Coalition formation based negotiation protocol for supply chain networks using game theory

Yu, Fang

(Degree)
博士（工学）
(Date of Degree)
2013-09-25
(Date of Publication)
2014-09-01
(Resource Type)
doctoral thesis
(Report Number)
甲第5945号
(URL)
https://hdl.handle.net/20.500.14094/D1005945

Doctoral Dissertation

Coalition Formation based Negotiation Protocol for Supply Chain Networks Using Game Theory

(ゲーム理論を用いたサプライチェーン・ネットワークのための提携形成に基づく交渉プロトコル)

By

Fang YU

July 2013

Graduate School of System Informatics
Kobe University

Acknowledgement

First and foremost, I would like to express my deep and sincere gratitude to my advisor Professor Toshiya Kaihara for his mentorship, patient guidance, invaluable suggestions and great encouragement. Many thanks go to him for accepting me as a PhD student, thanks for trying his best to understand me during doctor meetings even my presentations were so unkindly, and thanks for giving me inspirations when my research encountered bottlenecks. I also thanks him for providing me so many chances to go to international conferences which opened up a whole new world for me. Thanks also give for his support during my presentation, which made me feel relieved and confidence.

I would also like to thank Associate Professor Nobutada Fujii for his advices and understandings of my research. All his understandings and helpful explanations once made me escape from dilemma. I also grateful to Dr. Tomomi Nonaka for helping my research as well as my poor Japanese. Thanks also go to Sawada san for dealing processes related to my papers and for the happy lunch time.

Thanks also go to Professor Itsuo Hatono and Professor Hisashi Tamaki for reviewing my dissertation and for their helpful comments.

It is my pleasure to thank my colleagues in CS21 laboratory. I am grateful to masters and undergraduate students for their delicious coffee and beautiful study environment as well as the organization of laboratory events. I also grateful to Harumi Haraguchi, Edlira Hyka, and Jiali Zhu for the haunting cooking party. Specially, I thank Harumi Haraguchi for teaching me a lot of Japanese and Japanese culture, thank Jiali Zhu for our room sharing time. I also thank Dr Yi Qian gave me a lot of useful advises and experiences. I thank Gonglan Nan for helping me when I couldn't speak Japanese at all. I also thank Koji Kobayashi, Hiroyuki Tanohata, and Tomoya Yoshikawa for their helps during the conferences.

I appreciate my previous supervisor Professor Changyin Sun and Southeast University for providing me the opportunity and the platform to pursue higher education. I thank Associate Professor Zhenjiang Zhao for giving me a lot of help and useful advices.

Many thanks must also go to the China Scholarship Council for financial support along of my study in Japan.

Finally, I would like to thank my family. I thank my parents and my parents in law for their support and understandings, thank our brothers for getting rid of our affairs. Most of all, I thank my beloved person Wen Li for his loves and support throughout my study. Thanks for encouraging me when I was disappointed, thanks for making me happy when I was sad, and also thanks for giving me suggestions when I got into trouble in my research. Thanks for all our happiness times which I will never forget all my life.

Fang Yu

July 2013

Table of Contents

List of Figures

List of Tables

Synopsis

This dissertation focuses on multi-agent based negotiation between manufacturer agent (MA) and material supplier agent (MSA) of supply chain networks when orders of MAs are out of abilities of MSAs. Four different types of negotiations are discussed in this dissertation: single-attribute single-item (SASI) negotiation, single-attribute multi-item (SAMI) negotiation, multi-attribute single-item (MASI) negotiation, and multi-attribute multi-item (MAMI) negotiation.

A coalition formation based negotiation protocol is proposed in this dissertation to solve above mentioned negotiations. MSA are allowed to find partners to establish coalitions when orders of MAs are out of their abilities. A coalition can be established if and only if all members in coalition reach an agreement. The coalition, which maximizes profit of the out ability MSA, is determined as final coalition. A combined coalition formation protocol, which combines coalition formation for complementary and coalition formation for substitution, is proposed when multi-item are involved in negotiation. Lead time changes in multi-attribute negotiation which lead to the change of abilities of MSAs. In that case, coalitions which are in ability at initial step may become out of ability during negotiation. A modified coalition formation protocol, in which coalitions of MSAs change at each negotiation step, is proposed for negotiation when multi-attribute involved. After coalition is determined, profits are allocated according to contributions of members in order to keep stability of coalition.

