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UNIVERSITÉ DE MONTRÉAL

DYNAMIC MUTUAL ADJUSTMENT SEARCH FOR SUPPLY CHAIN OPERATIONS PLANNING COORDINATION

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ÉCOLE POLYTECHNIQUE DE MONTRÉAL

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Cette thèse intitule:

DYNAMIC MUTUAL ADJUSTMENT SEARCH FOR SUPPLY CHAIN OPERATIONS PLANNING COORDINATION

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en vue de l'obtention du diplôme de : Philosophiae Doctor (Ph. D.)

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DEDICATION

À lumière des cieux et de la terre.

To light of the heavens and the earth.

به نور آسمانها و زمین.

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I would like to first express my deepest appreciation to my research director, Professor Jean-Marc FRAYRET, for his guidance, great support and patience.

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RÉSUMÉ

Les chaînes d’approvisionnement sont des systèmes complexes comprenant plusieurs organisations indépendantes avec des objectifs différents dans un environnement incertain et dynamique. Une question clé dans la gestion de chaîne d’approvisionnement (Supply Chain Management) est la coordination des décisions de planification des opérations. Les systèmes de planification de chaîne d’approvisionnement introduits dans la littérature peuvent être classés en deux systèmes de planification principaux: les systèmes de planification centralisés et les systèmes de planification décentralisés. Les systèmes centralisés peuvent théoriquement optimiser les performances de la chaîne d’approvisionnement bien que leur mise en œuvre nécessite un haut degré d’échange d’informations entre les partenaires de la chaîne d’approvisionnement. Cela conduit à des difficultés lorsque des partenaires indépendants ne veulent pas partager l’information. Afin de répondre à ces difficultés, les systèmes décentralisés de planification des opérations sont conçus dans lesquels chaque membre est une entité économique distincte qui prend ses décisions opérationnelles de manière indépendante, mais avec un niveau minimal d’échange d’information.

Dans cette thèse, nous étudions dans un premier temps les méthodes de coordination des processus de planification des opérations dans les chaînes d’approvisionnement proposées dans la littérature. Ensuite, nous proposons un cadre de classification de ces méthodes basée sur la technologie mise en œuvre, et identifions des opportunités de recherches.

Dans un deuxième temps, nous proposons une approche de coordination décentralisée qui consiste en un ajustement mutuel des décisions de planification basé sur la programmation mathématique et l’échange d’incitatifs financiers. Ce mécanisme, contrairement à un système centralisé traditionnel, implique deux entreprises, qui interagissent l’une avec l’autre afin d’améliorer leur performance. Dans le cadre de cette approche, seul un petit sous ensemble des solutions de coordination sont considérées, et l’expérimentation montre que cette approche de coordination a un potentiel d’amélioration du profit global tout en préservant l’équité en termes de partage des bénéfices de l’amélioration.

Enfin, afin de proposer une méthode de coordination capable d’être utilisable dans le contexte dynamique des chaînes d’approvisionnement, cette thèse propose dans un premier temps une stratégie performante de négociation du fournisseur adaptée à l’approche de coordination proposée, ainsi qu'une stratégie de partage des revenus appliquée à un contexte d'horizon roulant. L'analyse de la performance de cette méthode particulière montre également que l'approche proposée produit une stratégie gagnante-gagnante pour les deux partenaires de la chaîne d'approvisionnement et améliore les résultats de planification.

Mots-clés: gestion de chaîne d'approvisionnement, coordination, mécanisme d'incitation, planification des opérations, programmation mathématique, recherche par ajustement mutuelle, et recherche opérationnelle.

ABSTRACT

Supply chains are complex systems, which include several independent organizations with different objectives, in dynamic uncertain environment. A key issue in supply chain management (SCM) is the coordination of supply chain operations planning decisions. Supply chain planning systems introduced in the literature can be classified into two main planning systems: centralized and decentralized planning systems. Centralized systems can theoretically optimize supply chain performance although its implementation requires a high degree of information exchange among supply chain partners. This leads to difficulties when independent partners do not want to share information. In order to address these difficulties, decentralized systems are designed for supply chains where each member is a separate economic entity that makes its operational decisions independently, yet with some minimal level of information sharing.

In this thesis, we first review supply chain operations planning coordination methods from centralized to decentralized approaches proposed in the literature. Next, we propose a classification scheme of these approaches based on the technology used by the authors. Finally, we identify research opportunities.

Second, we propose a decentralized operations planning coordination mechanism referred to as mutual adjustment search (MAS), which is based on a negotiation-like mutual adjustment of planning decisions with financial incentives and rooted in mathematical programming. This mechanism, unlike traditional centralized system, involves two independent enterprises linked by material and non-strategic information flows, which interact with each other in order to coordinate their operations planning, and to improve their individual and collective performance. In this approach, only a few coordination solutions (pairs of coordinated operations plans) are considered and computational analysis shows that this coordination mechanism has the potential to improve global profit, while maintaining fairness in terms of revenue sharing.

Finally, in order to develop an approach capable of supporting the dynamic coordination of operations planning in a rolling horizon context, this thesis first proposes a negotiation strategy for the supplier, as well as a revenue sharing protocol. Computational analysis shows that the proposed approach produces a win-win strategy for two partners of supply chain and improves the results of upstream planning.

Keywords: Supply chain management, coordination, incentive mechanism, operations planning, mathematical programming, mutual adjustment search, and operation research.

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INTRODUCTION

Supply chain is a complex network in a dynamic uncertain environment, which includes numerous independent organizations that produce and deliver value in the form of products or services to the final consumer through upstream and downstream linkages (Christopher 1998). These organizations have different objectives and operations planning domains. They are connected by information, physical and financial flows in order to provide products or services to consumers. In fact, this definition includes the internal networks of business units of integrated companies (Halal 1994, de Kok and Fransoo 2004). Therefore, supply chains are characterized by distinct, yet mutually interdependent decision domains with independent business objectives (Simchi-Levi et al. 2000), and by an asymmetrical distribution of information. A key issue in Supply Chain Management (SCM) is the coordination of decisions with respect to operations planning of these independent organizations in dynamic uncertain environments.

In other words, the general issue of supply chain management is to coordinate material release and resource utilization decisions across independent organizations characterized by disjoint planning domains and information asymmetry. In this context, poor coordination of production and distribution decisions caused by lack of decisional, organizational and informational integration leads to inefficiencies such as the bullwhip effect (Lee et al. 1997), which result in missed opportunities, delays, inefficient inventory decisions, poor capacity allocation and misuse of resources, all leading to increased cost. Therefore, in order to improve supply chain performance, companies have developed collaborative practices across different functions of the supply chain (Simatupang and Sridharan 2002), and academics from several disciplines have proposed a several number of coordination methods. The literature of supply chain coordination can be divided into two main streams of research: centralized vs. decentralized approaches.

Centralized supply chain planning is generally implemented in the form of a hierarchical planning system, which can theoretically produce optimal supply chain performance as it coordinates all supply chain units towards a unique goal. However, its implementation requires a high degree of collaboration and information exchange between supply chain units, which is why in practice it is limited to the supply chain units of large companies. This leads to difficulties when independent supply chain members do not want to share detailed information such as strategic objectives, production capacity utilization and costs.

In order to address such difficulties, decentralized forms of supply chain planning coordination have been proposed in the literature. These decentralized planning systems are designed for supply chains, which members are separate economic entities that make their own planning decisions independently, yet with some minimal level of information sharing. The general practice of distributed supply chain operations planning is described as a cascade process, referred to as upstream planning, in which partners locally plan their operations and send their dependent demand to their suppliers, who, in turn, do the same thing (Azevedo et al. 2005, Dudek and Stadtler 2005). More advanced methods, proposed in the literature, aim to improve supply chain performance in order to achieve near-optimal supply chain planning.

In this context, the specific research problem addressed in this thesis is how two interdependent operations planning decisions processes (of two manufacturing companies) can be coordinated in order to improve the performance of both partners (compared to upstream planning), while maintaining a fair sharing of their improved revenues. In addition to this specific research problem, this thesis aims at addressing the dynamic nature of supply chains. Indeed, decision parameters such as demand forecasts, customer orders, and resources status change over time from one planning cycle to the next. These dynamic changes require readjusting all coordinated plans directly or indirectly affected by the changes (Stadtler 2009).

CHAPTER 1 RESEARCH PROBLEM AND METHODOLOGY

This Ph.D. thesis takes the form of three journal papers presented in the following, which address three different aspects of the research problem introduced in the introduction.

Paper 1: Atour TAGHIPOUR & Jean-Marc FRAYRET, Coordination of operations planning in supply chains: A review. *International Journal of Business Performance and Supply Chain Modeling*, Submitted in November 2011.

Paper 2: Atour TAGHIPOUR & Jean-Marc FRAYRET, Mutual Adjustment Coordination with Incentive for Supply Chain Planning. *International Journal of Computer Integrated Manufacturing*, Submitted in October 2010, Accepted in November 2011.

Paper 3: Atour TAGHIPOUR & Jean-Marc FRAYRET, Dynamic Mutual Adjustment Search for Supply Chain Operations Planning Coordination, *International Journal of Production Research*, Submitted in November 2011.

This section first presents the general methodology used in this research project, which consists of two specific methodologies used for the literature review (first paper) and for the development of the proposed operations coordination approach (second and third paper).

1.1 Research problem and objectives

As mentioned in the introduction, the research problem that is addressed of this thesis concerns the coordination of two manufacturing supply chain partners with respect to their lot-sizing operations planning decisions in a dynamic context, where time passes and decision parameters are regularly updated.

In order to propose a solution to this general problem, we define the following specific objectives that the proposed solution must address:

(1) Proposed solution must allow the two interdependent operations planning processes of two manufacturing companies to be coordinated in order to improve the performance of both partners compared to upstream planning;

(2) Proposed solution must guaranty a fair sharing of their improved revenues;

(3) Proposed solution must maintain the coordination of operations plans in the dynamic context of supply chains, which includes the continuous updating of demand forecasts, customer orders, and resources status from one planning cycle to the next.

1.2 Research methodology

This section presents the two research methodologies used to respectively carry out the literature review of the distributed supply chain operations planning coordination approaches (first paper), and the development of the general and specific coordination approach (second and third paper).

1.2.1 Methodology of the literature review (Paper 1)

The first contribution of this thesis is to develop an in-depth analysis of the literature in the domain of distributed operations planning coordination in supply chains. In order to do that, this review proposes a classification framework of these coordination approaches based on their technologies, which includes operations research and multi-agent systems. To design this framework of analysis, we first focused on the literature of supply chain management. The main terms used in our queries to find articles are “coordination approach (mechanism)”, “supply chain” and “operation(s) planning”. More than 600 references appeared, including journal papers, books and conference papers, on the subject of supply chain coordination between 1970 and 2010. Next, we screened these references by eliminating the central coordination approaches. Then, we first focused our attention on contributions, whose authors have numerous publications and which number of citations is significant (except for the most recent contribution). Therefore, we selected almost 105 references in the literature of supply chain coordination, including research papers drawn from almost 50 journals, books and conference papers. More than 90% of references were drawn in the last two decades. 58% of these references have been published between 2006 and 2010. 29% have been published between 2001 and 2005, and 10% have been published between 1996 and 2000. Finally, less than 3 % of these references have been published between 1971 and 1995.

Next, we analyzed the selected contributions of the literature using a systematic analysis which focuses on three main criteria:

- Supply chain environment;

- Local planning characteristics;
- Coordination characteristics.

For each of the analyzed contribution, the first criterion was used in order to specify the structure of relations in the considered supply chain, while the two others specify the characteristic of each planning coordination approach. Each of these criterions is further sub-divided into several dimensions. Next, based on the results of the above analysis, we proposed a novel classification framework, which classifies the distributed approaches that deal with supply chain operations planning coordination, according to the technology used and the benefit of using these technologies.

1.2.2 Methodology for the coordination approaches (Paper 1& 2)

The contributions of the second and third papers concern the development of a general and specific distributed approach to coordinate the operations planning decisions of two supply chain members in static and dynamic environments. These approaches are quantitative methods, based on a mathematical programming modeling of the planning problems and a heuristic structure of information exchange to address coordination. The following sections describe the main phases of the development used in this thesis:

1.2.2.1 Operations planning and coordination problem

The specific operations planning problem addressed in this work is the supply chain coordination of two Multi-Level Capacitated Lot-Sizing Problem (MLCLSP) which in this thesis is referred to as a distributed Multi-Level Capacitated Lot-Sizing Problem. In other words, two manufacturing members of a supply chain, a supplier and a customer, have to plan their own multi-period multi-product lot sizes in order to maximize their profits. In the literature, the Multi-Level Capacitated Lot-Sizing Problem is generally modeled as a cost minimization problem. However, because this thesis proposes to use a financial incentive as the basic element of coordination, profit maximization is therefore adopted.

Using the literature related to the lot-sizing problem, we formulated two versions of this problem as well as two coordination approaches based on two different incentive mechanisms. The first version of the supplier's planning problem used some form of anticipation of the reaction of its customer (i.e., the manufacturer) in order to define an efficient incentive structure. This incentive would incite the manufacturer to adjust its plan toward a good coordination solution. However, because both partners have a local cost structure they do not share, as well as external demand to satisfy, they cannot accurately anticipate each other's input/output feasibility and economic performance. Therefore, this version of the planning problem was abandoned in order to develop a much simpler approach based on a heuristic exchange of non-strategic information.

This solution approach is proposed in the second paper and is referred to as a *Mutual-Adjustment Search* (MAS) with incentive, because unlike traditional centralized system, it involves two supply chain partners who interact directly with each other to mutually adjust their lot-sizes in order to improve their collective economic performance. This mutual adjustment search is a collective search of a solution within a coordination space that represents all possible Order Plans that can be agreed upon by both partners.

Next, in order to achieve the second and third objectives of the proposed research problem, we developed a negotiation strategy for the supplier, and we adapted the MAS approach to a rolling planning horizon context. This involved the design of two revenue sharing protocols based on the financial incentive structure designed previously.

1.2.2.2 **Computational evaluation**

First, in order to evaluate the performance of the proposed approach in the second paper, a complex test class is considered including two supply chain members and based on a global bill-of-material which contains 30 products of which 14 products are produced by manufacturer and 16 products by supplier, and finally four resources are used by partners including two resources for each partner.

In order to evaluate several scenarios, we designed six test case instances. These six instances were designed by combining two supplier demand/capacity ratios and three cost structures based on the average ratio between holding and setup costs at buyer and supplier. In addition, for each of the six test case instances, we systematically tested the 100 combinations of different points of the coordination space to give a clear image of the performance potential of the proposed approach. This results in 600 computational experiments. Furthermore, for each of the six scenarios, two benchmark solutions are computed in order to evaluate the overall performance. First, pure upstream planning was used as a lower bound for profit maximization. Second, a central planning model, containing both buyer and supplier domains, was considered as the upper bound.

Second, in the third paper, after developing a search algorithm to search the exact solutions and proposing two protocols of revenue sharing, in order to evaluate the capacity of the Mutual Adjustment Search to find good coordination solutions in a dynamic environment, a rolling horizon planning approach including four horizons was considered. The first planning cycle, included four new planning periods, starts by entering demand information and no information inherited from previous planning cycle. In the second to the fourth planning cycles, we used the data of the first period of the previous planning cycle to compute costs and revenues, and we used new demand information for the four other periods. For these experiments, we introduced two instances of test using the previous complex test class by combing one capacity utilization profiles and two costs.

Again, as carried out in Dudek and Stadtler (2005, 2007), for each scenario/horizon, two benchmark scales are created for more evaluation of the dynamic MAS: upstream solution against central solution. Upstream solution, as the starting point of the adjustment, represents the lower bound of profit maximization. On the other hand, the central solution represents the upper bound of profit maximization to a single, central planning model containing both manufacturer and supplier. All test cases were carried out ILOG OPL 6.3 and Cplex 10 to solve the optimization models.

1.3 Structure of thesis

The remainder of this thesis proceeds as follows. Chapter 2 is a critical review of the distributed supply chain operations planning coordination approaches. Chapter 3 is the first paper which addresses an analysis and a classification of the literature of supply chain operations planning coordination approaches. Next, Chapter 4 presents the second article and contribution of this thesis. It specifically introduces a mutual adjustment search with incentive for supply chain planning coordination. This paper has been accepted by International Journal of Computer Integrated Manufacturing (IJCIM). In Chapter 4, we present the third article and contribution of this thesis, which is a dynamic application of our developed mutual adjustment search. Finally, we conclude this thesis with a discussion and a conclusion came with some propositions of different research directions for future projects.

CHAPTER 2 CRITICAL REVIEW OF THE LITERATURE

The literature dealing with supply chain operations planning includes two main streams of research. In the first stream of research, coordination is achieved by a central and aggregated control unit which requires a high degree of information exchanges to coordinate the plans of the supply chain partners. This leads to difficulties when independent members do not want to share information, such as cost, profit margin, inventory level or capacity utilization. In the second stream of research, in order to address these difficulties, decentralized approaches of coordination of operations planning decisions based on some minimal information sharing have been proposed in many academic disciplines. This chapter presents the general approaches of decentralized coordination of operations planning in supply chains and conducts a critical review of this literature, which leads to the identification of research opportunities.

2.1 Introduction

Supply chains are networks of integrated organizations that create and deliver value in the form of products or services to the final consumer through upstream and downstream linkages (Christopher 1998). Therefore the lack of decisional, organizational and informational integration leads to inefficiencies related to poor coordination of production and distribution decisions, such as the bullwhip effect (Lee et al. 1997), which leads to cost increasing in supply chains. In this context, as proposed by De Kok and Fransoo (2004), the main objective of the *Supply Chain Operations Planning* is the "[coordination of] the release of materials and resources in the supply network under consideration such that customer service constraints are met at minimal cost".

In order to improve supply chain coordination, academics from several disciplines have proposed a number of coordination methods which can be divided into two main streams of research: centralized and decentralized approaches. Next section proposes a critical review of the decentralized approaches of operations planning coordination in supply chains, in order to reveal research opportunities.

2.2 State of the art of supply chain decentralized coordination planning

In this section, we study some of the main decentralized approaches of operations planning coordination in supply chains and we clarify the drawbacks of these approaches. Chapter 3 presents with more details and classifies this literature. The following sub-sections presents from a methodological point of view the various approaches proposed in the literature to address in a distributed manner supply chain operation planning coordination. For each of the approaches, we identify the major gaps that, we believe, remain to be studied.

2.2.1 Lagrange decomposition

In Lagrange decomposition (Barbarosoglu and Özgür 1999, , Ertogral and Wu 2000, Ghirardi et al. 2008, Jayaraman and Pirkul 2001, Jeong and Leon 2002 & 2003, Karakitsiu and Migdalas 2008, Xiao et al. 2007, Nishi et al. 2005a, Nishi et al. 2005b) a central block-separable supply chain planning model using mathematical programming is developed. Then the binding constraints of the natural sub-problems, which are typically the material flow constraints between supply chain partners are relaxed (by moving them in the objective function and adding a penalty vector for each constraint). Next, a distributed and synchronous iterative process must be developed to adjust the penalty vectors of these relaxed constraints in order to converge toward a near optimal solution.

In most approaches, a central master problem, which can be considered as a drawback, is used to calculate and adjust synchronously these penalties according to the current state of the local optimization processes using a sub-gradient optimization technique. In order to develop a coordination system that truly respects the distributed nature of supply chain, some authors (Ghirardi et al. 2008, Karakitsiu and Migdalas 2008, Nishi et al. 2005a) propose an asynchronous and decentralized adjustment process of these penalties.

Although these approaches are rather easy to implement, convergence towards optimality remains an issue to consider. Furthermore, sub-problems must be specifically formulated in order to process adequately the information provided by the mediator (i.e., central master problem). The dependency between the coordination process and the local decision process is thus specific to the decomposition approach. Therefore, such approaches remain academic methodologies of coordination.

2.2.2 Benders decomposition

This approach also exploits the block-separability property of the supply chain problem (Poundarikapuram and Veeramani 2004, Uster et al. 2007). In this approach, the common variables to several block problems are positioned in the master problem, while the local variables that define the sub-problems are positioned at a second level. The main difference with Lagrange decomposition is that feasibility and optimality are iteratively addressed by adding feasibility constraints and optimality cuts to the master problem.

Although it is a powerful mathematical tool to coordinate the local decision processes, the information exchanged between the sub-problems and the master problem is rather difficult to interpret for an operations manager. It is also rather a marginally exploited approach.

2.2.3 Dantzig-Wolfe decomposition

In Dantzig-Wolfe decomposition (Cheng et al. 2008, Holmgren et al. 2009, Sung and Yang 2008) the variables become solution vectors of the problem. Therefore, in order to solve to optimality, the problem is decomposed into a *Restricted Master Problem* (RMP), where only a small subset of solution vectors are investigated, and one or many pricing problems (as many as supply chain partners), which generate, according the dual costs of the current solution of the RMP, new interesting solution vectors (i.e., the columns) to be fed back in the RMP. This process is repeated until no new solution vectors can be found, guarantying therefore the optimal solution.

Although Lagrange decomposition has been adapted to this context, approaches such as Benders and Dantzig-Wolfe decompositions remain largely unexplored to solve such a complex planning context in a distributed manner.

2.2.4 Distributed search with constraint propagation

Proposed by Gaudreault et al. (2009), the coordination space of many heterogeneous planning problems of a linear supply chain is modeled as a tree. In the distributed and asynchronous search procedure proposed, agents must decide whether to produce an alternative solution to a customer demand plan for which they have already found a solution (i.e., an operations plan), or to produce a first solution to a demand plan for which they have not yet produced any solution.

One of the strengths of this approach is to only require the exchange of minimal information such as demand and supply plans. Furthermore, local planning problems are independently solved, which, unlike decomposition approaches, allow supply chain partners with heterogeneous planning systems to be coordinated. However, the quantity of information exchanged still remains rather important.

2.2.5 Greedy coordination

Greedy technique (Hax and Meal 1975, Simpson and Erenguc 2001) consists of a simple, one way exchange of information, referred to as *upstream planning* (Bhatnagar et al. 1993).

The main advantage of this approach is its simplicity, leading to a strict hierarchical dependency between planning domains with minimal exchange of information (i.e., demand plans flowing upstream the supply chain). The main disadvantage of upstream planning is its inability to explore alternative and more interesting coordination arrangements between partners.

2.2.6 Partial aggregation

Partial aggregation (Jayaraman and Ross 2003, Ozdamar et al. 1998, Pibernik and Sucky 2007, Masuchum and Petchmaneelumka 2009) is a coordination approach between centralized and upstream planning to fill the performance gap of upstream planning. The main idea of such approaches is to aggregate some planning decision domains into a single decision domain, while the interactions with the other decision domains is based on upstream planning.

In main disadvantage of this approach is the need to exchange information between all sub-problems aggreagated into a single central planner, which increases the complexity of these new fewer sub-problems. This can only be possible between business units under the same ownership structure. It is therefore not really applicable to supply chain with a heterogeneous ownership structure. Furthermore, like greedy approaches, this type of coordination is not capable of exploring alternative coordination solutions between the remaining planning domains.

2.2.7 Anticipation models

Anticipation models (Barbarosoglu 2000, Buakaew and Masuchun 2008, de Kok et al. 2005, Frayret et al. 2007, Gaonkar and Viswanad. 2001, Lee 2004, Moyaux et al. 2007, Omar et al. 2006, Schneeweiss 1999, Schneeweiss and Zimm. 2004, Váncza et al. 2008, Yu et al. 2001*)* use the idea of *upstream planning* using various forms of information exchange. For example, Schneeweiss (1999) proposes various modeling concepts to improve upper level decision-making through the anticipation of lower level decision processes.

All anticipation approaches are more or less advanced forms of information sharing or decision process reengineering. However, they do not provide a systematic search of the coordination space.

2.2.8 Distributed heuristic search with local optimization

In this approach (Dudek and Stadtler 2005, Jung et al. 2008a, Jung and Jeong 2005, Jung et al. 2008b, Kim and Cho 2010, Laub and Bailey 1978, Taghipour and Frayret 2010 & 2011) planning domains are modeled separately and coordination space is explored through iterative search techniques.

As an advantage, these approaches respect the distributed nature of supply chains, while involving rather simple forms of information exchange. However, they are for the moment limited to the coordination of two partners while the impact of the coordination effort of these partners on third parties is largely ignored. Furthermore, they are heuristic and not optimal approaches.

2.2.9 Meta-heuristic searches

Meta-heuristics approaches (Chen et al. 2007, Dayou et al. 2009, Homberger 2010, Silva et al. 2006, Mansouri 2006, Mansouri 2005, Yanling et al. 2010) exploit various meta-heuristics implemented in a distributed manner to meet the distributed nature of supply chains..

Although meta-heuristics approaches proposes advanced techniques to search for a good coordination solution, their practicality is rather limited because they force supply chain partners to adopt specific meta-heuristic-based advanced planning systems. Furthermore, the information exchanged between partners is rather difficult to interpret by operations managers.

2.2.10 Interaction-based techniques

Interaction-based coordination approaches (Azevedo et al. 2005, Bao and Xiao 2009, Blackhurst and Craighead 2008, Chen et al. 2008, Dodd and Kumara 2001, Dotoli et al. 2009, Drzymalski and Odrey 2008, Huang et al. 2008, Jain et al. 2007, Monteiro et al. 2007, Swaminathan et al. 1998, Tah 2005, Tang et al. 2008, Wang et al. 2008, Wu et al. 2010, Yahong 2010, Zhang et al. 2006, Zhang et al. 2009) propose explicit representations of the interaction processes, which are used in specific situations between agents (i.e., interaction protocols).

Although such explicit representations of interactions can be used by intelligent agents in order to create collective and heuristic processes of joint supply chain planning, these techniques are generally applied to reactive agent-based supply chain systems to automate inter-organizational business process.

2.2.11 Commitment-based approaches

Cloutier et al. (2001) propose a coordination mechanism in which deliberative agents have the ability to commit to do certain task, and to plan their own activities in order to meet these commitments. The commitment is the basic principle of coordination, because agents will adapt their behavior, and therefore their operations plans, to the situation in order to fulfill them.

This type of approaches is rather complex to implement because it requires to jointly use artificial intelligence planning technique (i.e., to plan the actions of the agents) and an advanced operations planning and scheduling algorithm (i.e., to create tentative operations plans). However, this type of approach holds the potential to create highly adaptive supply chain coordination techniques, while providing implementation tools for almost any kinds of coordination search mechanism. Therefore, they do not propose a specific planning coordination mechanism, but rather a general context of coordination within which one must develop a specific coordination mechanism.

2.2.12 Argument-based approaches

Argument-based agent (Brito et al. 2001, Chow et al. 2008, Darooei and Khayyambashi 2009, Hsairi et al. 2008, 2006, , Phan et al. 2008, Rahwan et al. 2004) involves the construction and exchange of arguments that agent believes will make their counterpart look more favorably upon their proposal (Jennings et al. 2001).

Although it is not a technique that is widely used in the supply chain context, some researchers are investigating this approach. Furthermore, it is a rather complex coordination approach as it requires the explicitly representation of some kind of goal systems or causal relationship map of local decision problems to allow intelligent agents to understand and react in a constructive manner to arguments.

2.2.13 Multi-behavior approaches

Like the commitment-based approach, multi-behavior agents (Forget et al. 2008, Ospina and Fouqeres 2009, Yang et al. 2009) can plan or select their own course of actions. They can even learn from their own past activities (Chengzhi and Zhaohan 2008, Jaber et al. 2010, Sun et al. 2010). These learning agents (Fox et al. 2000) can progressively discover through machine learning techniques the best course of action in specific situations.

These approaches have attributs that are similar to those of the commitment-based approach. Therefore, they propose general coordination frameworks, which are used to develop and implement specific coordination mechanisms.

2.2.14 Integrative negotiations

Other form of intelligent agents has the ability to coordinate its operations with others through the negotiation of several attributes or the processing of fuzzy information. These approaches use a form of negotiation that involves the iterative adjustment of an initial proposal. In other words, such an integrative negotiation involves the simultaneous negotiation of several attributes of the negotiated proposal.

2.2.15 Price-based planning coordination

In this mechanism (Kaihara 2008) each supplier agent proposes a price for its goods, which he iteratively adjusts according to market conditions.

Such a technique is rather simple to implement as no private information is exchanged. Indeed, supply chain competitors coordinate their operations planning decisions through market reactions. Also, in the particular context of Kaihara (2008), operations planning and the adjustment of the price are not linked methodologically. Therefore operations planning can be carried out by any operations planning tools. However, such an approach can hardly be extended to dyadic relationship, unless the customer is a large distributor and retailer with a large number of stores. Then, such a coordination problem is very well known and even solved to a certain point with the Collaborative Planning, Forecasting and Replenishment business process.

2.2.16 Contract-net and auctions

Contract-net and auction techniques (Ahn and Lee 2004, Ito and Salleh 2000, Jiao et al. 2006, Lau et al. 2006, Lee et al. 2008, Lou et al. 2004, Luh et al. 2003, Maturana and Norrie 1997, Neubert et al. 2004, Osman and Demirli 2010, Qinghe et al. 2001, Sun and Wu 2009, Tian et al. 2006, Calosso et al. 2003, Chen et al. 2005, D'Amours et al.1997, Ertogral and Wu 2000, Fan et al. 2003, Kutanoglu and Wu 1999, Lee and Kumara 2007, Zhang and Luo 2009, Zhou and Liu 2007) involve a process where a company sends a call-for-proposal to several potential suppliers, or on a blackboard, and receives bids from them. The coordination of operations planning involves the selection of matching sub-proposal from a set of bids sent by potential suppliers.

The use of auctions for the coordination of operations planning in supply chains involves the definition of some form of evaluation function. In addition, these approaches are based on a trustworthy coordination mechanism to share the information and in return to guarantee the right benefits to all the agents.

2.3 Research opportunities

From the above critical literature review a number of conclusions can be drawn which can be used as the starting point of this present research:

First, this review shows that a large part of techniques are based on exchange of strategic information which can be considered as a negative point for these approaches.

Second, most of the methods do not aim at finding an optimal coordination solution. So there is a lack of operations planning coordination approaches that are able to find (near) optimal solution at each planning cycle and within specified revenue and profit sharing regulations.

Third, the reviewed approaches are mostly in static environment and there is a gap of experimentation of proposed approaches in dynamic context.

Forth, nearly any proposed coordination approach is endued with a fair mechanism of revenue sharing.

In order to fill these gaps and answer to some critical points of the reviewed literature, following research opportunities and research questions are proposed and answered throughout of this research:

First, there is a research opportunity which invests in operations planning coordination of two interdependent manufacturing companies, without and any exchange of strategic information while improving the performance of both partners compared to upstream planning;

Second, it is recommended to endue any approach of operations planning coordination with the revenue sharing mechanism that guaranty a fair sharing of their improved revenues;

Finally, it is proposed to apply the proposed approach in a dynamic environment which includes the continuous updating of demand forecasts, customer orders, and resources status from one planning cycle to the next.

2.4 Contributions

In order to answer the negative points of actual researches and to address the three specific objectives of this research problem, this thesis proposes three contributions in the form of three journal papers.

2.4.1 Contribution 1

The first paper is a thorough review and analysis of the literature related to the proposed research problem. This contribution first describes and discusses the research problem. An analysis of the literature based on a formal three-dimensional framework of analysis, and a classification of the methodological tools used to address this problem are presented. This contribution also justifies the need to develop a new coordination approaches which possess certain characteristics, as proposed in this thesis. This paper has been submitted to the International Journal of Business Performance and Supply Chain Modeling in November 2011.

2.4.2 Contribution 2

The second paper proposes a general approach of coordination of the Multi-Level Capacitated Lot-Sizing Problem (MLCLSP) of two manufacturing enterprises (e.g., a manufacturer and its supplier). This approach includes: (1) different planning problems models; (2) a general information exchange protocol; (3) a financial incentive mechanism; as well as (4) a sub-model of the coordination space, which only represents part of the total solution space. This contribution also presents the results of quantitative experiments that demonstrate the potential of this general coordination approach. This paper has been accepted in November 2011 for publication in the International Journal of Computer Integrated Manufacturing (Submitted in October 2010).

2.4.3 Contribution 3

The third paper builds of the general coordination approach proposed in the second paper and proposes: (1) an efficient negotiation strategy that allows the supplier to focus the search for a coordination solution in a small part of the coordination space; (2) an implementation of this negotiation strategy within the proposed general coordination approach in a dynamic rolling planning horizon; and (3) two revenue sharing protocols that are used to adapt the general financial incentive proposed in the second contribution to a dynamic rolling planning horizon context. This paper has been submitted to the International Journal of Production Research in November 2011.

CHAPTER 3 : ARTICLE 1: COORDINATION OF OPERATIONS PLANNING IN SUPPLY CHAINS: A REVIEW

Supply chains are networks of loosely coupled business units characterized by distinct, yet mutually interdependent, planning decision domains. The main question that arises in the management of these networks is the coordination of supply chain members' operations with minimum exchange of information. In practice, supply chain operations are generally coordinated and planned hierarchically, through the central and aggregated control of a corporate planning unit, which requires a high degree of information exchanges, or through the relatively inefficient upstream planning approach, in which operations are planned and the derived dependent demand is sent to suppliers. High degree of information exchanges lead to difficulties when independent members do not want to share information, such as cost, profit margin, inventory level or capacity utilization. In order to address these difficulties, decentralized approaches of coordination of operations planning decisions based on some minimal information sharing have been proposed in many academic disciplines. This paper first proposes a systematic review of these approaches, and then outlines some research opportunities.

