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Advanced Supply Chain Planning Systems (APS) Today and Tomorrow

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1. Introduction

The Supply Chain Management (SCM) paradigm is widely discussed today in virtually all industry sectors. This paradigm emerged in the late 1980s, and became widespread in the 1990s as a way to organize a set of concepts, methods and tools for promoting a holistic view of the entire supply chain. Supply chain optimization greatly depends on the planning process (Jespersen & Skjott-Larsen, 2005). This process aims to obtain a balance between supply and demand, from primary suppliers to final customers, to deliver superior goods and services through the optimization of supply chain assets. This is quite a difficult task since it involves simultaneously synchronizing a large quantity of complex decisions, and dealing with other issues that can complicate the process, for instance the existence of conflicting objectives and the presence of stochastic behaviours (Lin et al., 2007; Camarinha-Matos and Afsarmanesh, 2004; Schneeweiss and Zimmer, 2004; Terzi & Cavalieri, 2003; Min and Zhou, 2002; Simchi-Levi et al., 2000).

To cope with the complexity of supply chain planning, a set of information technology (IT) tools can be used directly or indirectly. These systems are used for information integration, inventory management, order fulfilment, delivery planning and coordination, just to mention a few. Among the leading IT tools for Supply Chain Managemet, the Advanced Planning and Scheduling (APS) system is widely discussed today, which may be due to the fact that APS systems focus on a very relevant problem in supply chains, i.e. how to synchronize hundreds of real planning decisions at strategic, tactical and operational levels in a complex environment. This quite challenging objective requires an advanced solution.

Basically, APS are computer supported planning systems that put forward various functions of Supply Chain Management, including procurement, production, distribution and sales, at the strategic, tactical and operational planning levels (Stadtler, 2005). These systems stand for a quantitative model-driven perspective on the use of IT in supporting Supply Chain Management, for exploiting advanced analysis and supply chain optimization methods. In fact, APS systems have represented a natural evolution of planning approaches for the manufacturing area since the 1970s (Martel & Vieira, 2010). The first system approach was Material Requirements Planning (MRP), which evolved later into Manufacturing Resources Planning (MRP II), Distribution Resources Planning (DRP) and, during the 1990s, into Enterprise Resources Planning (ERP systems). APS systems arose to fill the gap of ERP systems, which are basically transactional systems and not planning systems (Stadtler, 2005). ERP's planning capabilities, although fundamental to the planning process, are limited when not leveraged by an APS system.

Despite many advances in this domain, there are some profound changes taking place in the key supply chain technology. We would like to call attention to some fundamental trends identified by some recent studies (Cecere, 2006; Van Eck, 2003): need to better deal with risk (robustness), agility, responsiveness and focus on multi-tier relationships. They can be divided into two major trends: firstly, trying to expand from an internal to an external supply chain point-of-view, in which relationships with partners and collaborations are considered to a greater extent; and secondly, paying more attention to the stochastic behaviour of the supply chain, managing risks and responding adequately to them.

In this chapter we discuss how APS systems are being used to deliver superior value in the context of complex supply chain problems (APS today). In addition, we explore some limitations and possible avenues of these systems (APS Tomorrow) to address the profound changes taking place in the supply chain technology.

In order to do so, this chapter is organized into two parts:

Part I – APS Today (Section 2): first, we highlight some advantages of APS systems towards obtaining superior supply chain plans, and in this sense, we discuss the capacity of these systems in employing optimization technology and their ability to integrate time frames ranging from long-term strategic periods to short-term operational ones. We also introduce and compare some typical systems in the market and we present some implementation approaches through three case studies in large companies. These case studies portray common situations in the APS area. They demonstrate that by utilizing current technology and modelling approaches, in practice one is mostly trying to implement and integrate the internal supply chains, not the entire supply chain.

Part II – APS Tomorrow (Section 3): we now explore the other side of the coin, i.e. the inherent limitations to model multi-tier supply chains and to perform experiments with large-scale real and complex problems. Two main issues are discussed: the inability of traditional approaches to create sophisticated simulation scenarios and the limitation in modelling distributed contexts to capture important business phenomena, like negotiation and cooperation. In order to overcome these handicaps, we introduce what we call a distributed APS system (d-APS) and we provide some insights from our experience with this kind of system in a Canadian softwood lumber industry, as being performed by the FORAC Research Consortium. Some preliminary and laboratory tests show interesting results in terms of the quality of the solution, planning lead-time and the possibility of creating complex simulation scenarios. We strongly believe that this new generation of APS systems will bring about a revolution in the market in the coming years, contributing to the improvement of the current APS practices.

Finally, Section 4 outlines some final remarks and conclusions.

2. Part I: APS today

2.1 Advanced planning and scheduling (APS) systems

The planning process is at the heart of APS systems. It aims to support decision-making by identifying alternatives for future activities and by selecting good strategies or even the best one (Fleischmann et al., 2004) while considering the decision-maker's objectives and constraints in the company's environment. In the authors' view, the main characteristics of APS are:

- *Integral planning*: planning of the entire supply chain. It can focus on internal supply chain issues (i.e. when a single company has several production sites, or distribution centres) and theoretically it can consider the whole supply chain (i.e. from the company's suppliers to the company's customers).
- *True optimization*: APS systems exploit advanced analysis and supply chain optimization technology (exact ones or heuristics) to carry out planning and scheduling activities. Optimization problems seek solutions where decisions need to be made in a constrained or limited resource context. Most supply chain optimization problems require matching demand and supply when one, the other, or both may be limited (Lapide & Suleski, 1998). The main optimization approaches employed are mathematical programming (largely linear and mixed integer programming), constraint programming, and heuristics (including scheduling methods like the theory of constraints or simulated annealing). Other quantitative approaches are also used, such as forecasting and time series analysis, exhaustive enumeration and scenario planning (what-if analysis and simulations). For a guide on the main optimization and quantitative issues in APS (e.g. how to define optimization problems for strategic, tactical and operational levels and solve them), the reader is referred to Van Eck (2003), Shapiro (2000), and Lapide & Suleski (1998).
- *A hierarchical planning system*: APS are typically hierarchical planning systems (Stadtler and Kilger, 2004; Hax and Meal, 1975).

In order to translate these three characteristics into an implementable APS system, two main aspects of the APS have to be considered: the architecture (how the system is organized, including the 'hierarchy' and 'integral planning') and the engine (how each part of the APS architecture performs its planning activities).

In terms of APS architecture, according to Meyr & Stadtler (2004), a typical system is organized though combinations of a set of building blocks encompassing decisions at three levels: strategic (long-term decisions), tactical (mid-term decisions), and operational (short-term decisions levels). In more specific terms, some typical building blocks are suggested by Meyr & Stadtler (2005):

- *Strategic network planning*: long-term planning normally dedicated to plant allocations and to designing the physical distribution network. In addition, other strategic decisions related to market strategies can be supported, such as determining which products to position in certain markets.
- *Demand planning*: represents sales forecast for long, medium and short terms, based on a set of quantitative and qualitative approaches. This results in expected demand, which acts as an input for several other building blocks.
- *Demand fulfilment & ATP (available-to-promise)*: an interface for the customers in which orders are tracked from order entry to delivery. It includes order promising, due dates settings and shortage planning.
- *Master planning*: aims to balance demand and capacity over a medium-term planning interval, coordinating procurement, production and distribution.
- *Production planning and scheduling*: while master planning coordinates the planning activities between sites, production planning and scheduling is done within each site.

Production planning is dedicated to lot-sizing, and scheduling is dedicated to two planning tasks, machine sequencing and shop floor control.

- *Distribution planning*: deals with materials flows in a more detailed manner than master planning, taking care of transport of goods directly to customers or via warehouses and cross-docking.
- *Transport planning*: aims to sequence customer locations on a vehicle's trip though vehicle routing.
- *Purchasing & material requirement planning*: a step further compared to traditional bill-of-material explosion and ordering of materials done by an ERP. It performs advanced purchase planning using alternative suppliers, quantity discount and lower/upper quantity analysis.

Rodhe (2004) mentions that, in addition to these building blocks, others can be included in an APS, for example, coordinating them with other systems, like OLTP (Online Transaction Processing) (e.g. ERP or legacy systems) or data warehouses.

As a hierarchical planning system, an APS has to coordinate and integrate information between building blocks. Information flows can be horizontal and vertical. Horizontal flows basically orient all building blocks according to customer needs. Examples of these flows include customer orders, sales forecasts, internal orders for warehouse replenishment, and purchasing orders for suppliers. Vertical flows, on the other hand, represent a way to coordinate lower level plans by means of the results of higher level plans (downward flows), or a way to inform upper levels about the performance of the lower level (upward flows) (Fleischmann et al., 2004).

We can understand APS systems as being composed of building blocks. These building blocks are very flexible and can be configured in many ways, or even bought and installed separately. For example, similarly to Meyr & Stadtler (2004), the FORAC Research Consortium employed this idea to represent the possible configuration of APS systems in the forest products industry in Canada. Figure 1 presents an instantiation for the softwood lumber industry, according to Frayret et al. (2004b).

To respect some particularities of this industry sector in Canada, several important adaptations were made with respect to Meyr & Stadtler (2004). For example, the building block labelled 'Synchronized Production-Distribution Lot-Sizing' stands for production planning and scheduling, as well as distribution and transportation planning. In this example, this happens because the loading of machine groups, with their respective lot-sizing, is highly influenced by the sequence of jobs in this industrial sector. In addition, it was decided to include the execution level below the short-term, so that the control becomes explicit. Some of these building-blocks were implemented and tested for the softwood industry, as we will discuss in Part II of the chapter.