Then, negotiation between MAs and MSAs (coalitions) starts to determine equilibriums. MAs in this dissertation are assumed have initiatives and more negotiation power. MAs choose strategies firstly and then MSAs observes MAs decisions and make their own strategies. Thus, iteration of negotiation between MA and MSA (coalition) to determine equilibrium can be seen as MA-Stackelberg game to find the Stackelberg equilibrium. In Stackelberg game, the leader must know ex ante that the follower observes his action. The follower must have no means of committing to a future non-Stackelberg follower action and the leader must know this. Indeed, if the "follower" could commit to a Stackelberg leader action and the "leader" knew this, the leader's best response would be to play a Stackelberg follower action. MAs and MSAs (coalitions) in MA-Stackelberg game determine their strategies according to their own preferences, and concessions among attributes and (or) items are considered to trade off one attribute and (or) item for another attribute and (or) item when multi-attribute and (or) multi-item are involved in negotiation. Weights for attributes are provided for MAs and MSAs (coalitions) to determine their own preferences. Strategy of MA which maximizes MA's profit and accepted by MSA will be determined as the final equilibrium.

Finally, MAs negotiate with MSAs (coalitions) to determine final allocation scheme which maximizes overall profit of supply chain networks. A two-person like game is introduced to determine final allocation scheme, where all MAs are combined together as player 1 and all MSAs are considered as player 2. Strategy of player 1 is allocation scheme of assigning MAs to MSAs, and strategy of player 2 is allocation scheme of assigning obtained orders from MAs to coalitions of MSAs. Objective of the game is to decide strategies of players which can maximize total profit of supply chain networks. Therefore, allocation scheme can be called as an equilibrium of the game if none of members of the players can benefit by changing its strategy while the other player keep its strategy unchanging. The proposed method, which decomposes $I \times J$ game into J-person cooperative game to find coalition if necessary, two-person Stackelberg game to find equilibrium, and two-person game to determine final allocation scheme, is a goody way to solve $I \times J$ game and greatly reduce complexity to solve $I \times J$ game.

It's verified that proposed protocols are feasible and effective in solving all four kinds of negotiations and are reciprocal protocols for both MAs and MSAs. For MAs, they can reduce costs to divide orders into pieces and allocate to different MSAs by selecting coalitions to keep integrities of orders, and reduce costs to buy materials by selecting suppliers which have lower price but once have been abandoned due to their limited abilities. For MSAs, the small-and-medium-sized MSAs have more opportunities to win orders which were once out of their abilities by establishing coalition. In addition, the proposed protocols can increase competitiveness of market. Furthermore, the proposed protocols are very flexible, because all MAs and MSAs can define weights of attributes and concession rates among different attributes and (or) items according to their own preferences. They not only can tradeoff one attribute to another, but also can tradeoff one item to another in order to maximize their total profits of whole order according to their own preferences rather than maximize each attribute or item.

Chapter 1 Research Overview

1.1 Introduction

Growing competition and emphasis on efficiency and cost reduction, as well as the satisfaction of consumer demands, have brought new challenges for businesses in supply chain networks (SCNs). At the same time, supply chains (SCs) have become increasingly globalized, and the world environment has become filled with uncertainty. Agent technology and particularly multi-agent systems was designed to capture many of challenges involved in supporting changing supply chain practices [Chaib-draa and Müller, 2006]. Negotiation is a very important problem of SCNs, which ranges from situations where resources must be allocated to agents to situations involving agent-to-agent bargaining [Shen et al., 2001]. The objective of the negotiation is to achieve Pareto optimality. Game theory has become a primary methodology used in supply chain (SC) related problems, because it's a powerful tool for analyzing situations in which the decisions of multiple agents affect each agent's payoff [Cachon and Netessine, 2003]. This research tries to solve negotiation problems under complex negotiation environment including multi-to-multi negotiation, multi-attribute negotiation and multi-item negotiation.

1.2 Research Backgrounds

1.2.1 Multi-agent based supply chain networks

Supply Chains (SCs) are made up of heterogeneous production subsystems gathered in vast dynamic and virtual coalitions. Intelligent distributed systems, e.g. multi-agent systems, enable increased autonomy of each member in SC. Each partner pursues individual goals while satisfying both local and external constraints [Maturana et al., 1999]. Therefore, one or several agents can be used to represent each partner in SC. Moreover, the agent paradigm is a natural metaphor for network organizations, since companies prefer maximizing their own profits than the profit of SC. The units of SC have the same characteristics as agents [Chaib-draa and Müller, 2006, Cloutier et al., 2001]:

- *Autonomy:* A company carries out tasks by itself without external intervention and has some kind of control over its action and internal state;

- *Social ability:* A company in SC interacts with other companies (e.g. by placing orders for products or services) ;
- *Reactivity:* A company perceives its environment, i.e. the market and the other companies, and responds in a timely fashion to changes that occur in it. In particular, each firm modifies its behavior to adapt to market and competition evolutions;
- *Pro-activeness:* A company can not only simply act in response to its environment, but also initiate new activities (e.g. launching new products on the market).