Keywords: planning coordination*;* supply chain; distributed planning; multi-agents; operations research, operations planning.

3.1 Introduction

Supply chains are networks of organizations that create and deliver value in the form of products or services to the final consumer through upstream and downstream linkages (Christopher 1998). In fact, this definition also includes the internal networks of business units of integrated companies (Halal 1994, de Kok and Fransoo 2004). Therefore, supply chains are characterized by distinct, yet mutually interdependent decision domains with independent business objectives (Simchi-Levi et al. 2000), as well as by an asymmetrical distribution of information. In this context, the lack of decisional, organizational and informational integration leads to inefficiencies related to poor coordination of production and distribution decisions, such as the bullwhip effect (Lee et al. 1997), which result in missed opportunities, delays, inefficient inventory decisions, poor capacity allocation and misuse of resources, all leading to increased cost. In order to improve supply chain coordination, companies have developed collaborative practices across different functions of the supply chain (Simatupang and Sridharan 2002), and academics from several disciplines have proposed a number of coordination methods. This paper analyses the literature on the coordination of operations planning decisions in supply chains. In other words, this paper focuses on the coordination methods that enable supply chain partners to coordination their operations plans. A classification framework of the different methodological tools used in the literature is proposed and analyzed in order to propose future research opportunities.

The remainder of the paper is organized as follows. After a general introduction, section 2 presents and analyzes previous supply chain coordination literature reviews. Section 3 outlines the research methodology used in this review. Sections 4 to 6 analyze the selected contributions and propose a technological classification framework of the literature. Finally, section 7 concludes and proposes some research perceptive.

3.2 Problem definition and previous literature review

De Kok and Fransoo (2004) define the objective of the *Supply Chain Operations Planning* (SCOP) problem as being the “[coordination of] the release of materials and resources in the supply network under consideration such that customer service constraints are met at minimal cost.” In this specific definition, the authors consider explicitly the release of materials and resources as constraints that must be dealt with simultaneously. In the review proposed in this paper, the problem that is specifically investigated focuses on methods that address the coordination of the operations planning function of supply chain partners. In other words, we are only concerned by the supply chain coordination problem in which several operations planning entities (e.g., companies or facilities) must, on the one hand create plans of production or logistic operations, and, on the other hand, coordinate their planning decisions with others. This involves making decisions such as what, how much and when to produce and deliver, and to whom. Therefore, the literature on multi-echelon inventory management is evacuated from this review. However, this problem includes various settings of supply chains, including relationships between a manufacturer and a logistic service provider. In other words, this problem consists in synchronizing the supply chain partners’ usage of their resources in order to avoid shortage and make sure materials, components and final products flow continuously whenever needed by downstream partners at minimal cost and subject to information asymmetry.

This specific coordination problem also includes supply chain contexts where partners are dynamically assembled to meet specific short terms business needs. For instance, in the context of virtual supply chains (i.e., supply chains assembled temporarily on-demand), managing the release of materials and planning the use of resources also involves making decisions about suppliers selection.

An important feature of this general coordination problem is its distributed nature. Decision rights in supply chains are distributed among independent companies with different operations management challenges that are directly related to the very nature of their core business and processes. Companies can make any decision and follow any decision process they want. Consequently, the most challenging aspect of this problem is to provide coordination systems and tools that respect this distributed nature as well as the specificities of the supply chain under consideration. The various contexts of supply chains and the multidisciplinary nature of this research domain have led the academic community to propose many approaches, methods and tools to cope with the coordination of supply chains operations planning.

In order to contextualize this analysis of the literature in relation to other review, we first introduce some relevant review frameworks presented in the selected literature (Albrecht 2010, stadtler 2009 and Bhatnagar et al. 1993).

First, Bhatnagar et al. (1992) proposes a classification based on a two-level coordination of supply chains. The first level is inter-function coordination, known as general coordination which is classified into three classes of coordination problems, including, supply and production planning, distribution and production planning and inventory and distribution planning. The second level is multi-plant coordination of the same function. The authors believe that, for multi-plant coordination, any coordination problem should deal with three important issues: demand nervousness, lot sizing, and provision for safety stock.

Along the same line, Stadtler (2009) proposes a more specific classification of the literature on collaborative planning, based on a review of 10 research articles. This classification is based of three distinct dimensions. The first dimension is the structures of the supply chains, which includes three elements: number of tiers, number of member in each tier, and business function of each member. The second dimension concerns the decision context of each member including: decision models, objectives, information status, and phases of collaboration. The last dimension represents the collaboration planning schemes, which includes the incorporation of a mediator, the nature of the initial solution, the number of rounds and stopping criteria, and the final results.

Finally, Albrecht (2010) proposes a classification scheme of supply chain master planning coordination mechanisms based on information accessibility status. On the one hand, some mechanisms are based on symmetric information and require that at least one party has access to information needed to solve a centralized planning model. On the other hand, other mechanisms are based on private information, which can either take the form of one-side information asymmetry, which deals with selection of partners, or multilateral information asymmetry, which includes auctions and their extensions.

These three classifications scheme are based on a limited list of references. In addition, these schemes are limited to a few number of coordination mechanisms within the operation research/management science literature and generally ignore coordination approaches from other academic disciplines, especially agent-based technology which is rather overlooked. Therefore, there is a need for a more inclusive framework.

3.3 Methodology of research

In this research, we focus on the supply chain management literature dedicated to the coordination of operations planning in supply chain with an emphasis on decentralized coordination approaches, which, in other words, deal with the development of distributed methods of coordination of operations planning decisions in multi-commodity supply chains. We first analyse selected contributions of the literature using a systematic analysis based on several dimensions. Next, using this analysis, we propose a classification scheme of these coordination approaches based on their underlying methodological tools. In other words, we propose a classification that emphasizes the methods, rather than the decision models' characteristics or the supply chain contexts. This allows us to analyse upfront the multidisciplinary nature of this domain of research. This section outlines both the methodology used to identify and select contributions from the literature, and the systematic framework of analysis.

3.3.1 Identification of contributions

In order to identify relevant contributions, several queries were used with the Compendex and Web of Knowledge databases. The main terms used in these queries are “coordination approach (mechanism)”, “supply chain”, and “operation(s) planning”. More than 600 contributions were revealed, including journal papers, books and conference papers between 1970 and 2010. Then, from these 600 contributions, we selected almost 105 references by considering different criteria in order to screen out contributions that are not relevant for this review, such as the contributions dealing with centralized coordination of supply chains or with inventory management, or more, generally, contributions that do not propose distributed methods of supply chain operations planning coordination (i.e., methods which outcome is not a distributed approach of coordinating the operations planning of supply chain partners).

More than 90% of these contributions are drawn in the last two decades. 58% of these references have been published between 2006 and 2010. 29% have been published between 2001 and 2005, and 10% have been published between 1996 and 2000. Finally, less than 3 % of these references have been published between 1975 and 1995.

3.3.2 Framework of analysis

Next, in order to investigate the specific structural and behavioural dimensions of the reviewed distributed coordination approaches identified in the literature, this analysis focuses on three main criteria, which emphasizes the characteristics of the coordination and the local operations planning methods:

- Supply chain environment;
- Local planning characteristics;
- Coordination characteristics.

The first criterion specifies the structure of relationship in supply chains, while the two others specify the characteristics of each planning coordination approach. Each of these criterions is further sub-divided into several dimensions, as presented below.

3.3.2.1 **Supply chain environment**

The supply chain environment includes three dimensions that are used to put into context the selected contributions, as it affects the complexity of the planning coordination problem. However, we did not adopt an in-depth analysis of the supply chain structure, such as Stadtler (2009), because the emphasis is rather put on the process of coordination and how it affects local operations planning. Therefore, this framework includes three dimensions that condition the nature of the planning context.

Number of supply chain partners: the simplest setup involves *two members* to coordinate, vs. supply chains with *more than two partners and echelon*;

Degree of certainty: two levels of certainty are used. *Deterministic* environment, in which all parameters are known and fixed; and *stochastic* environment, in which the problem of coordination includes uncertain and random parameters;

Dynamism: two levels of dynamic are used. The supply chain planning coordination is studied in a *dynamic* setting, such as in a rolling horizon, which includes several planning cycle (i.e., not just multi-period), or *static* environment, such as within a single planning cycle. Concerning this criterion, some approaches are referred to as dynamic, because they involve distributed iterative or concurrent processes of coordination. However, their outcome is a set of coordinated planning decisions for a single planning cycle. These approaches are therefore classified as static.

3.3.2.2 **Local planning**

The role of a coordination process is to create some form of integration of local planning decision processes. Therefore, it is essential to acknowledge the relationship between the coordination process and how partners make their decisions. Designing a local decision process that is tied to other local decision processes through a coordination process generally requires a clear understanding of the latter. Indeed, the coordination process defines in general terms the functions that must be performed by local decision processes in order to support the collective exploration of the coordination space, which can be defines as the set of all possible coordination solutions (i.e., vectors of operations plans of all considered supply chain partners) that satisfy all constraints. In our analysis, we discriminate between three elements of each local planning process:

Structure between local planning processes: two types of structure are used, *week hierarchical in which at least one partner has the power to impose his plan to other partners*, and *heterarchical* structure in which all partners have the same level of power to determine their plans;

Nature of local planning process: Two types of local planning process can be distinguished, the local planning process that use *exact* approaches or *heuristic* approaches.

Level of adaptability of local planning process: In the domain of multi agents systems, the concept of planning is related to the agents' ability to plan their own course of actions to pursue their goal. This concept is different from the planning of manufacturing and logistics operations, which is one of the many actions an agent can carry out beside learning and communicating with other agents. Therefore, in this analysis, four types of adaptability of local planning agents are considered, *multi-behavior*, when the agent has the ability to choose from a set of behaviors; *goal-driven*, when the agent decides its own course of actions; *multi-attribute*, when the agent can consider several criteria for making decision; and *learning capability*, when the agent can learn from past decisions and their consequences in order to improve their future decisions.

3.3.2.3 **Coordination scheme**

The coordination process is the main element of a supply chain planning coordination system. The design of a coordination process must explicitly consider the dependencies between two or more local decision problems. Each planning coordination approach can be distinguished by two important criteria:

Types of coordination: One can discriminate four types of coordination: *exact*, which aims to find the best coordination solution according to some objective function; *advanced search*, which provide a near optimal coordination solution; *heuristic*, which aims to find good solution; or simply by exchange of information as *greedy/one-way information exchange*;

Coordination issues: This criterion distinguishes between two main issues of supply chain coordination introduced previously, which involves the *synchronization of operations plans* of two or more partners, or the temporary *selection of supply partners*.

3.4 Analysis and discussion

Using this framework of analysis, each reference was analyzed according to these three dimensions. The results of this analysis are reported in Table 1 to 3. This Section analyses each dimensions individually.

3.4.1 Supply chain environment

Concerning the supply chain, the most common supply chain environment studied concerns more than two supply chain partners in a deterministic and static environment, which represent near 80% of the studied contexts. Stochastic environment accounts for 17% of the studied literature, and less than 20% of the coordination methods reported study dyadic environment (2 partners). Finally, less than 23% of the methods are developed in dynamic environment, in which time advances and change the state of the supply chain environment.

Table 3-1: Literature divisions based on supply chain environment criteria.

year	Authors	Supply chain environment		
		Numbers of SC partners (2, >2)	Stochastic (S)/ Deterministic (D)	Dynamic (D)/ Static (S)
1975	*Hax and Meal*	>2	D	S
1978	*Laub and Bailey*	>2	D	D
1985	*Wagner and Whitin*	2	D	S
1997	*D'Amours et al.*	>2	D	S
	Maturana and Norrie	>2	D	S
1998	*Ozdamar et al.*	>2	D	S
	Swaminathan et al.	>2	D&S	S&D
1999	*Barbarosoglu and Özgür*	2	D	S
	Kutanoglu and Wu	>2	D	S
	Schneeweiss	2	D	S
2000	*Barbarosoglu*	2	S	D
	Ertogral and Wu	>2	D	S
	Fox et al.	>2	D	S
	Ito and Salleh	>2	D	S
2001	*Brito et al.*	>2	D	D
	Cloutier et al.	>2	D	D
	Dodd and Kumara	>2	D	S

Table 3-1: Literature divisions based on supply chain environment criteria (continued).

	Gaonkar and Viswanadham	>2	D	S
	Jayaraman and Pirkul	>2	D	S
	Qinghe et al.	>2	S	D
	Simpson and Erenguc	>2	D	D
	Yu et al.	2	D	S
2002	*Jeong and Leon*	>2	D	S
	Verdicchio and Colombetti	>2	D	D
2003	*Calosso et al.*	>2	D	D
	Fan et al.	>2	D	S
	Jeong and Leon	>2	S	S
	Luh et al.	>2	D	S
2004	*Ahn and Lee*	>2	D	S
	Lee	2	D	S
	Lou et al.	>2	D	D
	Neubert et al.	>2	D	S
	Poundarikapuram and Veeramani	>2	S	S
	Rahwan et al.	>2	D	D
	Schneeweiss and Zimmer	2	S	S
2005	*Azevedo et al.*	2	D	D
	Chen et al.	>2	S	S
	de Dok et al.	>2	D	S
	Dudek and Stadtler	2	D	S
	Jung and Jeong	2	D	S
	Mansouri	2	D	S
	Nishi et al. (a)	>2	D	S
	Nishi et al. (b)	>2	D	D
	Tah	2	D	D
2006	*Hsairi et al.*	>2	D	S
	Jiao et al.	>2	S	S
	Lau et al.	>2	D	D
	Mansouri	>2	S	D
	Omar et al.	>2	D	S
	Silva et al.	>2	S	S
	Tian et al.	>2	D	D
	Zhang et al.	>2	S	D
2007	*Chen et al.*	2	D	S

Table 3-1: Literature divisions based on supply chain environment criteria (continued).

	Frayret et al.	2	D	S
	Jain et al.	2	D	D
	Lee and Kumara	>2	S	S
	Monteiro et al.	>2	D	S
	Moyaux et al.	>2	D	S
	Pibernik and Sucky	>2	D	S
	Uster et al.	>2	D	S
	Xiao et al.	2	D	S
	Zhou and Liu	>2	S	S
2008	*Blackhurst and Craighead*	>2	D	S
	Buakaew and Masuchun	>2	D	S
	Chen et al.	>2	D	S
	Cheng et al.	>2	D	S
	Chengzhi and Zhaohan	>2	S	S
	Chow et al.	>2	D	S
	Drzymalski and Odrey	>2	D	S
	Forget et al.	>2	S	S
	Ghirardi et al.	>2	D	S
	Hsairi et al.	>2	D	S
	Huang et al.	>2	D	S
	Jung et al.(a)	2	D	S
	Jung et al.(b)	2	D	S
	Kaihara	>2	D	S
	Karakitsiu and Migdalas	>2	D	S
	Lee et al.	>2	D	D
	Phan et al.	>2	S	S
	Sung and Yang	>2	D	S
	Tang et al.	>2	D	S
	Váncza et al.	2	S	D
	Wang et al.	>2	S	D
2009	*Bao and Xiao*	>2	D	S
	Darooei and Khayyambashi	>2	D	S
	Dayou et al.	>2	D	S
	Dotoli et al.	>2	D	S
	Gaudrealt et al.	>2	D	S
	Holmgren et al.	>2	D	S
	Jain et al.	>2	D	D

Table 3-1: Literature divisions based on supply chain environment criteria (end).

	Masuchum and Petchmaneelumka	>2	D	S
	Ospina and Fouqeres	>2	D	S
	Sun and Wu	>2	D	S
	Yang et al.	>2	D	S
	Zhang and Luo	>2	D	S
	Zhang et al.	2	D	S
2010	*Homberger*	>2	D	S
	Jaber et al.	>2	D	S
	Kim and Cho	>2	D	S
	Osman and Demirli	>2	D	S
	Sun et al.	>2	D	S
	Taghipour and Frayret	2	D	S
	Wu et al.	>2	D	S
	Yahong	>2	D	S
	Yanling et al.	>2	D	S

3.4.2 Local planning

Local planning characteristics describe the type of local decision support used in the coordination process. A little less than 60% of all the methods in the reviewed literature propose exact local planning tools. Almost 45% of the methods consider heterarchical relationship between the partners of supply chains. Finally 15% of proposed literature uses some forms of adaptability, which is more used in agent-based models.

Table 3-2: Exemple de tableau Literature divisions based on local planning characteristics.

Year	**Authors**	**Local planning characteristics**		
		Structure : Weak Hierarchical (WH), Heterarchical (Ht)	**Type : Exact (E), Heuristic (H)**	**Adaptability: Adaptable (A), Non-Adaptable (NA)**
1975	*Hax and Meal*	WH	E	NA
1978	*Laub and Bailey*	Ht	E	NA
1985	*Wagner and Whitin*	WH	E	NA
1997	*D'Amours et al.*	Ht	E	NA
	Maturana and Norrie	WH	H	NA
1998	*Ozdamar et al.*	WH	E	NA

Table 3-2: Exemple de tableau Literature divisions based on local planning characteristics (continued).

	Swaminathan et al.	Ht	H	NA
1999	*Barbarosoglu and Özgür*	WH	E	NA
	Kutanoglu and Wu	WH	E	NA
	Schneeweiss	WH	E	NA
2000	*Barbarosoglu*	WH	E	NA
	Ertogral and Wu	WH	E	NA
	Fox et al.	Ht	E	A
	Ito and Salleh	WH	E	NA
2001	*Brito et al.*	WH	H	A
	Cloutier et al.	WH	H	A
	Dodd and Kumara	WH	E	NA
	Gaonkar and Viswanadham	WH	E	NA
	Jayaraman and Pirkul	WH	E	NA
	Qinghe et al.	WH	E	NA
	Simpson and Erenguc	WH	E	NA
	Yu et al.	WH	E	NA
2002	*Jeong and Leon*	WH	E	NA
	Verdicchio and Colombetti	WH	H	NA
2003	*Calosso et al.*	WH	H	NA
	Fan et al.	Ht	E	NA
	Jeong and Leon	WH	E	NA
	Luh et al.	WH	E	NA
2004	*Ahn and Lee*	Ht	E	NA
	Lee	WH	E	NA
	Lou et al.	Ht	H	NA
	Neubert et al.	Ht	H	A
	Poundarikapuram and Veeramani	WH	E	NA
	Rahwan et al.	Ht	H	A
	Schneeweiss and Zimmer	WH	E	NA
2005	*Azevedo et al.*	WH	H	NA
	Chen et al.	WH	E	NA
	de Dok et al.	WH	E	NA

Table 3-2: Exemple de tableau Literature divisions based on local planning characteristics (continued).

	Dudek and Stadtler	WH	E	NA
	Jung and Jeong	Ht	E	NA
	Mansouri	WH	H	NA
	Nishi et al. (a)	WH	E	NA
	Nishi et al. (b)	WH	E	NA
	Tah	WH	H	NA
2006	*Hsairi et al.*	Ht	H	NA
	Jiao et al.	Ht	H	NA
	Lau et al.	Ht	E	NA
	Mansouri	Ht	H	NA
	Omar et al.	WH	E	NA
	Silva et al.	Ht	H	NA
	Tian et al.	Ht	H	NA
	Zhang et al.	Ht	H	NA
2007	*Chen et al.*	WH	E	NA
	Frayret et al.	WH	H	NA
	Jain et al.	Ht	H	NA
	Lee and Kumara	WH	E	NA
	Monteiro et al.	Ht	H	NA
	Moyaux et al.	WH	E	NA
	Pibernik and Sucky	WH	E	NA
	Uster et al.	WH	E	NA
	Xiao et al.	WH	E	NA
	Zhou and Liu	WH	E	NA
2008	*Blackhurst and Craighead*	WH	E	NA
	Buakaew and Masuchun	WH	E	NA
	Chen et al.	Ht	H	NA
	Cheng et al.	WH	E	NA
	Chengzhi and Zhaohan	Ht	H	A
	Chow et al.	Ht	H	A
	Drzymalski and Odrey	WH	H	NA
	Forget et al.	Ht	H	A
	Ghirardi et al.	WH	E	NA

Table 3-2: Exemple de tableau Literature divisions based on local planning characteristics (end).

	Hsairi et al.	Ht	H	A
	Huang et al.	Ht	H	NA
	Jung et al.(a)	WH	E	NA
	Jung et al.(b)	Ht	E	NA
	Kaihara	Ht	H	A
	Karakitsiu and Migdalas	WH	E	NA
	Lee et al.	Ht	H	NA
	Phan et al.	Ht	H	A
	Sung and Yang	WH	E	NA
	Tang et al.	Ht	H	NA
	Váncza et al.	Ht	E	NA
	Wang et al.	WH	H	NA
2009	*Bao and Xiao*	Ht	H	NA
	Darooei and Khayyambashi	Ht	H	A
	Dayou et al.	Ht	E	NA
	Dotoli et al.	Ht	H	NA
	Gaudrealt et al.	Ht	E	NA
	Holmgren et al.	Ht	E	NA
	Jain et al.	WH	H	A
	Masuchum and Petchmaneelumka	WH	E	NA
	Ospina and Fouqeres	WH	H	A
	Sun and Wu	WH	H	NA
	Yang et al.	Ht	H	NA
	Zhang and Luo	WH	H	NA
	Zhang et al.	Ht	H	NA
2010	*Homberger*	Ht	E	NA
	Jaber et al.	Ht	E	A
	Kim and Cho	Ht	E	NA
	Osman and Demirli	Ht	E	NA
	Sun et al.	Ht	E	A
	Taghipour and Frayret	Ht	E	NA
	Wu et al.	Ht	H	NA
	Yahong	WH	H	NA
	Yanling et al.	Ht	E	NA

3.4.3 Coordination scheme

The coordination scheme presents the general characteristics of the coordination process between supply chain partners. As mentioned previously, the nature of the coordination problem, the extent to which the coordination space is search to find an optimal solution, as well as the formalization of the coordination process within agents are described in Table 3. First, more than 63% of the proposed approaches involves simple search within the coordination space through simple heuristics or information exchanged. Second, 22% of methods address the problem of supply chain partner selection, while the other methods address the synchronization between partners.

Table 3-3: Literature divisions based on coordination characteristics.

Year	**Authors**	**Coordination characteristics**	
		Type of coordination : Exact (E), Comprehensive Search (CS), Heuristic (H), Greedy/one-way information exchange (G)	**Coordination Issue : Synchronization (S), Partners selection (PS)**
1975	*Hax and Meal*	G	S
1978	*Laub and Bailey*	H	S
1985	*Wagner and Whitin*	G	S
1997	*D'Amours et al.*	G	PS
	Maturana and Norrie	G	PS
	Ozdamar et al.	G	S
	Swaminathan et al.	H	S
1999	*Barbarosoglu and Özgür*	E	S
	Kutanoglu and Wu	G	PS
	Schneeweiss	G	S
2000	*Barbarosoglu*	H	S
	Ertogral and Wu	E	S
	Fox et al.	H	S
	Ito and Salleh	H	PS
2001	*Brito et al.*	H	S
	Cloutier et al.	H	S
	Dodd and Kumara	H	S

Table 3-3: Literature divisions based on coordination characteristics (continued).

	Gaonkar and Viswanadham	G	S
	Jayaraman and Pirkul	E	S
	Qinghe et al.	H	PS
	Simpson and Erenguc	G	S
	Yu et al.	G	S
2002	*Jeong and Leon*	E	S
	Verdicchio and Colombetti	H	S
2003	*Calosso et al.*	H	PS
	Fan et al.	H	PS
	Jeong and Leon	E	S
	Luh et al.	E	PS
2004	*Ahn and Lee*	H	PS
	Lee	G	S
	Lou et al.	H	PS
	Neubert et al.	H	PS
	Poundarikapuram and Veeramani	E	S
	Rahwan et al.	H	S
	Schneeweiss and Zimmer	G	S
2005	*Azevedo et al.*	H	S
	Chen et al.	E	PS
	de Dok et al.	H	S
	Dudek and Stadtler	G	S
	Jung and Jeong	H	S
	Mansouri	H	S
	Nishi et al. (a)	E	S
	Nishi et al. (b)	E	S
	Tah	H	S
2006	*Hsairi et al.*	H	S
	Jiao et al.	H	PS
	Lau et al.	H	PS
	Mansouri	H	S
	Omar et al.	G	S
	Silva et al.	H	S
	Tian et al.	H	PS
	Zhang et al.	H	PS

Table 3-3: Literature divisions based on coordination characteristics (continued).

2007	*Chen et al.*	H	S
	Frayret et al.	G	S
	Jain et al.	H	S
	Lee and Kumara	H	PS
	Monteiro et al.	H	S
	Moyaux et al.	G	S
	Pibernik and Sucky	G	S
	Uster et al.	E	S
	Xiao et al.	E	S
	Zhou and Liu	H	PS
2008	*Blackhurst and Craighead*	H	S
	Buakaew and Masuchun	G	S
	Chen et al.	H	S
	Cheng et al.	E	S
	Chengzhi and Zhaohan	H	S
	Chow et al.	H	S
	Drzymalski and Odrey	H	S
	Forget et al.	H	S
	Ghirardi et al.	E	S
	Hsairi et al.	H	S
	Huang et al.	H	S
	Jung et al.(a)	H	S
	Jung et al.(b)	H	S
	Kaihara	H	S
	Karakitsiu and Migdalas	E	S
	Lee et al.	H	PS
	Phan et al.	H	S
	Sung and Yang	E	S
	Tang et al.	H	S
	Váncza et al.	G	S
	Wang et al.	H	S
2009	*Bao and Xiao*	H	S
	Darooei and Khayyambashi	H	S
	Dayou et al.	H	S
	Dotoli et al.	H	S
	Gaudrealt et al.	CS	S

Table 3-3: Literature divisions based on coordination characteristics (end).

	Holmgren et al.	CS	S
	Jain et al.	H	S
	Masuchum and Petchmaneelumka	G	S
	Ospina and Fouqeres	H	S
	Sun and Wu	H	PS
	Yang et al.	H	S
	Zhang and Luo	H	PS
	Zhang et al.	H	S
2010	*Homberger*	H	S
	Jaber et al.	H	S
	Kim and Cho	H	S
	Osman and Demirli	H	PS
	Sun et al.	H	S
	Taghipour and Frayret	H	S
	Wu et al.	H	S
	Yahong	H	PS
	Yanling et al.	H	S

3.4.4 Discussion

Concerning the characteristics of the coordination methods proposed in the literature, this analysis highlights the fact that most approaches are based on heuristic mechanisms of exploration of the coordination space. In other words, most methods do not aim at finding an optimal coordination solution. This lack of formal exact methods may reflect the difficulties that arise from the intensity of information exchange needed to support exact coordination, which is an issue, not only in multi-enterprise supply chains but also in integrated corporate supply chains with limited communication bandwidth. However, although the notion itself of optimality is a rather delicate issue in such a context, especially with respect to revenue and profit sharing, this lack of exact methods remains an opportunity to develop further near optimal exploration of the coordination space.

Similarly, the development of adaptive tools of coordination is also in its infancy. The main difference with exact methods is that the focus of the coordination process is put on some form of intelligent and adaptive planning of coordination actions (i.e., what should a partner do to coordinate his operations plans with his supply chain partners), instead of a systematic, yet reactive, search within the coordination space. Because adaptive forms of coordination propose some kind of adaptive heuristic to search for a coordination solution, and are therefore not exact methods, they require less information exchange than both exact and purely heuristic approaches. They seem consequently more applicable to the industry from that perspective.

Therefore, because there is rather large variety of methodological tools from multiple disciplines used to develop supply chain operations planning coordination approaches, which have also never been classified in previous reviews of the literature, the next section proposes a classification of these approaches based on their methodological principles.

3.5 Classification of supply chain operations planning coordination methods

This analysis of the literature highlights the multi-disciplinary nature of this field of research. These contributions to supply chain operations planning coordination build their coordination methods on many different techniques, including, operations research, meta-heuristics, intelligent agent, and market mechanisms. Some of these methods are used in a static and deterministic context, within a single planning cycle, while others address more complex contexts, in which time advances from a planning cycle to the next, or where the environment is stochastic. Therefore, because the problem on hand is limited to the specific problem of operations planning coordination, this section proposes a classification of these different methods, according to their underlying methodological tools and techniques. This classification scheme includes five main classes of general techniques and different sub-classes of operations planning coordination methods, which include the following:

- Exact decomposition and constraint-based techniques
- Hierarchical planning and information sharing techniques
- Bidding-based techniques
- Intelligent and adaptive techniques
- Heuristic search techniques

The next sub-section introduces each of these classes.

3.5.1 Exact decomposition and constraint-based techniques

16 of the selected approaches exploit some form of mathematical decomposition methods to decompose a large supply chain planning problem into several sub-problems that are solved in a distributed manner. In brief, these methods propose mechanisms according to which decisions integration and coordination is carried out with the use of a rigorous mathematical technique that solves to optimality, or near optimality, the coordination problem in a distributed manner. The main characteristics of these approaches are the use of exact local planning process as well as exact coordination process. These techniques include *Lagrange decomposition*, *Bender's decomposition*, *Dantzig-Wolfe decomposition*. A recently proposed method is also added to this group of techniques as it proposes a comprehensive search of the coordination space. It is referred to as *distributed search with constraint propagation*.

3.5.1.1 **Lagrange decomposition**

The main decomposition approach used in the literature of supply chain planning coordination, with 10 contributions, is Lagrange decomposition (Barbarosoglu and Özgür 1999, , Ertogral and Wu 2000, Ghirardi et al. 2008, Jayaraman and Pirkul 2001, Jeong and Leon 2002 & 2003, Karakitsiu and Migdalas 2008, Xiao et al. 2007, Nishi et al. 2005a, Nishi et al. 2005b). This approach exploits the block-separability property of such a problem. Its principle is to first develop a central block-separable supply chain planning model using mathematical programming, then relax the binding constraints of the natural sub-problems, which are typically the material flow constraints between supply chain partners, by moving these constraints in the objective function (and adding a penalty vector for each constraint). Next, a distributed and synchronous iterative process must be developed to adjust the penalty vectors of these relaxed constraints in order to converge toward a near optimal solution. Lagrange decomposition solves iteratively the sub-problems in order to progressively restore the feasibility and the coherence of the local plans, therefore coordinating them through the adjustment of the penalty vectors. In most approaches, a central master problem is used to calculate and adjust synchronously these penalties according to the current state of the local optimization processes using a sub-gradient optimization technique, which requires the use of a central *mediator* whose function is to gather the tentative plans and adjust the penalty vectors that are sent back to the supply chain partners until the plans are also feasible (i.e., constraints are meet) or until a limited number of iterations is reached. These approaches then need to restore feasibility of the constraints that still remain violated. In order to develop a coordination system that truly respects the distributed nature of supply chain, some authors (Ghirardi et al. 2008, Karakitsiu and Migdalas 2008, Nishi et al. 2005a) propose an asynchronous and decentralized adjustment process of these penalties. In this approach, there is no need of a central mediator to coordinate the supply chain partners operations planning processes.

Although these approaches are rather easy to implement, convergence towards optimality remains an issue to consider. Furthermore, sub-problems must be specifically formulated (in particular the objective function) in order to process adequately the information provided by the mediator. The dependency between the coordination process and the local decision process is thus specific to the decomposition approach.

3.5.1.2 **Benders decomposition**

Bender decomposition is another exact decomposition method, which also exploits the block-separability property of the supply chain problem. It is, used in 2 of the selected contributions (Poundarikapuram and Veeramani 2004, Uster et al. 2007). In this approach, the common variables to several block problems are positioned in the master problem, while the local variables that define the sub-problems are positioned at a second level. The main difference with Lagrange decomposition is that feasibility and optimality are iteratively addressed by adding feasibility constraints and optimality cuts to the master problem. In other words, the master problem is used to propose global solutions and each supply chain partner; using tis own sub-problem, analyses these solutions. If a sub-problem is infeasible, its dual cost is infinite and a positive cost ray is identified. Therefore, the sub-problem generates and adds a feasibility constraint to the master problem. If a sub-problem has an optimal solution of greater cost, than an optimality cut is added to the master problem. If not, the current solution is fathomed. In both cases, the master problem is solved again with the new added constraints until no new cut can be added.

Although it is a powerful mathematical tool to coordinate the local decision processes, the information exchanged between the sub-problems and the master problem is rather difficult to interpret for an operations manager. It is also rather a marginally exploited approach.

3.5.1.3 **Dantzig-Wolfe decomposition**

Finally, Dantzig-Wolfe decomposition is another exact decomposition method, which is also only used in 3 of the selected contributions (Cheng et al. 2008, Holmgren et al. 2009, Sung and Yang 2008). For instance, Holmgren et al. (2009) applied Dantzig-Wolfe decomposition to a specific instance of the coordination problem of operations planning in supply chain. Based on column generation, this technique consists in reformulating the global problem using the Dantzig-Wolfe mathematical modeling technique. In this formulation, the variables become solution vectors of the problem. Therefore, in order to solve to optimality such a reformulated problem, one must know initially all possible solution vectors, which is unrealistic in practice. Consequently, the problem is decomposed into a *Restricted Master Problem* (RMP), where only a small subset of solution vectors are investigated, and one or many pricing problems (as many as supply chain partners), which generate, according the dual costs of the current solution of the RMP, new interesting solution vectors (i.e., the columns) to be fed back in the RMP. This process is repeated until no new solution vectors can be found, guarantying therefore the optimal solution.