Apart from architectural reorganizations, supply chain planning systems are very flexible in terms of the APS engine they employ. By engine we understand the mathematical approach they use, which is basically models and algorithms. The literature provides a diversity of studies in this domain, such as Gaudreault et al. (2007), Chen & Ji (2007), Lee et al. (2002), Kuroda et al. (2002), and Azouzi & Massicotte (2001).

There have been many practical and theoretical developments in terms of APS architecture and engine to date. In the next section, we present the main systems available on the market, according to a study performed by AMR Research.

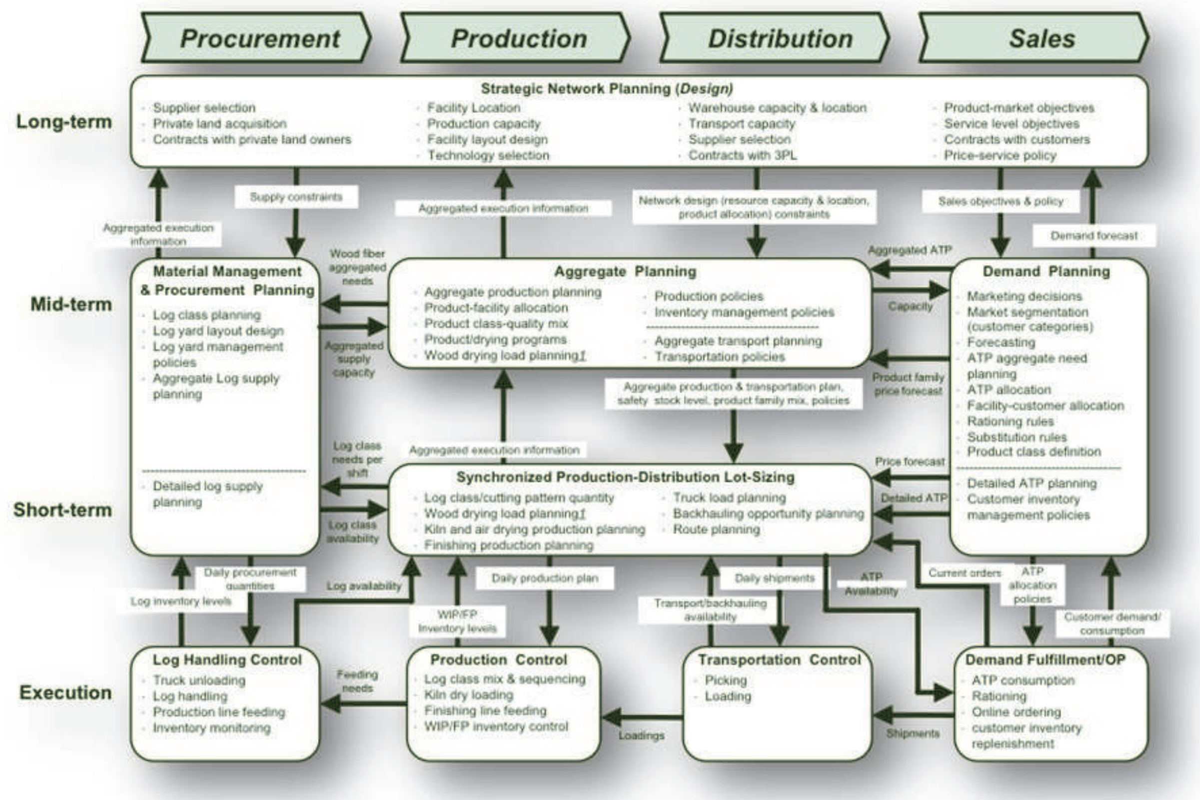

Fig. 1. Supply chain planning for the Forest Products Industry

2.2 Some systems available on the market

Based on AMR's 'The Supply Chain Management Market Sizing Report 2007-2012' (Fontanella et al., 2008), the world's top eight Supply Chain Management vendors that offer APS systems on the market are SAP, Oracle, Manhattan Associates, i2 Technologies, IBS, RedPrairie, Infor and JDA Software. By visiting each vendor's product portfolio we can classify each one into two vendor categories:

- Enterprise suite vendors such as SAP, Oracle, and Infor that in the late 90s started to buy or develop an APS system to add to their product portfolio.
- Best-of-Breed suite vendors such as i2 Technologies, RedPrairie and Manhattan Associates that started as specialized Supply Chain Management solutions vendors.

With a closer look at each solution, it can be noted that all of them offer a similar core functional scope that covers all APS building blocks previously described. The main differences are related to industry focus and presence of functional blocks. For example, SAP does not offer a solution that covers business requirements at the strategic level of planning, leaving it with a partner solution. Another difference is in the industry vertical bias of each software vendor, mainly due to the fact that some of them started their product development in a specific industry such as IBS in the Chemical Industry, JDA (who acquired Manugistics) and RedPrairies in the Retail Industry.

The top two vendors in the list are SAP and Oracle and their APS contributions are those we will analyze. Both are ERP vendors that identified a software revenue potential in the Supply Chain Management market and added supply chain planning solutions to their product portfolio. As biggest rivals, each adopted a different strategy to enhance their solution offering. SAP developed its SAP Supply Chain Management system from scratch and Oracle acquired best-of-breed solutions and packaged them in Oracle's Supply Chain Management Applications suite. These paths resulted in APS solutions with different characteristics in some aspects, such as functional scope and technical architecture.

Building Block	SAP	Oracle
Strategic Network Planning	N/A – Partner Solution	Strategic Network Optimization
Demand Planning	SAP APO: DP - Demand Planning	Demantra Demand Management
Master Planning	SAP APO: SNP - Supply Network Planning	Advanced Supply Chain Planning
Distribution Planning	SAP APO: DPLY - Deployment	Advanced Supply Chain Planning
Production planning and scheduling	SAP APO: PPDS - Production Planning / Detailed Scheduling	Oracle Production Scheduling
Transport Planning	SAP APO: TPVS - Transportation Planning / Vehicle Scheduling	Oracle Transportation Management
Demand Fulfillment & ATP	SAP APO: GATP - Global Available-to-Promise	Global Order Promising
Inventory Planning	SAP APO: Safety Stock Planning	Inventory Optimization
Supply Chain Monitoring	SAP APO: SCC - Supply Chain Cockpit	Advanced Planning Command Center
Collaborative Planning	SAP SNC - Supply Network Collaboration	Collaborative Planning

P = Product / M = Module / F = Functionality

Table 1. Main building blocks for SAP's Supply Chain Management system and Oracle's Supply Chain Management suite

We have had the opportunity to analyze each suite in detail and they seem to be quite similar in many terms (see Table 1). Both cover all aspects of APS system building blocks but the difference appears in a detailed analysis. Oracle's solution is a best of breed acquisition system and presents some advantages especially in the transportation planning area due to the fact that this functionality was a result of a best of breed software acquisition. On the other hand SAP has some advantages regarding technical architecture. Its APS is a single system called SAP Advanced Planning and Optimization (SAP APO) and is divided into five modules. An outside-the-box real-time integration is possible between all planning levels resulting in minimal effort to cascade the plans from strategic to operational levels. Additionally, companies employing SAP ECC (SAP ERP Core Component) as their ERP system will also have an outside-the-box integration between planning and transactional levels, which considerably facilitates integration. However, Oracle's Supply Chain Management suite is a group of about seven different products, each with its own data set, data model and technical design, some of them already with a plug-in that guarantees integration while some are real-time integration and mostly in batch mode.

In brief, it can be stated that, if minimum integration issues are required and for those already having an SAP ERP system, the SAP APO is recommended. If not, either system will provide quite a good functional scope. For those who would like to confront both systems, we recommend a detailed functional analysis so a good decision between Oracle and SAP can be made. However, a functional analysis alone is not enough. There are other important aspects to consider as well, when deciding which system best suits the company's requirements, such as:

- *Experienced consulting ecosystem*: are there consulting companies with enough available consultants that are proficient on the tool? Are there enough success cases of companies that have implemented that particular system?
- *Vendor pricing model*: will the entire solution have to be bought to get the Return On Investment after deploying all functionalities or can we effect a pay by deployed model?
- *Deployment flexibility*: does the solution have technical flexibility that allows a phased implementation or are there so many dependencies that it is better to deploy the whole solution to achieve a reasonable cost/benefit equation?

In the next subsection some typical implementation projects are discussed, from our practical experience.

2.3 A typical implementation project

When desiring to start an APS implementation project, it is a good plan to gather insights and advice in the field. By doing so, companies will gain a more precise idea of what they should not do, because the fact is that there are more unsuccessful APS implementation stories than successful ones. We will explore some reasons for this in the following.

Due to the extensive promotion of ERP implementation in the late 1990s, many companies whose systems had failed to operate properly found themselves trapped, having made a huge investment promising large Returns On Investment that simply did not materialize. At this same time, most software vendors, such as SAP, Oracle, JD Edwards were launching their Supply Chain Management solutions, which turned out to be good timing for positioning these new systems as the solution that would guarantee those promised Returns On Investment. It was commonly believed that implementing all the new advanced planning functionality along with the ERP would surely result in immense benefits. Marketing campaigns employed interesting arguments, such as "boost ERP benefits with an APS" or "use the experience from ERP implementation to guarantee a worry-free APS project".