Therefore, a SC can be defined as a system consists of material supplier agents (MSAs), manufacturer agents (MAs), distributor agents, retailer agents, and consumer agents as Figure 1.1, where materials flow downstream from MSAs to customer agents and information flows in both directions [Ganeshan et al., 1999].

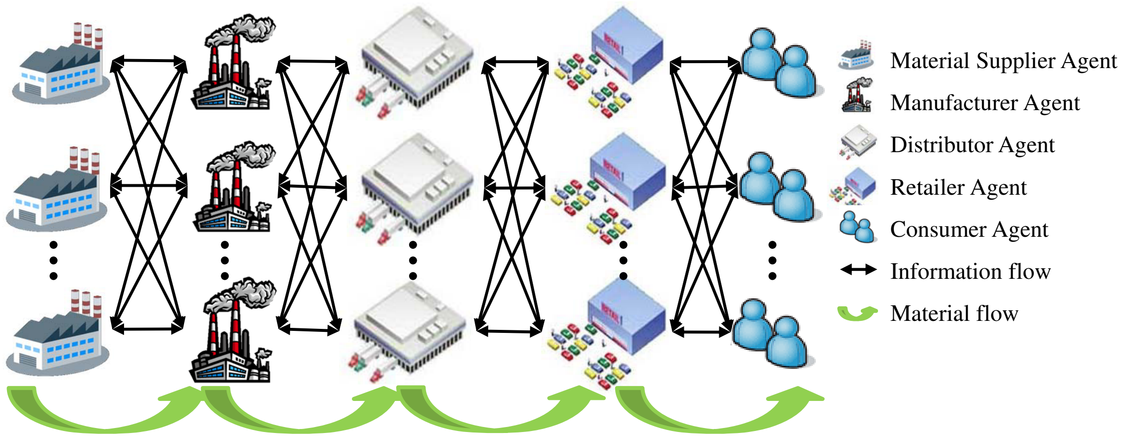


Figure 1.1: Negotiation model of supply chain networks

1.2.2 Multi-agent based negotiation of supply chain networks

Negotiation mechanisms have been studied widely in field of multi-agent systems. They possess a variety of features that enable agents be negotiate with each other even in open environments. However, mainly because of limited computational power, there are several assumptions that traditionally limit the degree of openness. Negotiation is restricted to cognitive agents which possess an explicit knowledge of their environment, and interact and engage in cooperation with other agent.

A negotiation agent contains seven modules as Figure 1.2 [Wooldridge, 2001]:

• Environment sensing module: senses resource information of negotiation environment;

• Information processing module: calculates inventory level and bids;

• Communication module: negotiation mechanism is embedded in this module;

• Knowledge database: stores transaction information and partner information;

• Task: store and manage task information;

• Intelligent control and decision module: establishment of negotiation mechanism, delivery arrangement, how to offer a bidder and how to select a partner are done in this module;

• Execution module: orders are accomplished in this module including produce and delivery.

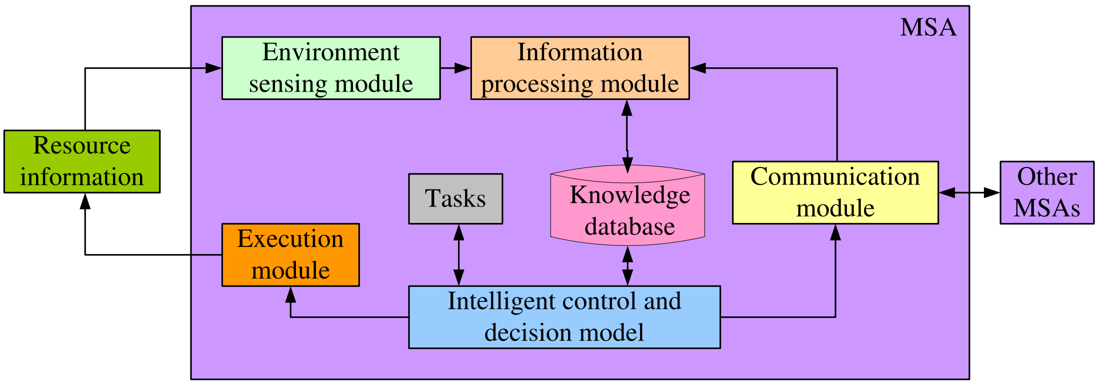


Figure 1.2: Architecture of negotiation agent

Negotiation is done by exchanging messages among agents (often only two). Since the process involves several messages, a discussion will take place in which each agent's attitude will be an important factor. This attitude is governed by an agent's beliefs and goals and by the global situation. The negotiating process follows tactical rules, which implement a strategy. Time may be important in limiting the length of negotiation [Shen et al., 2001]. In general, negotiation process on multi-agent paradigm is divided into three phases as Figure 1.3 [Jiao et al., 2006]:

