different manner Φ_{ij}. Variable costs for product family j from component $-i$ to product $-j$ comprise order cost C_{o-ij}, production cost C_{p-j}, total inventory cost h_i, backorder cost C_{b-ij}, shortage cost C_{sh-ij} and setup cost $C_{S(j)}$ for determining lot size q_{ij}.

Some lot sizing models are available, such as the classical economic order quantity (EOQ) model (equation (8)), shortage permitted EOQ model (equation (9)), production and consumption model (equation (10)), production and consumption with shortage model (equation (11)), and EOQ with shortage and lead time model (equation (12)), depending on the SC inventory policy. Because of space limitation, this paper directly shows the lot sizing models as follows:

$$q_{ij} = \sqrt{\frac{2\cdot\lambda_{ij}\cdot C_O}{h_i}} \text{ (Classical EOQ)} \tag{8}$$

$$q_{ij} = \frac{\sqrt{(\lambda_{ij}\cdot h_i\cdot C_{b-ij})\cdot\left(2\cdot h_i(h_i+C_{b-ij})-C^2_{sh-ij}\right)}}{h_i\cdot C_{b-ij}} \tag{9}$$

(Shortage permitted EOQ model)

$$q_{ij} = \sqrt{\frac{(2\cdot C_{O-ij}\cdot\mu_j)}{h_i\cdot(\mu_j-\lambda_{ij})}} \text{ (Production and consumption model)} \tag{10}$$

$$q_{ij} = \sqrt{\frac{(2\cdot C_{O-ij}\cdot\mu_j\cdot\lambda_{ij})(h_i+C_{b-ij})}{h_i\cdot(\mu_j-\lambda_{ij})C_{b-ij}}} \tag{11}$$

(production and consumption model with shortage)

$$q_{ij} = \frac{\sqrt{(\lambda_{ij} \cdot h_i \cdot C_{b-ij}) \cdot \left(2 \cdot h_i (h_i + C_{b-ij}) - C^2_{sh-ij}\right)}}{h_i \cdot C_{b-ij}} \cdot \frac{W_j}{L_{ij}} \quad \text{(EOQ model with shortage and lead time)} \tag{12}$$

L_{ij} in equation (12) represents the predicted lead times from component $-i$ to product $-j$ before the demand forecasting information comes. We notice that μ_j as production rate is compulsory information for finding optimum lot size where we can obtain it from master planning.

4.2.3 Strategic inventory allocation module. The objective of strategic inventory allocation is to generate the optimum safety stock level in each SC member to give order promising or ATP. Strategic inventory allocation will be matched with lot size information from purchasing to minimize simultaneously delivery lateness and excess inventory level.

This module uses optimum production rates μ_j from master planning to decide on base stock location by considering the least non-negative μ_j value at stage $-j$. This decision is used to calculate the optimum service time of each stage as $W_j = (\mu_j/\lambda_j) \cdot W_{q-j}$ and so we have maximum production time T_j as $T_j = W_j - W_{q-j}$.

In the case of a busy production facility as the second condition ($W_j > W_i$), it is better to delay the orders to the suppliers by $W_{q-j} - W_i$. This suggests a different approach to Graves and Willems (2000) in satisfying a 100 percent service level by finding the maximum waiting time in a queue as production time T_j. Finding T_j satisfies the maximum possible demand over the net replenishment time τ for stage $-j$ where it is replenishment time $W_i + T_j$ minus its service time W_j or $\tau = W_i + T_j - W_j$.

Following the formulation of Graves and Willems (2000) for the expected inventory $E(I_j)$ that represents the safety stock held at stage $-j$, $E(I_j)$ can be found as the difference between cumulative replenishment and cumulative shipment, as follows:

$$E(I_j) = D_j(\tau) - \lambda_j(\tau) \tag{13}$$

$$D_j(\tau) = \tau \cdot \lambda_j + z_j \cdot \sigma_D \cdot \sqrt{\tau} \tag{14}$$

Equation (14) expresses the expected safety stock at maximum possible demand by finding the demand bound $D_j(\tau)$ where it is equal to maximum stock during τ at a certain level of customer service level at stage $-j$ z_j (Graves and Willems, 2000). It is possible to get $E(I_j) = 0$, which means we can manage stage $-j$ as make-to-order (MTO) instead of mak-to-stock (MTS). Our model extends Graves' and Willems' (2000) strategic safety stock allocation by adding production time as the third variable that is optimized.