From a business transformation viewpoint, this can be quite misleading. All typical APS implementation projects are normally executed with a methodological approach that ignores critical transformation aspects for a successful APS implementation. They are:

- Unified *Vision*: are all stakeholders in agreement as to the expected benefits from the APS project? Since a supply chain has intrinsic conflicting objectives, it is quite natural that each area will expect benefits that are at variance to the others. If these expectations inside the company are not aligned frustrations will emerge.
- Clear *Strategy*: is there a detailed roadmap that outlines all the organizational transformations necessary to achieve these benefits? Believing that an APS implementation is like an ERP implementation might lead to some surprises. The methodological approach is very different. Specific organizational changes must occur

in the right order and volume to allow an adequate organizational maturity to capture the return on the APS project investment. How much change the organization can absorb should also be taken into account.

- Structured *Processes*: are considered to be a key dimension, because APS systems demand a coherent and streamlined planning process. They are systems with a high degree of modelling flexibility, meaning that they tend to accept almost anything. If business rules and decision criteria are not explicit and clear for the company, this can become a problem because incoherent rules and criteria can be modelled in the system.
- Aligned *KPIs*: as many firms know, good initiatives in different directions add up to zero. Misaligned indicators can implode all efforts to streamline the supply chain resulting in wasted efforts. Revisiting KPIs is vital to guarantee a coherent incentive structure and it must be built considering intrinsic supply chain trade-offs.
- Aligned *Organizational* Structure: to guarantee that local efforts will result in an overall optimum, knowing exactly what is expected from each is clearly essential. This means that each role and responsibility should be defined and done so considering all supply chain dependencies to eliminate dysfunctional empowerment where one's effort could be undermined by that of another.
- Educated and Prepared *People*: since transformation is ultimately achieved only through individual change, it is critical to involve, educate and train the supply chain team. In contrast to an ERP, users can abandon an APS system and go back to their comfortable spreadsheets with no important consequences, at least in the short term. Underestimating the need of user involvement, persuasion and behavioural orientation to drive an effective change management can be risky.
- The right *Technology*: technology is where most of the business processes will materialize. Specialists like to say that process and technology is the same thing; i.e. one materializes the other. It Obviously, not much thought is required to say that if one does a perfect job in designing processes and chooses the wrong technology all efforts will be lost.

Having explained this framework of seven transformation dimensions, it would be interesting to share some relevant practical lessons. Three typical case studies of APS implementation are presented, from the author's experience.

2.4 Case studies

In this subsection we present three case studies that aptly represent the following situations:

- APS Readiness: a company has no APS solution and has decided to adopt one but is doubtful of being ready for it. The challenge then is to make sure that it can deal with such a transformation process.
- APS Maximization: a company wants to extract much more from their investment in the APS solution. The challenge is to find more benefit areas and achieve quick gains to finance future solution evolution.
- APS Recovery: a company has invested substantially in an APS project and finds itself in a situation where the system has almost shut down, the spreadsheets have come back and are replacing the APS system. The challenge is to recover this investment.

2.4.1 APS readiness

This study was performed in a consumer goods manufacturer with USD 5.35 billion revenue in the fourth quarter of 2008, with 37 product categories, ranging from frozen food to fresh meat and with 11 brands in its product portfolio. Their supply chain comprises 17 plants, 10 distribution centres and 17 sales offices. The company was interested in implementing SAP APO to support its planning processes that had gone through revision. The question here was knowing whether the company was ready for such a technology since there were critical pre-requisites that would put a condition on full value capture of an investment in such a complex supply chain.

The APS Readiness assessment was applied in all seven-transformation dimensions (vision, strategy, processes, organization, KPIs, technology and people). It consisted in confronting subject areas in all dimensions against an ideal situation. Table 2 shows what subject areas were analyzed and with what ideal reference they were confronted.

Dimension	What is Verified?	How?	Ideal Reference.
Vision	Stakeholder Expectation of APS total benefits	C-Level Interviews Management Level Interviews	Alignment among stakeholders
Strategy	Project alignment with corporate strategy	Interviews	Alignment with corporate strategy
Processes	Planning Processes Planning Hierarchies Process Documentation Planning Model Adherence Enabling Processes	Adjusted O.W. Survey Process Analysis Documentation Analysis Interviews System and Process Analysis	O.W. ABCD Checklist/APICS O.W. ABCD Checklist/APICS Consulting experience O.W. ABCD Checklist/APICS
Technology	Technical Readiness Check	Infrastructure Check ERP Configuration Check	APS Quick Sizing Tool APS Best Practices
KPIs	Current KPI Structure KPI Analysis Processes	KPI Hierarchy Analysis Process Analysis	SCORE Model O.W. ABCD Checklist
People	Team Skill Set Check SCM Knowledge	Curriculum Analysis SCM Test	APICS APS Education Curriculum
Organization	Roles & Responsibilities	RACI Matrix Analysis	APICS

N.B.: O.W. stands for Oliver White™; RACI is R (Responsible), A (Accountable), C (communicated), I (Informed) is a matrix to define roles and responsibilities.

Table 2. APS Readiness Assessment Methodology

For each verified subject area a specific methodology was used to collect information from the company's actual situation and then the result was structured and compared to the ideal situation. A rationale was used to give a readiness score. As shown in Table 3, a 100% grade meant full readiness. Different scores from this ideal goal indicated that work had to be done to achieve an acceptable number. The final result was presented in a format demonstrated in Table 3. The company overall weighted average readiness was 64% of 100%.

Dimension	Item Verified	Score	Reference Score	Weight
Vision	Executive Alignment	65%	80%	1
	Expected Benefits Alignment	57%	80%	1
Strategy	Alignment with strategy	80%	80%	1
Process	Adherence to Reference Model	79%	80%	1
	Planning Processes	56%	80%	3
	Planning Hierarchy	49%	80%	2
	Process Documentation	85%	80%	2
	Enabling Processes	68%	80%	3
Technology	Hardware Sizing	100%	80%	1
	ERP Configuration	73%	80%	2
	Process Requirements	50%	80%	2
KPIs	KPI Analysis Process	74%	80%	3
	KPI Structure	89%	80%	1
People	Curriculum Analysis	51%	70%	2
	SCM Test	48%	80%	3
Organization	RACI Matrix Analysis	45%	80%	2
	Average	67%	**80%**	

Table 3. APS Readiness Result

The weight used for each subject area considered the difficulty necessary to elevate the readiness level. It is possible to see that most effort usually went into Planning Process revision, Enabling Process revision, KPI Management revision, and Team Education. The overall score was the company's distance from the ideal readiness situation. Table 4 shows the scale that was used to indicate whether or not they were ready to start an APS implementation project.

Readiness Check	
81-100%	**Ideal for best value capture of APS project**
61-80%	**Adequate together with an improvement plan during APS project**
41-60%	**Inadequate, demanding corrective actions before APS project**
21-40%	**Inadequate, demanding maturing actions before APS project**
0-20%	**Inadequate, demanding revision actions before APS project**

Table 4. APS Readiness Scale

Since 64% was the overall readiness, they embarked on the project but with an improvement plan to address the subject areas that received a low readiness grade. Some of the improvement initiatives were: aligning stakeholders about expected benefits, planning processes revision, planning hierarchy revision, process documentation and team education in Supply Chain Management concepts and APS training.

The final product from this analysis was a roadmap with these initiatives that ranged all seven dimensions to guarantee a full value capture of the APS system.

2.4.2 APS maximization

This study was done in a steel manufacturer with USD 1.26 billion revenue in 2008 with a product line that includes rolled tubes, drawn tubes for automotive applications, industry in general, oil industry and civil construction. They have an integrated mill plant with a 550.000 tons-per-year installed capacity divided into five sub-plants that offer a unique production synchronization challenge.

Initially, the company started a transformation process with a pre-implementation assessment in all seven-transformation dimensions (vision, strategy, processes, organizational structure, KPIs and people) that pointed out the root causes for their supply chain inefficiencies. The root causes identified were:

- Lack of Supply Chain Management concepts in the organization.
- Lack of an adequate product hierarchy across all planning processes.
- Lack of alignment between their KPI structure and their supply chain strategic objectives.
- Lack of planning hierarchy to deploy strategy to execution and a feedback loop.
- Lack of an integrated planning system.
- Their ERP and legacy system did not support integrated supply chain logic.

Based on this, a roadmap was built to eliminate all root causes. Unfortunately, the roadmap was not taken seriously because the implementation was executed by a vendor that had won the bid with a very aggressive proposal that promised an implementation in much less time and effort than originally estimated. The result was a faulty system with some modules almost shutting down. The worst case was the Production Planning & Detailed Scheduling (PPDS) module.

The company therefore decided to make an APS maximization effort. A post-optimization analysis was executed to find out what the issues were for the PPDS sub-utilization. The final result was:

- Bad shop floor information due to the lack of standard procedures and KPIs to enforce good shop floor confirmations.
- Process orders with remaining quantities below minimum tolerance were integrated to the SAP APO system resulting in the need for a time-consuming consistency check before actual production sequencing.
- Lack of a clear sequencing logic between upstream and downstream resources causing a bullwhip effect from downstream resources.
- A business strategy that focused on flexible fulfilment and at the same time shop floor KPIs that oriented production for high capacity utilization.

All of these issues culminated in some major symptoms such as:

- 1000 exception alerts that led to no credibility in the information the system was generating.
- Need for manual sequencing due to so many exceptions and information inconsistencies.
- An hour and a half daily effort for data cleansing and validation and five hours for manual sequencing and result analysis.