The interesting aspect of this approach is that the pricing problem can be formulated and solved individually for each planning domain of the supply chain. In other words, each supply chain partners can solve their own pricing problem, which includes their local constraints and private information, in order to generate their partial solution vector to the coordination problem. These partial solutions are then gathered and used in the RMP to generate first a feasible global solution, which is equivalent to selecting the subset of partial solution vectors that optimize the current problem, and second identify the dual costs of the optimal current solution to be used by the pricing problems. In Holmgren et al. (2009), the authors use a technique known as branch-and-price, which is similar to this one with the introduction of a branching mechanism in order to deal with the integer variables of the initial problem.

Although Lagrange decomposition has been adapted to this context, these approaches by mathematical decomposition remain largely underutilized or unexplored to solve such a complex planning context in a distributed manner.

3.5.1.4 **Distributed search with constraint propagation**

Another method, proposed by Gaudrealt et al. (2009), models the coordination space of many heterogeneous planning problems of a linear supply chain as a tree, that is systematically searched in order to find a good solution (theoretically the optimal solution if there is no time limit). The modeling principle is a simple extension of the upstream planning approach in which the legacy planning system of each planning domain is capable of producing all possible alternative solutions of any instances of its planning problem (the solution that maximizes its objective function, the second one, the third one, etc). In the distributed and asynchronous search procedure proposed by the authors, agents, that are responsible for a planning domain, must decide whether to produce an alternative solution to a customer demand plan for which they have already found a solution (i.e., an operations plan), or to produce a first solution to a demand plan for which they have not yet produced any solution. In an advanced search procedure presented in Gaudreault et al. (2008), the authors have also investigated the possibility of using learning to improve the agents' ability to identify a more appropriate action to take. In other words, such a procedure provides a means of searching the coordination space in order to find a set of local operations plans that are collectively better in terms of the supply chain performance indicator that is optimized. One of the strengths of this approach is to only require the exchange of minimal information such as demand and supply plans. However, the quantity of information exchanged still remains rather important. This coordination process is also independent from the planning tools that are used to produce agents' local operations plans.

3.5.2 Hierarchical planning and information sharing techniques

Initiated by Hax and Meal (1975), one of the first attempts to address the coordination of operations planning of supply chains involves simplifying complex decision problems into a hierarchy of mutually inter-dependent decision problems. More than 19 references in the selected literature propose to decompose the overall decision problem into a hierarchy problem and sub-problems linked by master/slave relationship. Here, coordination is carried out in a cascade process from long term to short term decisions, or from customer to suppliers. This decomposition leads to simpler and interdependent planning functions. The most significant characteristic of these approaches is the use of greedy/one-way information exchange. Several sub techniques have extended this principle in various ways, which include *greedy coordination*; *information sharing and anticipation model*; and *partial aggregation of decision domains.*

3.5.2.1 **Greedy coordination**

3 contributions (Hax and Meal 1975, Simpson and Erenguc 2001, Wagner and Whitin 1958) use the most simple model-based coordination approach found in practice which consists of a simple, one way exchange of information, referred to as *upstream planning* (Bhatnagar et al. 1993). In *upstream planning* each upstream partner, in order to meet local customer demand, defines its operations plan according to its local objectives and subject to its manufacturing constraints. Then, upstream dependent demands derived from this plan are forwarded to the appropriate downstream suppliers. All suppliers repeat this process asynchronously (i.e., following their own planning cycle) until it reaches the downstream raw material suppliers. The main advantage of this approach is its simplicity, leading to a strict hierarchical dependency between planning domains with minimal exchange of information (i.e., demand plans flowing upstream the supply chain). The main disadvantage of upstream planning is its inability to explore alternative and more interesting coordination arrangements between partners. Computational experiments (Simpson and Erenguc 2001) found that Wagner and Whitin's algorithm (Wagner and Whitin 1958), which has a similar decentralized structure, shows a 14.1% average gap to centralized planning. Similarly, Dudek and Stadtler (2005) found that upstream planning has a variable gap to optimality between 2.9% and 75.6% according to the capacity profile of the partners.

3.5.2.2 **Partial aggregation of decision domains**

4 contributions apply a hybrid (Jayaraman and Ross 2003, Ozdamar et al. 1998, Pibernik and Sucky 2007, Masuchum and Petchmaneelumka 2009) coordination approach between centralized and upstream planning to fill the performance gap of upstream planning. In other words, these approaches propose the partial centralized optimization of sub-networks within the overall supply chain. Therefore, they tend to simplify the structure of the distributed supply chain planning problem by aggregating sub-problem and consequently increasing the complexity of these new fewer sub-problems, which might be possible with business units under the same ownership structure, but not really applicable to supply chain with a heterogeneous ownership structure. For example, Gaonkar and Viswanadham (2001) propose to aggregate part of all sub-problems into a single central planner with who supply chain partners exchange information.

3.5.2.3 **Information sharing and anticipation models**

Finally as the last sub-group of techniques in the hierarchical planning, 12 contributions (Barbarosoglu 2000, Buakaew and Masuchun 2008, de Kok et al. 2005, Frayret et al. 2007, Gaonkar and Viswanad. 2001, Lee 2004, Moyaux et al. 2007, Omar et al. 2006, Schneeweiss 1999, Schneeweiss and Zimm. 2004, Váncza et al. 2008, Yu et al. 2001*)* propose to extend the idea of *upstream planning* using various forms of information exchange. For instance, Váncza et al. (2008) propose a supply chain coordination mechanism in a rolling horizon approach, in which customers send their own forecast demand overtime and use a penalty mechanism that customers must pay for any forecast error. Here, the supplier is committed to deliver whatever is specified in the customer forecasts, but it is protected from any error or opportunistic behavior of the customer.

In the context of natural resource, for which supply capacity is the major driver of operations planning, Frayret et al. (2007) propose a two-phase planning process that allows partners to communicate demand targets in an upstream planning phase and supply capacity constraints in a downstream planning phase in order to improve the result of upstream planning and adapt to the context of a natural resource industry.

Differently, another approach of information sharing exploits the ideas initially proposed by Hax and Meal (1975). In brief, as presented by Stadtler (2005), supply chain planning problems can be modeled as a matrix from long term to short term decisions and from supply, to production, to distribution and to sales planning functions, which exchange decisions and information. The dependencies between these planning functions lead to complex aggregation/disaggregation problems. In this context, Schneeweiss (1999) proposes various modeling concepts to improve upper level decision-making through the anticipation of lower level decision processes. Along this line, Schneeweiss and Zimmer (2004) believe that the upstream member’s anticipated decision parameters can be used to improve the downstream planning decision process. The idea is simple and, in its most complex implementation, requires solving simultaneously the manufacturer and an anticipation of the supplier planning problems in order to send the supplier a demand plan that is more likely to accommodate the real supplier decision problem. Here, there is a trade-off between both decision problems with real exchange of information. Although it leads to a significant improvement over pure upstream planning, the manufacturer must possess an accurate model of its supply chain partner, which is rather unrealistic except for very specific cases.

In the specific context of operations planning coordination in supply chains, *Philips Electronics* is one of the first companies to have implemented an advanced collaborative planning process that directly addresses this problem (de Kok et al. 2005). Their collaborative process involves the operations managers of several production and assembly facilities through weekly virtual meetings where they exchange information, evaluate alternative plans of materials release using a central advanced planning tool, which propose globally optimal aggregate solution, in order to select a plan that is agreed upon by all supply chain members. This process involves a more or less formal distributed exploration of the coordination space where each operations manager can assess the local impact of a global coordination solution and, in turn, communicate constraints or a new partial solution to the coordination problem. This process involves some form of centralized planner which role is to assess the repercussions of any tentative local plan.

All these approaches are more or less advanced forms of information sharing or decision process reengineering. However, they do not provide a systematic search of the coordination space.

3.5.3 Heuristic search techniques

32 references in our selected literature involve more or less advanced forms of iterative information exchange, during which supply chain partners progressively adjust their local initial plan through local search procedures (i.e., small incremental deviations). Such procedures allow the partners to mutually adjust their plans according to the constraints or capabilities of their partners. This form of coordination techniques requires the design of a convergence mechanism in order to guarantee the improvement and the feasibility of the collective plan, as well as termination conditions in order to stop the incremental process of mutual adjustment. The main characteristic of these approaches is the use of heuristic search in the coordination process. Because of the heuristic nature of such coordination, these techniques are termed heuristic search techniques. Three sub-techniques have been identified in the literature: distributed heuristic search with local optimization, meta-heuristic search, and interaction based coordination. Some of these coordination heuristics only deal with the coordination of two supply chain partners (Dudek and Stadtler 2005), while others encompass more partners, or even the entire supply chain (Silva et al. 2006). Furthermore, some of these heuristics methodologically embed their

coordination mechanim with their local decision processes (Silva et al. 2006), while other heuristics propose coordination mechnisms that can support virtually any local decision process.

3.5.3.1 **Distributed heuristic search with local optimization**

This type of approaches, used by 7 of our selected contributions (Dudek and Stadtler 2005, Jung et al. 2008a, Jung and Jeong 2005, Jung et al. 2008b, Kim and Cho 2010, Laub and Bailey 1978, Taghipour and Frayret 2010 & 2011), represent what Stadtler (2009) referrers to as heuristic decomposition, although there is no real problem decomposition, as it is already distributed in nature. Planning domains are modeled separately and not generated by the use of decomposition methods as in the exact decomposition approaches. Furthermore, the coordination mechanism involves the exploration of the coordination space through iterative techniques, sometimes by using economics techniques. Generally, the convergence of the coordination toward a globally efficient solution remains an issue to address. For instance, Dudek and Stadtler (2005), and Taghipour and Frayet (2011), exploit similar forms of distributed neighborhood search of the coordination space where supply deliveries can by advanced or delayed compared to what is demanded by the partners, in order to allow both partners to investigate alternative neighbor solutions that are more interesting from their point of view, yet, not too far from their partners solution. These approaches have the advantage to respect the distributed nature of supply chains, while involving rather simple forms of information exchange. However, they are for the moment limited to the coordination of two partners while the impact of the coordination effort of these partners on third parties is ignored.

3.5.3.2 **Meta-heuristic searches**

Meta-heuristics approaches have also been used in order to provide a coordination framework of supply chain operations planning coordination. 7 of the selected contributions (Chen et al. 2007, Dayou et al. 2009, Homberger 2010, Silva et al. 2006, Mansouri 2006, Mansouri 2005, Yanling et al. 2010) have exploited various meta-heuristics. For instance, Silva et al. (2006) proposes a coordination process based on *Ant Colony Optimization* (ACO) and implemented in a distributed setting. In other word, the authors propose to use ACO to solve each partner’s operations planning problem, generating in the process pheromone matrixes that are iteratively exchange in order to mutually influence its partner’s decision process.

Although these approaches are interesting and innovative, their practicality is rather limited because it forces supply chain partners to adopt specific meta-heuristic-based APS systems. Furthermore, the information exchanged between partners is rather difficult to interpret by operations managers.

3.5.3.3 **Interaction-based planning coordination**

In the context of this review almost 18 references in the selected literature propose some form of interaction-based coordination approaches (Azevedo et al. 2005, Bao and Xiao 2009, Blackhurst and Craighead 2008, Chen et al. 2008, Dodd and Kumara 2001, Dotoli et al. 2009, Drzymalski and Odrey 2008, Huang et al. 2008, Jain et al. 2007, Monteiro et al. 2007, Swaminathan et al. 1998, Tah 2005, Tang et al. 2008, Wang et al. 2008, Wu et al. 2010, Yahong 2010, Zhang et al. 2006, Zhang et al. 2009). These approaches propose explicit representations of the interaction processes, which are used in specific situations between agents (i.e., interaction protocols). Although such explicit representations of interactions can be used by intelligent agents, this sub-class of heuristic coordination techniques only applies to reactive agent-based supply chain systems. Indeed, advanced form of coordination approaches that use deliberative agents are classified in the intelligent and adaptive coordination techniques because the interaction representation is not the implementation of a heuristic, but rather the description of an activity that the intelligent agent could do.

An interaction protocol is generally modeled as finite-state machine graphs (Cloutier et al. 2001), Petri nets (Monteiro et al. 2007), UML interaction diagrams (Wang et al. 2008, Wong and Fang 2010), or Grafcet (Nissen 2001). Such protocols model all possible states and outcomes of a given interaction and define at the same time all possible actions that can be performed by the agents within this interaction, according to their role in the interaction and the actions performed by the other agents. In a given active state of an interaction, agents have a limited set of actions to perform. According to the situation and its internal state, reactive agents use fixed ruled to select this activity. This is why such approach can be considered as a form of heuristic coordination base on the explicit interactions between agents.

Within an interaction, agent adopts specific local decision processes (described in their fixed set of rules) in order to link their ability to interact with one another with the management of their own operations planning. This can be seen as some form of inter-organizational business process integration. Some agents exploit simple heuristic to solve their local planning problem and contribute to the coordination of the operations planning effort. Others use advanced OR-based tools to solve more complex combinatorial problems.

3.5.4 Intelligent and adaptive techniques

Another class of supply chain operations planning coordination relies on intelligent software agents that have the ability to plan their own course of activities in order to achieve some goals or maximize their utility. This class is clearly different from the previous sub-class of interaction-based planning coordination because, here, agents are not limited to a heuristic sequence of activities to perform. These agents are called deliberative agents because they have advanced mechanisms to locally determine what activities to perform. Although they can use explicit description of interaction mechanisms, these agents may, or may not, use them according to the situation, their past experience, as well as some representation of their internal state and goals.

Almost 16 contributions in our selected literature are based on such advanced form of agents capable of coordinating their actions with other agents. More specifically, instead of focusing on the interaction as the main mode of coordination, these approaches of coordination focus on how agents should behave in order to contribute to the coordination problem. The coordination is achieved through some form of adaptive heuristic manner.

3.5.4.1 **Commitment-based approaches**

one contribution (Cloutier et al. 2001) propose a commitment-based coordination approach, in which deliberative agents have the ability to commit to do certain task, and to plan their own activities in order to meet these commitments. A commitment is a set of actions to perform that is agreed upon by two agents (i.e., the committed agent and the beneficiary agent). The commitment is therefore the basic principle of coordination, because agents will adapt their behavior to the situation in order to fulfill them.

3.5.4.2 **Argument-based approaches**

Similarly, argument-based agent (Brito et al. 2001, Chow et al. 2008, Darooei and Khayyambashi 2009, Hsairi et al. 2008, 2006, , Phan et al. 2008, Rahwan et al. 2004) involves the construction and exchange of arguments that agent believes will make their counterpart look more favorably upon their proposal (Jennings et al. 2001). Arguments are information that is added to an offer sent by an agent in order to influence its counterpart. In other words, this aims at identifying or creating new opportunities in the coordination space, or modifies how agents value their counterparts' offers, in order to facilitate the coordination process. Although it is not a technique that is widely used in the supply chain context, some researchers are investigating this approach. For instance, Hsairi et al. (2008) introduce an argument-based negotiation approach for conflict resolution for the extended enterprise. Along the same line, Chow et al. (2008) proposes an argument-based technique in the context of a logistic service provider to dynamically solve conflicts in operations management.

3.5.4.3 **Multi-behavior and learning-based approaches**

Multi-behavior agents are another form of adaptive techniques (Forget et al. 2008, Ospina and Fouqeres 2009, Yang et al. 2009). These agents can plan or select their own course of actions according to, specific goals or specific situation, in order to maximize a utility function or reach a goal.

Advanced for of multi-behavior agent can even learn from their own past activities (Chengzhi and Zhaohan 2008, Jaber et al. 2010, Sun et al. 2010). These learning agents (Fox et al. 2000) can progressively discover through machine learning techniques the best course of action in specific situations. In other words, such agents learn through a decision process which actions maximize their utility in certain situations.

3.5.4.4 **Integrative negotiations**

Other form of intelligent agents has the ability to coordinate its operations with others through the negotiation of several attributes or the processing of fuzzy information. Two contributions use such advanced intelligent agents. These approaches use a form of negotiation that involves the iterative adjustment of an initial proposal. In other words, such an integrative negotiation involves the simultaneous negotiation of several attributes of the negotiated proposal. In general, each attribute is evaluated using different techniques. For instance, Neubert et al. (2004) uses a compensation matrix that describes the relative importance of each attribute in order to manage trade-offs between attributes and generate a fair counter-offer. Fuzzy logic is often utilized to model the importance (i.e., weigh) of each attribute, as well as to evaluate specific offers (Jain et al. 2009). In fact, fuzzy modeling of information is used to enable the agent to make decision with such imprecise information in the context of supply chain.

3.5.4.5 Price-based planning coordination

In our review of literature, one approach is inspired by spot market mechanisms. Kaihara (2008) proposes a mechanism, in which each supplier agent proposes a price for its goods, which he iteratively adjusts according to market conditions. For instance, if a quantity of goods has been purchased on the market, the supplier will increase the price of the goods at the next round of transactions and adjust its operations plans to increase its profit. On the contrary, if no goods have been purchased, then the price of the goods is iteratively decreased until it is sold or taken out of the market. Here, supplier agents also adjust their operations plans in order to take into account the decreased potential revenue due to the unsold goods. Such a technique is rather simple to implement as no private information is exchanged. Indeed, supply chain competitors coordinate their operations planning decisions through market reactions. Also, in the particular context of Kaihara (2008), operations planning and the adjustment of the price are not linked methodologically. Therefore operations planning can be carried out by any operations planning tools.

3.5.5 Bidding-based techniques

Almost 22 references in our selected literature (Ahn and Lee 2004, Ito and Salleh 2000, Jiao et al. 2006, Lau et al. 2006, Lee et al. 2008, Lou et al. 2004, Luh et al. 2003, Maturana and Norrie 1997, Neubert et al. 2004, Osman and Demirli 2010, Qinghe et al. 2001, Sun and Wu 2009, Tian et al. 2006, Calosso et al. 2003, Chen et al. 2005, D'Amours et al.1997, Ertogral and Wu 2000, Fan et al. 2003, Kutanoglu and Wu 1999, Lee and Kumara 2007, Zhang and Luo 2009, Zhou and Liu 2007) exploit one form or another of bidding technique. These approaches are rooted in economics and based on so-called negotiations. Supply chain partner selection is the coordination problem addressed by the use of these techniques. These approaches can also be termed contract-net and auctions.

3.5.5.1 **Contract-net and auctions**

The Contract-Net protocol was initially introduced in Davis and Smith (1983) in order to solve a decentralized task allocation problem. In brief, Contract-net involves a process where a company sends a call-for-proposal to several potential suppliers, or on a blackboard, and receives bids from them. Such bids can either be selected individually against one another, or collectively, in order to assemble an entire virtual supply chain (D'Amours et al. 1997, Tian et al. 2006). Similarly, although bids are generally derived from one single planning alternative (Ahn and Lee 2004, Calosso et al. 2003, Hu et al. 2001), they can also contain several sub-proposals to choose from, each one being derived from different local operations planning alternatives, as proposed in D'Amours et al. (1997). Here, the coordination of operations planning involves the selection of matching sub-proposal from a set of bids sent by potential suppliers. This specific coordination mechanism is typically a hybrid approach as it uses a mathematical programming model to evaluate collectively all sub-proposal. In the Contract-Net approach, the structure of the communication channel is one-to-many.

Along the same line McAfee and McMillan (1987) define an auction is "*a market institution with an explicit set of rules determining resource allocation and prices on the basis of bids from market participants*." The use of auctions for the coordination of operations planning in supply chains involves similarly the definition of some form of evaluation function (i.e., the winner determination problem) that allows a manager to assess the contribution of a bid or an offer to the overall performance of the supply chain. Various types of auction mechanisms have been used from first-price sealed-bid, to combinatorial auctions. For instance, Lee and Kumara (2007) propose a hierarchical (cascade) auction structure to coordinate the allocation of jobs in a distributed manner. In fact, in this approach using a trustworthy coordination mechanism for dynamic lot-sizing, distributed partners are motivated to share their information and in return it guarantees the right benefits to all the agents.

3.5.6 Summary of analysis and research opportunities

The proposed classification scheme is summarized in Table 4. Based on our analysis, the most commonly used techniques are heuristic search techniques with 31% of our literature, followed by bidding-based techniques and hierarchical and information sharing techniques, respectively with 21% and 18% of our approaches. Exact decomposition and constraint-based techniques as the most complex techniques take just 15% of our reviewed mechanisms. At the same level of utilization, intelligent and adaptive techniques are also a rather new technology, for which there are significant research opportunities.

This classification shows that most methodological approaches, whatever there discipline, are based on heuristic techniques which do not propose any optimal solution to a coordination problem, while exact techniques, which leads to the (near) optimal solution, only represent a small portion of the coordination approaches. This lack of exact approaches may be related to several factors, one of them being the relatively recent interest of the operations research community in distributed operations management problems solved in a distributed manner, and more specifically distributed optimization. Another explanatory factor may be the nature of such solutions, which involve some kind of central system design and development methodology that is rather inconsistent with the multi-company nature of supply chains. Therefore, there is a research opportunity to overcome these difficulties and develop operations planning coordination approaches that are able to find (near) optimal solution at each planning cycle and within specified revenue and profit sharing regulations.

Along the same line, another set of research opportunities involves the integration of different methodological tools including intelligent agent technology and operations research. The supply chain environment is dynamic and uncertain. The use of a technology, such as intelligent agent, enables the development of coordination systems that can learn to adapt to any situations, while operations research enables the development of systematic and highly efficient coordination mechanisms. Both technologies are complementary in that respect.

Another interesting aspect of supply chain operations planning is the notion of legacy planning systems. Indeed, companies use different tools to plan their own operations. Because supply chain coordination requires some forms of information exchange that is embedded within the coordination process, these tools must be interoperable at the information exchange level, but also at the decision support process level. In other words, these decision processes must be compatible and complementary with respect to the information that is exchanged and locally processed. Consequently, the development of collaborative planning standards seems to be required in order to guaranty the compatibility of advanced tools developed by two different software companies.

Along the same line, this kind of systems requires a good level of trust and openness because companies tie their decision support process with the systems of other companies. Therefore, it is necessary to better understand the implications of this type of advanced planning technology on the loss of control that could be expected.

Table 3-4: Supply chain planning coordination framework.

Main techniques	Sub techniques	Characteristics
Exact decomposition and constraint-based techniques	Lagrange decomposition	*Type of local planning: exact* *Type of coordination: exact or comprehensive search*
	Benders decomposition	
	Dantzig-Wolf decomposition	
	Distributed search with constraint propagation	
Hierarchical planning and information sharing techniques	Greedy coordination	*Type of local planning: exact or heuristic* *Type of coordination: greedy/one-way information exchange*
	Partial aggregation of decision domains	
	Information sharing and anticipation models	
Heuristic search techniques	Distributed-heuristic search with local optimization	*Type of local planning: exact or heuristic* *Type of coordination: heuristics* *Formalization of interactions: programmed/implicit (P/I) or declarative/explicit (D/E)*
	Distributed meta-heuristic search	
	Interaction-based coordination	
Intelligent and adaptive techniques	Commitment-oriented coordination	*Type of local planning: exact or heuristic* *Type of coordination: heuristics* *Local planning adaptability: multi-behaviour, goal-driven, multi-attribute or learning capability* *Formalization of interactions: declarative/explicit or adaptive*
	Argument-based coordination	
	Multi-behavior based coordination	
	Learning-based coordination	
	Integrative negotiations	
	Price-based planning coordination	
Bidding-based techniques	Contract-net and auctions	*Coordination issue: selection*

3.6 Conclusion

We analysed almost 105 contributions to the general problem of supply chain operations planning coordination. Based on our analysis of the different techniques and tools used by these contributions, we propose a five-class classification of the coordination and local planning tools of these methods. This analysis highlights several important aspects of the development of such approaches. First, less than 23% of the reviewed approaches are in dynamic environment, as well as less than 17% of these approaches are in stochastic context. Therefore, there is an opportunity to develop more dynamic and stochastic mechanisms of planning coordination of supply chains. Second, our analysis highlights a research direction that proposes to integrate exact approaches with other technique such as intelligent agents in order to exploit their complementarities. Finally, intelligent and adaptive techniques, which are a rather new concept in supply chain operations planning coordination. There is also an opportunity to develop collaborative planning standard, on which advanced planning tools could be based in order to guaranty both the complementarity of these tools as well as the freedom of companies to adopt any planning tools.

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CHAPTER 4 : ARTCILE 2: MUTUAL ADJUSTMENT COORDINATION WITH INCENTIVE FOR SUPPLY CHAIN PLANNING

Supply chains are complex systems, which include several independent organizations with different objectives. A key issue in supply chain management (SCM) is the coordination of supply chain planning decisions. Supply chain planning systems introduced in the literature can be classified into two main planning systems: centralized and decentralized planning systems. Centralized systems can theoretically optimize supply chain performance although its implementation requires a high degree of information exchange among supply chain partners. This leads to difficulties when independent partners do not want to share information. In order to address these difficulties, decentralized systems are designed for supply chains where each member is a separate economic entity that makes its operational decisions independently, yet with some minimal level of information sharing. In this paper, we propose a decentralized coordination mechanism based on a negotiation-like mutual adjustment of planning decisions, rooted in mathematical programming. This mechanism, unlike traditional centralized system, involves two enterprises, which interact with each other in order to improve their individual and collective performance. Computational analysis shows that the proposed negotiation-like coordination mechanism leads to near optimal results when compared to central coordination, while maintaining fairness in terms of revenue sharing.

Keywords: Supply chain management; coordination; incentive mechanism; mathematical programming; operations planning

4.1 Introduction

Supply chains are complex systems which include numerous independent organizations, with different objectives and operations planning domains, connected by information, physical and financial flows in order to provide products or services to consumers. A key issue in Supply Chain Management (SCM) is the coordination of planning decisions of these independent organizations, such as what to purchase, produce and deliver and when over a planning horizon, in order to improve supply chain performance. The SCM literature proposes centralized and decentralized approaches for such coordination.

Centralized supply chain planning is generally implemented in the form of hierarchical planning systems. In such systems, a central (e.g., corporate) unit provides near-optimal aggregated plans to lower planning levels (e.g., plant), which implement them at a more granular level subject to higher-level decisions. Centralized supply chain planning can theoretically produce optimal supply chain performance as it coordinates all supply chain units towards a unique goal. However, its implementation requires a high degree of collaboration and information exchange between supply chain units, which is why; in practice it is limited to the supply chain units of large companies. This leads to difficulties when independent supply chain members do not want to share detailed information such as strategic objectives, production capacity utilization and costs.

In order to address such difficulties, decentralized forms of supply chain planning coordination have been proposed in the literature. These decentralized planning systems are designed for supply chains in which the members are separate economic entities that make their own planning decisions independently, yet with some minimal level of information sharing. They aim to improve supply chain performance in order to achieve near-optimal supply chain planning. Section 2 summarizes the literature on this topic, which emphasizes the multi-disciplinary aspect of this research domain. In this context, this paper addresses the specific issue of how two independent supply chain partners can coordinate their planning decisions.

The reminder of this paper is organized as follows. Section 3 first defines the problem on-hand, and then presents an overview of the main concepts of the proposed coordination approach. Next, Section 4 proposes a mutual adjustment coordination mechanism with incentive for supply chain planning coordination. An illustrative example and a computational performance analysis are presented in Section 5. Finally, Section 6 concludes and presents future research directions.

4.2 Literature review

The literature dealing with decentralized supply chain planning proposes several coordination paradigms in order to improve the collective performance of distributed supply chain partners with independent objectives. In Taghipour and Frayret 2010, we classify this literature according to three main research disciplines: operations research, artificial intelligence (agent-based) and economy. Each discipline can be further categorized into different sub-classes, based on the proposed structure of information sharing (following table). The next sections review these supply chain coordination approaches.

Table 4-1: Classification of decentralized operations planning coordination approaches in supply chain management literature.

Operations research	Hierarchical planning with information sharing	• Upstream planning • Partial central optimization • Information sharing
	Decompositions approaches	• Lagrangian decomposition • Dantzig-Wolfe decomposition • Bender’s decomposition
	Distributed search	• Distributed metaheuristic search • Distributed search with constraint propagation • Distributed heuristic search with local optimization
Artificial intelligence	Interaction-based planning	• Protocol-based interactions
	Behavior-based planning	• Commitment-oriented manufacturing • Argument-based agents • Multi-behavior agents • Learning agents
Economy	Game Theory	• Game theory
	Newsvendor (newsboy) modeling	• Newsvendor modeling
	Price-based coordination	• Price-based coordination
	Negotiation and bidding-based planning	• Contract-net protocol • Automated negotiation

4.2.1 Operations Research

Supply chain planning coordination based on Operations Research is mainly rooted in mathematical programming. It can be classified into three main coordination approaches: Hierarchical planning with information sharing, decomposition approaches and distributed search techniques.

4.2.1.1 **Hierarchical planning with information sharing**

This form of coordination is based on the implementation of hierarchical flows of information between supply chain members. It includes three main sub-categories: upstream planning, partial central optimization and information sharing.

Upstream planning- The simplest and widely spread form of decentralized planning is a one-way information flow, called upstream planning (Azevedo *et al.* 2005, Dudek and Stadtler 2005, Frayret *et al.* 2007), in which supply chain partners independently plan their operations using their own planning tools (e.g., dynamic lot-sizing optimization) and propagate their dependent demand to their suppliers. It is a cascade form of coordination that can be assimilated to a weak form of hierarchy (Schneeweiss 2003). From a methodological point of view, upstream planning is used in this paper in order to produce lower bounds for comparison.

Partial central optimization- The nearest approach to completely centralized planning is partial central optimization, in which sub-sets of distributed supply chain planning activities (e.g., planning of manufacturing operations of several supply chain partners) are modeled into a single planning problem in order to achieve the partial centralized optimization of these sub-problems within the overall supply chain (Pibernik and Sucky 2007). In order to reach a solution that is acceptable to all supply chain partners, this approach proposes that different alternative plans be collectively investigated. The challenge with such an approach is to find a balance between information sharing requirements, optimization complexity and the need to accommodate supply chain partners with locally efficient plans.

Information sharing- The third category of hierarchical planning is information sharing. These approaches are proposed in order to improve local decision-making using simple forms of information exchange, such as the exchange of forecast information (Váncza *et al.* 2008), or more advanced forms of information sharing, where suppliers' decision problems are partially incorporated into the manufacturer's planning problem in order to find dependent demand patterns that are efficient for both partners (Schneeweiss and Zimmer 2004).

4.2.1.2 **Decompositions approaches**

These approaches decompose a large supply chain planning problem into several sub-problems that are solved in a distributed manner using known decomposition approaches. Three main approaches are used: *Lagrangian decomposition*, *Bender's decomposition* and *Dantzig-Wolf decomposition*.

Lagrangian decomposition- In this approach, the constraints that bind several planning domains (typically the flow conservation constraints between several business units) are relaxed and moved to the objective function. A penalty vector is added in order to penalize the objective function if these constraints are not satisfied. Then, a distributed iterative process is used to adjust the penalty vectors of these relaxed constraints and converge towards a near optimal set of supply chain operations plans. Usually, a central master problem is used to calculate and adjust synchronously these penalties according to the current state of the local optimization processes (Ghirardi *et al.* 2008, Luh *et al.* 2003).

Dantzig-Wolfe decomposition- This approach, also referred to as column generation, is usually applied to solve large linear programming problems. It consists in reformulating large problems using the Dantzig-Wolfe modeling technique, where variables are solution vectors of the problem. In order to solve to optimality such a reformulated problem, one must know initially all possible solution vectors, which is unrealistic in practice. Therefore, the problem is, on the one hand, decomposed into a *Restricted Master Problem* (RMP), where only a small subset of solution vectors are investigated, and, on the other hand, one or many pricing problems, which generate, according the dual costs of the current solution of the RMP, new interesting solution vectors (i.e., the columns) that are fed back in the RMP. This process is repeated until no new solution vectors can be found. The interesting aspect of this approach is that the pricing problem can be formulated and solved individually for each planning domain of the supply chain, as proposed by Holmgren *et al.* (2009).

Bender's decomposition- Similarly, Poundarikapuram and Veeramani (2004) have adapted Benders decomposition to the supply chain planning coordination problem. This approach also exploits the planning domain separability of this problem. The variables common to several planning domain sub-problems are taken care of in a master problem, while the local variables that define these sub-problems are taken care of at a lower level. The main difference with Lagrangian decomposition is that feasibility and optimality are iteratively addressed by adding feasibility constraints and optimality cuts to the master problem. In other words, given the current solution of the master problem, if a sub-problem is infeasible, this technique generates and adds a feasibility constraint to the master problem. Similarly, if a sub-problem has an optimal solution of greater cost, then an optimality cut can be added to the master problem. In both cases, the master problem is solved again with the new added constraints until no new cut can be added.

4.2.1.3 **Distributed search**

Distributed search approaches involve iterative forms of information exchange between partners, during which they progressively adjust their initial local plan through local search procedures. Such procedures allow the partners to mutually adjust their plans according to the constraints or benefit of their partners. This form of coordination requires the design of a convergence mechanism to guarantee the improvement of the collective plan, as well as, termination conditions in order to stop the distributed search. The main approaches in this group are: *Distributed metaheuristics*, *distributed search with constraint propagation* and *distributed heuristic search with local optimization*.