4.2.4 Demand-supply matching module. The production process in stage $-j$ should meet demand during net replenishment time τ or $D(\tau)$ that requires all of the delivered components $-i$ from stage $j - 1$ to stage $-j$ which must be received by the manufacturer of product $-j$ to start production process of product $-j$. Thus, we need to find the maximum inbound service time W_i for receiving the component $-i$ from stage $j - 1$ as follows:

$$\overline{L_{ij}} = \max\left(1, \frac{D_j(\tau)}{q_{ij}}\right) \cdot W_i \tag{15}$$

4.2.5 Scheduling module. We use a traveling salesman problem for making scheduling by considering that it cannot produce illegal sets of operation sequences (infeasible symbolic solutions) or non-optimum scheduling by putting higher $t_j - t_k$ (Kempf *et al.*, 2000). The problem assumed that in stage $-j$ there are $-J$ operations that can be formulated as follows:

$$Min(\tau_j - T_j) \cdot \lambda_j \tag{16}$$

$$\text{Subject to } \; t_j - t_k \geq T_j, \quad (k,j) \in O \tag{17}$$

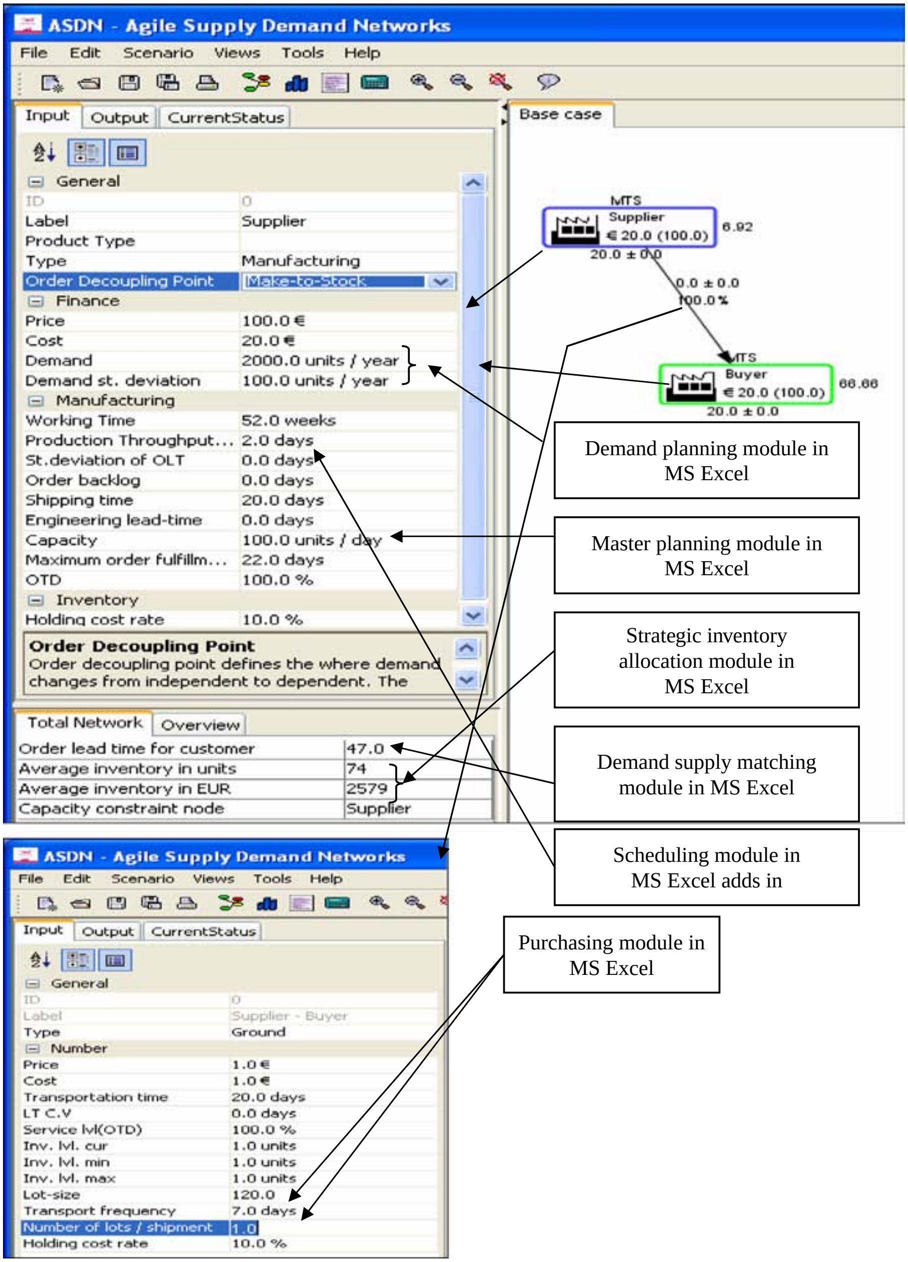
$$t_j - t_k \geq T_j \quad (k,j) \in E_n, n \in M \tag{18}$$