Once all issues were identified, a small project was organized to eliminate them. Also, a study was executed to understand exactly what sequencing logic the production scheduler used and when this was understood, a scheduling heuristic was adapted.

Even though the software vendor had declared PPDS was not an adequate tool for sequencing the hot rolling mill, the assessment showed that the logic used was much simpler than expected and PPDS was an adequate system for this purpose, with the condition that all root causes and issues identified be addressed properly.

The lesson learned in this case was that an APS system sub-utilization usually is a symptom and not a root cause, which usually involves another dimension such as unclear operating logic (process), misaligned indicators (KPI), unclear roles and responsibilities (organization) or a lack of knowledge on the system logic or Supply Chain Management logic (people). Certainly there are problems related to the system (technology), but usually they are the easiest to remedy. The challenge is to ensure that all other dimensions are at the same level of maturity to allow maximum system value capture.

2.4.3 APS recovery

This study was performed in an Iron Pellet and Iron Pellet Feed manufacturer with 15% world market share having USD 1.37 billion revenue in 2007. This company has a quite simple supply chain with two manufacturing facilities, two iron ore pipelines, two mines and a port with two berths. Their initial APS system implementation goal was to support the strategic, tactical and operational planning processes. At the tactical level, the main objective was to define optimal product formulation and mix to achieve strategic goals, service level and profitability. At the tactical level the objective was to balance supply with demand, particularly considering port variability that had a high impact in plant production and pipeline flow. On the operational level the goal was to reduce demurrage costs by better synchronization and sequencing of ships' loads.

The SAP APO system had brought minimal benefits and from all implemented functionalities only the ship scheduling solution was being used with many restrictions. The first thing to do was to apply a 'technological diagnosis' to find out what had really gone wrong. It consisted of an analysis in five main areas:

- Technical: identify any problem related to bad hardware sizing, poorly developed programs, or network problems.
- Functional: identify any problem related to poor functional scope offered by the system and gap analysis. In other words, verify whether the system has the proper functionality to support the business process in an adequate way.
- Modelling: identify any problem related to poorly implemented and misused standard functionality. The main objective was to find out if there was anything forcing the system, something it was not meant to do. Another aspect was to find out if the important business variables necessary for quality decision-making were actually modelled in the system.
- Business Process: identify problems related to business process design. There might be a business logic that is wrong according to business needs and best practices. Since typically a system is built based on best practices and proven methods, if the process design contains wrong assumptions something might be expected from the system that it cannot deliver.
- End-user: investigate whether the end-user is properly trained on the tool and educated on the logic behind it.

It was possible to show in a structured way what the system problem actually was. It turned out that the minor problem was technical or functional. The most important ones were end-user knowledge of the system and process design. Together with this analysis it was also possible to conduct a broader and additional assessment in all other six-transformation dimensions (vision, strategy, process, indicators, people, and organization) to bring to light other root causes for supply chain dysfunctions. The main lesson learned from a 'recovery' perspective was that implementing an APS tool without a structured planning process and company maturity in terms of the seven dimensions mentioned might result in a recovery initiative.

Based on this analysis, a three-year roadmap was then built, which was:

- *Phase one – Structure Integrated Planning process and support with SAP APO*: structure a sales & operations planning process and configure the SAP APO using simple heuristics so the results are easy to understand and digest. Align some configurations in the ERP system so as to support the new planning process. Functional scope: Demand Planning and Supply Network Planning modules.
- *Phase two - Structure short term planning processes and extend collaboration with suppliers*: leverage short-term results with stronger planning process integration with suppliers (CPFR - Collaborative Planning, Forecasting, and Replenishment). Functional scope: Supply Network Planning with optimization and Production Planning & Detailed scheduling module.
- *Phase three - Extend planning capabilities*: include real-time supply chain visibility with SAP's Event Manager system and support stronger integration with a collaborative demand planning process with internal sales representatives and clients, and support further collaboration with suppliers in short-term planning with SAP Supply Network Collaboration (supplier managed inventory scenario) and extend the Supply Network Planning module for the mid-term planning (extend procurement plan visibility).

This three-year roadmap revealed an interesting conclusion: apart from phase one, which was successfully implemented and resulted in the company effectively capturing the value of the APS tool with sales & operations planning process and with several what-if simulation capabilities, phases two and three were not actually implemented. Carrying out these two phases means going beyond the company's boundary, which is a complex procedure using the current technology and modelling approaches. This is the main topic of the Part II.

3. Part II: APS tomorrow

In the first part of this chapter we highlighted some advantages of APS systems for obtaining superior supply chain plans. In this sense, we discussed the power of these systems, we introduced and discussed some typical systems on the market and we presented three implementation approaches through case studies in large companies. As can be noted, while the current practice and technology allow for dealing with the internal supply chain, the entire supply chain has not been properly considered so far.

In Part II we now explore inherent limitations of traditional APS systems in modelling distributed contexts to capture important business phenomena, like negotiation and cooperation, as well as in creating sophisticated simulation scenarios. To overcome these drawbacks, we introduce what we call a distributed APS system (d-APS) and we provide some insights about our experience with this kind of system in a Canadian softwood lumber industry.

3.1 Limitations, trends and opportunities

Recent studies in the domain demonstrate that APS is a fruitful field in practice and in academia today. Similarly, it is also a fertile area in the software systems market, with, for example, 44 available software packages having been surveyed by Elliott (2000). More recently, McCrea (2005) claimed that Supply Chain Management software is facing a sustainable growing market with at least 127 global vendors. The top four in revenue were SAP, i2 Technologies (which was incorporated by JDA), Oracle and Peoplesoft. This accounts for the explosion in the market in only five years.

This fast-paced dynamism brings about significant market transformation. For example, Lora Cecere, a former research director for AMR Research, discussed the profound changes taking place in the key supply chain technology (Cecere, 2006). We would like to call attention to some key issues pointed out by this study: need to deal better with risk (robustness), agility, responsiveness, multi-tier and focus on relationships. These can be divided into two major trends: firstly, trying to expand from an internal supply chain point-of-view to an external one, in which relationships with partners and collaborations are considered to a greater extent; and secondly, paying more attention to the stochastic behaviour of the supply chain, managing risks and responding adequately to them.

In terms of the first trend, despite the fact that the Supply Chain Management paradigm preconizes the coordination and integration of operations and processes throughout the supply chain, few APS, such as the one proposed in Dudek & Stadtler (2005), have the ability to cross organizational boundaries to properly address this purpose. As discussed before, APS procedures are normally used for internal supply chains and collaboration is a complex task. In order to cope with this approach, we will later introduce the distributed APS approach.

As for robustness, the software modules of APS are dedicated to deterministic planning (Meyr & Stadtler, 2004), which does not allow for robust planning. In fact, the management of uncertainties is a significant limitation of APS systems (Stadtler, 2005). The deterministic planning algorithms of the APS systems react quickly to changes while on the other hand, uncertainties are coped with through some limited approaches. First, flexibility can be incorporated into the production system and/or even reserved capacity to cope with uncertainty. For example, by being flexible (or having extra capacity), one can absorb non-expected demand from clients. Second, stochastic data is presented by the expected or worst-case value, and then 'what-if' simulations are applied afterwards (Van Eck, 2003).

'What-if' simulation in APS is an attention-grabbing functionality today. It allows for scenario analysis in stochastic and complex contexts. Basically, as explained by Musselman et al. (2002), this kind of simulation is mainly composed of experiments where one or more parameters or data of the APS are changed so that different scenario results can be compared. For example, the demand forecast can be changed manually and the master planning be executed in a 'simulated mode', so that different demand scenarios are generated. Or, for day-to-day activities, if one or more orders are not 'schedulable' because capacity and demand are not balanced in the short term, a set of strategies to temporarily augment the system's capacity can be used (e.g. additional work hours or even an extra shift at the bottleneck, outsourcing etc.). The advantage is in being able to investigate several variants of a system without disrupting its operations. Moreover, some vendors provide complete facilities to compare plans and schedules, allowing for multiple copies of different plans visible for side-by-side comparison. Some vendors also provide the ability to produce cost analyses of various planning options.

The major problem in current commercial APS systems is that the potential of simulation is limited to single runs of deterministic 'what-if' tests of plans, in which only a few exceptions situations can be tested in a a 'copied' version of the APS. This is a reactive approach, and as a consequence this can lead to nervous planning (Van Eck, 2003). These sensitivity analysis-type simulations do not necessarily lead the model towards a robust solution (Genin et al., 2007).

If more sophistication is necessary (e.g. considering the stochastic nature of supply chain), integration with other simulation-dedicated approaches can be required. For example, Landeghem & Vanmaele (2002) developed a tactical planning method embedded with a Monte Carlo simulation approach for allowing the assessment of uncertainties in supply chains. Additionally, the integration of a traditional APS system could be made with some discrete-event simulation approaches, such as the one proposed by Lendermann et al. (2001). Within their simulation framework, APS procedures represent the decision system and a discrete-event simulation approach is used to represent the manufacturing and logistics operations. The simulation models of each supply chain member exchange data with the APS in the same way as real manufacturing or logistics nodes.

A more pro-active approach is needed to discover solutions that are less sensitive to parameters uncertainties. A way of doing so is to include uncertainties in the model itself so that the algorithms can attempt to find a robust solution (Van Eck, 2003). Many efforts have been made to overcome this drawback, like the emergence of APS employing stochastic programming, or a special type of this approach called robust optimization. These techniques combine models for optimum resource allocation under uncertain conditions in order to produce a robust decision-making approach. These are powerful approaches when the uncertainty can be described permitting the evaluation of several scenarios under uncertainties to find the optimum solution.