Distributed metaheuristic search- These approaches are inspired by metaheuristics and implemented in a distributed manner in order to provide both local planning decision support and the means to integrate local decision. For instance, Silva *et al.* 2006 adapted Ant Colony Optimization in order to solve each partner's operations planning problem, during which pheromone matrixes are generated and iteratively exchanged to mutually influence partners' decision process. This approach is innovative. However, in a supply chain composed of independent business, it requires partners to use specific decision planning tools, which is a limit to the approach. Similarly, Chen *et al.* 2007 propose an approach based on genetic algorithm for a two-factory capacity planning problem. Here, two factories of a company negotiate with each other in a quasi-heterarchic manner (i.e., the initiating factory acts as mediator) in order to balance efficiently excess order and excess capacity based on the price of resource capacity. The interesting aspect of this approach is that it addresses simultaneously both capacity utilization and financial flows.

Distributed search with constraint propagation- This approach has been recently proposed by Gaudreault *et al*. (2009). Here, the coordination space of the many heterogeneous planning problems of a linear supply chain is modeled as a tree. In this distributed and asynchronous process, agents must decide whether to produce an alternative solution to a customer demand plan for which they have already found a solution, or to produce a first solution to a demand plan for which they have no solution yet. This procedure provides a means of searching the coordination space to find a set of local plans that are collectively better in terms of supply chain performance. One of the strengths of this approach is that it only requires the exchange of minimal information such as demand and supply plans. However, compared to other approaches, it is more computationally intensive. This coordination process is also independent from the planning tools that are used to produce agents' local operations plans.

Distributed heuristic search with local optimization- In such an approach, planning domains are modeled and optimized separately, while they are coordinated using an iterative heuristic approach to adjust local optimization and therefore explore the coordination space in order to achieve near-optimal solutions or improve the result of upstream planning. This type of approaches can be assimilated to some form of iterative negotiation. Negotiation is here a coordination mechanism in which supply chain partners exchange iteratively messages in order to develop their operation plans with minimum information exchange. In this context, Dudek and Stadtler (2005, 2007) proposes a non-hierarchical, negotiation-based collaborative planning scheme, which can be used to synchronize operations plans between two independent supply chain partners linked by material flows. This approach extends the simple coordination form of upstream planning by giving the collaborating partners the opportunity to modify suggested order/supply patterns in an iterative manner. Plans are generated using mathematical programming models. Specific versions of these models are utilized for evaluating material orders or supplies proposed by the partners and for generating counter-proposals. The only information exchanged are order/supply proposals, as well as the associated changes in total cost, which can be seen as a barrier for some enterprises which would not accept to exchange such information. Furthermore, the authors do not propose a scheme for sharing to the benefit of local cost reduction.

4.2.2 Artificial Intelligence

Rooted in computer science, these approaches propose distributed artificial intelligence methods to achieve supply chain planning coordination. The two main sub-classes in this group are: Interaction-based and behavior-based coordination.

4.2.2.1 **Interaction-based planning**

These approaches are based on the modeling and implementation of interaction protocols, which are used to describe the possible sequences of information to be exchange in specific situations in order to reach specific goals. For instance, an interaction protocol can be modeled using finite state diagrams, petri-nets or UML (Unified Modeling Language) interaction diagrams in order to negotiate the postponement of a delivery date. Such a protocol has to identify the possible sequence of information exchange and how these exchanges are linked to local planning in order to reach the goal supported by the protocol. This is done by considering the possible outcomes of the interactions as well as by designing contingency plans to handle exceptions. Artificial Intelligence techniques are used in order to plan the agents' activities required to interact with other agents and make local decision about supply chain operations. Among others, Cloutier *et al*. 2001, Azevedo *et al.* 2005, Monteiro *et al*. 2007 and Wang *et al*. 2008 propose such approaches of supply chain coordination based on different processes of interactions.

4.2.2.2 **Behavior-based planning**

Behavior-based planning approaches involve the ability of an intelligent software agent to adapt its behavior according to the situation in order to reach a goal. Several approaches have been proposed. Commitment-oriented manufacturing (Cloutier *et al.* 2001) is a coordination approach where manufacturing agents commit to do specific things with other agents (e.g., deliver goods at specific time periods), and act accordingly to fulfill their commitments and therefore achieve their goals. In other words, commitments force the agents to adapt their behavior and their actions/operations when they commit to do something. Similarly, argument-based agent involves the construction and exchange of arguments that agents believe will make their partners look more favorably upon their proposal (Jennings *et al.* 2001). Arguments are information that is added to an offer sent by an agent in order to influence its partner. In other words, this aims at identifying or creating new opportunities in the coordination space, or modifies how agents value their partners' offers, in order to facilitate the coordination process. Although it is not a technique that is widely used in supply chain, some researchers have investigated this approach. For instance, Hsairi *et al.* (2008) introduce an argument-based negotiation approach for conflict resolution for the extended enterprise. Along the same line, Chow *et al.* (2008) proposes an argument-based technique in the context of a logistic service provider to dynamically solve conflicts in operations management. Multi-behavior agents (Forget *et al.* 2008) are yet another form of behavior-based agents capable of planning or selecting their own course of actions in order to reach specific goals or to maximize a utility function. Similarly, learning-agents (Fox *et al.* 2000) can progressively discover through machine learning techniques the best course of action to follow in specific situations. In other words, such agents have the ability to learn by making decisions in time and observing the outcome of these decisions so as to maximize their utility. Similarly, based on the approach presented in Gaudreault *et al*. (2009), Gaudreault *et al*. (2008) propose an approach where intelligent agents can learn (using the quality of the explored solutions) to focus their local search in order to collectively execute a concurrent search of distributed supply chain coordination space.

4.2.3 Economy

Inspired by market mechanisms, these approaches propose several coordination methods from semi-centralized to pure-decentralized planning approaches. The main techniques used in this group are Game Theory, Newsvendor (newsboy) modeling, Price-based and negotiation-based planning.

4.2.3.1 **Game Theory**

According to Cachon (2006), Game Theory contributes to supply chain coordination through two main families of approaches: cooperative games and non-cooperative games. On the one hand, in cooperative games, each partner possesses individual objectives, while all partners make an informational coalition with binding agreements. At the end of the game, the created value is distributed among the members of the coalition. On the other hand, in non-cooperative games, partners involved in a negotiation process must anticipate the reaction of the other party in order to converge towards an agreed upon solution. These two families of approaches can be seen as a source of inspiration for the design of agent-based supply chain coordination systems, which involve the creation of agent coalitions or competitive agents.

4.2.3.2 **Newsvendor (newsboy) modeling**

These approaches can be considered as yet another family of solution rooted in economy. They focus on the determination of single-period inventory levels under uncertain demand with fixed prices. For instance, in Cachon (2004), one partner uses a revenue sharing in the form of buyback payments and a return policy, in order to encourage other partners to participate in the supply chain coordination process. Therefore, by maximizing their profits, partners contribute to supply chain coordination through adjustments of order quantities.

4.2.3.3 **Price-based coordination**

These approaches are based on the balance of offer and demand. For instance, in Kaihara (2008), seller and buyer agents adjust round after round their price/demand according to market conditions. For example, a seller agent will increases the price of the goods if a specified quantity of goods has been purchased on the market during the last round. On the contrary, if no good has been purchased, then the price of the goods is iteratively decreased until it is sold or taken out of the market.

4.2.3.4 **Negotiation and bidding-based planning**

Negotiation and bidding-based planning (and contract design) exploits other forms of market mechanisms based on negotiation and bidding principles. The main mechanisms include the *contract-net protocol* and *automated negotiation*.

C*ontract-net protocol* (Davis and Smith 1983) - these approaches involve a request-for-tender sent by an initiator agent and one or several offers sent by participator agents the initiator. Some kind of utility function is used to evaluate and award one, or a sub-set, of offers. The object of the request-for-tender is generally a spot contract for a specific delivery or operation to perform for a specific time period. For instance, D'Amours *et al.* 1996 propose a Contract-net-based approach for virtual supply chain design. Here, several offers from multiple sub-contractors are evaluated and selected altogether to form virtual supply chain partners, which are collectively responsible for the spot production and delivery of goods. Along this line, Jiao *et al.* (2006) also propose an extension of the Contract-net approach in order to include the simultaneous negotiation of several contracts, instead of simple bilateral contract. Again, Ahn and Lee (2004) propose a supply coordination model based on an iterative Contract-net approach and data envelopment analysis to improve the evaluation and selection of suppliers.

A*utomated negotiation*- these approaches exploit agent-technology in order to implement in an automated manner the offer-counteroffer principle between agents. These approaches are used to automatically negotiate the interdependent attributes of supply chain contracts, such as price, volume, and delivery date. Different intelligent techniques can be used to improve the efficiency of the negotiation process, such as the creation of bundles of offers (Neubert *et al.* 2004) or the use of fuzzy-logic (Jain *et al.* 2009).

4.2.4 Classification of the proposed approach

The supply chain coordination approach proposed in this paper can be classified as a *distributed heuristic search with local optimization*. In order to improve individual and collective performance, local decision making domains are linked by an iterative distributed search for a collective solution. The only information exchanged between partners is supply and order proposals, as well as an incentive in the form of a discount plan. Such an incentive is used to incite the partner to participate in the coordination process. This work was initially inspired by the coordination scheme proposed by Dudek and Stadtler (2005, 2007), which proposes a negotiation-based coordination scheme combining different aspects of contract design, agent technology and mathematical programming. The next section presents the problem addressed here, and defines the main concepts underlying the proposed solution.

4.3 Problem statement and approach overview

The specific supply chain coordination problem addressed here is a Distributed Multi-Level Capacitated Lot-Sizing Problem (DMLCLSP). In other words, a supplier and a manufacturer (also referred to as the partners) have to plan their own lot sizes, in terms of: what to produce, in what quantity and when over a planning horizon. In order to do that, they take into account bill-of-material and capacity constraints. They may adjust capacity level using overtime. Similarly, they take into account their mutual input/output constraints that bind together their local planning domains. Because both partners have a local cost structure they do not share, as well as external demand to satisfy, they cannot accurately anticipate each other’s input/output feasibility and economic performance.

The solution approach proposed in this paper is referred to as a *Mutual-Adjustment Search* (MAS) with incentive because, unlike traditional centralized system, it involves two supply chain partners, which interact directly with each other to mutually adjust their lot-sizes in order to improve their individual and collective economic performance. This mutual adjustment search is a collective search of a solution within a *coordination space* that represents all possible *Order Plans* (OP) that can be agreed upon by both partners. An OP is a matrix defined as the manufacturer’s order to the supplier for all products and all time periods of the planning horizon. As mentioned earlier, the manufacturer and the supplier only know their local set of constraints that defines the *coordination space*. Therefore, when one partner makes a proposal, the other partner must evaluate the proposal in order to know its feasibility, as well as its impact on profit.

During this mutual adjustment search, the supplier uses an incentive mechanism to incite the manufacturer to adjust its original *OP* (also referred to as the upstream planning order plan). In this mechanism, described in details in the next section, the supplier first identifies a local negotiation objective. This objective represents its optimal OP, which is calculated in the neighborhood of the manufacturer's original OP. The positive difference between its optimal OP and the manufacturer's original OP is referred to as the *Additional Supply Plan (ASP)*, which represents how the supplier wants the manufacturer to increase its order for specific products at specific time periods. Next, the supplier calculates the *Maximum Discount* (MD) that can be offered to the manufacturer if he accepts the supplier's optimal OP. The *Maximum Discount* is defined as the gap between the profit generated from delivering its optimal OP and the profit generated from delivering the manufacturer's original OP. Finally, using the ASP and the MD, the supplier defines and offers a *Discount Plan* (DP) to the manufacturer, which consists in offering part of the *MD* for an adjustment of the original OP equal to part of the *ASP*. In other words, if the manufacturer accepts to increase its order for specific products at specific time periods up to at least the specific portion of the ASP, then a fixed discount is offered to the manufacturer.

These negotiation-like interactions are based on minimal level of information sharing (Figure 1). Unlike the pioneer approach proposed by Dudek and Stadtler (2005), which requires partners to exchange cost improvements along with OP at each step of the negotiation process, the proposed approach propose to use a dynamic discount structure that is progressively adjusted in order to find a compromise OP without sharing cost information. Furthermore, the proposed approach addresses the coordination of both material and financial flows.

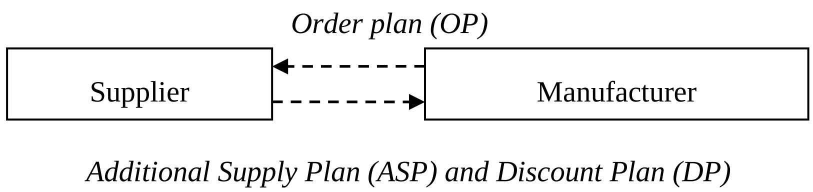

Figure 4-1: Exchanged information.

4.4 Mutual Adjustment Supply Chain Coordination

The proposed mutual adjustment coordination process involves a series of interactions between the partners (Figure 2) and several optimization models. These mechanisms are described in details in this section.

4.4.1 Mutual adjustment search procedure

The basic steps of this procedure are summarized as follow (Figure 2).

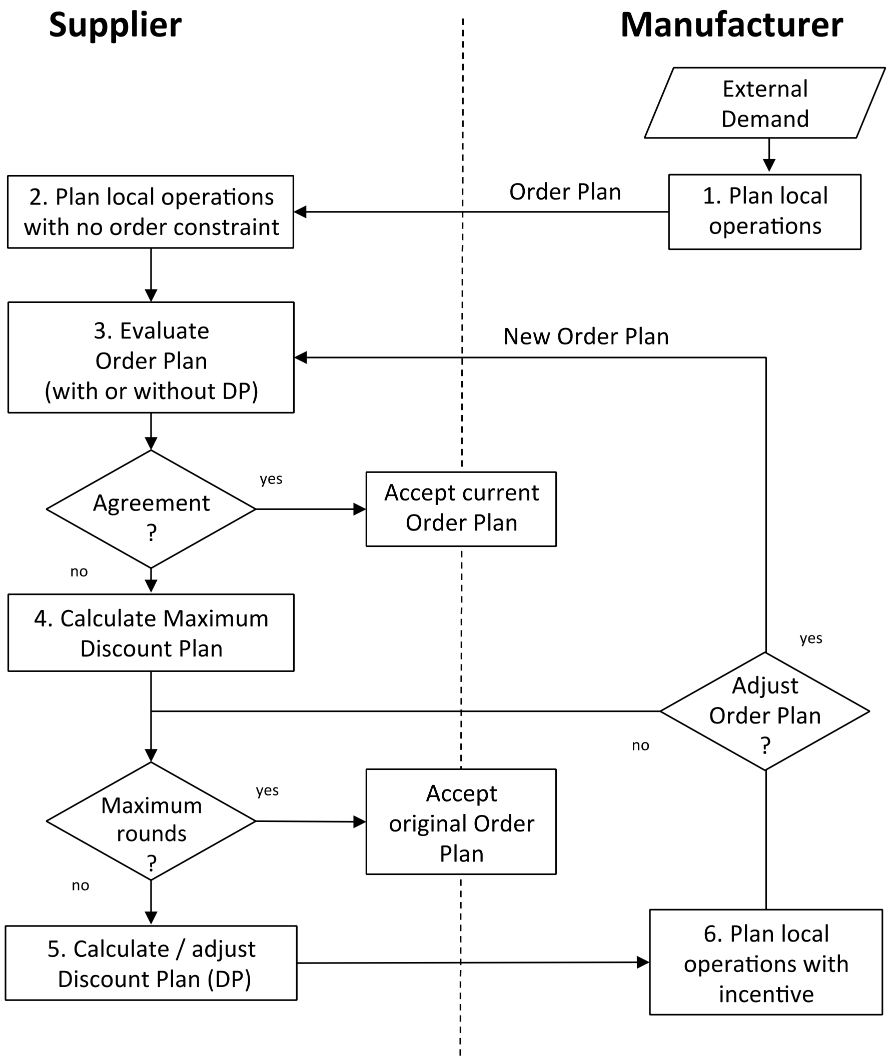

Figure 4-2: Negotiation based coordination between two partners.

<u>Step 1: Manufacturer plans his operations</u>

During the first stage, the manufacturer has received the external demand from its distributor. With this information, he optimizes its operations plan in order to maximize profit. As mentioned previously, the manufacturer's operations management problem is a capacitated lot-sizing profit optimization problem, from which he computes its dependent OP (i.e., $Demandm_{f,t}$) and sends it to the supplier.

Step 2: Supplier optimizes its operations with relaxed input/output constraints

Once the supplier receives the manufacturer's OP, he first computes a relaxed lot-sizing plan, which considers an aggregated input/output constraint that consists in satisfying the total quantity ordered by the manufacturer over the planning horizon, and not the exact demand pattern. The OP proposed by the supplier to the manufacturer can thus be considered as being in the neighborhood of the initial OP. During the research project, several less aggregated neighborhood structures were tested, such as the aggregation of groups of two or three periods instead of the aggregation of the entire planning horizon. The results were significantly less interesting in terms of improvement as they offer less flexibility to find alternative solutions.

Step 3: Supplier optimizes its operations without relaxed input/output constraints

Once the relaxed plan is computed, the supplier optimizes again its lot-sizes with the full input/output constraints as ordered by the manufacturer. This leads to a second lot-sizing plan, which, in terms of profit, is at best equivalent to the relaxed plan. During this phase, if the negotiation has already came through one or several rounds then this evaluation includes the last *Discount Plan* (DP) offered by the supplier. In both cases, the supplier computes the difference between the profits calculated from these two plans in order to evaluate if there is a potential profit improvement. If there is a significant potential improvement then the negotiation goes on for another round. If not, the last OP of the manufacturer is agreed upon, and the last DP, if any, is included in the price.

Step 4: Calculate Maximum Discount Plan

The fourth step is the calculation of the maximum discount plan (Figure 3). To do that, the supplier first calculates the *Additional Supply Plan* and the *Maximum Discount* (i.e., the potential profit improvement) as illustrated in Figure 3. Next, the *Additional Supply Plan* is normalized in order to know how the *Maximum Discount* should be split between all products and all time periods to focus the incentive towards the most significant elements of the gap between both lot-sizing plans. This results in the definition of a *Maximum Discount Plan* as shown in Figure 3.

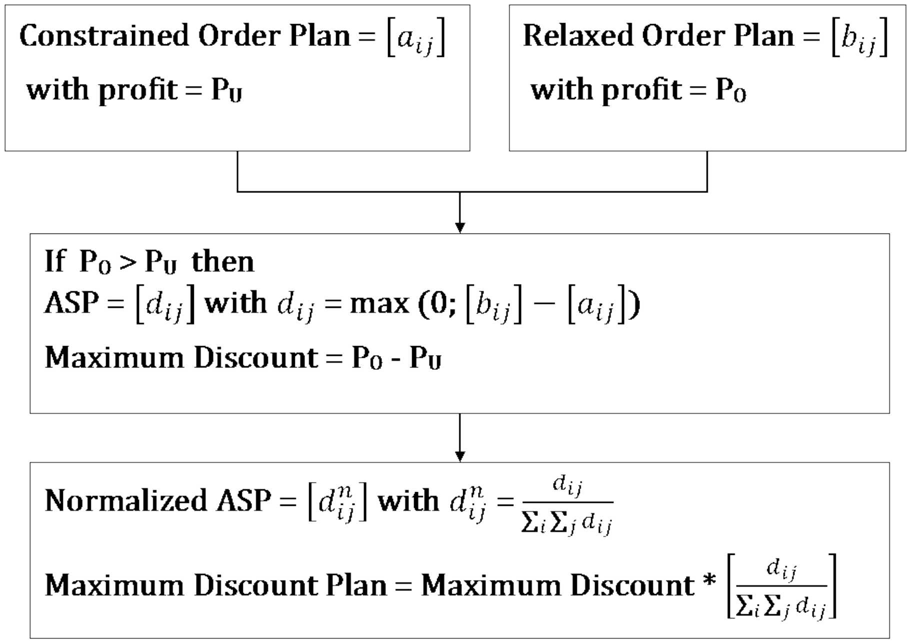

Figure 4-3: Evaluation and discount calculation.

<u>Step 5: Calculate/adjust discount plan</u>

Next, if the maximum number of negotiation rounds has not been reached, the supplier initiates, or adjusts if at least one round has been done before, a mutual adjustment procedure with the manufacturer. In other words, at each round of this procedure, a percentage $\alpha \in [0,1]$ of the *Maximum Discount Plan* is offered if the manufacturer accepts to increase his order above a percentage $\beta \in [0,1]$ of the *Additional Supply Plan*. This incentive structure is referred to as the *Discount Plan*. In other words, if the manufacturer accepts to increase his previous order quantities of specific amounts as specified by the discount plan, a fixed discount is offered to the manufacturer.

<u>Step 6: Manufacturer optimizes his lot-sizes with new incentive</u>

Next, the manufacturer computes new lot-sizes taking into account the discount plan sent by the supplier. If a new OP is computed, then it is sent to the supplier for evaluation (Step 3) in order to know the impact of this new OP and its associated discount plan on his profit. If the maximum number of negotiation rounds has not been reached, the supplier can then either accept this new OP or propose a more incentive *Discount Plan*. Similarly, if the manufacturer does not change his original OP, the supplier can either accept it, returning to the initial upstream planning solution, or again propose a more incentive *Discount Plan*.

4.4.2 Mathematical models

During steps 1, 2, 3 and 6, mathematical models are used to optimize lot-sizes in specific situations. This section presents these models. As mentioned previously, these models are four multi-level capacitated lot-sizing models, which are thoroughly presented in Erengüc *et al.* (1999). Although, most are cost minimization problems, these models presented here are profit maximization models in order to address both material and financial flows coordination. This allows both partners to adjust capacity utilization in order to increase revenues by improving external demand satisfaction. In other words, if the supplier can convince the manufacturer to adjust his demand pattern, then the supplier could offset the discount offered to the manufacturer by being able to free part of his capacity to satisfy more external demand.

Model 1 (Step 1): First Manufacturer Optimal Plan (Z_1)

The first models correspond to Step 1 when the manufacturer first optimizes his lot-sizes without considering any incentive.

Index sets

T *Set of time periods*

J *Set of products produced by the manufacturer*

J_j^s *Set of products directly succeeding product j in the bill of material (BOM)*

Indices

t *Time period, $t \in T$*

j *Products produced by the manufacturer, $j \in J$*

Parameters

ps_f *Unit price of product f produced by supplier*

$penalty_j$ *Back order penalty for the manufacturer product j delivered to distributor*

$D_{j,t}$ *Demand for product j in period t (produced by manufacturer)*

$u_{j,g}$ *Unit requirement of product j by successor operation/product g* ($g \in J$)

pm_j *Unit price of final product j produced by manufacturer*

cfm_j *Fixed production setup cost of product j produced by manufacturer*

cvm_j *Unit variable production cost for product j produced by manufacturer*

chm_j *Unit holding cost for product j produced by manufacturer*

com_r *Unit cost of overtime (capacity expansion) of resource r for manufacturer*

$cm_{r,j}$ *Unit requirement of resource r to produce one unit of product j by manufacturer*

$Cm_{r,t}$ *Production capacity of resource r in period t for manufacturer*

M *A large number, which corresponds to the maximum quantity of product j that can be produced in a time period*

Variables

$dm_{j,t}$ *Tentative delivery quantity of product j in period t to the distributor*

$om_{r,t}$ *Overtime of resource r in period t for manufacturer*

$xm_{j,t}$ *Output of operation/product j produced (or demanded from supplier) by manufacturer in period t (order plan)*

$ym_{j,t}$ *Setup binary variable for production of product j produced by manufacturer in period t*

$im_{j,t}$ *Inventory level of product j in period t*

$bom_{j,t}$ *Back order of product j produced in time t by manufacturer and delivered to distributor*

$Max\ Z_1$

$S.t.$:

1.1) $$Z_1 = \sum_{j\in J}\sum_{t\in T}\left(pm_j dm_{j,t} - cfm_j ym_{j,t} - cvm_j xm_{j,t} - chm_j im_{j,t} - ps_j xm_{j,t} - penalty_j bom_{j,t}\right) - \sum_{r\in R}\sum_{t\in T} Com_r om_{r,t}$$

1.2) $im_{j,t-1} + xm_{j,t} = dm_{j,t} + \sum_{g \in J_j^s} u_{j,g} xm_{g,t} + im_{j,t} \qquad \forall j \in J, \forall t \in T$

1.3) $bom_{j,t} = bom_{j,t-1} - dm_{j,t} + D_{j,t} \qquad \forall j \in J, \forall t \in T$

1.4) $\sum_{j \in J} cm_{r,j}\, xm_{j,t} \leq Cm_{r,t} + om_{r,t} \qquad \forall j \in J, \forall t \in T$

1.5) $xm_{j,t} \leq M\, ym_{j,t} \qquad \forall j \in J, \forall t \in T$

1.6) $xm_{j,t} \geq 0 \qquad \forall j \in J, \forall t \in T$

1.7) $dm_{j,t} \geq 0 \qquad \forall j \in J, \forall t \in T$

1.8) $om_{j,t} \geq 0 \qquad \forall j \in J, \forall t \in T$

1.9) $im_{j,t} \geq 0 \qquad \forall j \in J, \forall t \in T$

1.10) $bom_{j,t} \geq 0 \qquad \forall j \in J, \forall t \in T$

1.11) $ym_{j,t} \in \{0,1\} \qquad \forall j \in J, \forall t \in T$

The objective function 1.1 maximizes the total profit of the manufacturer, which represents the profit incurred from the revenue generated by products sold minus the cost of production, inventory, purchasing, penalty for back order and capacity expansion through overtime. Constraint 1.2 captures the flow balance between, inventory, production, delivery and internal consummation of products for production. Next constraint 1.3 captures the back orders. Constraints 1.4 represent capacity restrictions. Constraints 1.5 through 1.11 specify domains of variable values.

Model 2 and 3 (Steps 2 and 3): Supplier relaxed and constrained plan (Z_2 and $\overline{Z_2}$)

During Step 2, the supplier first computes its optimal relaxed lot-sizing plan, which consists in satisfying the total ordered quantity over the planning horizon.

Index sets

T *Set of planning periods*

F *Set of products managed by supplier*

F_f^s *Set of products directly succeeding product f in the BOM*

Fs *Set of product sold by the supplier to the manufacturer*

Indices

t *Planning period,* $t \in T$

f *Products produced by supplier,* $f \in F$

Parameters

ps_f *Unit price of product f in period t produced by supplier*

cfs_f *Fixed production setup cost of product f produced by supplier*

cvs_f *Unit variable cost for product f produced by supplier*

chs_f *Unit holding cost for product f held by supplier*

$De_{f,t}$ *Demand for product f produced by supplier in period t from external customer*

$v_{f,g}$ *Unit requirement of product f by successor operation g*

cos_r *Unit cost of overtime (capacity expansion) of resource r for supplier*

$cs_{r,f}$ *Unit requirement of resource r to produce one unit of product f by supplier*

$Cs_{r,t}$ *Production capacity of resource r in period t for supplier*

$Demandm_{f,t}$ *Initial manufacturer order of product f in period t*

M *Large number*

Variables

$xs_{f,t}$ *Output of product f produced by supplier in period t*

$ys_{f,t}$ *Binary setup variable for production of product f by supplier in period t*

$is_{f,t}$ *Inventory level of supplier product f in period t*

$ds_{f,t}$ *Delivery quantity of product f in period t to manufacturer*

$de_{f,t}$ *Delivery quantity of product f in period t to external manufacturer*

$os_{r,t}$ *Overtime of resource r in period t for supplier*

$Max\ \ Z_2$

$s.t.$:

2.1) $Z_2 = \sum_{f\in F}\sum_{t\in T}\left(ps_f\left(de_{f,t} + ds_{f,t}\right) - cfs_f ys_{f,t} - cvs_f xs_{f,t} - chs_f is_{f,t}\right) - \sum_{r\in R}\sum_{t\in T} cos_r os_{r,t}$

2.2) $is_{f,t-1} + xs_{f,t} = de_{f,t} + ds_{f,t} + \sum_{g\in F_f^S} vs_{f,g} xs_{g,t} + is_{f,t} \qquad \forall f \in F, \forall t \in T$

2.3) $de_{f,t} \le De_{f,t} \qquad \forall f \in Fs, \forall t \in T$

2.4) $\sum_{t\in T} ds_{f,t} \le \sum_{t\in T} Demandm_{f,t} \qquad \forall f \in Fs$

2.5) $\sum_{f\in F} cs_{r,f}\, xs_{f,t} \le Cs_{r,t} + os_{r,t} \qquad \forall f \in F, \forall t \in T$

2.6) $xs_{f,t} \le M ys_{f,t} \qquad \forall f \in F, \forall t \in T$

2.7) $xs_{f,t} \ge 0 \qquad \forall f \in F, \forall t \in T$

2.8) $ds_{f,t} \ge 0 \qquad \forall f \in Fs, \forall t \in T$

2.9) $de_{f,t} \ge 0 \qquad \forall f \in Fs, \forall t \in T$

2.10) $os_{f,t} \ge 0 \qquad \forall f \in F, \forall t \in T$

2.11) $is_{f,t} \ge 0 \qquad \forall f \in F, \forall t \in T$

2.12) $ys_{f,t} \in \{0,1\} \qquad \forall f \in F, \forall t \in T$

The objective function 2.1 maximizes the supplier’s profit, which represents the profit incurred from the revenue generated by sold products minus the cost of production, inventory, purchasing and capacity expansion through overtime. Constraint 2.2 captures the flow balance between inventory, production, delivery to the manufacturer, and internal consummation of products for production. Constraint 2.4 represents aggregated manufacturer demand satisfaction. Constraint 2.5 shows capacity restrictions. Constraints 2.6 through 2.12 specify domains of variable values. Next in Step 3, the supplier computes its constrained lot-sizing plan. To do this, constraint 2.4 is replaced by constraint 2.4-1, while the same objective function is optimized (referred to as $\overline{Z_2}$ in this version of the model). Constraint 2.4-1 is used in order to satisfy exactly the manufacturer demand pattern.

2.4-1) $ds_{f,t} = Demandm_{f,t} \quad \forall f \in Fs, \forall t \in T$

Once, both plans are computed, the supplier used equations 3.5 to 3.7 to compute the discount structure $Discount_{\text{f,t}}$.

$ASP_{f,t}$ *Additional Supply Plan for product f at period t*

3.5) $ASP_{f,t} = \max(0;\ ds_{f,t} - Demandm_{f,t}) \quad \forall f \in Fs, \forall t \in T$

3.6) $\text{Maximum Discount} = Z_2^* - \overline{Z_2^*}$

3.7) $Discount_{\text{f,t}} = (ASP_{f,t} / \sum_{f \in F} \sum_{t \in T} ASP_{f,t}) * \text{Maximum Discount}$

In brief, $Discount_{\text{f,t}}$ represents the maximum part of the discount that can be allocated to specific (product, periods) couples, in order to increase their “attractiveness” to the manufacturers. Once this discount structure is calculated, the supplier proposes a percentage of the discount ($\alpha * Discount_{\text{f,t}}$ with $\alpha \in [0,1]$) if the manufacturer accept to increase specific part of its order plan by a percentage of the Additional Supply Plan ($\beta * ASP_{f,t}$ with $\beta \in [0,1]$). This process can be repeated several times. At each round of negotiation the manufacturer receives a new discount plan in order to further improve the coordination.

Once the manufacturer receives a discount plan, he optimizes again its lot-sizes taking into account the discount plan. To do that, the objective function and several constraints are adjusted and added.

Model 4 (Step 6): Manufacturer Optimal Plan with discount (Z_3)

Parameters

$Demandm_{j,t}$ *Initial order of products j in period t by manufacturer*

α *Percentage of a complete discount plan offered to manufacturer*

β *Percentage of a complete ASP plan demanded by supplier*

$ASP_{j,t}$ *Additional supply plan proposed by supplier to manufacturer*

$Discount_{j,t}$ *Maximum Discount Plan proposed by the supplier to the manufacturer.*

Variables

$q_{j,t}$ *Volume of product j ordered (without discount) in period t below the initial order plan*

$eq_{j,t}$ *Volume of product j ordered (with discount) in period t above the initial order plan*

z *and* $w_{j,t}$ *Binary variables used to enforce the discount structure*

Modified objective function

$Max\ Z_3$

$S.t.$:

4.1) $$Z_3 = \sum_{j\in J}\sum_{t\in T}\Big(pm_j dm_{j,t} - cfm_j ym_{j,t} - cvm_j xm_{j,t} - chm_j im_{j,t} - penalty_j bom_{j,t} - ps_{j,t} q_{j,t} - (ps_{j,t}\ eq_{j,t} - \alpha * \ Discount_{j,t} * z)\Big) - \sum_{r\in R}\sum_{t\in T} com_r om_{r,t}$$

New constraints:

4.2) $xm_{j,t} = \ q_{j,t} + eq_{j,t} \qquad \forall j \in Js, \forall t \in T$

4.3) $Demandm_{j,t} - q_{j,t} \le Mw_{j,t} \qquad \forall j \in Js, \forall t \in T$

4.4) $eq_{j,t} \le M_j(1 - w_{j,t}) \qquad \forall j \in Js, \forall t \in T$

4.5) $\sum_{t \in T} (eq_{j,t} + q_{j,t}) = \sum_{t \in T} Demandm_{j,t} \qquad \forall j \in Js, \forall t \in T$

4.6) $eq_{j,t} \geq \beta * ASP_{j,t}\, z \qquad \forall j \in Js, \forall t \in T$

4.7) $eq_{j,t} \leq ASP_{j,t} \qquad \forall j \in Js, \forall t \in T$

The objective function is similar to 1.1 except that it includes the discount (the value of α is concealed from manufacturer). Binary variable z, together with constraint 4.6, is used in order to make sure that the discount is offered if and only if all increases of order quantity demanded by the supplier are made by the manufacturer. In other words, if for a couple (product, period) the manufacturer does not respect the order increase corresponding to $\beta * ASP_{j,t}$, then the discount is not given.