where T_j is the total makespan of the operations at stage $-j$ within machine $-n$, t_j and t_k represent the precedent operations $-j$ and $-k$ where their end and start time cannot be overlapped (equation (17)) by considering operations $-j$ processing time T_j. Furthermore, E_n denotes the set of pairs of operations to be performed on machine $-n$ and which cannot overlap in time. Thus, the start time operation $-j$ cannot overlap the start time operation $-k$ in the same machine $-n$ from the total number of machines $-M$ (equation (18)). This problem will be solved by applying MS-Excel add-in facility for optimal sequencing.

4.3 Attaching the APS with collaboration process with ASDN

This section is used to attach APS analytical models into the ASDN simulator. In this part, firms generally focus on long-term strategic planning and design of their SC (Figure 1). Therefore, it is related to long-term decisions, such as plant location and physical distribution structure (Meyr *et al.*, 2002). During the process, some compulsory information, for instance the product family structure and market share, potential suppliers and manufacturing capability (delivery lot size, service rate, production system (MTO, MTS, etc)), is utilized to decide on optimum ASDN. Firms may choose to develop their own business by locating some facilities (factories, distribution centers and warehouses) or consolidating with another existing company by using APS with collaboration process. It also possible to re-evaluate the previous strategic plan, for instance the manufacturer intends to relocate its factories to a country with cheaper labor costs. This brings them advantages such as a cheap labor market, low cost of raw materials and the opportunities for new business markets locally.

Owing to its impact on long-term profitability and competitiveness within a company, the planning depends on aggregate demand forecasting and economic trends in the market. It is, therefore, a challenging task, since the planning period ranges from three to ten years, and all the decision parameter conditions may change: for instance, customer demand behavior, market power and supplier capability. Thus, by aligning APS into ASDN (Figure 5), the changing of decision parameter can be transferred to the SCs to create a common and mutually agreed upon plan with faster updating and resulting in more accurate planning. Therefore, the model will collect information from APS modules (master planning, purchasing, demand and supply matching, strategic inventory allocation, and demand planning) to be optimized against supply and demand network configuration.



General	
ID	0
Label	Supplier
Product Type	
Type	Manufacturing
Order Decoupling Point	Make-to-Stock
Finance	
Price	100.0 €
Cost	20.0 €
Demand	2000.0 units / year
Demand st. deviation	100.0 units / year
Manufacturing	
Working Time	52.0 weeks
Production Throughput...	2.0 days
St.deviation of OLT	0.0 days
Order backlog	0.0 days
Shipping time	20.0 days
Engineering lead-time	0.0 days
Capacity	100.0 units / day
Maximum order fulfillm...	22.0 days
OTD	100.0 %
Inventory	
Holding cost rate	10.0 %

Order Decoupling Point
Order decoupling point defines the where demand changes from independent to dependent. The

Order lead time for customer	47.0
Average inventory in units	74
Average inventory in EUR	2579
Capacity constraint node	Supplier

General	
ID	0
Label	Supplier - Buyer
Type	Ground
Number	
Price	1.0 €
Cost	1.0 €
Transportation time	20.0 days
LT C.V	0.0 days
Service lvl(OTD)	100.0 %
Inv. lvl. cur	1.0 units
Inv. lvl. min	1.0 units
Inv. lvl. max	1.0 units
Lot-size	120.0
Transport frequency	7.0 days
Number of lots / shipment	1.0
Holding cost rate	10.0 %

Demand planning module in MS Excel

Master planning module in MS Excel

Strategic inventory allocation module in MS Excel

Demand supply matching module in MS Excel

Scheduling module in MS Excel adds in

Purchasing module in MS Excel

Figure 5.
Attaching the APS with collaboration process to ASDN simulator

Figure 5 shows the attaching process of the APS with collaboration MS Excel modules into ASDN simulator software. Two nodes of supplier and buyer in Figure 5 have their own input, output and current status window. Currently, all outputs of APS modules are attached into ASDN manually. Currently, there is no interface between APS with collaboration Excel-file and ASDN. However, the main purpose of building APS with collaboration process in ASDN can be accomplished in the current development. Finally, the attachment benefit can be viewed from the profit and inventory statement of the model as in Section 5.