For exemple, Santoro et al. (2005) present a stochastic programming approach for solving strategic supply chain design problems of realistic scales, where a huge number of scenarios can be computed. However, at the tactical and operational levels, stochastic programming models problem sizes may still be hard to solve, especially in the APS context and in general real-sized problems (Genin et al., 2008). The difficulty is in the growth of the model size when several scenarios are evaluated in a multi-period model. In spite of these drawbacks, stochastic programming is still a promising approach (Stadtler, 2005). Similarly to stochastic programming, some criticisms related to robust programming formulations concern their computational burden (Landeghem & Vanmaele, 2002), but as shown by some recent advances in this domain (e.g. Kazemi et al., 2010), calculation performance is being considered tractable even for realistic cases.

Even if stochastic programming-related approaches live up to their promise, traditional APSs will still be restrained by their inability to deal with supply chain relationships, i.e. they are not conceived to deal with negotiation and collaboration schemas. For example, in the three examples provided in Part I, collaboration was not considered, mainly due to the inability of the modelling approach and technology being employed. These are crucial elements in modern supply chain that companies are striving to catch up with. The first question is how to integrate different supply chain partners in a collaborative APS. There are possibilities of collaborating in two directions, i.e. with customers and with suppliers, spanning multiple planning domains. Kilger & Reuter (2004) propose that the APS systems of different partners can be interconnected, as shown in Figure 2.

Despite the fact that collaborations are a hot topic today and practitioners and academics alike mention their benefits and potential, in actual fact the notion is quite complicated. In theory, one APS for the whole supply chain can be possible, however few companies have

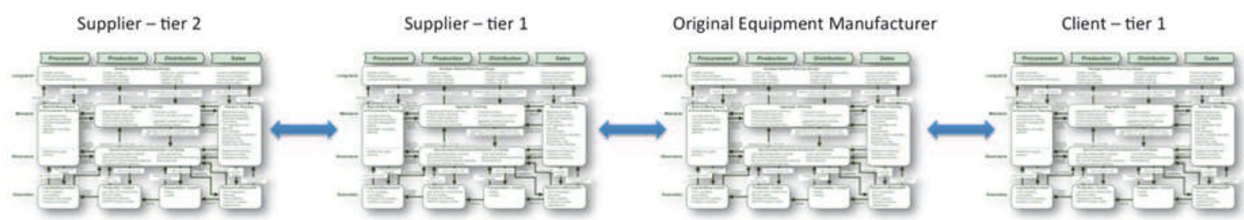

Fig. 2. APS and collaboration

succeeded in implementing one system for diverse partners. Most companies are still having trouble achieving the integration of the internal supply chain, as indicated in Part I of this chapter.

On the other hand, in theoretical terms collaborations between two APS systems seem to be less complicated. Collaborations can be two-tier (e.g. focal company – one key supplier), but they also can span multi-tiers (tier 3 – tier 2 – tier 1 – customer). They can be done in the domains of demand management, inventory management, transportation management, as well as other domains. But, in practice Kilger & Reuter (2004) argue that collaboration in APS is quite complex, and typical challenges are related to master data integration, access to user-specific secure data and the mutual decision-making process.

In today's APS software, part of it can be done manually or by using an exchange platform created for that purpose. Despite this possible collaboration, a real and more profound integration across supply chains through APS systems faces important barriers related to interconnection among business models, which requires sharing strategies, timely information, resources, profits and loss, which can be a quite delicate topic in a very fast and competitive world.

Other gaps exist between APS theory and practice (e.g. see Lin et al., 2007). However an interesting way to improve simulation and collaboration capabilities of APS systems and contribute to overcoming all these discussed limitations is the concept of d-APS (distributed APS) systems. Derived from the artificial intelligence field, this concept encompasses different ways of understanding and modelling supply chain planning systems using an agent-based reasoning. The concept of d-APS will be introduced in the next subsection.

3.2 The emergence of the distributed and agent-based approaches

Distributed advanced planning and scheduling systems (hereafter d-APS) arise from the convergence of two fields of research. On one hand, the first field deals with APS, and it generally proposes a centralized perspective of supply chain planning. On the other hand, the second field concerns agent-based manufacturing technology, which entails the development of distributed software systems to support the management of production and distribution systems.

Before discussing d-APS systems, it is interesting to briefly explain what an agent-based system stands for. The agent-based modelling approach aims to build complex software entities interacting with each other using mechanisms from distributed artificial intelligence, distributed computing, social network theory, cognitive science, and operational research (Tweedale, 2007; Samuelson, 2005). Examples of this mechanism include: *Autonomy*: the capacity to act without the intervention of humans or other systems; *Pro-activeness*: agents do not just act in reaction to their environment, but they are able to show goal-directed behaviour in which they can take initiative; *Social ability*: agents interact with other agents

(and perhaps humans beings), and normally they have the ability to engage in social activities (e.g. cooperative problem solving or negotiation) in order to achieve their goals.
This sophisticated social capability is quite interesting in this domain. Examples of these abilities include: *Cooperation capability*: working together to attain a common goal; *Coordination capability*: organizing the problem resolution process in a way that makes it possible to prevent problematic interactions and stimulate exploitation of beneficial interactions; *Negotiation capability*: managing an acceptable agreement for the parts involved, dealing with possible conflicts.
Since the early 1990s, several developments address the context of distributed decision-making across the supply chain using agent technology, but these approaches do not clearly address the integration of advanced planning functions with agents. More recently, d-APS appears to consider these issues explicitly (Santa-Eulalia et al. 2011; Santa-Eulalia et al., 2008). It models the supply chain as a set of semi-autonomous and collaborative entities acting together to coordinate their decentralized plans. By using the agent–based approach, the concept of d-APS goes farther than traditional APS, as it includes extended capabilities, such as the utilization of negotiation and artificial intelligence mechanisms to coordinate, integrate and synchronize supply chain planning decisions. In this sense, d-APS systems may provide more modelling functionalities, thus allowing a higher level of complexity to be captured in comparison to classic APS systems.
As discussed before in Part I of this chapter, traditional systems have a large hierarchical structure for optimizing different areas (procurement, production, distribution, etc.) at diverse decision levels (strategic, tactical and operational). On the other hand, in a d-APS system we have a distributed structure where different agents encapsulate diverse planning functions and work semi-autonomously, interacting with each other following complex social protocols.
In such a model of the supply chain, each agent (i) makes local decisions, using its ability to exploit mathematical models to plan supply chain operations, and (ii) collectively interacts with other agents to coordinate their decisions and reach a compromise. More specifically, an agent's social ability represents some form of heuristic that is used to coordinate the local decision-making tools, allowing complex social behaviours to be performed, such as negotiations and collaboration. In other words, the agents can be seen as a general construct that represents various types of supply chain entities, through which distributed advanced planning tools can be plugged together and collaborate. These entities can be, for example, APS modules for operational planning or for tactical planning (Santa-Eulalia et al., 2008).

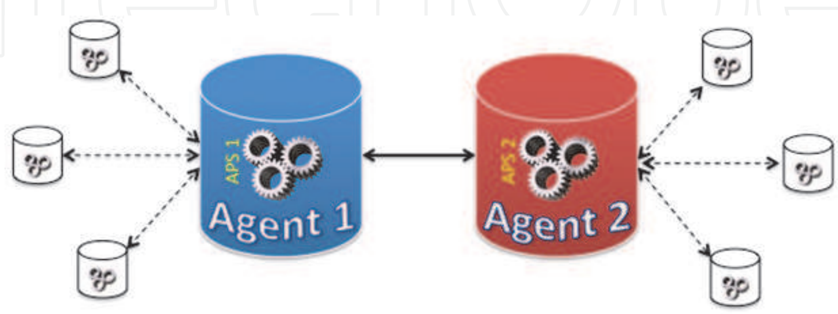

Fig. 3. A general schema for a d-APS (inspired by Santa-Eulalia et al., 2008)

Figure 3 schematizes this concept. Agent 1 encapsulates an APS tool dedicated to a specific planning domain 1 (e.g. a product assembler) while Agent 2 encapsulates specialized APS for the planning domain 2 (e.g. a distributor). Agent 1 interacts with 2, exchanging information or negotiating. Also, the assembler interacts with a set of suppliers and the distributor cooperates with a set of customers. Each agent has its own specialized APS tool, which can provide solutions for its own planning problem. Each planning problem can be quite different from each other to respond to different behaviours of supply chain partners, such as the ones defined by Gattorna (2006): agile, flexible, lean and continuous replenishment behaviours. The entire supply chain planning takes place when all agents interact with one another collaboratively to reconcile their local plans with the global plan for the entire supply chain.

In Figure 3 we do not represent the control structure of these systems. The reader may have the impression that the relationships between different agents in d-APS are sequential. This figure is a mere representation of the encapsulation of diverse APS tools and the consequent multiple coordination process among those entities, but it does not aim to represent their control structure. In reality, the coordination and control structures of d-APS are quite flexible and do not follow a typical hierarchical system, as in traditional APS systems. As mentioned by Frayret et al. (2004a), agent-based manufacturing approaches do not restrict or force the design of specific control architectures. According to the authors, diverse architectures can be found in the literature to define how the responsibilities are distributed across the organization, such as open architectures (Barber et al., 1999), heterarchical (Duffie, 1996), quasiheterarchical (Shen et al., 2000) and others. Due to this diversity of possible control architectures to manage the interdependencies among activities, diverse mechanisms for coordination exist.