Constraints 4.2 to 4.4 are used to calculate the part of the new order plan that is above the original order plan. Constraint 4.5 is used to limit the overall quantity of products ordered by the manufacturer to the level previously ordered. Similarly, thanks to constraint 4.7, the manufacturer cannot increase these quantities more than the ASP calculated by the supplier, as the impact of such increases on the supplier's profit would difficult to anticipate. If the new resulted order plan is different from the original order plan, than it is sent to the supplier to be evaluated. The supplier can then either accept this new order plan, or propose a new discount if the maximum number of round has not been reached. In this case, Step 4 does not have to be repeated.

4.5 Illustration example, quantitative analysis and discussion

This section presents an example to illustrate the proposed coordination mechanism. Next, a quantitative analysis of the performance of this mechanism is presented. Finally, a discussion of the implications of such a technique concludes this section.

4.5.1 Illustration example

Our approach is exemplified in the Tables 2, 3, 4 and 5 by considering a simple supply chain, which aims to plan the production of two products over two planning periods. In this example, the upstream planning approach produces a total supply chain profit of 1500 (Table 2). However, as suggested in the same table, which shows the result of both Step 2 (relaxed lot-size plan) and Step 3 (constrained plan), it is more profitable for the supplier to switch the production of 20 units of product 1 from period 1 to period 2, with a local potential profit increase of 1500 - 500 = 1000. In other words, this means that if the manufacturer accepts the delivery plan (i.e., relaxed plan) of the supplier, this latter will be able to increase his profit. Because the initial order plan of the manufacturer is optimal from his point of view, changing it will result in local loss of profit for the manufacturer. Therefore, in order to incite the manufacturer to do so, the supplier computes a discount to share this potential profit increase.

Table 4-2: Constrained and relaxed order plans.

				Upstream plan		Relaxed plan	
		Manufacturer (Profit = 1000)		Supplier (Profit = 500)		Supplier (Potential profit = 1500)	
		Periods		Periods		Periods	
		1	2	1	2	1	2
Products	1	20	0	20	0	0	20
	2	10	0	10	0	10	0

In order to offer a discount, the supplier computes the Additional Supply Plan and Maximum Discount Plan (Step 4), which are presented in Table 3. Because, the supplier only wants the manufacturer to increase its order for product 1 at period 2 from 0 to 20 units, the Maximum Discount Plan is entirely distributed to product 1, period 2.

Table 4-3: Supplier's additional supply plan and maximum discount plan.

		Additional Supply Plan		Maximum Discount Plan	
		Periods		Periods	
		1	2	1	2
Products	1	0	20	0	1000
	2	0	0	0	0

In the next stages, the supplier proposes in a first round of negotiation, 10% of this maximum discount plan ($\alpha = 0.1$), if the manufacturer increase its order plan for product 1, period 2, from 0 to 2 units (10% of the ASP) ($\beta = 0.1$). See Table 4.

Table 4-4: First round of negotiation.

		Proposed discount ($\alpha = 0.1; \beta = 0.1$)		Manufacturer Plan (profit = 1000)		Supplier Plan (profit = 500)	
		Periods		Periods		Periods	
		1	2	1	2	1	2
Products	1	0	100	20	0	20	0
	2	0	0	10	0	10	0

In this example, because the incentive is not sufficient to change the manufacturer order plan, the supplier increases the offered discount to 20% of the Maximum Discount Plan ($\alpha = 0.2$), for a similar increase of its order plan for product 1, period 2, from 0 to, at least, 2 units (10% of the ASP, $\beta = 0.1$), which results in both partners benefiting from improved profit compared to the original solution, as shown in Table 5.

Table 4-5: Second round of negotiation.

		Proposed discount ($\alpha = 0.2; \beta = 0.1$)		Manufacturer Plan (profit = 1200)		Supplier Plan (profit = 1000)	
		Periods		Periods		Periods	
		1	2	1	2	1	2
Products	1	0	200	10	10	10	10
	2	0	0	10	0	10	0

4.5.2 Test case experiments and results

In order to evaluate the performance of the proposed approach in different scenarios, this section presents the results of a quantitative analysis using a test case of two supply chain partners. The bill-of-material structure of this test case compared to the ones used in Dudek and Stadtler (2005) is rather complex, as illustrated in Figure 4.

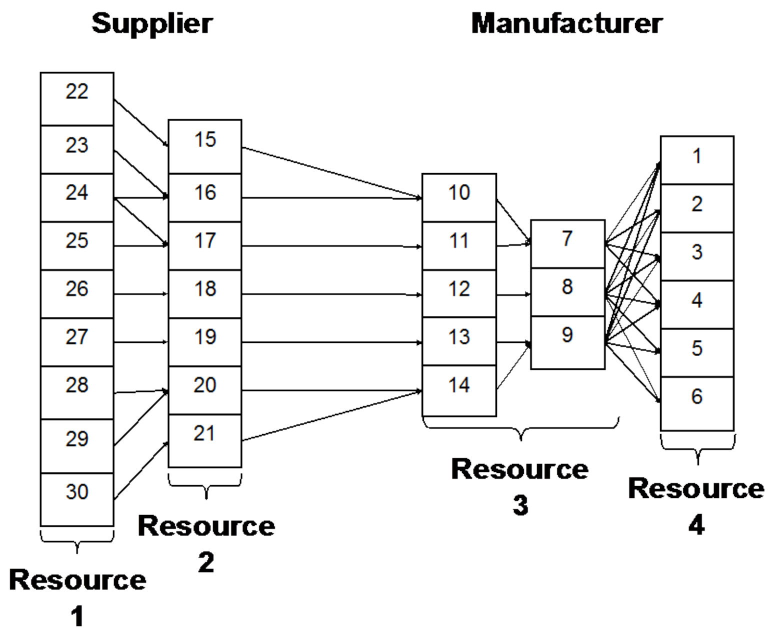

Figure 4-4: Test case bill-of-material.

The structure of the proposed test case contains 30 products for a global five-level bill-of-material produced by two partners, each of which using two resources. Five mathematical programming models were created as presented previously. Inspired by Dudek and Stadtler (2005), in order to evaluate several scenarios in terms of supplier demand/capacity ratio and overall cost structure, we designed six problems instances as presented in Figure 5., these six instances were designed by combining two supplier demand/capacity ratios and three cost structures based on the average ratio between holding and setup costs at buyer and supplier (high at manufacturer/low at supplier; low at buyer/high at supplier; equal).

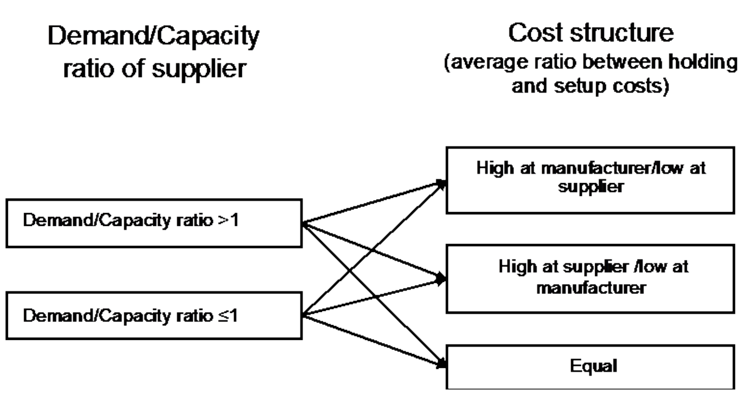

Figure 4-5: Test case instances.

In addition, for each of the six test case instances, we systematically tested the 100 combinations of α and β ($\alpha \in \{0; 0.1; 0.2; \dots; 1\}$ and $\beta \in \{0; 0.1; 0.2; \dots; 1\}$), resulting in 600 computational experiments. Furthermore, for each of the six scenarios, two benchmark solutions are computed in order to evaluate the overall performance. First, pure upstream planning was used as a lower bound for profit maximization. Second, a central planning model containing both buyer and supplier domains was considered, as carried out in Dudek and Stadtler (2005, 2007), as an upper bound of the overall problem.

The optimization models were solved using ILOG OPL 6.3 as the modeling environment and ILOG Cplex 10 as the mathematical programming solver. All problems were solved within one minute. The results are compiled in Figures 6 to 11.

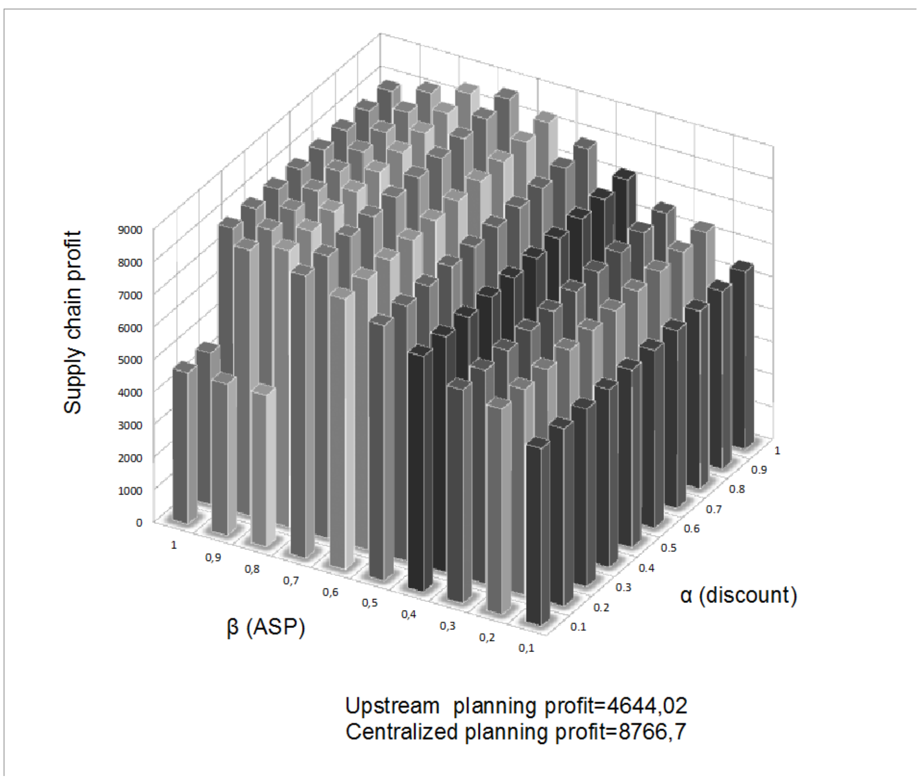

Figure 4-6: Instance 1: Demand/Capacity Ratio >1 and the average ratio between holding and setup costs are high at manufacturer/low at supplier.

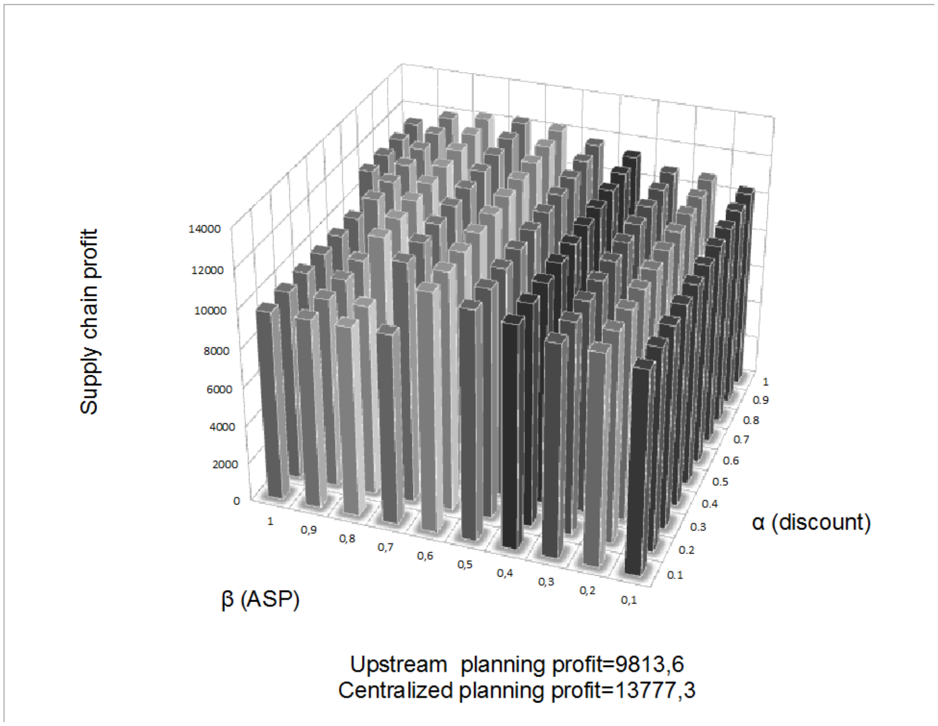

Figure 4-7: Instance 2: Demand/Capacity Ratio <=1 and the average ratio between holding and setup costs are high at manufacturer/low at supplier.

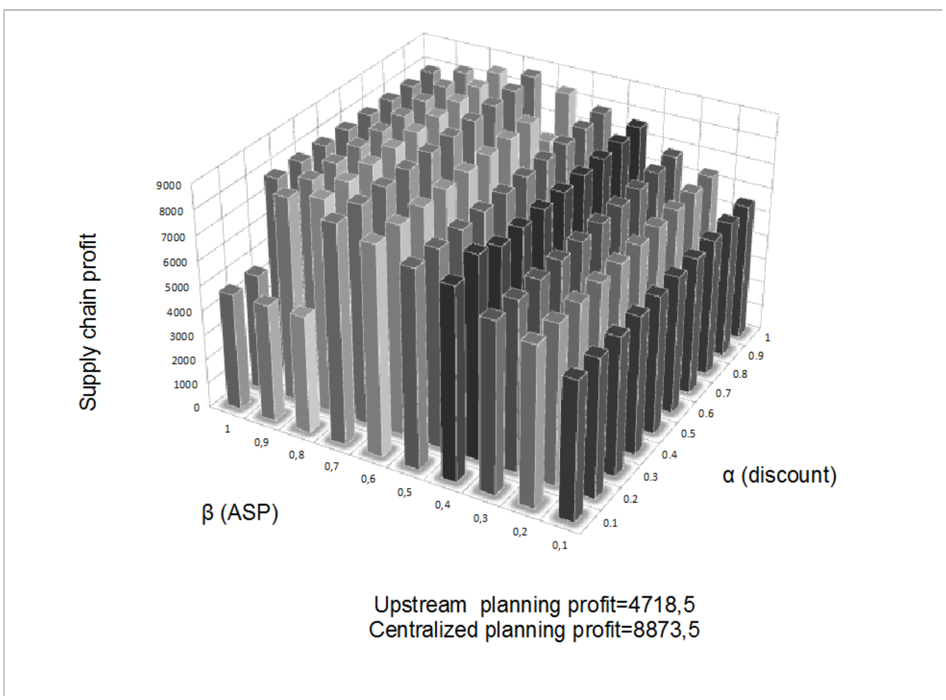

Figure 4-8: Instance 3: Demand/Capacity Ratio >1 and the average ratio between holding and setup costs are high at supplier/low at manufacturer.

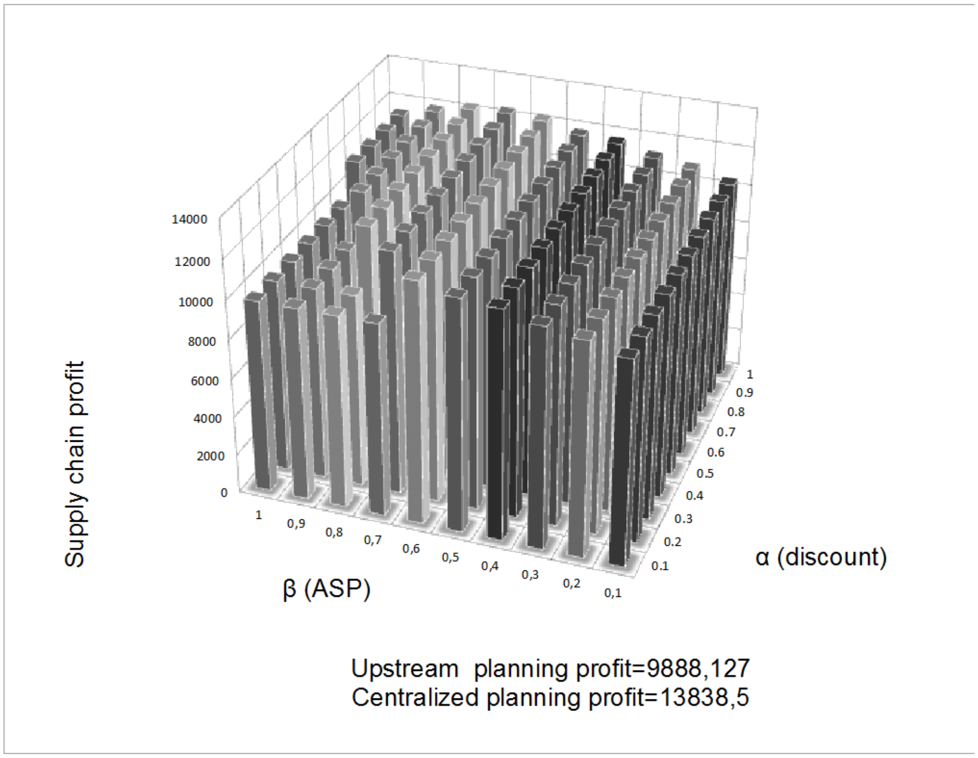

Figure 4-9: Instance 4: Demand/Capacity Ratio <=1 and the average ratio between holding and setup costs are high at supplier/low at manufacturer.

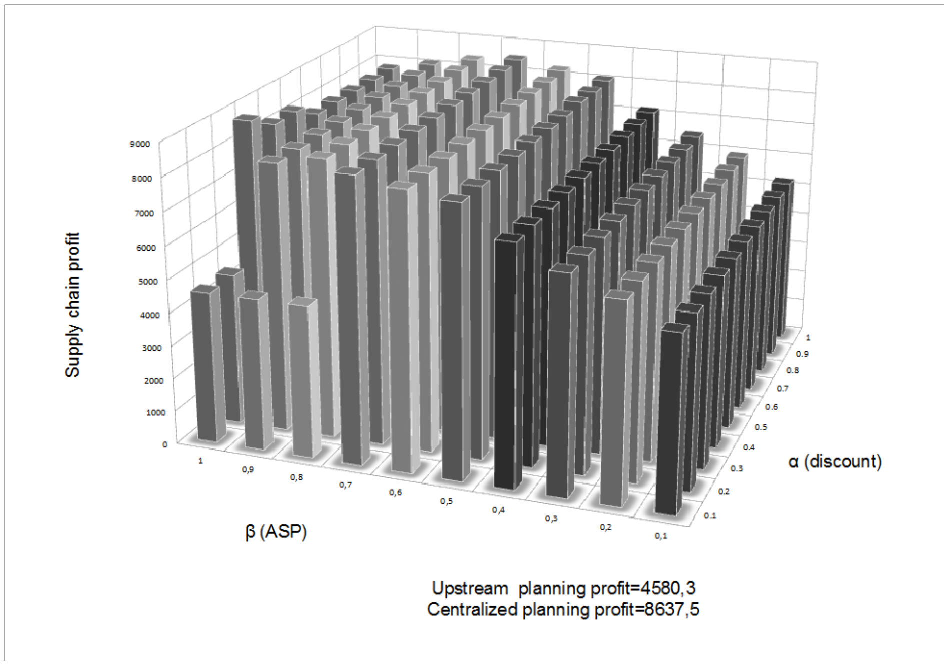

Figure 4-10: Instance 5: Demand/Capacity Ratio >1 and the average ratio between holding and setup costs are equal.

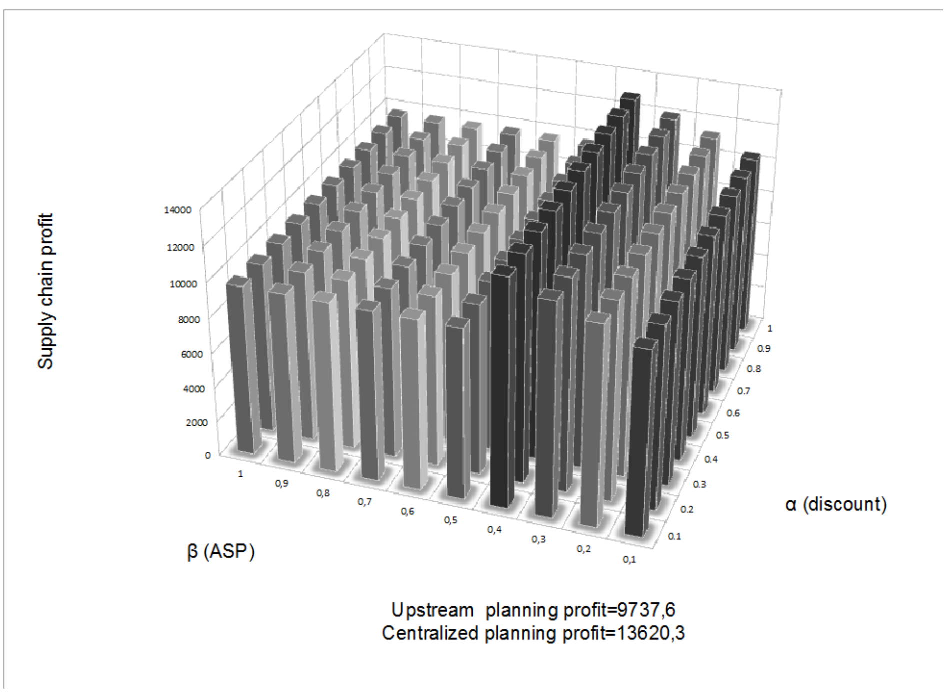

Figure 4-11: Instance 6: Demand/Capacity Ratio <=1 and the average ratio between holding and setup costs are equal.

4.5.3 Analysis and discussion

First, the results of the experiments show that the proposed coordination approach improves, for all test case instances, the overall supply chain profit compared to upstream planning. Similarly, the best combinations of α and β, within the negotiation process, increase supply chain profit near central optimality. Table 6 reports the gaps between the proposed Mutual Adjusted Search (MAS) approach and both upstream planning and central optimality in terms of supply chain profit. Table 6 reveals that the MAS approach seems to perform better when the supplier demand/capacity ratio is above 1. This is to be expected because in a context of no flexibility and scarce capacity (with respect to demand), the supplier cannot increase revenue from increased external sales. Therefore, the possibility to adjust capacity utilization profile (i.e., lot-sizes) by changing the manufacturer's demand pattern allows the supplier to generate more revenues and share part of these revenues with the manufacturer.

Table 4-6: Results of tests.

	Instances of test		**Gap between best MAS scenario and**	
			Central	Upstream
Demand/capacity ration > 1	1	High inventory cost at manufacturer	1,5 %	46 %
	3	High inventory cost at supplier	1%	46%
	5	Similar cost structure	1%	20%
Demand/capacity ration <= 1	2	High inventory cost at manufacturer	1,3 %	46 %
	4	High inventory cost at supplier	5 %	25 %
	6	Similar cost structure	11%	20%

Furthermore, from all six test case instances, it seems that α, which represents the percentage of the maximum discount offered to the manufacturer, has a stepwise impact on the overall performance when β is above a threshold, and little impact on either sides of the step. In other words, if the cost of adjusting the manufacturer's order plan can be offset by the discount offered by the supplier, then increasing this discount has no effect on the supply chain performance.

Indeed, this only increases revenue sharing, not revenue. Furthermore, the bigger the adjustment of the manufacturer's order plan (i.e, β), the bigger the discount (i.e., α) must be to offset the cost of this adjustment.

On the other hand, β has a more linear impact on performance. Indeed, when α is above a threshold, in other words when the discount is big enough to incite the manufacturer to change his order plan, then increasing β tends to increase supply chain performance. This can be explained by the fact that the closer the manufacturer's order plan to the supplier's optimal order plan, the better the performance of the supplier. This results increase profit, for the supplier through improved external sales, whether this profit is shared or not.

Furthermore, the analysis of the impact of the proposed approach on the individual profit of both partners (Figure 12) reveals that the average individual profit of both partners calculated using the best solutions (i.e., best combinations of α and β) of the six test case instances, is superior in terms of fairness to central planning, and in terms of performance to upstream planning. More specifically, this result shows that the central optimal solution is achieved at the cost of a loss of profit for the supplier, while the proposed approach improves upstream planning by increasing both partners' profit. Although the results reported in Dudek and Stadtler (2005) show similar performance in terms of cost reduction, this specific aspect cannot be compared to their approach, which do not directly address revenue sharing.

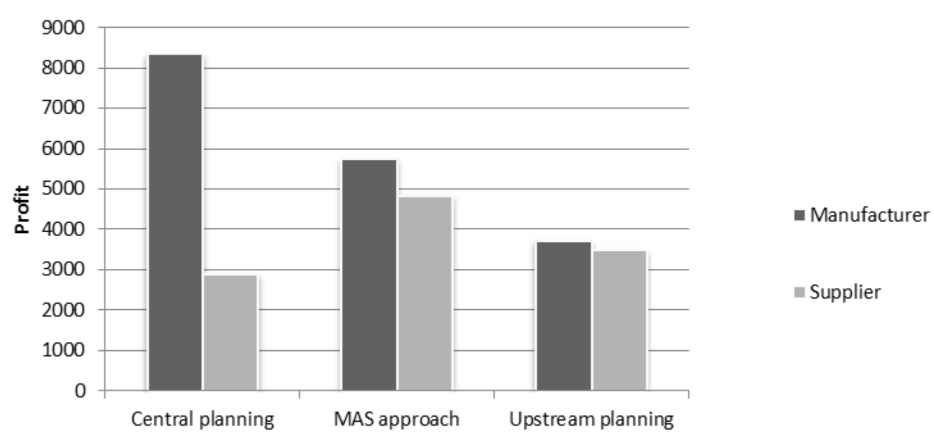

Figure 4-12: Individual profits comparison.

Although the overall results are encouraging, the proposed approach is based on the hypothesis that even a partial adjustment of the manufacturer's order plan towards the optimal supplier's order plan can improve the economic performance of both partners. Even if this seems empirically the case, the mathematical proof of this hypothesis is complex. Therefore, the performance of this type of incentive must be studied further. Another aspect that must be carefully studied is the impact of the principles of added value (i.e., value creation) and product convergence on the performance of such techniques. In other words, many supply chains are systems that add value throughout their processes by assembling products together. Therefore the value of products produced downstream is superior to the components and subassembly produced upstream, which may suggest higher opportunity cost downstream. Consequently, one may hypothesize that adjusting downstream operations might be more costly than adjusting upstream operations, which tends to limit the usability of such incentives. For instance, if the supplier proposes to deliver earlier, due to limited inventory holding capacity or for transportation consolidation, then the discount must compensate for an increased cost of inventory for the manufacturer, who does not have to adjust his production operations. However, if the supplier proposes to delay the delivery, then his discount must compensate for a series of more complex effects on the manufacturer's cost structure, mainly related the bill-of-material. More specifically, if a component of a product has a delayed delivery, then the production of this product has to be delayed as well incurring potentially penalty cost for late delivery to the distributor, missed opportunities due to unavailable capacity, and inventory hold cost for the other components. However, manufacturer discounts exist and are used in practice, although not for direct coordination purpose, but to increase sales. Therefore, this type of incentive should also be carefully studied with respect to its practical usability and impact.

Finally, the proposed approach is a distributed heuristic search with local optimization because only a small part of the coordination space is collectively investigated. Indeed, the coordination space is discretized through the use of a finite set of β's values, which limits the investigated solutions between the original order plan of the manufacturer and the optimal relaxed plan of the supplier. No other solution further from these solutions is investigated. Therefore, although it is a quick improvement of the upstream planning solution, optimality cannot be guaranteed.

4.6 Conclusion and future directions

In this paper, we present a distributed heuristic search with incentive to coordinate operations planning between two partners of a supply chain. This approach is based on an iterative negotiation between two local decision making units. It is a non-hierarchical mechanism, which gives the same decision authority to both partners without any exchange of sensitive information, unlike the pioneer approach of Dudek and Stadtler (2005 and 2007), in which cost information is exchanged in the form of compensations requested by buyer, to offset his cost increase above his initial cost. The proposed incentive system is used in order to encourage the manufacturer to participate in coordination process and to address simultaneously material and financial flows. Computational results show promising results, with significant improvements compared to upstream planning, as well as small gaps with the centralized planning approach for all test instances.

Future work may be carried out in several directions. First, this approach is currently being investigated within a rolling horizon planning context, which addresses the practical usability and performance of the approach. Second, the negotiation-based coordination can be extended to the relationships of more than two partners in order to consider supply chain practical environments. Third, the concept of distributed local search and the design of alternative neighborhood structures is also an interesting aspect to study as other neighborhood structures could generate better solutions while being less disruptive for the manufacturer. Fourth, the need to address the usability of such coordination mechanisms in realistic environment, which involved heterogeneous planning support systems, requires studying the possibility to create standards of coordination incentive mechanisms. Such standards would allow different planning support systems to exchange and exploit information in a coherent manner in order to coordinate supply chain partners. Many other incentives structures can be designed and standardized for specific applications. Finally, another more complex issue to address is the concept of behavior anticipation. During the negotiation-like process, partners could learn over time how to anticipate the reaction of their counterpart in order to further improve coordination. In the proposed approach, it is necessary for the supplier to evaluate the new manufacturer order plan in order to know how the incentive was used and ultimately whether or not it leads to improved profit for the supplier. Therefore, the design of more efficient coordination incentive structures might be enabled through the design of effective anticipation mechanisms, which could investigate more promising solutions of the coordination space.

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CHAPTER 5 : ARTCILE 3: DYNAMIC MUTUAL ADJUSTMENT SEARCH FOR SUPPLY CHAIN OPERATIONS PLANNING COORDINATION

Operations Planning is an activity carry out by all manufacturing and logistic companies. Its coordination with supply chain partners aims at synchronizing resources utilisation in order to minimize inefficiencies, such as unnecessary inventory holding, or in order to improve revenue through better resource utilization. It is a rather complex process as partners have different objectives and information asymmetry is part of any effort to find good coordination solutions. Furthermore, because supply chains evolve in a dynamic and uncertain environment, once a coordination of operations plans is achieved, input data, such as forecasts or resources' status, can change and affect on hand plans. These dynamic changes not only require updating the plan that is directly affected by the changes, but it also requires the adjustment of all plans that are part to the same coordination solution (Stadtler 2009). Therefore, the development of a practical coordination approach should be capable of dealing with these dynamic changes. This paper proposes a dynamic mutual adjustment search heuristic, which can be used to coordinate the operations plans of two independent supply chain partners, linked by material and non-strategic information flows. Computational analysis shows that the proposed approach produces a win-win strategy in the context of two supply chain partners, and improves the results of upstream planning in each planning cycle, and also improves the fairness of revenue sharing when compared to optimal centralized planning.

Keywords: Supply chain management, coordination, mutual adjustment search, rolling horizon planning

5.1 Introduction

Supply chains are distributed networks of interacting companies in a dynamic environment, which have to plan their operations in order to fulfill their commitments (e.g., the delivery of goods, the providing of a service) and achieve their performance objectives. The goal of supply chain management is the improvement of supply chain performance through the coordination of supply chain partners' resource utilization in this dynamic environment. A more specific approach to achieving this goal is the coordination of operations planning activities in order to synchronize operations plans. Here, the concept of coordination space represents the set of all possible coordination solutions (i.e., vectors of operations plans of all considered supply chain partners) that satisfy the constraints of all partners.

The literature on supply chain operations planning coordination can be divided into two main streams of research: centralized vs. decentralized approaches. In centralized approaches, a central unit provides optimal plans for all supply chain members. Because they use a global view of supply chain operations, these approaches can theoretically produce an upper level of supply chain performance. In spite of performance optimization, the implementation of centralized approaches requires a high degree of collaboration and information exchange among supply chain partners. Sometimes it is even necessary to share strategic information, like cost structures or bill of material, which could be used against partners to gain an undue advantage. Furthermore, centralized approaches of coordination are generally implemented through hierarchical relationships, which are only seen in large integrated supply chains. Therefore, centralized approaches of operations planning coordination are not practical solutions when supply chain partners are different companies that do not want share their critical information.

Opposite to central approaches, decentralized approaches are designed by explicitly considering the distributed nature of supply chains, in which each member is modeled as a separate decision-making entity with private strategic information. The simplest form of decentralized planning is upstream planning, or a one-way information flow (Azevedo et al. 2005, Dudek and Stadtler 2005), which can be considered as a weak form of hierarchy (Schneeweiss 2003). In fact, it is a cascade form of coordination in which partners independently plan their operations and send their own dependent demand to their suppliers. Because it is a rather simple form of coordination that is actually used in practice, upstream planning produces a lower bound of supply chain performance.