5. Results and analysis

ASDN calculates the benefit of APS with collaboration in terms of lead time to customer (days), cycle time (days), inventory holding cost (Euro), safety stock holding cost (euros/year) and inventory turns (turns/year). Thus, combining APS with collaboration into ASDN gives advantage to SCs for giving ATP to end customers as well as measuring the benefit of the APS with collaboration process (Figure 6).

Furthermore, we also compare the developed APS with collaboration process with the existing APS software (Table I). The results show that the proposed APS with collaboration process has strength in ATP and flexible scheduling that can be updated according to received demand information and inventory allocation policy. On the other hand, the existing APS software emphasizes distribution optimization by using rule-based ATP to give guaranteed lead times. In the later case, the supplier cannot get a guaranteed order from the buyer since the buyer has autonomy in finding appropriate suppliers to meet the customer demands. Thus, the collaboration strength between buyer and supplier is not as strong as the proposed APS with collaboration process.

6. Implications

The concept of APS is shown by giving emphasis to information availability in the SC and the company giving value added in each step of order processing. It ensures that customers have accurate information about the available product configuration and allows them to configure not only the product but also the lead times. This mechanism can be applied within APS with collaboration process because the supply and demand functions are matched (Figure 4). The APS with collaboration process makes possible firm interoperability within the SC by making an interface between strategic inventory allocating and purchasing modules. This interface creates information exchange

	Base case
Safety Stock Holding Cost [EUR / year]	0.0
Lead time to customer [days]	23.5
Cycle time [days]	52.0
Inventory turns [turns/year]	0.0
Inventory Holding Cost [EUR]	786.03

Figure 6.
Financial statement for measuring the benefit of APS with collaboration process in ASDN

Table I.
Comparison between existing APS software and the proposed APS with collaboration process

SAP APO	I2 RHYTIM	IBM SC simulator	APS with collaboration process in ASDN
Demand planning			
1. Promotional planning, causal analysis 2. Life-cycle concept 3. Collaborative forecasting	Forecasting process through statistical methods and multiple inputs from different organization units	Forecasting and previous aggregate demand data	Aligning demand information to purchasing module through master planning to convert demand forecast that results in production rates of each product variant
ATP			
1. Rule-based ATP 2. Multi-level multi-site ATP 3. Capable to promise function	User-friendly product catalog and product configuration	Available to product material substitution and location selection	Strategic inventory allocation module for giving the promised lead times to end customers and optimum lot sizes to suppliers
Advanced scheduling			
1. Simultaneous material and capacity planning and scheduling 2. Cost-based optimization	1. Scheduling and sequencing based on genetic algorithm (GA) 2. Interactive schedule editor	Assembly line and its production plan and inventory control, also enabling to supplier modeling	Traveling salesman problem is used for minimizing production throughput. The scheduling can be updated according to demand information and inventory allocation policy

(*continued*)

SAP APO	I2 RHYTIM	IBM SC simulator	APS with collaboration process in ASDN
3. Using GA and constraints-based programming	Use transportation modeler, optimizer and manager order by customer service and financial settlement	1. Distribution centers modeling until retail store. Modeling includes inventory policy	ASDN simulator is used to measure the benefit of APS with collaboration process. It covers supplier, warehouse, sales company, end customer, distributor, retailer, and sub-contractor. Transportation modeling includes time, vehicle and transportation costs, order batching policies and its resources
Distribution planning 1. Transportation planning and vehicle scheduling to multi-site optimization by GA and additional heuristic components 2. VMI support 3. Demand supply synchronization by linear and mixed integer programming		2. Transportation modeling including time, vehicle and transportation costs, order batching policies and its resources	

Table I.

between at least two firms within the SC. This suggests that SC managers should encourage information sharing between at least two connected firms.

Related to value SC integration, this APS model makes the planning task coordinated and integrated (Figure 4). This coordination and integration gives APS distinctive functionality to ERP or MRP II. Without intending to replace the roles of ERP and MRP II, APS should be emphasized as a coordination and integration tool for multi-tier and multi-site production. This makes ERP or MRP II suitable for analyzing non-critical planning (Rohde, 2002).