Another interesting advantage of d-APS system is related to simulation. Agents are largely used for simulation, since they naturally model the simultaneous operations of multiple agents in an attempt to re-create and predict the actions of complex phenomena. Thus, simulating actions and interactions of autonomous individuals in a supply chain (e.g. vendors, manufacturers, distributors, clients etc.) and with the possibility of assessing their effects on the system as a whole is one interesting property of this system. It can naturally generate stochastic behaviours of supply chains (like orders arrivals, machines breakdown, etc.), such as traditional discrete-event simulation usually modelled through simulation packages like Arena® or Promodel®.

Therefore, to sum-up, we propose the following as the main characteristics of d-APS systems:

- d-APS are agent-based systems for supply chain planning and they incorporate optimization technology such as traditional APS systems, to perform distributed planning activities.
- A d-APS is composed of semi-autonomous APS tools, each dedicated to a specialized modelling domain, which are normally different in nature from one another, and that can act together in a collaborative manner employing sophisticated interaction schemas.
- Despite the fact that APSs are hierarchical systems, d-APS systems can exhibit more complex control structures, where more autonomy can be given to some decision-making entities of the entire planning system.
- As agent societies, these systems have to perform planning decisions considering both local and global objectives as well as constraints.
- Furthermore, these systems employ concepts from discrete-event simulation to perform stochastic and dynamic (time-advancement) experimentations, not only deterministic what-if analysis, as traditional APS do.

- These systems incorporate issues from artificial intelligence, including social and local intelligence related mainly to collaboration and negotiation possibilities, learning abilities, and pro-activity.

This is not an exhaustive list, but is the first step towards a more rigorous definition of what d-APS systems are.
It is important to mention at this point that this d-APS concept is being used successfully mostly in laboratorial research. However, we strongly believe that it is not far from being ready to reach the market, as some recent industrial experiences demonstrate. The FORAC Research Consortium in Canada had the opportunity to develop and test a d-APS system in the softwood lumber industry in Québec, Canada, with interesting success. In this next subsection we quickly present this concept and how it was tested in industry.

3.3 Prototyping in a Canadian lumber industry

The FORAC Research Consortium[1] is a centre of expertise dedicated to Supply Chain Management in the forest products industry in Canada. It has experts from several domains, including forestry engineering, industrial engineering, mechanical engineering, management sciences such as operations management and strategic management. Its efforts are divided into two sectors: research & knowledge and technology transfer activities. FORAC has been working with agent-based systems for supply chain management since 2002. As a result, a d-APS, referred to as the FORAC Experimental Planning Platform (hereafter the FORAC Platform), was developed and experimented with for this specific industry sector.
The platform was conceived based on a general and well-accepted model for supply chain management, the SCOR (Supply-Chain Operations Reference) from the Supply Chain Council (SCC, 2010; Stephens, 2000) in such a way as to guarantee that the d-APS would be able to solve a large number of supply chain planning problems and be easily used by companies. This allows the creation of a general agent shell for the d-APS.
In order to do so, the supply chain was organized into business units, in which the overall problem is split into smaller sub-problems, which allows that each agent models a smaller scale problem employing specialized planning tools. In order to solve the entire supply chain problem, agents make use of sophisticated interaction mechanisms.
Figure 4 presents the basic architecture of the FORAC Platform. Some planning agents have been developed to support a business unit, i.e. an internal supply chain where the same company owns all production units. The following agents are responsible for the operational planning:

- *Deliver* agent: manages all relationships with the business unit's external customers and fulfils all commitments to them;
- *Make* agents: several make agents are responsible for carrying out production planning functions, each one in charge of a part of the overall planning functions by means of specialized planning capabilities. Several make agents can be used inside a planning unit;
- *Source* agent: manages the relationship with all business units' suppliers, forwarding procurement needs to the right suppliers.

[1] www.forac.ulaval.ca

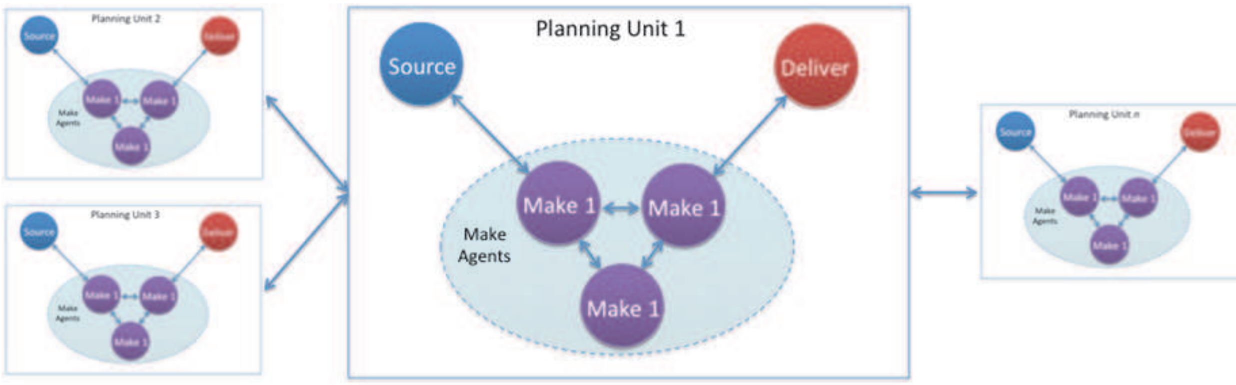

Fig. 4. Overview of the Platform

This architecture can be seen as a general framework that can be applied in diverse fields. For example, the FORAC Platform was implemented in the softwood industry in the province of Québec, Canada. By using dataset from two companies, the research consortium implemented the d-APS schematized in Figure 5.

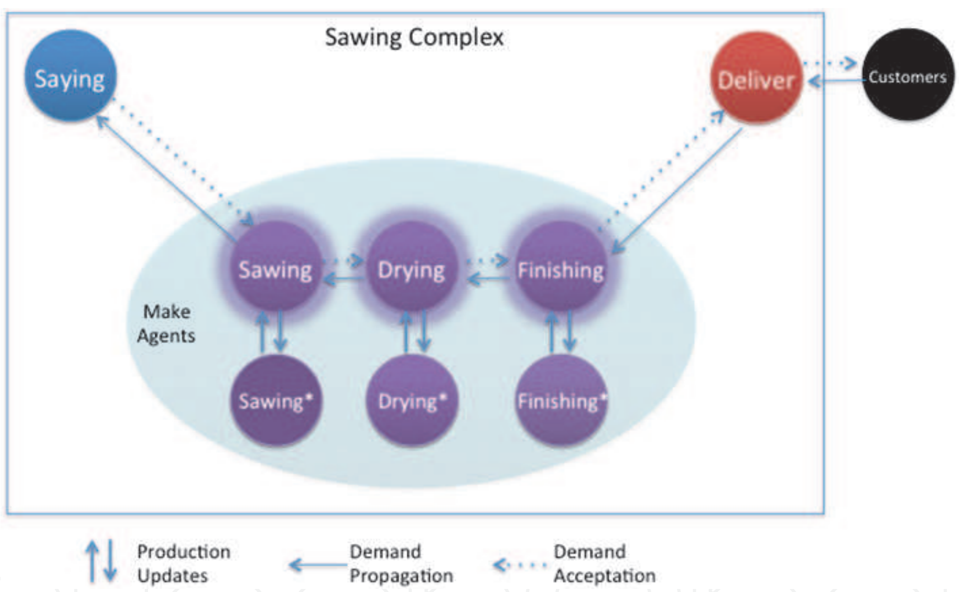

Fig. 5. Specialization in the Softwood Lumber Industry in Québec

The implemented agents are: deliver agent (manages all relationships with the business unit's external customers and fulfils all commitments to them); three make agents (sawing, drying and finishing) responsible for carrying out production planning functions, each one being in charge of a part of the overall planning functions by means of specialized planning capabilities; source agent (manages the relationship with all the business units' suppliers, forwarding procurement needs to the right suppliers), customer agent (generates the demand for products and evaluates supply chain offers). In addition, each agent responsible for production planning has a counterpart agent responsible for executing the production plan (sawing*, drying* and finishing*), referred to as execution agents. This platform can be used for planning a supply chain, or it can be used for performing simulation with stochastic number generation and time advancement.