The research question addressed in this paper is how independent operations planning efforts can be coordinated in order to achieve near-optimal planning in a simple dyadic supply chain in a dynamic environment. Dynamic environment are characterized by continuously changing input data, such as updated forecasts or resource status, which has a ripple effect on partners because past decisions need to be updated. More specifically, we extend an approach first introduced in Taghipour and Frayret (2011b), and develop a mutual adjustment search (MAS) mechanism, in the form of a negotiation strategy, and evaluate the performance of this mechanism in a rolling horizon approach, in order to address the coordination of operations planning of a simple dyadic supply chain in a dynamic environment.

In brief, this mechanism involves two independent manufacturing companies, which interact with each other in a dynamic environment in order to improve their collective performance. Both companies plan their operations and decide, for each time period, what and how much to produce and deliver (i.e., multi-level capacitated lot-sizing problem). In the context of dynamic environment, input data, such as demand forecasts, are updated (between two planning cycle), and the output-input dependencies of both companies are updated using a mutual adjustment search, described in Section 3.2.

This approach requires only a minimum level of information sharing, because partners use financial incentives in order to influence their partner's planning, allowing them to deal simultaneously with material flows coordination and revenue sharing, unlike the pioneer approach of Dudek and Stadtler (2005 and 2007).

Our objective is to develop and to demonstrate that MAS can improve supply chain coordination in a dynamic environment, compared to centralized planning and upstream planning. As discussed previously, these approaches are respectively used as upper and lower bounds in order to benchmark our approach. Computational tests show that MAS can coordinate supply chain partners, improve result of upstream planning, even produce near-optimal solution in certain instances, as well as achieve a more fair sharing of increase revenue than central planning.

The reminder of this paper is organized as follows. A literature review is presented in Section 2. Then, Section 3 introduces the MAS approach. Section 4 present the experiments carried out to demonstrate the performance of the proposed approach in a dynamic context. Finally, Section 5 concludes and presents directions for future research.

5.2 Literature review

As mentioned in the Section 1, centralized planning cannot be reasonably implemented as an efficient coordination of operations planning in supply chains with different companies. Indeed, it requires an unrealistic level of information exchange that is a deterrent to such a practice. In order to deal with these difficulties, the literature proposes many different paradigms of decentralized planning to address the coordination of independent partners.

Based on an analysis presented by Taghipour and Frayret (2011a), the literature that specifically deals with supply chain operations planning coordination can be classified into five main techniques and different sub-techniques. Following is a brief description of these coordination approaches.

Exact decomposition and constraint-based techniques

Based on mathematical decomposition techniques, these approaches decompose a large supply chain planning coordination problem into several distributed sub-problems, which are solved, generally by using some form of mediator, which acts as a coordinating agent that does not really make any decision, but rather support the other company agents coordinate their operations plans. Because these techniques are rooted in exact mathematical decomposition approaches, the coordination process involves generally an exact search within the coordination space, as well as exact local optimizations techniques. The adapted decomposition techniques are: *Lagrange decomposition* (Barbarosoglu and Özgür 1999, Chen and Chu 2003, Ertogral and Wu 2000); *Bender's decomposition* (Poundarikapuram and Veeramani 2004, Uster et al. 2007)*; Dantzig-Wolfe decomposition* (Holmgren et al. 2009). To this class of approaches, we also include a comprehensive *distributed search with constraint propagation* (Gaudrealt et al. 2009), which has theoretically the potential to identify the optimal solution. Although these are powerful mathematical tools to coordinate local decision processes, the main issue of their application concerns the difficulty to interpret the information exchanged between the sub- and the master problems by operations managers. Furthermore, only the last approach of *distributed search with constraint propagation* is a method that has a weak dependency link between the coordination process and the local planning tools (i.e., which can be legacy advanced planning and scheduling systems-APS), and requires minimal information exchange.

Hierarchical planning and information sharing techniques

Initiated by Hax and Meal (1975), some authors propose to decompose the overall decision problem into a hierarchy problem and sub-problems linked by master/slave relationship in order to simplify the central complex problem into interdependent planning functions. Coordination is carried out in a cascade process from long term to short term decisions, or from customer to supplier. These approaches use some form of greedy/one-way information exchange to coordinate their input/output dependencies. This basic principle has implemented in various coordination techniques, referred to as: *greedy coordination*; *information sharing and anticipation model*; and *partial aggregation of decision domains.* The simplest technique in this class of coordination approaches is *greedy coordination*, which consists in a simple one way exchange of information, also referred to as *upstream planning* (Bhatnagar et al. 1993). *Partial aggregation of decision domains* is a hybrid (Pibernik and Sucky 2007) coordination approach between centralized and upstream planning in order to fill the performance gap of upstream planning. Finally in *information sharing and anticipation model*, partners exchange more or less strategic information to coordinate one another. For instance, Váncza et al. (2008) proposes a mechanisms in which one partner sends its non-strategic information like its demand forecast as well as its penalty mechanism in order to improve the upstream planning approach. The main issue with the class of coordination approach is the absence of a systematic search of the coordination space.

Heuristic search techniques

In this class of techniques, partners progressively adjust their local initial plans through some form of local search procedures that involve iterative information exchange. Here, partners are capable of mutually adjusting their operations plans according to the constraints or capabilities of their partners. This form of coordination techniques requires the design of a convergence mechanism to guarantee the improvement and the feasibility of the collective plan, as well as termination conditions in order to stop the incremental process of mutual adjustment. These techniques use a heuristic search (i.e., not an exact method) during the coordination process. Interaction mechanisms between supply chain partners can be either implicit (i.e., fixed and programmed) or explicitly formalized as an interchangeable interaction protocol that can be selected via an intelligent proces (i.e., used by intelligent software agents). This class of approaches can be divided into several sub-classes: distributed heuristic search with local optimization (Dudek and Stadtler 2005, Jung and Jeong 2005, Taghipour and Frayret 2010 & 2011b), meta-heuristic search (Silva et al. 2006), and interaction based coordination (Azevedo et al. 2005). Distributed heuristic search with local optimization involves the exploration of the coordination space through iterative techniques between two partners that optimize their own operations plans with advanced planning and scheduling tools. Meta-heuristic searches propose to adapt meta-heuristics, such as ant colony optimization, in order to develop local optimization tools capable of exchanging specific information, such as pheromone matrix, to coordinate local operations planning. These approaches, however, are less practical because they tend to force supply chain partners to adopt highly specific meta-heuristic APS systems. Finaly, interaction-based coordination approaches propose to formalize interaction protocols (e.g., finite state machine, UML, Petri nets) used within a fixed set of business rules by reactive software agent. These approaches implement heuristic form of specific information exchange tied with the use of specific local optimization tools in order to carry out the operations planning coordination process.

Intelligent and adaptive techniques

Based on intelligent agent technology, this class of approaches exploits various advanced technics of goal-driven planning and learning in order to develop software agents capable of adapting to their environments in order to choose the most appropriate action to perform to coordinate their planning decisions with other agents. In fact, in this class, instead of focusing on the interaction as the main mode of coordination (as in interaction-based coordination), the focus is put on the adaptive behavior of the agents, which of course involves interacting with others. Because of this, such coordination approach can be referred to as adaptive heuristic coordination because the coordination process still remains heuristic. For instance, Cloutier et al. (2001) propose a *commitment-based coordination approach*, in which deliberative agents have the ability to commit to do certain task, and plan their own course of actions to plan their manufacturing and logistics operations in order to meet these commitments. Similarly, *argument-based agent* involves the construction and exchange of arguments that agents believe will make their counterpart look more favorably upon their proposal (Jennings et al. 2001). Another form of adaptive techniques are *multi-behavior agents* (Forget et al. 2008), which also have the ability to select their own course of actions according to, specific goals to maximize a utility function or reach a goal. *Learning-based* *agents* (Fox et al. 2000) can also adapt by progressively discovering, through machine learning techniques, the best course of action in specific situations.

Bidding-based techniques

Rooted in economics and market mechanisms, these techniques involve several forms of coordination techniques based on negotiation. The general form of coordination of operations between an initiating company and others is made through the selection of partner(s), whose offers are more efficiently coordinated with the initiating company. These approaches are often based on the Contract-net introduced in Davis and Smith (1983), which is intended for decentralized tasks allocation. In this technique, an initiator company sends a call-for-proposal to several potential partners, and receives bids from them. Although bids are generally derived from one single planning alternative (Ahn and Lee 2004, Calosso et al. 2003, Hu et al. 2001), they can also contain several alternative sub-proposals to choose from, each one being derived from different local planning alternatives, as proposed in D'Amours et al. (1997). Another, bidding technique that is also used is auction, as proposed by Lee and Kumara (2007), who developed a hierarchical auction structure of tasks allocation and coordination.

Based on the analysis of the literature presented by Taghipour and Frayret (2011a), out of almost 120 selected contributions to the supply chain planning coordination problem, less than 23 % of these contributions consider the dynamic nature of supply chain coordination. This paper proposes to contribute to this gap by extending the approach introduced by Taghipour and Frayret (2011b) and introduce a *distributed heuristic search with local optimization* coordination technic, in which two partners iteratively explore the coordination space using a heuristic search algorithm based on financial incentives.

5.3 Problem statement and approach overview

The specific supply chain planning coordination problem addressed in this paper is a distributed Multi-Level Capacitated Lot-Sizing Problem (d-MLCLSP) in a dynamic environment. In other words, two supply chain partners, bound by input/output constraints, must simultaneously solve their local MLCLSP, while coordinating their decisions with their supply chain partner, taking into account their local capacity constraints, which may be adjusted using overtime, and their local bills-of-material. The design of the coordination approach presented hereafter was driven by the need to not share any kind of strategic information, such as cost structures, capacity utilization profiles and external demands. In this specific contribution, we also considered the need to develop a method that directly addresses the dynamic nature of supply chain coordination.

The proposed approach is called *Dynamic Mutual Adjustment Search* (DMAS) and uses financial incentive. In fact, the use of an incentive system allows partners to iteratively explore a small set of alternative *Order Plans* (OP), in order to improve the plans initially created through upstream planning.

An OP is the matrix of the manufacturer's order to the supplier for all products and all time periods of the planning horizon. In the proposed iterative coordination process, partners exchange proposal in the form of alternative order plans and financial incentive, which must be evaluated by the partner in order to assess its feasibility and its impact on profit. In this mechanism, financial incentives are used by supplier to incite the manufacturer to adjust its original *OP,* referred to as the upstream planning order plan.

In this mechanism, the supplier first identifies its optimal plan, in the neighborhood of the plan derived from the manufacturer's original OP. The positive difference between these two plans (supplier optimal plan and plan derived from manufacturer's original plan) is referred to as the *Additional Supply Plan (ASP)* matrix, which represents the supplier's desire to increase the original order for specific products at specific time periods in order to improve its profit. Next, the supplier calculates the *Maximum Discount* (MD) that can be offered to the manufacturer if he accepts in totality to coordinate his OP in accordance with the *Additional Supply Plan (ASP)* of supplier. The *Maximum Discount* is defined as the gap between the profit generated from delivering its local optimal plan and the profit generated from delivering the manufacturer's original OP. Finally, using the ASP and the MD, the supplier defines and offers a *Discount Plan* (DP) to the manufacturer, which consists in offering part of the *MD* for an adjustment of the original OP equal to part of the *ASP*. In other words, if the manufacturer accepts to increase its original order plan for specific products at specific time periods up to at least the specified portion of the ASP, than a fixed discount is offered to the manufacturer. This incentive is radically different from typical quantity discount, which are proportional of the volume order. In this approach, the incentive is a fixed amount that is either given or not according to its impact on the manufacturer's profit.

These negotiation-like interactions are based on minimal level of information sharing (Figure 1). Unlike the pioneer approach proposed by Dudek and Stadtler (2005), which requires partners to exchange cost improvements along with the OP at each step of the negotiation process, the proposed approach propose to use a dynamic discount structure that is progressively adjusted in order to find a compromise OP without sharing cost information. Furthermore, this approach addresses the coordination of both material and financial flows simultaneously.

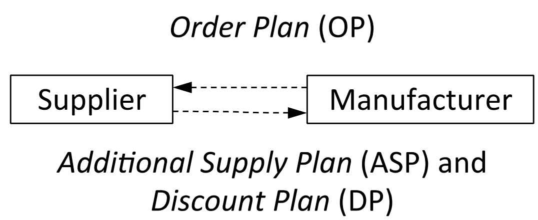

Figure 5-1: Exchanged information (Taghipour and Frayret 2011b).

5.3.1 Calculation of Maximum Discount Plan (MDP)

As it is mentioned in the above section, after calculating the plan derived from manufacturer's proposed original OP (i.e., upstream plan) and identifying his optimal plan, in the neighborhood of this proposed original OP, supplier calculates the positive difference between these two plans, referred to as the *Additional Supply Plan (ASP),* The ASP represents the supplier's desire to increase the original order plan for specific products at specific time periods. In addition, the supplier calculates the *Maximum Discount*, as the gap between the profits generated from these two plans.

In the next step, the *Additional Supply Plan* is normalized in the form of a weight matrix (in which the sum of all elements is equal to one and each element is less than or equal to one), in order to know how the *Maximum Discount* should be split between all products and all time periods to focus the incentive towards the most significant elements of the gap between both lot-sizing plans.

Indeed, the weight matrix, which is referred to as the *Normalized ASP* shows the degree of importance of each element of ASP, simply by dividing each element of ASP matrix by the sum of all rows and columns of this matrix. The rebate structure (plan) is calculated by distributing the

Maximum Discount to all product-period couples proportionally to the *Normalized ASP*. This results in the definition of a *Maximum Discount Plan* as shown in Figure 2.

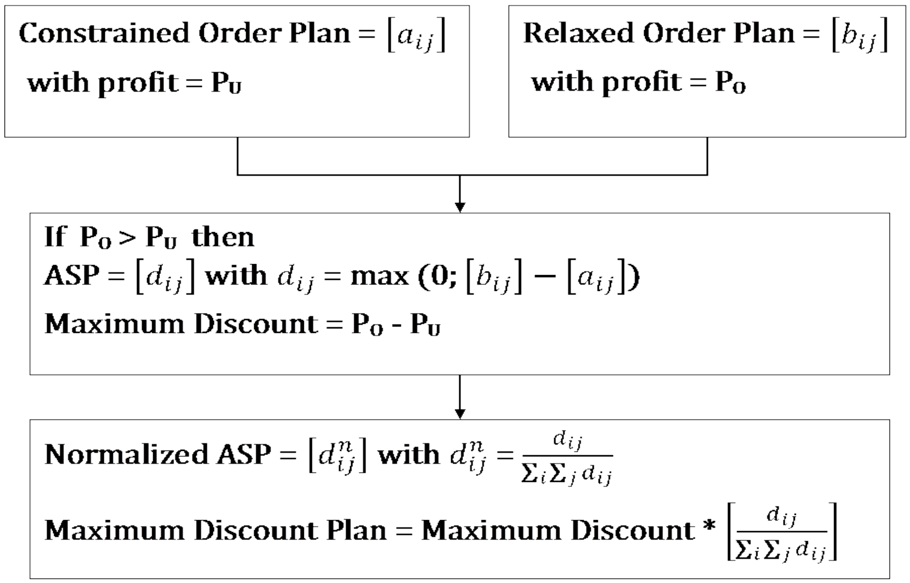

Figure 5-2: Generation of rebate plan by supplier (Adapted from Taghipour and Frayret 2011b).

The aim of this *Maximum Discount Plan* is to generate a base in order to propose different *Discount Plans* (DP) to encourage manufacturer deviate from its original order plan.

5.3.2 A negotiation strategy as a heuristic coordination search

First, as proposed by Taghipour and Frayrer (2011b), a mutual adjustment search can be used between two partners in order to mutually adjust their plans by exploring the coordination space and to improve the result of upstream planning, which is only optimal for the manufacturer. As explained in the previous sections, the supplier produces and proposes iteratively different *Discount Plans (DP)* derived from his *Maximum Discount Plan* in order to incite the manufacturer to participate in the planning coordination action. The goal of proposing a discount is to compensate the manufacturer from any deviation of his optimal plan. In other words, the manufacturer can gain a *Discount Plan*, if he accepts to increase his original order plan for specific products at specific time periods up to at least the proposed specific portion of the *Additional Supply Plan (ASP)* proposed by the supplier. More specifically, at every round of the mutual adjustment, α percent of *Maximum Discount Plan*, referred as *Discount Plan (DP)* (DP= α * MD, 0≤α≤1) is proposed to the manufacturer, if he accepts to increase his original OP up to β percent of *Additional Supply Plan (ASP)* (β * ASP, 0≤β≤1). In this coordination approach, the coordination space that is potentially explored is therefore limited to any combination of α and β, which is a small subset of the actually coordination space. A simple example of exploring this coordination sub-space is presented in following figure. Here, the oriented arcs represent the potential moves from a discount plan proposal to another according to the heuristic proposed in this paper.

First, if the manufacturer refuses a given discount plan, the supplier simply reduces the deviation asked to receive the discount (i.e., β) until the manufacturer accepts the discount plan. At this point, the supplier must validate any adjustments made to the order plan by the manufacturer upon the receipt of this discount plan. If the supplier does not improve its initial profit with this new order plan, it decreases the discount (i.e., α) offered to the manufacturer without adjusting the deviation asked (i.e., β). This process is based on the hypothesis that the manufacturer trusts the supplier's will to improve the total profit of both partners. If there is no trust, for instance if the supplier only decreases the discount (i.e., α) in order to increase its own profit by simply taking advantage of the manufacturer, it is highly likely that over time, the negotiation will fail and the initial upstream planning solution will be used.

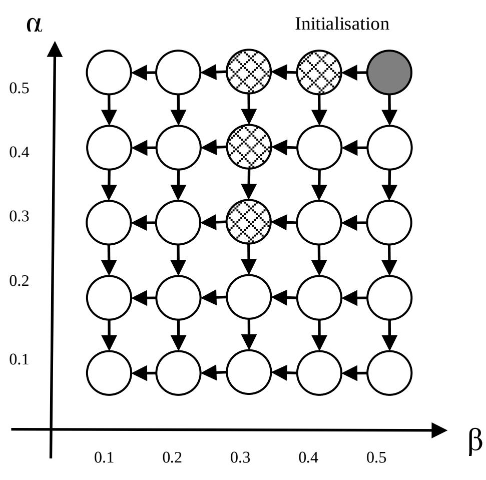

Figure 5-3: Mutual exploration of coordination space by couples of α & β.

Figure 3 illustrates the proposed heuristic negotiation to improve the result of upstream planning. The supplier starts the adjustment by proposing a predefined couple α and β (for example α=0.5 and β=0.5). Using these values, the manufacturer optimizes its operations trying to take advantage of the discount plan. If the manufacturer accepts this discount plan, he sends a new order plan to the supplier. If he does not accept the discount plan, he does not change his original order plan. In this case, the supplier adjusts what he asked the manufacturer by decreasing the portion of ASP demanded with an inferior value for β (here, β=0.4), but keeping the same *discount* (same α). This adjustment continues until the manufacturer accepts the discount and sends a new order plan. At this point, the supplier evaluates whether or not this new order plan increases his profit. If his profit does not increase its profit, then he does not accept the new order plan and adjusts the discount by reducing the value of α (here, α=0.4). This process continues until both partners accept the discount plan and its associated new order plan. If there is no agreement, then the upstream planning solution is the final solution. The mutual adjustment search can be terminated after certain number of iteration.

Figure 5-4: Mutual adjustment including a search algorithm to explore the coordination space by couples of α and β.

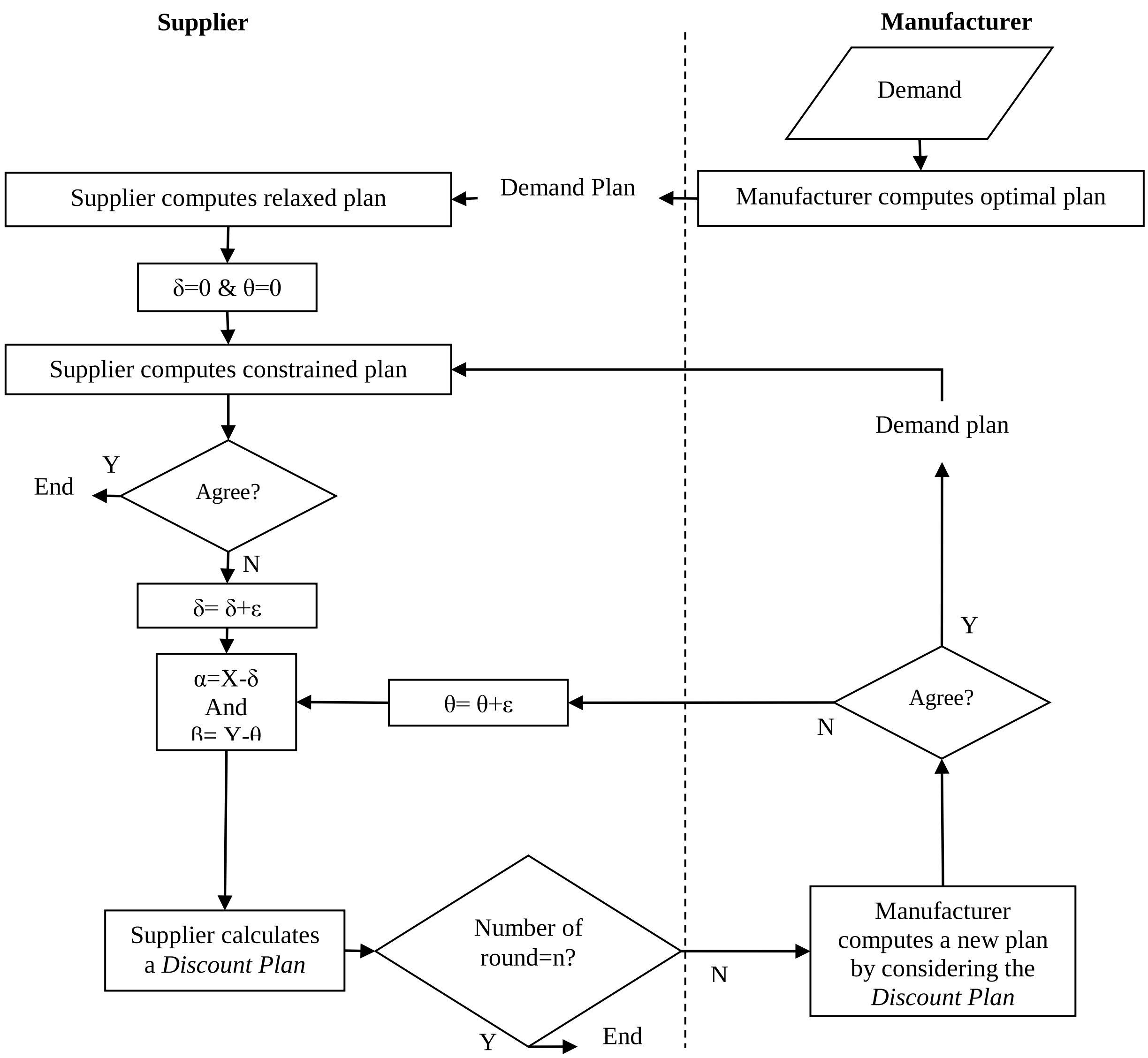

Figure 4 presents the complete Mutual Adjustment Search (MAS), which includes the negotiation strategy described above. This heuristic approach can be summarized as follow.

<u>Step 1: Manufacturer plans his operations</u>

During the first stage, the manufacturer receives its external demand from his distributor and optimizes his operations plan to maximize his profit, and sends his derived dependent OP (i.e., $Demandm_{f,t}$) to the supplier.

Step 2: Supplier optimizes its operations with relaxed input/output constraints

When the supplier receives the manufacturer's original OP, he first computes a relaxed lot-sizing plan, which only considers an aggregated input/output constraint that consists in satisfying the total quantity ordered by the manufacturer over the planning horizon, and not the exact demand pattern.

Step 3: Supplier optimizes its operations without relaxed input/output constraints

Next, the supplier calculates his upstream plan by considering the exact manufacturer's original order plan (i.e., constraint based plan). This new plan leads to a second lot-sizing plan, which, in terms of profit, is, at best, equivalent to the relaxed plan.

Step 4: Supplier evaluation

If there is a significant difference of profits between these two plans (profit derived from relaxed plan-profit derived from upstream plan), the supplier calculates a *Discount Plan* in order to initiate the mutual adjustment process and incite the manufacturer to change his initial order plan.

Step 5: Calculate Discount Plan

As explained previously, the supplier first calculates the *Additional Supply Plan* and the *Maximum Discount* (i.e., the potential profit improvement) as illustrated in Figure 2. Next, the *Additional Supply Plan* is normalized in order to know how the *Maximum Discount* should be split between all products and time periods in order to focus the incentive towards the most significant elements of the gap between both lot-sizing plans. Then, *Maximum Discount* is multiplied by the *Normalized ASP*. The result is the *Maximum Discount Plan*. Next, using the heuristic negotiation strategy, at each round of the procedure, α percentage ($\alpha \in [0,1]$) of the *Maximum Discount Plan (Discount Plan*= α * *Maximum Discount Plan*, $0 \leq \alpha \leq 1$) is offered for an increase of the manufacturer order plan equivalent to a β percentage ($\beta \in [0,1]$) of the *Additional Supply Plan*.

Step 6: Manufacturer optimizes his lot-sizes with new incentive

Next, the manufacturer computes the new lot-sizes taking into account the proposed *Discount Plan* sent by the supplier. If a new OP is computed, then it is sent to the supplier for evaluation in order to know the impact of this new OP and its associated discount plan on his profit. The supplier can then either accept this new OP or propose a more encouraging *Discount Plan* as discussed previously. Similarly, if the manufacturer does not change his original OP, the supplier can either accept it, returning to the initial upstream planning solution, or again propose a more encouraging *Discount Plan*.

The mutual adjustment can be terminated if both partners accept the discount and the new order plan, or after a certain number of iterations, which implies that no solution has been found and that the original order plan is the final solution.

5.3.3 Mathematical models

During the different steps presented in the previous section, mathematical models are used to optimize lot-sizes in specific situations. As mentioned previously, these planning models are multi-level capacitated lot-sizing models, inspired by Erengüc *et al.* (1999) and presented in Taghipour and Frayret (2011b). They are profit maximization in order to address both material and financial flows coordination.

Model 1 (Step 1): First Manufacturer Optimal Plan (Z_1)

The first models correspond to Step 1 when the manufacturer first optimizes his lot-sizes without considering any incentive.

Index sets

T *Set of time periods*

J *Set of products produced by the manufacturer*

J_j^s *Set of products directly succeeding product j in the bill of material (BOM)*

Indices

t *Time period, $t \in T$*

j *Products produced by the manufacturer, $j \in J$*

Parameters

ps_f *Unit price of product f produced by supplier*

$penalty_j$ *Back order penalty for the manufacturer product j delivered to distributor*

$D_{j,t}$ *Demand for product j in period t (produced by manufacturer)*

$u_{j,g}$ *Unit requirement of product j by successor operation/product g ($g \in J$)*

pm_j *Unit price of final product j produced by manufacturer*

cfm_j *Fixed production setup cost of product j produced by manufacturer*

cvm_j *Unit variable production cost for product j produced by manufacturer*

chm_j *Unit holding cost for product j produced by manufacturer*

com_r *Unit cost of overtime (capacity expansion) of resource r for manufacturer*

$cm_{r,j}$ *Unit requirement of resource r to produce one unit of product j by manufacturer*

$Cm_{r,t}$ *Production capacity of resource r in period t for manufacturer*

M *A large number, which corresponds to the maximum quantity of product j that can be produced in a time period*

Variables

$dm_{j,t}$ *Tentative delivery quantity of product j in period t to the distributor*

$om_{r,t}$ *Overtime of resource r in period t for manufacturer*

$xm_{j,t}$ *Output of operation/product j produced (or demanded from supplier) by manufacturer in period t (order plan)*

$ym_{j,t}$ *Setup binary variable for production of product j produced by manufacturer in period t*

$im_{j,t}$ *Inventory level of product j in period t*

$bom_{j,t}$ *Back order of product j produced in time t by manufacturer and delivered to distributor*

$Max\ Z_1$

$S.t.$:

1.1) $$Z_1 = \sum_{j \in J} \sum_{t \in T} \big(pm_j dm_{j,t} - cfm_j ym_{j,t} - cvm_j xm_{j,t} - chm_j im_{j,t} - ps_j xm_{j,t} - penalty_j bom_{j,t} \big) - \sum_{r \in R} \sum_{t \in T} Com_r om_{r,t}$$

1.2) $$im_{j,t-1} + xm_{j,t} = dm_{j,t} + \sum_{g \in J_j^s} u_{j,g} xm_{g,t} + im_{j,t} \qquad \forall j \in J, \forall t \in T$$

1.3) $$bom_{j,t} = bom_{j,t-1} - dm_{j,t} + D_{j,t} \qquad \forall j \in J, \forall t \in T$$

1.4) $\sum_{j \in J} cm_{r,j}\, xm_{j,t} \leq Cm_{r,t} + om_{r,t} \qquad \forall j \in J, \forall t \in T$

1.5) $xm_{j,t} \leq M\, ym_{j,t} \qquad \forall j \in J, \forall t \in T$

1.6) $xm_{j,t} \geq 0 \qquad \forall j \in J, \forall t \in T$

1.7) $dm_{j,t} \geq 0 \qquad \forall j \in J, \forall t \in T$

1.8) $om_{j,t} \geq 0 \qquad \forall j \in J, \forall t \in T$

1.9) $im_{j,t} \geq 0 \qquad \forall j \in J, \forall t \in T$

1.10) $bom_{j,t} \geq 0 \qquad \forall j \in J, \forall t \in T$

1.11) $ym_{j,t} \in \{0,1\} \qquad \forall j \in J, \forall t \in T$

The objective function 1.1 maximizes the total profit of the manufacturer, which represents the profit incurred from the revenue generated by products sold minus the cost of production, inventory, purchasing, penalty for back order and capacity expansion through overtime. Constraint 1.2 captures the flow balance between, inventory, production, delivery and internal consummation of products for production. Next constraint 1.3 captures the back orders. Constraints 1.4 represent capacity restrictions. Constraints 1.5 through 1.11 specify domains of variable values.

Model 2 and 3 (Steps 2 and 3): Supplier relaxed and constrained plan (Z_2 & $\overline{Z_2}$)

During Step 2, the supplier first computes its optimal relaxed lot-sizing plan, which consists in satisfying the total ordered quantity over the planning horizon.

<u>Index sets</u>

T *Set of planning periods*

F *Set of products managed by supplier*

F_f^s *Set of products directly succeeding product f in the BOM*

Fs *Set of product sold by the supplier to the manufacturer*

Indices

t *Planning period,* $t \in T$

f *Products produced by supplier,* $f \in F$

Parameters

ps_f *Unit price of product f in period t produced by supplier*

cfs_f *Fixed production setup cost of product f produced by supplier*

cvs_f *Unit variable cost for product f produced by supplier*

chs_f *Unit holding cost for product f held by supplier*

$De_{f,t}$ *Demand for product f produced by supplier in period t from external customer*

$v_{f,g}$ *Unit requirement of product f by successor operation g*

cos_r *Unit cost of overtime (capacity expansion) of resource r for supplier*

$cs_{r,f}$ *Unit requirement of resource r to produce one unit of product f by supplier*

$Cs_{r,t}$ *Production capacity of resource r in period t for supplier*

$Demandm_{f,t}$ *Initial manufacturer order of product f in period t*

M *Large number*

Variables

$xs_{f,t}$ *Output of product f produced by supplier in period t*

$ys_{f,t}$ *Binary setup variable for production of product f by supplier in period t*

$is_{f,t}$ *Inventory level of supplier product f in period t*

$ds_{f,t}$ *Delivery quantity of product f in period t to manufacturer*

$de_{f,t}$ *Delivery quantity of product f in period t to external manufacturer*

$os_{r,t}$ *Overtime of resource r in period t for supplier*

$Max \;\; Z_2$

$s.t.$:

2.1) $Z_2 = \sum_{f \in F} \sum_{t \in T} (ps_f(de_{f,t} + ds_{f,t}) - cfs_f ys_{f,t} - cvs_f xs_{f,t} - chs_f is_{f,t}) - \sum_{r \in R} \sum_{t \in T} cos_r os_{r,t}$

2.2) $is_{f,t-1} + xs_{f,t} = de_{f,t} + ds_{f,t} + \sum_{g \in F_f^S} vs_{f,g} xs_{g,t} + is_{f,t} \qquad \forall f \in F, \forall t \in T$

2.3) $de_{f,t} \leq De_{f,t} \qquad \forall f \in Fs, \forall t \in T$

2.4) $\sum_{t \in T} ds_{f,t} \leq \sum_{t \in T} Demandm_{f,t} \qquad \forall f \in Fs$

2.5) $\sum_{f=1}^{F} cs_{r,f}\, xs_{f,t} \leq Cs_{r,t} + os_{r,t} \qquad \forall f \in F, \forall t \in T$

2.6) $xs_{f,t} \leq Mys_{f,t} \qquad \forall f \in F, \forall t \in T$

2.7) $xs_{f,t} \geq 0 \qquad \forall f \in F, \forall t \in T$

2.8) $ds_{f,t} \geq 0 \qquad \forall f \in Fs, \forall t \in T$

2.9) $de_{f,t} \geq 0 \qquad \forall f \in Fs, \forall t \in T$

2.10) $os_{f,t} \geq 0 \qquad \forall f \in F, \forall t \in T$

2.11) $is_{f,t} \geq 0 \qquad \forall f \in F, \forall t \in T$

2.12) $ys_{f,t} \in \{0,1\} \qquad \forall f \in F, \forall t \in T$

The objective function 2.1 maximizes the supplier's profit, which represents the profit incurred from the revenue generated by sold products minus the cost of production, inventory, purchasing and capacity expansion through overtime. Constraint 2.2 captures the flow balance between inventory, production, delivery to the manufacturer, and internal consummation of products for production. Constraint 2.4 represents aggregated manufacturer demand satisfaction. Constraint 2.5 shows capacity restrictions. Constraints 2.6 through 2.12 specify domains of variable values.