Last but not least, the APS with collaboration process has two advantages. The first is that the APS structure becomes more modular and simple where it finally increases its processing speed and inter-operability. The second is that APS can have a strong relationship with ERP without an overlapping of each other's functions.

7. Conclusions

This paper has discussed value chain re-engineering, which is represented by a new APS model. We may summarize the results derived from the model as follows:

- APS module integration needs to be addressed in the APS with collaboration process discussion. The integration makes for faster decisions and information flows amongst the modules.
- Information exchange between the purchasing and strategic inventory allocation modules from two different sites reflects the APS with collaboration process. Furthermore, technological support and purchasing activity need to be involved in the main activities of the manufacturing process. Purchasing should have a strategic position in the business activities.
- The first limitation of this APS is that the model does not incorporate customer and service department interface in assuming that the sales department is replaced by e-marketing. On the other hand, this situation has the advantage of offering a new future research direction with regard to the possibility of organization interchangeability by developing collaborative APS where it requires information sharing amongst sites in SCs.
- Attaching APS into ASDN simulator reflects the integration of strategic, tactical and operational planning, resulting in delivering orders at minimum cost and a high level of responsiveness.
- The second limitation is that there is no solution to support the function of the sales mode. It would be necessary to conduct future research on the personalization of the sales function by employing information technology to give added value to the APS.

References

Chen, K. and Ji, P. (2007), "A mixed integer programming model for advanced planning and scheduling", *European Journal of Operations Research*, Vol. 184, pp. 512-22.

Chen, W.L., Huang, C.Y. and Lai, Y.C. (2009), "Multi-tier and multi-site collaborative production: illustrated by a case example of TFT-LCD manufacturing", *Computers in Industry*, Vol. 57, pp. 61-72.

Coronado, M., Adrian, E. and Lyons, A.C. (2007), "Evaluating operations flexibility in industrial supply chains to support built-to-order initiatives", *Business Process Management Journal*, Vol. 30 No. 4, pp. 572-87.

Feitzinger, E. and Lee, H.L. (1997), "Mass customization at Hewlett Packard: the power of postponement", *Harvard Business Review*, January-February, pp. 116-21.

Fleischmann, B., Meyr, H. and Wagner, M. (2002), "Advanced planning", in Stadtler, H. and Kilger, C. (Eds), *Supply Chain Management and Advanced Planning: Concepts, Models, Software and Case Studies*, 2nd ed., Springer, Berlin, pp. 71-95.

Graves, S.C. and Willems, S.P. (2000), "Optimizing strategic safety stock placement in supply chains", *Manufacturing and Service Operations Management*, Vol. 2 No. 1, pp. 68-83.

Gross, D. and Harris, C.M. (1974), *Fundamental of Queueing Theory*, Willey, New York, NY.

Guba, E.G. and Lincoln, Y.S. (1994), "Competing paradigms in qualitative research", in Denzin, N.K. and Lincoln, Y.S. (Eds), *Handbook of Qualitative Research*, Sage, Thousand Oaks, CA, pp. 105-17.

Healy, M. and Perry, C. (2000), "Comprehensive criteria to judge validity and reliability of qualitative research within the realism paradigm", *Qualitative Market Research: An International Journal*, Vol. 3 No. 3, pp. 118-26.

Kassmann, D. and Allgor, R. (2006), "Supply chain design, management, and optimization", paper presented at the 16th European Symposium on Computer Aided Process Engineering and 9th International Symposium on Process Systems Engineering, 10 July.

Kempf, K., Uzsoy, R., Smith, S. and Gary, K. (2000), "Evaluation and comparison of production schedules", *Computers in Industry*, Vol. 42, pp. 203-20.

Kilger, C. (2002), "The definition of supply chain project", in Stadtler, H. and Kilger, C. (Eds), *Supply Chain Management and Advanced Planning: Concepts, Models, Software and Case Studies*, 2nd ed., Springer, Berlin, pp. 241-59.

Kilger, C. and Reuter, B. (2002), "Collaborative planning", in Stadtler, H. and Kilger, C. (Eds), *Supply Chain Management and Advanced Planning: Concepts, Models, Software and Case Studies*, 2nd ed., Springer, Berlin, pp. 223-37.

Kilger, C. and Scheeweiss, L. (2002), "Demand fulfillment and ATP", in Stadtler, H. and Kilger, C. (Eds), *Supply Chain Management and Advanced Planning: Concepts, Models, Software and Case Studies*, 2nd ed., Springer, Berlin, pp. 161-71.