In what follows, we explain its planning and simulation approach together. Generally speaking, Figure 5 can be understood through its products processing sequence: logs are sawn into green rough lumber, which are then dried, leading to dry rough lumber, the latter finally being transformed into dry planed lumber during the finishing process. Arrows represent the basic planning and control sequence. Essentially, the FORAC Platform functioning is divided into five basic steps:

1. *Production update*: before starting a planning cycle, all planning agents update their inventory level states. Actually, all execution agents (sawing*, drying* and finishing*) receive the last planned inventory for the current period from the planning agents (sawing, drying and finishing). The execution agents perform perturbations on the inventory level to represent the stochastic behaviour of the execution system and send the perturbed information back to their respective planning agents. This perturbation in the execution system can be seen as an aggregated representation of what happens on the shop floor, i.e. a set of uncertainties that cause the manufacturing system to have a stochastic output, which is ultimately reflected in the physical inventory level of the supply chain. It can also be real ERP information from the shop floor.
2. *Demand propagation*: with the planned inventory updated, all agents are ready to perform operations planning. The first planning cycle is called demand propagation because the customer demand is transmitted across the whole supply chain. First, the deliver agent receives customers' orders for finished products (dry planed lumber) and sends this demand to the finishing agent. If no products are available in stock, the finishing agent will perform an infinite capacity planning for this demand and will send its requirements in terms of dry rough lumber to the drying agent. The drying agent now performs its planning operations also using an infinite capacity planning logic, and its requirements in terms of green rough lumber will be sent to the sawing agent. Then, sawing executes an infinite capacity planning process to generate its needs for logs, which are transmitted to the source agent. The source agent will confirm with sawing whether all requirements will be sent on time. Now, the supply propagation starts.
3. *Supply propagation*: based on the supply offer from the source agent, sawing now performs finite capacity planning in a way to respect the demand from drying in terms of green rough lumber (pull planning approach), and respecting its own limitation in terms of production capacity. In addition, sawing tries to identify if it still has some available capacity for performing a push planning approach. If there are resources with available capacity, sawing allocates more production based on a price list to maximize the throughput value, meaning that it makes a complementary plan to occupy the additional capacity with products of high market prices. The sawing plan containing products to answer drying demands and products to occupy the exceeding capacity is finally sent to drying. Drying, in return, uses the same planning logic (first a pull and after a push planning logic) and sends an offer to the finishing agent. Finishing performs the same planning approach and sends an offer to the deliver agent. Deliver send its offer to the customer agent. In summary, the general idea of the supply propagation is to perform finite capacity planning, where part of the capacity can be used to fulfil orders (pull approach) and part of it to push products to customers so as to better occupy capacity.
4. *Demand acceptation*: the customer agent receives offers from deliver and evaluates whether they satisfy all its needs. Part of this offer can be accepted by the customer and part can be rejected, for example, because it will not arrive at the desired time. This information is sent to the deliver agent. Now, as part of the demand is no longer

necessary, deliver will send the adjusted demand for the finishing in the form of a new demand propagation with fewer products. This new demand will be propagated backwards (step 2) to the source agent. Next, from source this demand will be forwarded in the form of a supply propagation (step 3) up to the deliver agent. During the demand propagation, all planning agents will have more available capacity to be occupied with high market price products. The planning cycle finishes here.

5. *Time advancement*: due to the fact that the FORAC Platform uses the rolling horizon approach, after the end of a planning cycle involving these four steps, the simulation time moves ahead for the next planning period. In this case, the next planning period is the next 'replanning date', which is delimited by the control level (replanning frequency). It can vary within any time period, from one day to several months, and it depends on the interest of the supply chain planner. The planning cycle (i.e. the above-mentioned four steps) is repeated at each replanning date until the end of the simulation horizon.

These five steps represent the basic logic of the operations planning. Some mechanisms useful for simulation during these five steps are detailed in the following.

First, for the production update, one has to understand how the perturbation arrives at the beginning of each planning cycle. This is explained in Figure 6.

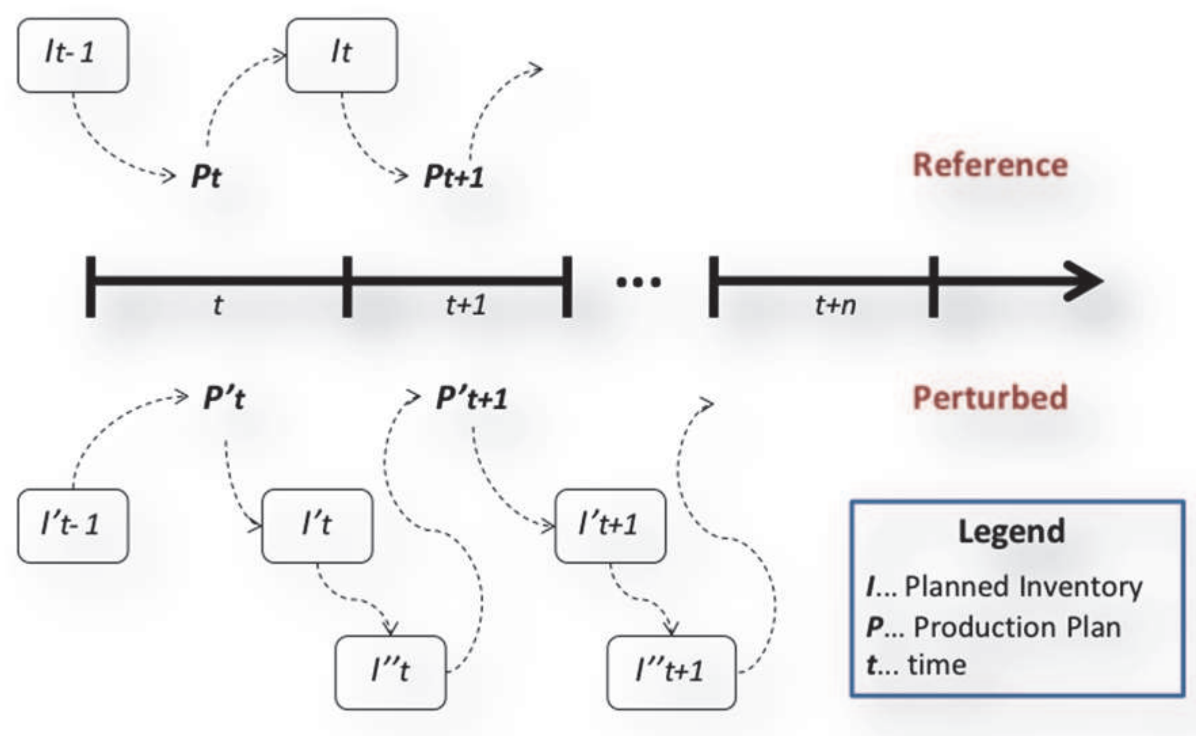

Fig. 6. Production update logic

Figure 6 shows two situations. In the upper half, the situation called 'reference' can be found, where no perturbation takes place. It is an ideal world where all plans are executed exactly when they are supposed to be, i.e. no uncertainties are taken into account. In this situation, at time *t*, a given agent performs its planning activities resulting in a plan called P_t. Plan P_t is calculated based on the inventory level of the execution system at *t-1* (i.e. I_{t-1}) which is obtained though the Production Update procedure. Together with P_t, the I_t is also calculated and used as input information for the planning process of the time *t+1* (i.e., P_{t+1}). This is repeated until the end of the simulation horizon (*t+n*).

In a real world situation, uncertainties happen all the time and what has been planned as an inventory level for a given moment is not exactly what is really obtained. This is due, for example, to machine breakdowns or the stochastic process of the production system. This situation is represented in the 'perturbed' side of Figure 6. As one can see in this figure, the inventory level planned for time *t-1* (I_{t-1}) is different, and we call it I'_{t-1}. This perturbed inventory level will affect the ideal P_t, resulting in a perturbed P'_t, which in turn generates a perturbed planned inventory level for the period *t* (I'_t). This perturbed planned inventory considered past influence (*t*-1, *t*-2, ...) on the present (*t*), i.e. perturbation is being accumulated across time. In addition, this planned inventory (I'_t) will also suffer from uncertainty occurring at time *t*, resulting in a double perturbed inventory level for *t*, which is called I''_t. Now, inventory I''_t considers past and present perturbations.
When time advances from *t* to *t*+1, the planned inventory I''_t is used to calculate the production plan at *t*+1, which is called P'_{t+1}. Based on this plan, a perturbed planned inventory level for *t+1* (I'_{t+1}) is calculated. Then, similarly to time *t*, a double perturbed inventory level for *t*+1, is generated, giving us the I''_{t+1}. This logic is repeated until the end of the simulation at *t*+*n*.
It is important to note that the agents try to cope with these accumulated perturbations by adjusting their plans, which is a quite relevant aptitude of supply chain planning and control systems. Figure 7 demonstrates the FORAC Platform control mechanisms that affect its resilience, i.e. the ability to bounce back from unforeseen disruptions (Klibi et al., 2011), by comparing the perturbed inventory to the reference inventory in a simulation. The reference is the ideal case where no perturbation exists and all agents can determine the optimum inventory levels according to their objective functions and constraints.
To exemplify this mechanism, the graph in Figure 7 shows the results of inventory disruptions (i.e. $[(I''_t - I'_t)/ I_t]*100$) for the time bucket of one day and a simulation horizon of 181 days (i.e. t = 1, 2, ..., 181 days). As one can see, inventory perturbations were introduced at the sawing agent level every 14 days. In this case, every 14 days the sawing agent has to replan all activities to compensate for perturbations. The first perturbation (14th day) was positive, i.e. more inventory than planned resulted from the production process. The next two perturbations were also positive, while the fourth was negative leading the system to attain the ideal situation. The remaining perturbations were negative, that is, fewer inventories than planned resulted from the production process. In all cases, it can be noted

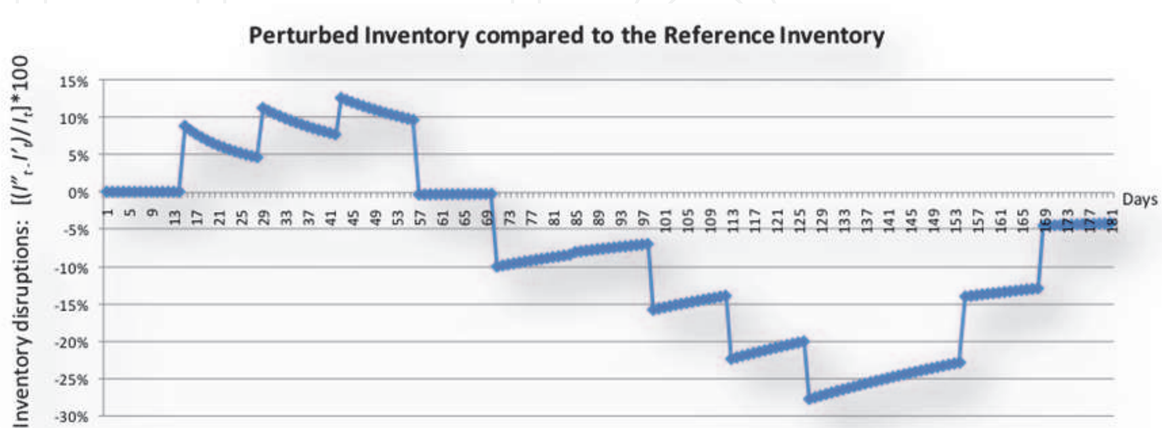

Fig. 7. Drying agent: absorbing uncertainties from the manufacturing system

that the agent tries to adjust the plans for each time period so that the reference (ideal situation, i.e. 0%) can be attained.