Next in Step 3, the supplier computes its constrained lot-sizing plan. To do this, constraint 2.4 is replaced by constraint 2.4.1, while the same objective function is optimized (referred to as $\overline{Z_2}$ in this version of the model). Constraint 2.4.1 is used in order to satisfy exactly the manufacturer demand pattern.

2.4.1) $ds_{f,t} = Demandm_{f,t} \quad \forall f \in Fs, \forall t \in T$

Once, both plans are computed, the supplier used equations 3.5 to 3.7 to compute the discount structure of $Discount_{\text{f,t}}$.

$ASP_{f,t}$ Additional Supply Plan for product f at period t

3.5) $ASP_{f,t} = \max(0;\ ds_{f,t} - Demandm_{f,t}) \quad \forall f \in Fs, \forall t \in T$

3.6) $\text{Maximum Discount} = Z_2^* - \overline{Z_2^*}$

3.7) $Discount_{\text{f,t}} = (ASP_{f,t} / \sum_{f \in F} \sum_{t \in T} ASP_{f,t}) * \text{Maximum Discount}$

In brief, $Discount_{\text{f,t}}$ represents the maximum part of the discount that can be allocated to specific (product, periods) couples, in order to increase their "attractiveness" to the manufacturers. Once this discount structure is calculated, the supplier proposes a percentage of the discount ($\alpha * Discount_{\text{f,t}}$ with $\alpha \in [0,1]$) if the manufacturer accept to increase specific part of its order plan by a percentage of the Additional Supply Plan ($\beta * ASP_{f,t}$ with $\beta \in [0,1]$). This process can be repeated several times. At each round of negotiation the manufacturer receives a new discount plan in order to further improve the coordination. Once the manufacturer receives a discount plan, he optimizes again its lot-sizes taking into account the discount plan. In order to do that, the objective function and several constraints are adjusted and added.

Model 4 (Step 6): Manufacturer Optimal Plan with discount (Z_3)

<u>Parameters</u>

$Demandm_{j,t}$ *Initial order of products j in period t by manufacturer*

α *Percentage of a complete discount plan offered to manufacturer*

β *Percentage of a complete ASP plan demanded by supplier*

$ASP_{j,t}$ *Additional supply plan proposed by supplier to manufacturer*

$Discount_{\text{j,t}}$ *Maximum Discount Plan proposed by the supplier to the manufacturer.*

<u>Variables</u>

$q_{j,t}$ *Volume of product j ordered (without discount) in period t below the initial order plan*

$eq_{j,t}$ *Volume of product j ordered (with discount) in period t above the initial order plan*

z and $w_{j,t}$ *Binary variables used to enforce the discount structure*

<u>Modified objective function</u>

$Max\ Z_3$

$S.t.$:

4.1) $$Z_3 = \sum_{j\in J}\sum_{t\in T}\big(pm_j dm_{j,t} - cfm_j ym_{j,t} - cvm_j xm_{j,t} - chm_j im_{j,t} - penalty_j bom_{j,t} - ps_{j,t} q_{j,t} - (ps_{j,t}\, eq_{j,t} - \alpha * Discount_{j,t} * z)\big) - \sum_{r\in R}\sum_{t\in T} com_r om_{r,t}$$

New constraints:

4.2) $xm_{j,t} = q_{j,t} + eq_{j,t} \quad \forall j \in Js, \forall t \in T$

4.3) $Demandm_{j,t} - q_{j,t} \leq M w_{j,t} \quad \forall j \in Js, \forall t \in T$

4.4) $eq_{j,t} \leq M_j(1 - w_{j,t}) \quad \forall j \in Js, \forall t \in T$

4.5) $\sum_{t\in T}\big(eq_{j,t} + q_{j,t}\big) = \sum_{t\in T} Demandm_{j,t} \quad \forall j \in Js, \forall t \in T$

4.6) $eq_{j,t} \geq \beta * ASP_{j,t}\, z \quad \forall j \in Js, \forall t \in T$

4.7) $eq_{j,t} \leq ASP_{j,t} \quad \forall j \in Js, \forall t \in T$

The objective function is similar to 1.1 except that it includes the discount. Binary variable z, together with constraint 4.6, is used in order to make sure that the discount is offered if and only if the manufacturer makes all increases of order quantity demanded by the supplier. In other words, if for a couple (product, period) the manufacturer does not respect the order increase corresponding to $\beta * ASP_{j,t}$, then the discount is not given.

Constraints 4.2 to 4.4 are used to calculate the part of the new order plan that is above the original order plan. Constraint 4.5 is used to limit the overall quantity of products ordered by the manufacturer to the level previously ordered. Similarly, thanks to constraint 4.7, the manufacturer cannot increase these quantities more than the ASP calculated by the supplier, as the impact of such increases on the supplier's profit would be difficult to anticipate. If the new resulted order plan is different from the original order plan, then it is sent to the supplier to be evaluated. The supplier can then either accept this new order plan, or propose a new discount if the maximum number of round has not been reached. In this case, Step 4 does not have to be repeated.

5.3.4 Illustration example

In order to illustrate the complete approach, an example is presented through the tables 1 to 3. This example considers a supply chain that produces two products over two planning periods. First table shows result of upstream planning as well as supplier relaxed plan. If the supplier accepts the initial order plan of the manufacturer, the supply chain total profit is 1500 monetary units (the Manufacturer gains 1000 and the supplier gains 500 monetary units). The supplier then computes a relaxed optimal plan (with potential profit of 2000 monetary units) and finds a significant profit gap between the constrained plan (upstream planning) and the relaxed optimal plan (2000-500=1500). This profit gap (potential gain) indicates the *Maximum Discount* that can be proposed to manufacturer.

Table 5-1: Upstream planning and supplier relaxed plan.

Upstream planning (Supply chain profit=1500)						**Supplier relaxed optimal plan**		
Manufacturer			Supplier			Supplier		
Profit=1000			**Upstream Profit=500**			**Optimal Profit=2000**		
Product \ Period	1	2	Product \ Period	1	2	Product \ Period	1	2
1	20	0	1	20	0	1	0	20
2	10	0	2	10	0	2	0	10

In the second table, in order to propose a *Discount Plan* to manufacturer, supplier calculates the Normalized ASP and the resulting *Maximum Discount Plan* matrix.

Table 5-2: Supplier rebate calculation.

<table>
<tr><th colspan="11">Supplier Maximum Discount Plan calculation</th></tr>
<tr><td colspan="3">ASP matrix</td><td></td><td colspan="3">Normalized ASP
(ASP $_{f,t}$ / $\sum_{f \in F} \sum_{t \in T}$ ASP f, t)</td><td></td><td colspan="3">Maximum Discount Plan
(Contributing the Maximum Discount (2000-500=1500) to Normalized ASP)</td></tr>
<tr><td>Product \ Period</td><td>1</td><td>2</td><td></td><td>Product \ Period</td><td>1</td><td>2</td><td></td><td>Product \ Period</td><td>1</td><td>2</td></tr>
<tr><td>1</td><td>0</td><td>20</td><td></td><td>1</td><td>0</td><td>20/30</td><td></td><td>1</td><td>0</td><td>1000</td></tr>
<tr><td>2</td><td>0</td><td>10</td><td></td><td>2</td><td>0</td><td>10/30</td><td></td><td>2</td><td>0</td><td>500</td></tr>
</table>

The following table shows the mutual adjustment process. In order to incite the manufacturer to participate in the coordination process, a couple ($\alpha * \ Maximum\ Discount\ Plan_{j,t},\ \beta * ASP_{j,t}$), which in this example are based of the value α=50 % and β=50 %, is proposed to the manufacturer. The values of α is concealed from the manufacturer. In this example, the first proposed *Discount Plan* is not high enough to incite the manufacturer to modify his original order plan. Therefore, the supplier adjusts the couple ($\alpha * \ Maximum\ Discount\ Plan_{j,t},\ \ \beta * ASP_{j,t}$) to incite the manufacturer a little more. In the following table, the proposed ASP is adjusted by considering an inferior value for β (50%-10%=40%), keeping the same rebate structure (α=50%). Therefore, in the second round, the coordination is achieved with an improvement of the supplier and the manufacturer profits (respectively 1000-500=500 monetary units for the supplier, and 1200-1000=200 monetary units for the manufacturer). Finally, because of a better utilization of both their capacities, the result of upstream planning is improved for the entire supply chain (2200-1500=700 monetary units).

Table 5-3: Mutual adjustment.

<table>
<tr><th colspan="11">Mutual adjustment</th></tr>
<tr><td colspan="3">First Discount Plan</td><td></td><td colspan="3">First ASP plan</td><td></td><td colspan="3">Manufacturer & Supplier agreed plan</td></tr>
<tr><td colspan="3">α=0.5</td><td></td><td colspan="3">β=0.50</td><td></td><td colspan="3" rowspan="4">No agreement</td></tr>
<tr><td>Product \ Period</td><td>1</td><td>2</td><td></td><td>Product \ Period</td><td>1</td><td>2</td><td></td></tr>
<tr><td>1</td><td>0</td><td>500</td><td></td><td>1</td><td>0</td><td>10</td><td></td></tr>
<tr><td>2</td><td>0</td><td>250</td><td></td><td>2</td><td>0</td><td>5</td><td></td></tr>
<tr><td colspan="11"></td></tr>
<tr><td colspan="3">Second Discount Plan</td><td></td><td colspan="3">Second ASP plan</td><td></td><td colspan="3">Manufacturer & Supplier agreed Plan</td></tr>
<tr><td colspan="3">α=0.5</td><td></td><td colspan="3">β=0.40</td><td></td><td colspan="3">Supply chain profit= 2200 (Manufacturer=1200, Supplier=1000)</td></tr>
<tr><td>Product \ Period</td><td>1</td><td>2</td><td></td><td>Product \ Period</td><td>1</td><td>2</td><td></td><td>Product \ Period</td><td>1</td><td>2</td></tr>
<tr><td>1</td><td>0</td><td>500</td><td></td><td>1</td><td>0</td><td>8</td><td></td><td>1</td><td>12</td><td>8</td></tr>
<tr><td>2</td><td>0</td><td>250</td><td></td><td>2</td><td>0</td><td>4</td><td></td><td>2</td><td>6</td><td>4</td></tr>
</table>

5.4 Application of mutual adjustment search in a dynamic environment

The heuristic approach of coordination described in the previous section addresses the supply chain planning coordination problem from a single planning cycle perspective, which is how most coordination approaches proposed in the literature address this problem (Taghipour and Frayret, 2011a). However, in the real business environment, as time passes, decision parameters, such as demand forecasts, customer orders, and resources status are updated, which affects on hand plans and renders their coordination obsolete. In other words, these local dynamic changes require that all affected coordinated plans must be adjusted (Stadtler 2009), while part of the plans is implemented (i.e., first few periods). Furthermore, in the context of a coordination approach based on financial incentives that are distributed throughout the entire planning horizon, several issues must be resolved. These issues are first discussed in the next sub-section. Next, in order to adapt our general coordination approach to a dynamic environment, we first use a rolling planning horizon approach, within which we apply the mutual adjustment search (MAS). Then, we propose two revenue sharing protocols that enable partners to share their increased revenue gained from the implementation of the first period of the planning horizon.

5.4.1 Issues

In order to illustrate the issues involved in the development of a dynamic operations planning coordination approach, let’s consider a rolling planning horizon that consists of four time periods, four planning cycles, and a planning cycle time of one time period, as shown in Figure 5.

At the beginning of each planning cycle, the manufacturer and the supplier mutually negotiate and adjust their operations plans for the four time periods (i.e., the entire planning horizon). However, although all planning periods are planned, only the planning decision of the first period is implemented at the next planning cycle. Here, we do not consider a frozen horizon, because it does not affect results and it does not add any particular difficulty in term of implementation.

The first practical issue here is the fact that after the beginning of a planning cycle, demand information changes for all periods, including the three first time periods, which were already negotiated and planned in the previous planning cycle. Therefore, it is necessary that both partners update the non-implemented time periods (i.e., periods 2 to 4 of the previous planning cycle) by mutually readjusting their plans, subject to these changes. This implies that any give time period of the planning horizon is planned four times before it is implemented.

Furthermore, because only the first time period of the negotiated planning horizon is implemented, while all time periods are considered for the computation of the incentive, it is necessary to apply a revenue sharing protocol based on the proposed incentive structure in order to reward the contributions made by the manufacturer in the first time period to the general coordination problem (i.e., any positive or negative adjustments that contribute to achieving the desired order plan pattern).

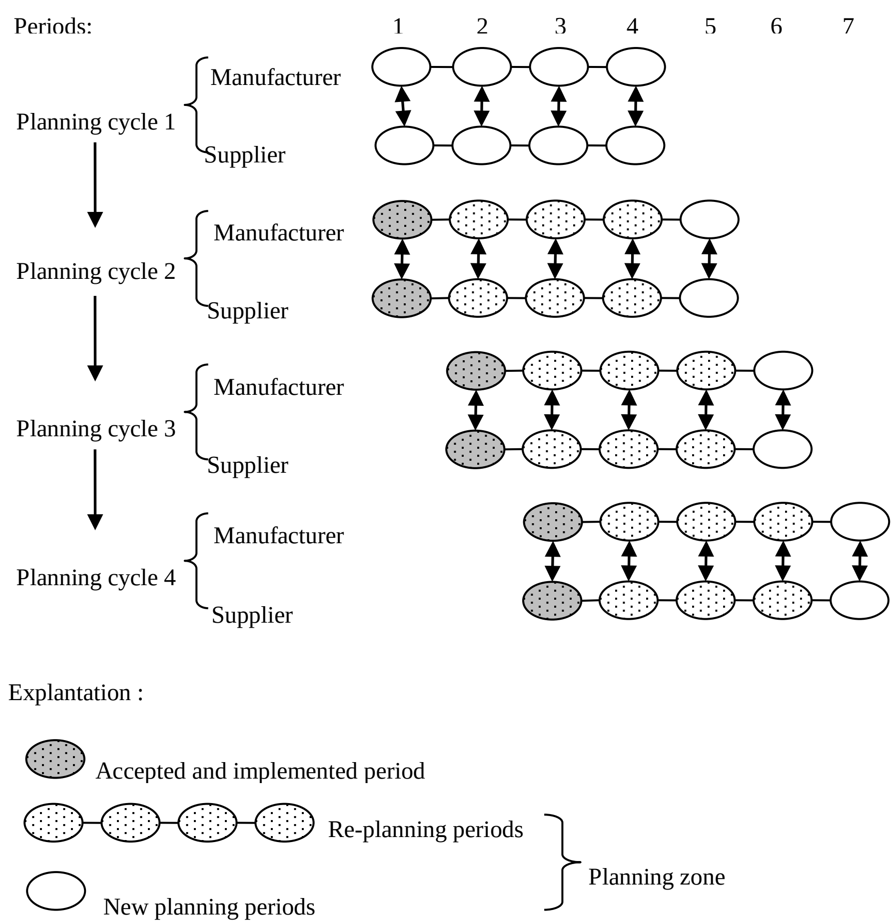

Figure 5-5: Mutual rolling horizons considered for test.

Therefore, one contribution of this paper is to propose two revenue sharing protocols to address this issue. One of the objectives of the experiments proposed in Section 5 is to verify that these protocols do not affect the fairness of revenue sharing over time.

5.4.2 Revenue sharing protocols for dynamic mutual adjustment search

As mentioned in the previous section, it is necessary to develop and apply a profit sharing protocol for the first implemented period. In this paper we propose two protocols. In our first profit sharing protocol, we consider the discount derived from the first period of the Discount Plan and the contribution of this first implemented period to the adjustment of other periods of the plan, but limited by the supplier's ASP (equation 5.1). In our second protocol, we consider the relative contribution of the adjustments made in the first period with respect to the sum of all adjustments (i.e., for all periods) of the manufacturing's order plan, regardless of their direct contribution to achieving the desired order plan adjustment pattern (equation 5.2).

<u>Parameters</u>

$Paid\ Discount$ *Profit shared for the first implemented period of product j*

$ASP_{j,t}$ *Additional Supply Plan for product j at period t*

$a_{j,1}$ *Contribution of the first implemented period of product j in the adjustment*

$d_{j,t}$ *Discount Plan for the adjustment of product j at period t according to the ASP*

First revenue sharing protocol:

5.1) $Paid\ Discount$

$$= \sum_{j \in J} \left(\left(\sum_{t \in T} d_{j,t} \right) * \frac{\left[Min\left(\sum_{t \in T} ASP_{j,t}; |a_{j,1}|; Max\left(ASP_{j,1}; ASP_{j,1} - a_{j,1} \right) \right) \right]}{\sum_{t \in T} ASP_{j,t}} \right)$$

Second revenue sharing protocol:

5.2) $$Paid\ Discount = \sum_{j \in J} \sum_{t \in T} d_{j,t} * \frac{|a_{j,1}|}{\sum_{t \in T} |a_{j,t}|}$$

In order to illustrate the impacts of these two protocols, we propose the two following examples.

Table 5-4: Discount paid for the adjustment of this first implemented period (example 1).

Periods	1	2	3	4	Periods	1	2	3	4
Initial Manufacturer's Order Plan	15	5	10	5	$ASP_{p,t}$	0	2	4	0
New Order Plan	7	7	14	7	Discount Plan ($d_{p,t}$)	0	5	20	0
Adjustments ($a_{p,t}$)	-8	+2	+4	+2					
Paid discount (first protocol)	25								
Paid discount (second protocol)	12,5								

In the above example according to our first protocol, the first period of the initial manufacturer's order plan contributes to an adjustment of 2 units of the second period and 4 units of the third period of the supplier's proposed order plan. Therefore, the paid discount for the first implemented period of manufacturer is 25 monetary units. When considering the second protocol, the relative contribution of the adjustments made in the first period is 50%. Consequently, the profit shared to the manufacturer is 50% of the sum of the discount plan for this product.

Table 5-5: Discount paid for the adjustment of this first implemented period (example 2).

Periods	1	2	3	4	Periods	1	2	3	4
Initial Manufacturer's Order Plan	15	0	10	10	$ASP_{p,t}$	10	0	0	0
New Order Plan	25	0	0	10	Discount Plan ($d_{p,t}$)	20	0	0	0
Adjustments ($a_{p,t}$)	10	0	-10	0					
Paid discount (first protocol)	20								
Paid discount (second protocol)	10								

In the second example, according the first protocol, the third period of the initial manufacturer's order plan contributes to an adjustment of 10 units of the first period of the supplier's proposed order plan. Therefore, the paid discount for the first implemented period of manufacturer is 20 monetary units. When using the second protocol, the relative contribution of the first period is

50%, for a paid discount of 10 monetary units. These examples illustrate that the first protocol is more generous for the manufacturer than the second protocol.

5.5 Experimentations

In the context of a static environment application of MAS approach, Taghipour and Frayret (2011b) proposed a systematic analysis of the potential of such a coordination approach. To do this, we calculated the improvement of the initial order plan for all possible combinations of α (0..1) and β (0..1) for several scenarios. The best combination for these scenarios showed that MAS has the potential to improve global supply chain profit (compared to upstream planning), as well as each partner's profit (Figure 6). In other word, the coordination of the partners' operations (leading to increasing profit) and the fair sharing of these increased profit can be done simultaneously without any exchange of strategic information, contrary to other approaches like Dudek and Stadtler (2005 and 2007).

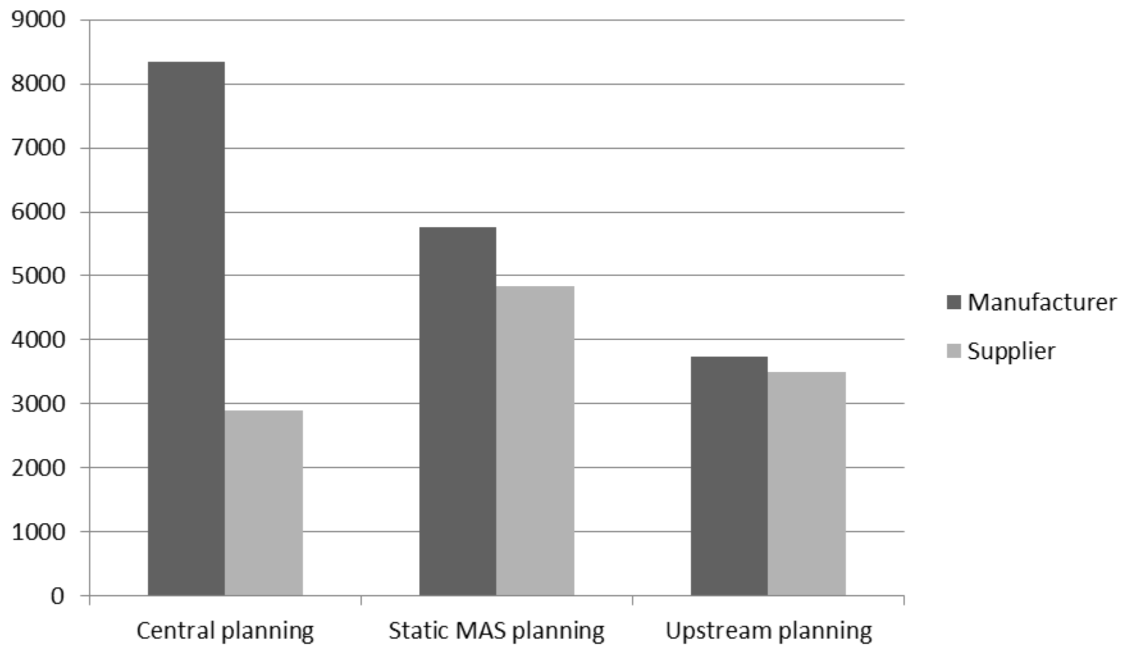

Figure 5-6: Average profit distribution comparison.

In this paper, and in order to assess the performance of this dynamic application of the MAS approach, a series of experiments have been conducted. The next section describes the experimental design and the results obtained.

5.5.1 Experiment design and performance measures

The objective of these experiments is to demonstrate that the proposed approach can lead to improved coordination compared to both upstream planning and centralized planning (in terms of profit improvement and revenue sharing fairness) in a dynamic environment. In order to analyse the dynamic implementation of the MAS approach and the revenue sharing protocols, a set of experiments were derived from a test class described in Figure 7. These tests include two partners, each of which possesses two manufacturing resources. The product structure considered has a five-level bill-of-material, which includes 30 products and components, produced by these two partners.

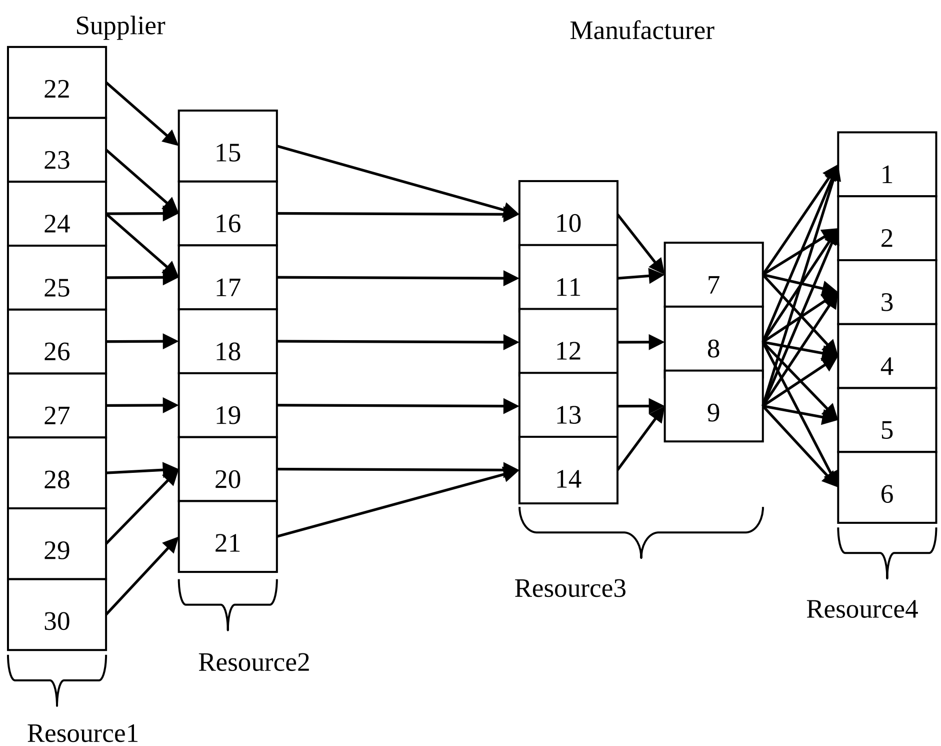

Figure 5-7: Complex test class for single supplier and manufacturer.

The four mixed integer models presented in the previous section were implemented. Next, we derived two instances of test using this structure by combing one capacity utilization profiles and two cost structures created based on average ratio between holding and setup costs at buyer and supplier (equal, high at manufacturer/low at supplier), as described in Figure 8. In addition, 5 values for α and β were considered (α=0.1 ... 0.5 and β=0.1... 0.5) in order to evaluate further the performance of MAS across the entire planning horizon. Then, in each planning cycle a new set of demand parameters is used by considering demand forecast and customer order adjustments. These adjustments are drawn from normal distributions with zero mean and a standard deviation of 10% of average demand of each sold product. These combinations of scenarios result in [2 (two instances) * 5 (five values for α) * 5 (five values for β)] 50 computational experiments in each of the four planning cycles. Finally, the two proposed profit sharing protocols were also considered in order to compute the profits of both supply chain partners in the first implemented period of each planning cycle.

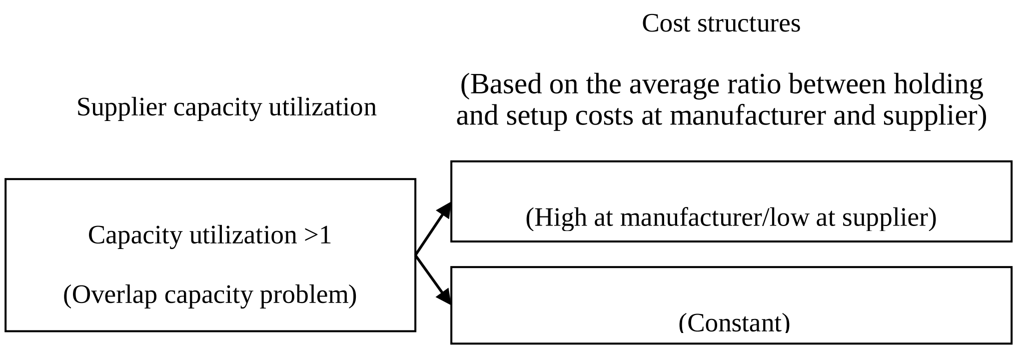

Figure 5-8: Instances of test.

In order to benchmark the solutions of the MAS approach, we also computed two benchmark tests by calculating the profit of the first implemented period of each planning cycle for each partner according a lower bound solution (i.e., upstream planning) and an upper bound solution (i.e., centralized planning). ILOG OPL 6.3 and Cplex 10 mathematical programming solver were used to solve the optimization models (taking almost one minute for solving each model). An overview of the test results is given in the next section.

5.5.2 Computational results and analysis

In order to evaluate the performance of the MAS approach, two analyses were considered. The first analysis deals with the performance of each planning cycle by considering the profit over the entire planning horizon, as in a static environment. This set of experiments is used to specifically evaluate the performance of the heuristic negotiation strategy proposed in this paper. The second set of experiments and analysis deals with the profit generated dynamically, in which only the performance of the first implemented period of each planning cycle is considered.

5.5.2.1 **Performance of MAS in a static environment**

Based on the results of the experiments described in Section 4.1, figure 9 to 16 present the results for the entire planning horizon. Each Figure includes the 25 coordination solutions investigated, which represent the total supply chain profit computed over all planning periods. In addition, the values (1) and (n)* respectively represent the start and the end of the MAS negotiation process in order to illustrate the improvement of quality of solution.

In the first scenario, and considering only the first planning cycle, the MAS approach starts with the supplier's first proposal with a discount plan (i.e., numbered (1)) with α=0.5 and β=0.5, as seen in figure 9. Because there is non-agreement at this stage of the negotiation, the supplier proposes a new discount plan (i.e., numbered (2)*) with α=0.5 and β=0.4. At this stage, an agreement is reached with a 9% improvement ($Supply\ chain\ improvement\ rate = \frac{MAS\ profit - Upstream\ profit}{MAS\ profit}$) over the upstream planning for the global supply chain.

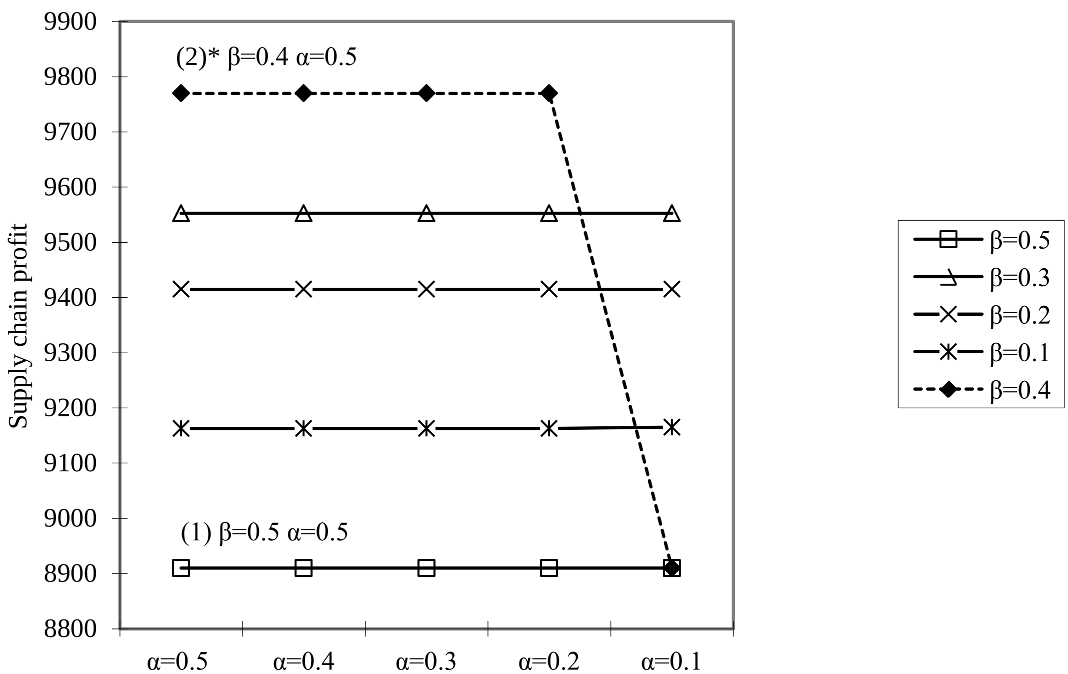

Figure 5-9: Potential supply chain profit improvement for scenario 1- planning cycle 1.

For the second planning cycle of the first scenario, the negotiation starts identically (1) and an agreement is also reached for the supplier's second proposal (2)* with α=0.5 and β=0.4. This agreement represents a 2% improvement in the results of upstream planning for the global supply chain.

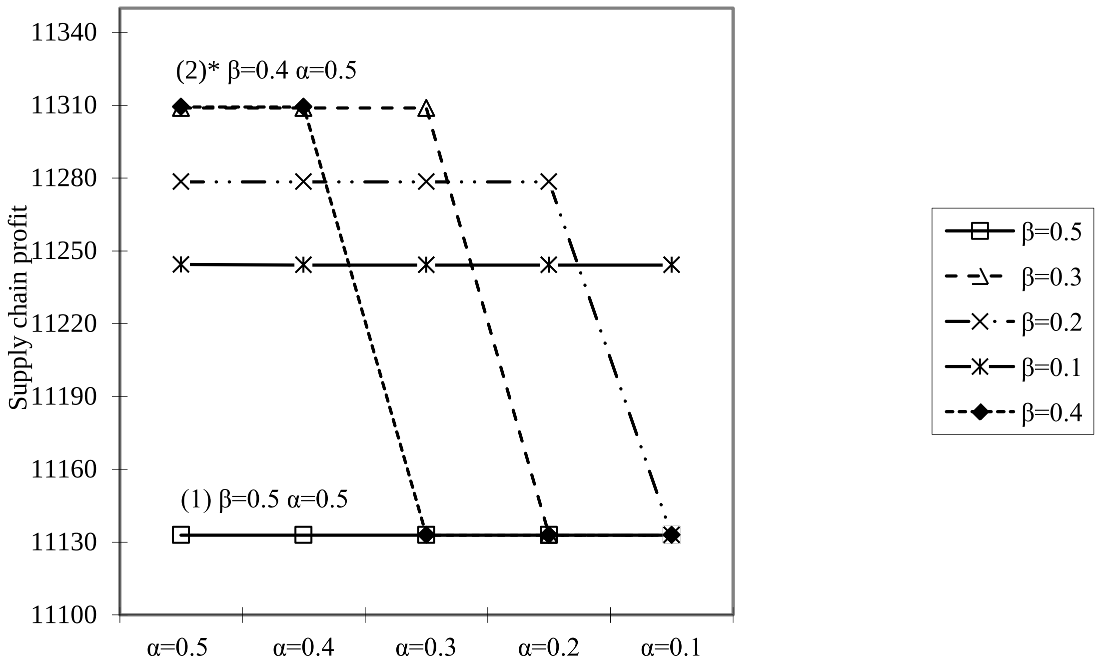

Figure 5-10: Potential supply chain profit improvement for scenario 1- planning cycle 2.