Kristianto, Y. and Helo, P. (2009), "Strategic thinking in supply and innovation in dual sourcing procurement", *International Journal of Applied Management Science*, Vol. 1 No. 4, pp. 401-19.

Lee, H.L. (2004), "The triple a supply chain", *Harvard Business Review*, October, pp. 1-12.

Lee, Y.H., Jeong, C.S. and Moon, C. (2002), "Advanced planning and scheduling with outsourcing in manufacturing supply chain", *Computers in Industry*, Vol. 43, pp. 351-74.

Lockamy, A. III and McCormack, K. (2004), "Linking SCOR planning practices to supply chain performance: an exploratory study", *International Journal of Operations & Production Management*, Vol. 11/12, pp. 1192-2003.

Meyr, H., Rohde, J., Schneeweiss, L. and Wagner, M. (2002), "Structure of advanced planning system", in Stadtler, H. and Kilger, C. (Eds), *Supply Chain Management and Advanced Planning: Concepts, Models, Software and Case Studies*, 2nd ed., Springer, Berlin, pp. 99-104.

Moon, C., Kim, J.S. and Gen, M. (2004), "Advanced planning and scheduling based on precedence and resource constraints for e-plants chain", *International Journal of Production Research*, Vol. 42 No. 15, pp. 2941-55.

Nishioka, N. (2004), “Collaborative agents for production planning and scheduling (CAPPS): a challenge to develop a new software system architecture for manufacturing management in Japan”, *International Journal of Production Research*, Vol. 42 No. 17, pp. 3355-68.

Rohde, J. (2002), “Coordination and integration”, in Stadtler, H. and Kilger, C. (Eds), *Supply Chain Management and Advanced Planning: Concepts, Models, Software and Case Studies*, 2nd ed., Springer, Berlin, pp. 211-22.

Sanchez, R. (2002), “Using modularity to manage the interactions of the technical and industrial design”, *Design management Journal Academic Review*, Vol. 2, pp. 8-19.

Stadtler, H. (2002a), “Production planning and scheduling”, in Stadtler, H. and Kilger, C. (Eds), *Supply Chain Management and Advanced Planning: Concepts, Models, Software and Case Studies*, 2nd ed., Springer, Berlin, pp. 177-95.

Stadtler, H. (2002b), “Supply chain management – an overview”, in Stadtler, H. and Kilger, C. (Eds), *Supply Chain Management and Advanced Planning: Concepts, Models, Software and Case Studies*, 2nd ed., Springer, Berlin, pp. 7-29.

Stadtler, H. (2005), “Supply chain management and advanced planning-basic, overview and challenges”, *European Journal of Operations Research*, Vol. 163, pp. 575-88.

Van Eck, M. (2003), “Advanced planning and scheduling”, BWI paper, p. iii, available at: http://obp.math.vu.nl/logistics/papers/vaneck.doc (accessed 2 January 2008).

Wiers, V.C.S. (2002), “A case study on the integration of APS and ERP in a steel processing plant”, *Production Planning & Control*, Vol. 552 -560.

Further reading

Buxmann, P. and König, W. (2000), *Inter-organisational Co-operation with SAP Systems: Perspectives on Logistics and Service Management*, Springer, Berlin.

Du, X., Jiao, J. and Tseng, M.M. (1999), “Identifying customer need patterns for customization and personalization”, *Integrated Manufacturing System*, Vol. 14 No. 5, pp. 387-96.

About the authors

Yohanes Kristianto is now a Post-doctoral researcher in Industrial Management at University of Vaasa, Finland. His research interests are in the area of supply-chain strategy/management and production/operations management. He has 11 years of working experience in the areas of quality management, logistics and process engineering.

Mian M. Ajmal is currently working as Assistant Professor of Management at Abu Dhabi University, Abu Dhabi, UAE. He holds DSc (Economics and Business Administration) and MBA degrees. He has been involved in many research projects during the last few years. His research interests pertain to knowledge, and project management, entrepreneurship, internationalization of firms along with organizational behavior and culture. He has been publishing his research articles in several international journals and conferences. Mian M. Ajmal is the corresponding author and can be contacted at: mian.ajmal@adu.ac.ae

Petri Helo is a Research Professor and the Head of Logistics Systems Research Group, Department of Production, University of Vaasa. His research addresses the management of logistics processes in supply demand networks, which take place in electronics, machine building, and food industries.