Besides manufacturing system perturbations, another relevant supply chain uncertainty (Davis, 1993) can be modelled in the platform, the demand. The demand agent can generate stochastic demand following a method developed by Lemieux et al. (2009). The basic principle consists in randomly generating a total quantity of products for each relation *client-deliver-product* and for the entire simulation horizon. Next, products from this total quantity have their delivery dates set stochastically, as well as the date when the demand will be sent to the deliver agent. This stochastic generation can use a seasonality factor, if desired. Two types of typical demand behaviour can be simulated: spot (sporadic customers) and contract (long-term relationship, whose demand cannot be cancelled and penalties apply in the case of late fulfilment). More detailed information about this mechanism is provided by Lemieux et al. (2009).

All these perturbations are performed by the platform through a traditional random number generation approach and since a lot of data is needed a fast and flexible generator is employed. The selected uniform number generator was the Mersenne Twister (Matsumoto & Nishimura, 1998), which provides random numbers for a considerably long period of time without slowing down the algorithm. The transformation of the random numbers into random variables follows a simple method for discretizing the density function of the probability distribution desired. Simulation analysts can select different probability distribution functions, such as normal, exponential or triangular. More details about number variables generation in the FORAC Platform is found in Lemieux et al. (2009).

Other important technical information concerns how agents perform their planning activities. Both Demand Propagation and Supply Propagation for each agent are geared up with specialized optimization models. They are depicted in Table 5 in terms of objective functions, processes and optimization method, according to Frayret et al. (2007).

The planning approaches described in Table 5 are radically different from each other in regard to their nature, as explained by Frayret et al. (2007). The authors mention that the Sawing agent (both Demand and Supply Propagations) are designed to identify the right mix of log type in order to control the overall divergent production process. What changes for the demand and for the supply propagation are the objective functions and constraints.

Drying, on the other hand, is batch-oriented and tries to simultaneously find the best type of green rough lumber to allocate to the kilns and the best drying process to implement. What is interesting in this approach is that it tries to find a feasible solution in a short time, but if more time is available, it will try to find a better solution using a search algorithm through the solution tree.

Finishing employs a heuristic approach to find what rough dry lumber type will be used and how much should be planed considering setup time. For more details on how planning engines work, the reader is referred to Gaudreault et al. (2009).

The last issue concerning simulation functioning is the time advancement mechanism used to manage all these uncertain events and planning activities. We opted for a central simulation clock, which aims at guaranteeing that all agents are synchronized so that none of them are late or in advance. In this case, all agents use the same simulation clock instead of each agent having its own clock. This was used to simplify the time management effort. The general functioning logic is simple. The simulator has a list of all agents participating in

	Objective Function for Demand Propagation	Objective Function for Supply Propagation	Optimization Method Employed	Processes Characteristics
Sawing Agent	Minimize lateness	Maximize production value	Mixed-Integer Programming	Divergent product flows; co-productions; alternative process selection; only compatible processes can be executed within the same production shift
Drying Agent	Minimize lateness	Maximize production value	Constraint Programming	Divergent product flows; co-productions; alternative process selection
Finishing Agent	Minimize lateness	Maximize production value	Heuristic	Divergent product flows; co-productions; alternative process selection; only compatible processes can be executed within the same production shift

Table 5. Planning engines for each agent

the simulation and their corresponding state, which can be 'calculating' or 'standby'. When at least one agent is working (sometimes more than one could be calculating in parallel), time advances in real time. When all agents are on standby, time advances according to the simulation list. This means that the simulator looks for the next action to accomplish and advances the simulation time until the realization moment of this action. Next, the simulator asks the concerned agent to perform this action. This central clock management mechanism implies that when an agent receives a message involving an action, it adds this action and its respective time of occurrence to the simulation list. This action can be triggered immediately or later, depending on its time of occurrence.

The prototype in the softwood industry was implemented in a large Canadian lumber industry in order to validate the d-APS architecture. The validation was conducted over 18 months of close collaboration with the planning manager and his team. Outputs were therefore validated both, in an industrial context and a changing environment. Results of the FORAC Platform compared to the company's approach were very encouraging. Two main advantages were identified: the quality of the solution of the proposed d-APS system was superior, and the resolution time was considerably shorter. This allows the supply chain planner to create several simulated plans quickly.

The FORAC Platform and the dataset of this company is also currently being used in several research projects in the FORAC Research Consortium. For example, Santa-Eulalia et al. (2011) evaluated through simulation the robustness of some tactical planning and control tactics under several supply chain uncertainties, including the demand, the manufacturing operations and the supply. Cid-Yanez et al. (2009) study the impact of the position of the decoupling point in the lumber supply chain. Gaudreault et al. (2008) evaluated different coordination mechanisms in supply chains. Forget et al. (2009) proposed an adaptive multi-behaviour approach to increase the agents' intelligence. Lemieux et al. (2009) developed several simulation mechanisms in order to provide the FORAC Platform with a d-APS with simulation abilities, such as a time advancement method, random numbers generation, and so forth. Several other developments are being incorporated in this d-APS in order to transform it into the first commercial system in the world employing the distributed planning technology for the forest products industry.

4. Final remarks

This chapter discusses the present and the future of APS systems in two parts. First, in Part I, traditional APS systems are introduced theoretically followed by a discussion of some systems available on the market and, finally, on how APS systems can be properly implemented in practice, according to our experience in the domain. It is interesting to notice that each solution on the market is different and offers different advantages and drawbacks. Companies desiring to implement such a system have to manage several trade-offs in order to discover the best application for their business requirements, which can be tricky in some situations.

In addition, Part I also discusses three case studies in large companies in order to illustrate the current practice through three typical APS projects: system recovery, system maximization and system readiness. Our experience in recovering APS indicates that implementing such a tool without a structured planning process and without maturity from the company in terms of the seven dimensions of the transformation might lead to project failure. In terms of APS maximization, system subutilization is normally a symptom of problems related to operating logic, misaligned indicators, unclear roles and responsibilities or a lack of knowledge about the system logic or Supply Chain Management logic. Problems related to the technology are also present, but they tend to be the least demanding. Finally, in our experience with APS readiness, we discussed and illustrated the importance of making a complete study prior to the system implementation to assure that the company is ready for a transformation path.

In Part II we pointed out that traditional technology and practice still have many limitations, thus we explore possible avenues for APS systems. By highlighting some flaws in traditional approaches in creating sophisticated simulation scenarios and modelling distributed contexts, we introduce what we call a distributed APS system and we provide some insights about our experience with this kind of system in a Canadian softwood lumber industry.

The system proposed by FORAC Research Consortium explicitly addresses simulation and distributed planning approaches. Practical experience with this system is producing interesting results in terms of the quality of the solution, planning lead-time and the possibility of creating complex simulation scenarios including complementary possibilities, such as different negotiation protocols between planning entities within a supply chain. Several improvements are planned for d-APS in order, in the coming years, to deliver the first commercial d-APS in the world employing agent-based and distributed technologies.

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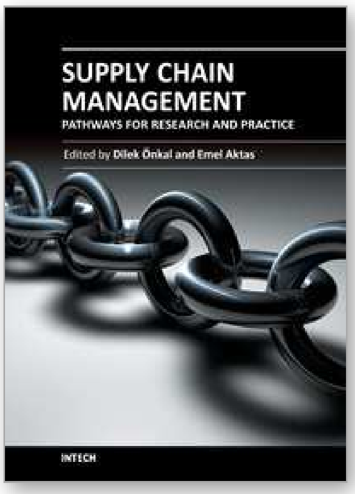

Supply Chain Management - Pathways for Research and Practice

Edited by Prof. Dilek Onkal

ISBN 978-953-307-294-4
Hard cover, 234 pages
Publisher InTech
Published online 01, August, 2011
Published in print edition August, 2011

Challenges faced by supply chains appear to be growing exponentially under the demands of increasingly complex business environments confronting the decision makers. The world we live in now operates under interconnected economies that put extra pressure on supply chains to fulfil ever-demanding customer preferences. Relative attractiveness of manufacturing as well as consumption locations changes very rapidly, which in consequence alters the economies of large scale production. Coupled with the recent economic swings, supply chains in every country are obliged to survive with substantially squeezed margins. In this book, we tried to compile a selection of papers focusing on a wide range of problems in the supply chain domain. Each chapter offers important insights into understanding these problems as well as approaches to attaining effective solutions.

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