For the third and fourth planning cycles of the first scenario, difference between the results of centralized planning and upstream planning is less than 0.4%. The MAS approach did not improve the initial solution; therefore, the upstream planning solution is used.

For the first planning cycle of the second scenario, after three rounds of negotiation (shown as (1), (2) and (3)*), an agreement is reached. The two first proposals of the supplier do not change the results of upstream planning, with respectively α=0.5 and β=0.5, and α=0.5 and β=0.4. However, with values of α=0.5 and β=0.3, the supply chain profit improves by more than 7% the results of upstream planning for the global supply chain.

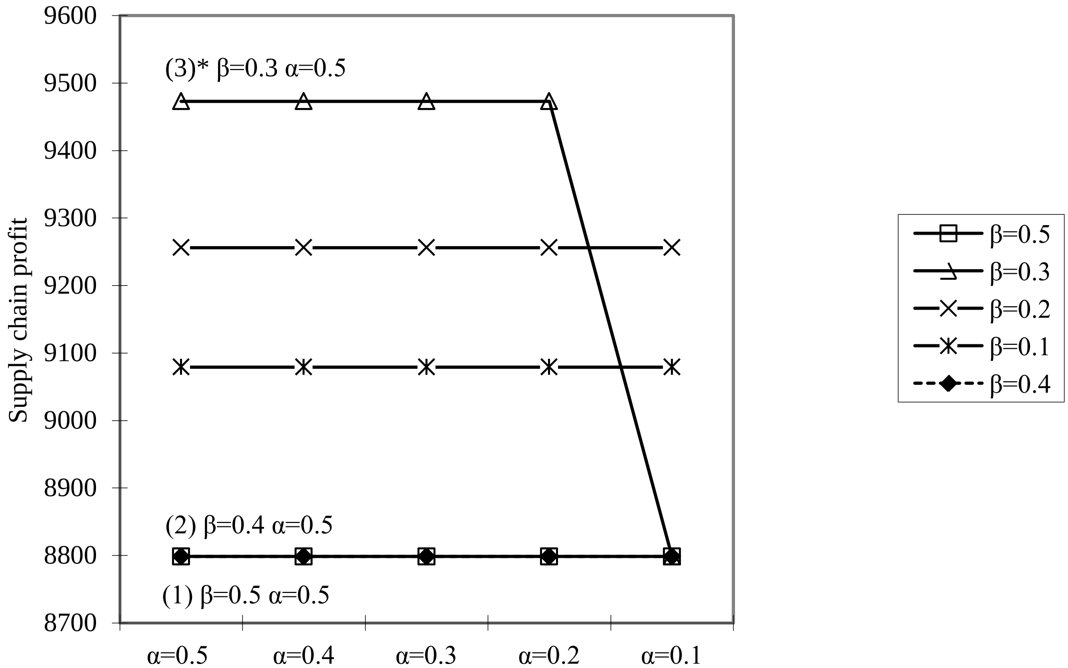

Figure 5-11: Potential supply chain profit improvement for scenario 2- planning cycle 1.

For the second planning cycle of the second scenario, the agreement is achieved with the first supplier's proposal with α=0.5 and β=0.5, for a more than 1% improvement in the results of upstream planning for the global supply chain.

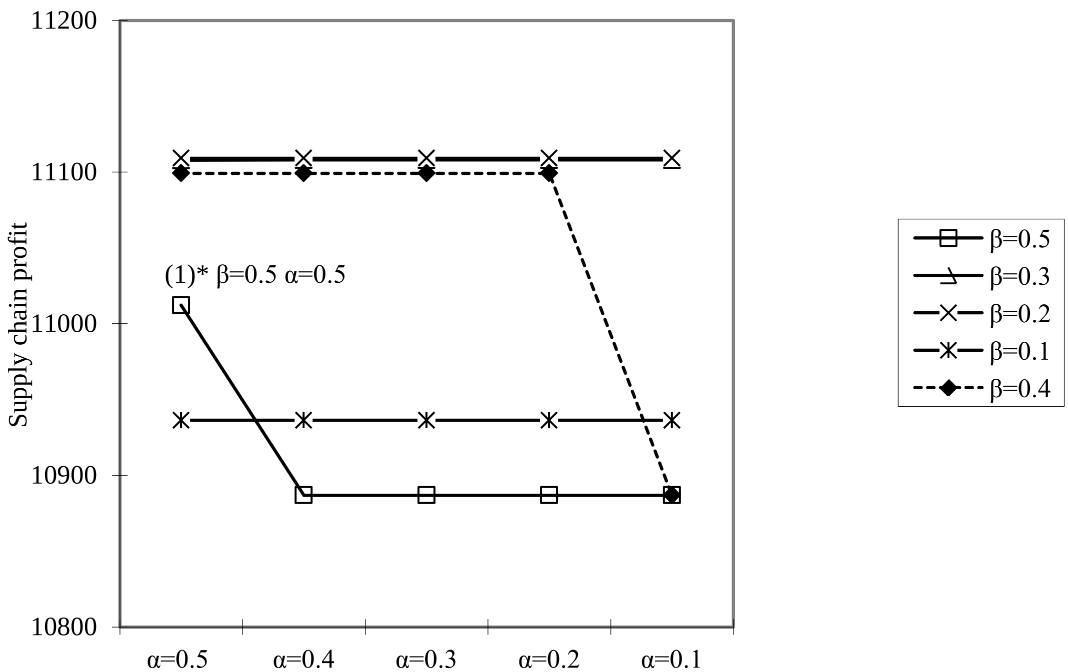

Figure 5-12: Potential supply chain profit improvement for scenario 2- planning cycle 2.

For the third planning cycle of the second scenario, the agreement is achieved after five rounds of negotiation (shown as (1), (2), (3), (4) and (5)), with α=0.5 and β=0.1, and a less than 0.3% improvement for the global supply chain.

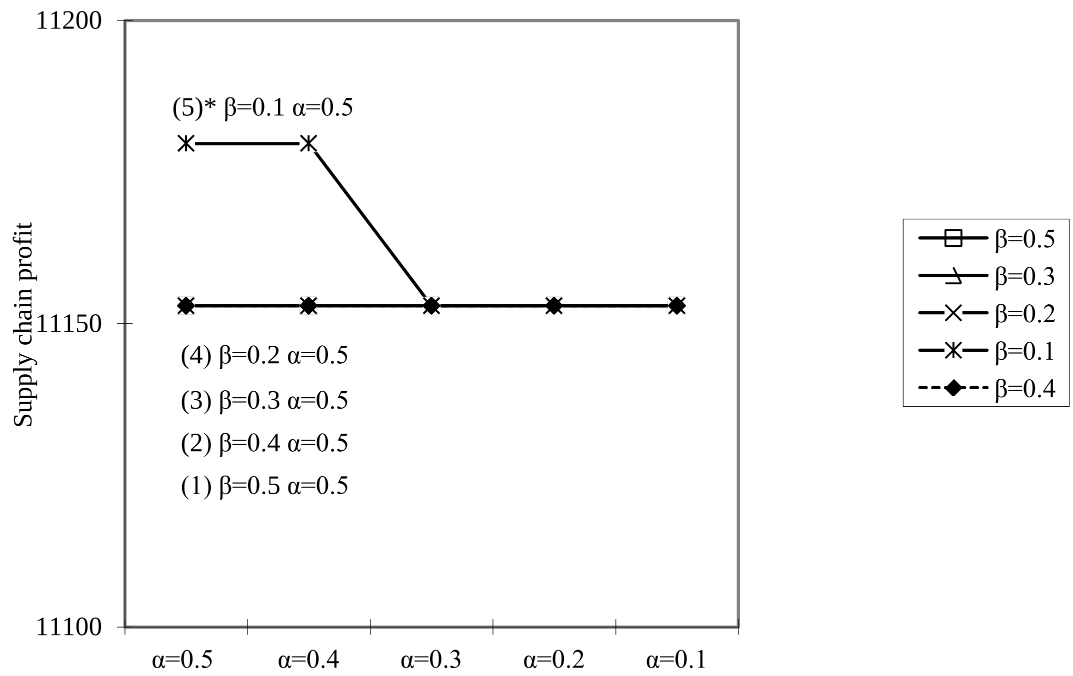

Figure 5-13: Potential supply chain profit improvement for scenario 2- planning cycle 3.

Finally, for the fourth planning cycle of the second scenario, the agreement is achieved after three rounds of negotiation, with α=0.5 and β=0.3, which represents less than 0.5% improvement.

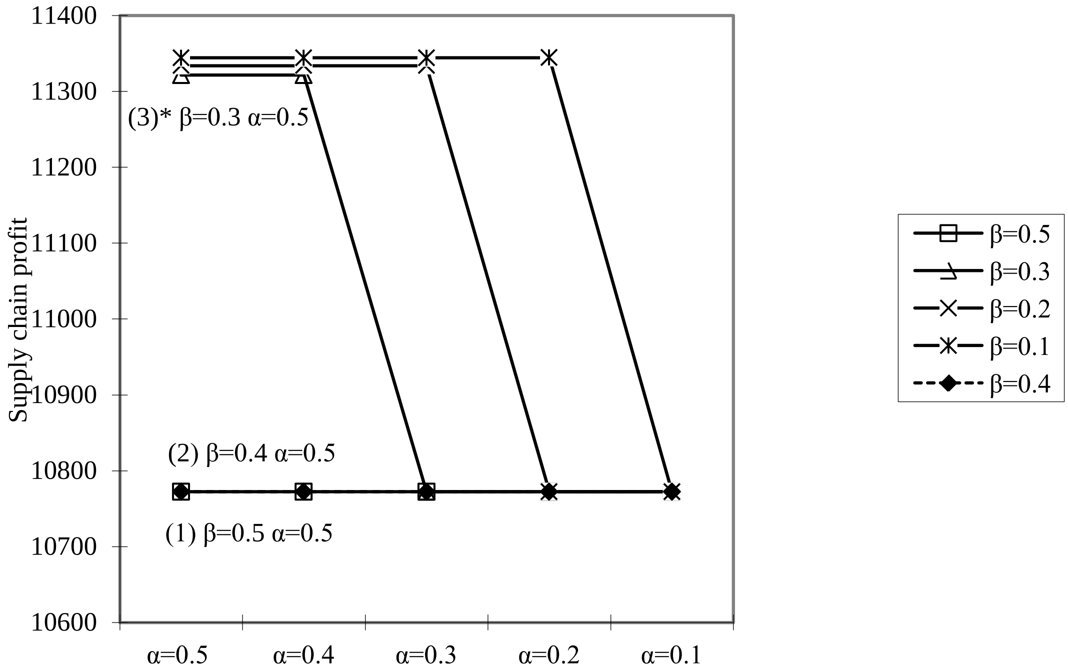

Figure 5-14: Potential supply chain profit improvement for scenario 2- planning cycle 4.

The deviations between the best results of MAS approach and other approaches (centralized and upstream planning), visualized in table 4, show that by using this MAS approach, partners can achieve a coordination pattern which improves profit of supply chain up near to the result of central planning.

5.5.2.2 **Performance of the dynamic MAS approach**

As mentioned previously, this section presents the results of a set of experiments designed to evaluate, on the one hand, the performance of the dynamic implementation of the MAS approach, which only concerns the first implemented periods of the entire planning horizon, and, on the other hand, the two revenue sharing protocols proposed in this paper. The results are compared to the equivalent solutions generated by the upstream planning and the central planning solutions reported in figures 15 to 18.

As shown in these figures, the level of performance of the d-MAS approach depends on the selected profit sharing protocol. In these experiments, the fairness of the central planning approach is actually very good as both partners show an improved profit compared to upstream planning.

Next, these experiments show that giving a higher degree of importance to the first implemented period in the calculation of the discount paid (i.e., first revenue sharing protocol) can generate an average of 19% profit increase for the manufacturer and less than 7% profit for the supplier compared to upstream planning in the first scenario. However, in the second scenario, the manufacturer experiences an average profit increase of almost 39% while the supplier experiences a loss compared to upstream planning. In the second scenario, the use of the second revenue sharing protocol within the d-MAS approach produces an average profit increase for both partners.

These experiments show empirical evidences supporting the fact that the use of the d-MAS approach in conjunction with the use of second revenue sharing protocol produces, on average, an improved profit for both partners. Similarly, these results also show that the first revenue sharing protocol can lead to unfair revenue sharing, and should therefore be avoided.

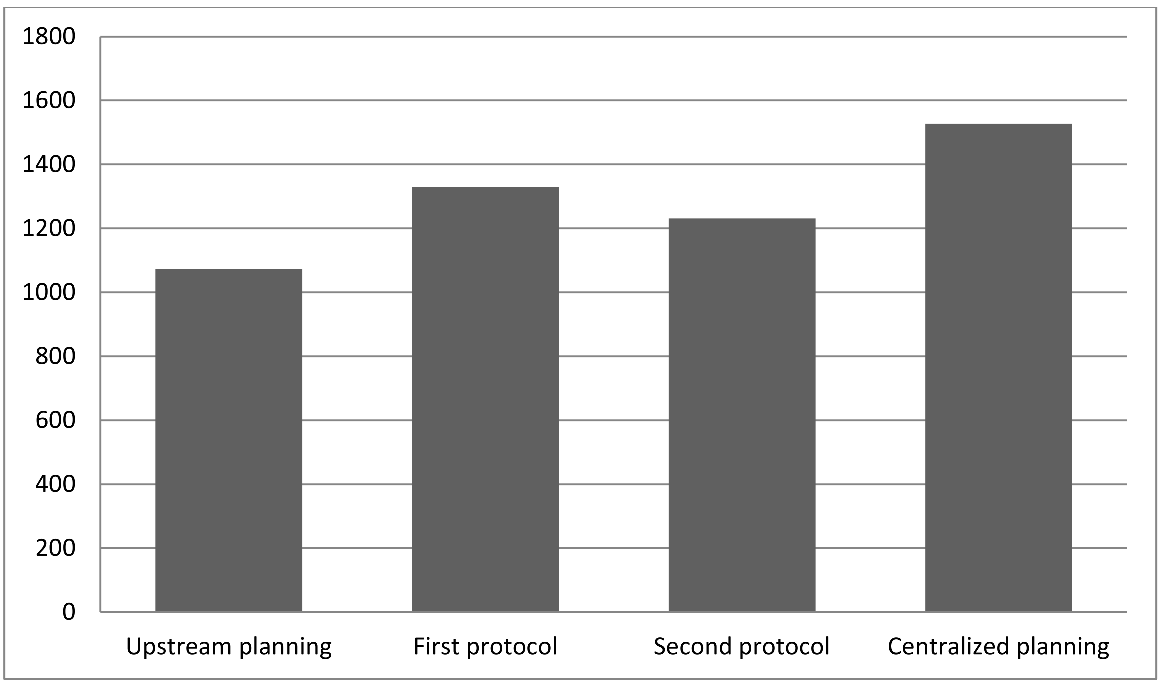

Figure 5-15: Manufacture’s average shared profit for the implemented periods in scenario 1.

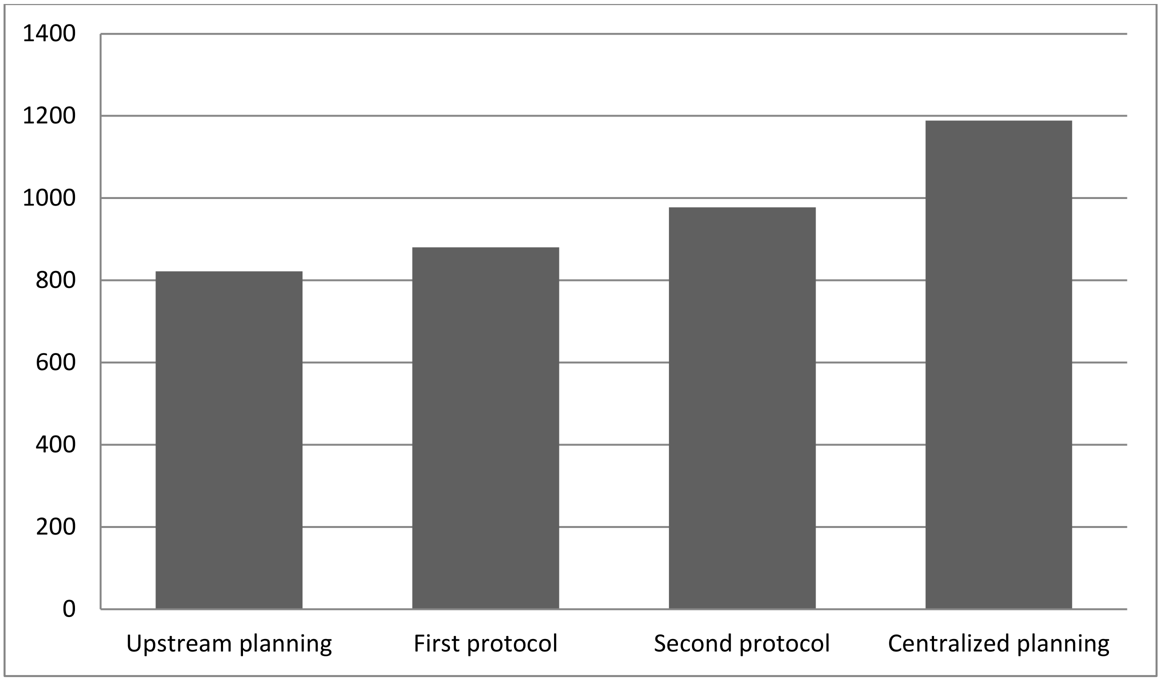

Figure 5-16: Supplier’s average shared profit for the implemented periods in scenario 1.

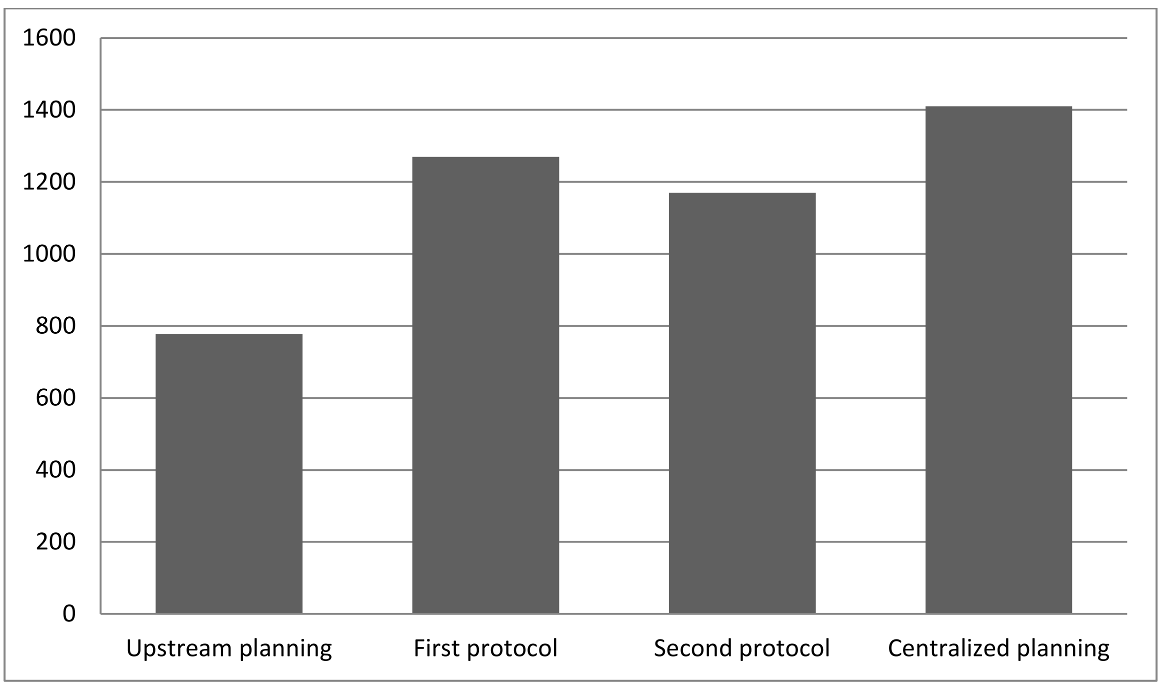

Figure 5-17: Manufacture’s average shared profit for the implemented periods in scenario 2.

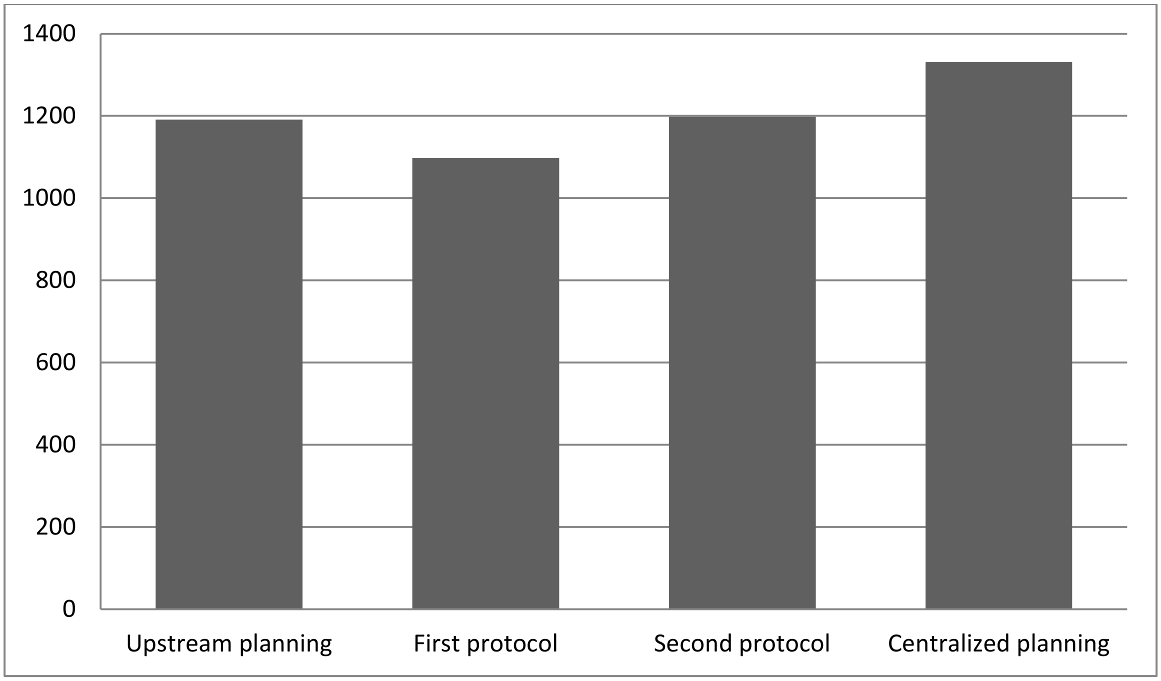

Figure 5-18: Supplier’s average shared profit for the implemented periods in scenario 2.

5.6 Conclusion

In order to coordinate supply chain partners in a dynamic environment, this paper proposed a dynamic Mutual Adjustment Search (MAS) based on mathematical rolling horizon programming approach, to coordinate two partners of a supply chain in a dynamic environment. Our approach is a distributed decision making problems which gives the same decision authority to all partners without any exchange of strategic information. An incentive system is used to encourage partners to participate in the coordination process. Computational analysis shows that the proposed approach produces a win-win strategy for two partners of supply chain and improves the results of upstream planning in each cycle of planning.

Proposed MAS approach for bilateral coordination can be extended to the relationships of more than two partners in order to consider supply chain realistic condition. As another extension for the future research the re-negotiations of already accepted plans in a dynamic environment can be considered in order to improve the results of accepted plans.

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CHAPTER 6 GENERAL DISCUSSION

In this chapter first, in a general discussion, we highlight the links between our three papers and we talk about industrial application of our research.

6.1 Analysis of operations planning coordination in supply chains

First, the main results obtained from our first paper showed that the most commonly used techniques are heuristic search techniques with 31% of our literature. This means that most of the methods do not aim at finding an optimal coordination solution. This lack of exact approaches may be related to several factors, one of them is the relatively recent interest of the operations research community in distributed operations management problems. Another explanatory factor may be the nature of such solutions, which involve some kind of central system design and development methodology that is rather inconsistent with the multi-company nature of supply chains. Therefore, this fact conducted us to a research opportunity to overcome these difficulties and develop operations planning coordination approaches that are able to find (near) optimal solution at each planning cycle and within specified revenue and profit sharing regulations. In addition, most of the presented approaches in the first paper are based on exchange of strategic information which can be considered as a negative point for these approaches. So, this fact also conducted us to an approach based on non-strategic exchange of information. Finally, our first paper showed that less than 23% of the reviewed approaches are in dynamic environment, as well as less than 17% of these approaches are in stochastic context. Therefore, there was an opportunity to develop more dynamic mechanisms of planning coordination of supply chains which is the subject of our third paper.

6.2 Mutual adjustment research for supply chain planning

In the second research project, first using the literature related to the lot-sizing problem, we formulated two versions of lot-sizing problem as well as two coordination approaches based on two different incentive mechanisms. The first version of the supplier's planning problem used some form of anticipation of the reaction of its customer (i.e., the manufacturer) in order to define an efficient incentive structure. This incentive would incite the manufacturer to adjust its plan toward a good coordination solution. However, because both partners have a local cost structure they do not share, as well as external demand to satisfy, they cannot accurately anticipate each other's input/output feasibility and economic performance. Therefore, this version of the planning problem was abandoned in order to develop a much simpler approach based on a heuristic exchange of non-strategic information.

As the result of the second research project, a solution approach is proposed in the second paper which is referred to as a *Mutual-Adjustment Search* (MAS) with incentive, because unlike traditional centralized system, it involves two supply chain partners who interact directly with each other to mutually adjust their lot-sizes in order to improve their collective economic performance. This mutual adjustment search is a collective search of a solution within a coordination space that represents all possible Order Plans that can be agreed upon by both partners. Our second paper showed that the proposed coordination approach improves, for all test case instances, the overall supply chain profit compared to upstream planning. Similarly, in the best condition of negotiation, supply chain profit increases near central optimality. Furthermore, the analysis of the impact of the proposed approach on the individual profit of both partners reveals that the average individual profit of both partners calculated using the best solutions (i.e., best combinations of α and β) of the six test case instances, is superior in terms of fairness to central planning, and in terms of performance to upstream planning. More specifically, this result shows that the central optimal solution is achieved at the cost of a loss of profit for the supplier, while the proposed approach improves upstream planning by increasing both partners' profit. Although the results reported in Dudek and Stadtler (2005) show similar performance in terms of cost reduction, this specific aspect cannot be compared to their approach, which do not directly address revenue sharing.

6.3 Dynamic application of Mutual adjustment research for supply chain planning

The results obtained from our second paper conducted us to investigate in a heuristic algorithm which can search an exact solution for our approach instead of showing the general performance of approach as it is presented in second paper and in order to apply it in a dynamic environment, the third paper proposed a dynamic Mutual Adjustment Search (MAS) based on mathematical rolling horizon programming approach, to coordinate two partners of a supply chain in a dynamic environment. In this paper also we proposed two protocols. In our first profit sharing protocol, we consider the discount derived from the first period of the Discount Plan and the contribution of this first implemented period to the adjustment of other periods of the plan, but limited by the supplier's ASP. In our second protocol, we consider the relative contribution of the adjustments made in the first period with respect to the sum of all adjustments (i.e., for all periods) of the manufacturing's order plan, regardless of their direct contribution to achieving the desired order plan adjustment pattern.

6.4 Application in industrial context

At the end of this discussion, this research can be applied in a context of operations planning of two independent manufacturing enterprises which produce the general products and which are coordinated based on minimum exchange of information in a dynamic environment. For applicability in a network of enterprises it is necessary to be developed this approach in order to consider more than a two partner supply chain. From a technical point of view, companies should use the same tools (APS) to plan their own operations. For companies with different planning tools decision processes must be compatible and complementary. Consequently, the development of collaborative planning standards is required to guarantee the compatibility of advanced planning tools developed by two different software companies.

CONCLUSION

This thesis includes three journal articles, which deal with the problem of supply chain operations planning coordination. In the first paper, we analysed almost 120 decentralized planning coordination approaches, which are proposed to coordinate supply chain partners' planning decisions. We used three criteria for the analysis of the selected literature including: supply chain environment, characteristics of local planning systems, and characteristics of coordination systems. Based on this analysis, we proposed a five-class classification of the decentralized planning coordination approaches in the supply chains. This analysis highlights several important aspects of the development of such approaches. First, only 23% of the analyzed literature proposes coordination mechanisms that are capable of dealing with dynamic environment, such as rolling planning horizon, and almost 17% of these approaches deal with stochastic parameters.

Therefore, this thesis proposed a coordination approach capable of dealing with dynamic environments. Second, because of difficulties related to the nature of information exchanges between supply chains members, the proposed approach of coordination is based on a heterarchical form of supply chain relationship with minimal exchange of information, which represents 43% of the reviewed approaches. Finally, intelligent and adaptive techniques, which are rather a new concept in operations planning coordination in distributed networks, can be integrated with other proposed technique to develop more agile and adaptable coordination approaches.

In the second paper, we present a distributed heuristic search with incentive to coordinate operations planning between two supply chain partners. This approach is based on an iterative negotiation between two local decision making units. It is a non-hierarchical mechanism, which gives the same decision authority to both partners without any exchange of sensitive information, such as cost variations, unlike the pioneer approach of Dudek and Stadtler (2005 and 2007), in which cost information is exchanged in the form of compensations requested by buyers, to offset his cost increase above his initial cost. The proposed incentive system is used in order to encourage the manufacturer to participate in coordination process and to address simultaneously material and financial flows. Computational results show promising results, with significant improvements compared to upstream planning, as well as small gaps with the centralized planning approach for some test instances.

Finally, in our third paper, in order to coordinate supply chain partners in a dynamic environment, this paper proposes a *dynamic-Mutual Adjustment Search* (d-MAS) based on planning rolling horizon approach. This approach is a distributed Advanced Planning and Scheduling (APS) system, which gives the same decision authority to all partners without any exchange of strategic information. Incentive systems are used to encourage partners to participate in the coordination process. Computational analysis shows that the proposed approach produces a win-win strategy for two partners of supply chain and improves the results of upstream planning in each cycle of planning.

Future work may be carried out in several directions:

- It is interesting to investigate to the other neighborhood structures, which could generate better solutions for two partners of a supply chain.
- Considering a whole supply chain, the negotiation-based coordination can be extended to the relationships of more than two partners in order to consider supply chain practical environments.
- In the context of a dynamic supply chain the re-negotiations of already accepted plans in a dynamic environment can be considered in order to improve the results of accepted plans.
- The need to address the usability of such coordination mechanisms in realistic environment, which involved heterogeneous planning support systems, requires studying the possibility to create standards of coordination incentive mechanisms. Such standards would allow different planning support systems to exchange and exploit information in a coherent manner in order to coordinate supply chain partners. Many other incentives structures can be designed and standardized for specific applications.
- During the negotiation-like process, partners could learn over time how to anticipate the reaction of their counterpart in order to further improve coordination. In the proposed approach, it is necessary for the supplier to evaluate the new manufacturer order plan in order to know how the incentive was used and ultimately whether or not it leads to improved profit for the supplier. Therefore, the design of more efficient coordination incentive structures might be enabled through the design of effective anticipation mechanisms, which could investigate more promising solutions of the coordination space.

- The impact of the principles of added value (i.e., value creation) and product convergence on the performance of such techniques. In other words, many supply chains are systems that add value throughout their processes by assembling products together. Therefore the value of products produced downstream is superior to the components and subassembly produced upstream, which may suggest higher opportunity cost downstream. Consequently, one may hypothesize that adjusting downstream operations might be more costly than adjusting upstream operations, which tends to limit the usability of such incentives. For instance, if the supplier proposes to deliver earlier, due to limited inventory holding capacity or for transportation consolidation, then the discount must compensate for an increased cost of inventory for the manufacturer, who does not have to adjust his production operations. However, if the supplier proposes to delay the delivery, then his discount must compensate for a series of more complex effects on the manufacturer's cost structure, mainly related the bill-of-material. More specifically, if a component of a product has a delayed delivery, then the production of this product has to be delayed as well incurring potentially penalty cost for late delivery to the distributor, missed opportunities due to unavailable capacity, and inventory hold cost for the other components. However, manufacturer discounts exist and are used in practice, although not for direct coordination purpose, but to increase sales. Therefore, this type of incentive should also be carefully studied with respect to its practical usability and impact.
- The proposed approach is a distributed heuristic search with local optimization because only a small part of the coordination space is collectively investigated. Indeed, the coordination space is discretized through the use of a finite set of β's values, which limits the investigated solutions between the original order plan of the manufacturer and the optimal relaxed plan of the supplier. No other solution further from these solutions is investigated. Therefore, although it is a quick improvement of the upstream planning solution, optimality cannot be guaranteed.
- It is proposed to apply this approach in the real industrial context of a supply chain with two partners who produce multi general products in a dynamic environment.

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