• *Inviting*: manager agent inviting supplier agents when a task comes;

• *Bidding*: supplier agents bidding for task;

- *Awarding*: supplier with maximal utility is selected as a winner, and the winner supplier is awarded the contractor.

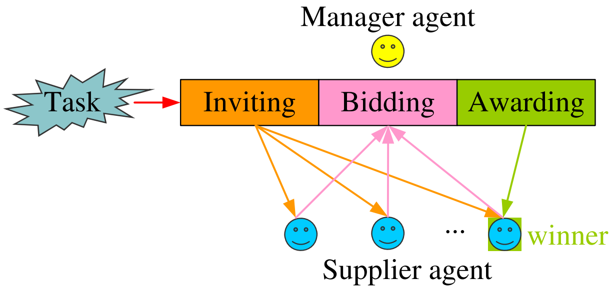


Figure 1.3: Processes of the negotiation

Recent studies have tended to focus on completely open and highly uncertain environments that apply agent systems to the real world [Ito et al., 2008]. Negotiation can be seen as the process of arriving at a state that is mutually agreeable to a set of agents and it is intimately related to coordination. The negotiation process can be used as a part of a multi-agent coordination algorithm that implements, for instance, a contracting mechanism for getting one agent to commit to solving a subproblem for another agent [Shen et al., 2001]. Negotiation is done by exchanging messages among agents (often only two) and there are different kinds of negotiations among MSAs, MAs, distributor agents, retailer agents, and consumer agents as shown in Figure 1.1. However, all negotiations can be concluded as negotiation between seller and buyer as Figure 1.4, where the seller has diversity products to sell and the buyer has money to buy. This research focuses on the negotiation between MAs (buyer) and MSAs (seller), and the results can be generalized into the other negotiations as well.

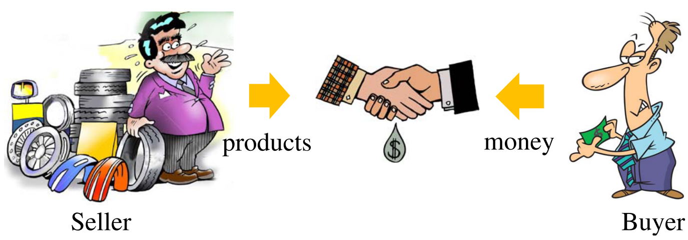


Figure 1.4: Negotiation model between seller and buyer

1.2.2.1 Negotiation protocol and negotiation strategy

Negotiation protocols set stage for negotiation process, which contain basic rules for negotiation process and communication. In addition to using a protocol, each agent will develop and use a negotiation strategy appropriate to the problem to be solved. Negotiation protocols and negotiation strategies will be quite different for different categories of negotiation, where negotiation protocols govern exchange of proposals among agents and negotiation strategies decide position of a particular agent during negotiation process. As noted by [Alonso, 1998]:"A strategy is a function from the history of the negotiation to the current offer that is consistent with the protocol. It specifies precisely how an agent will continue (what move it will make) given the protocol, the negotiation up to this point, and its actual beliefs and intentions." Each agent strategy will depend strongly on the type of application that each agent is involved in. [Shen et al., 2001] classified negotiation strategies into following categories:

- *Contract based negotiation*: Each agent (manager) having some work to subcontract broadcasts an offer and wait for other agents (contractors) to send bids. After some delay, the best offers are retained and contracts are allocated to one or more contractors who process their subtasks. The contract-net protocol provides for coordination in task allocation, with dynamic allocation and natural load balancing. The approach is quite simple and can be efficient. However, when the number of nodes is large, the number of messages on the network increases, which can lead to a situation where agents spend more time processing messages than doing the actual work. In the worst case that causes the system stop through being flooded by messages. The choice of a contractor is done by comparing bids corresponding to a particular offer and using whatever mechanism relevant to the problem.

- *Market based negotiation*: In a market-based approach, the goal is to solve a distributed resource allocation problem. Equilibrium is reached when the prices of goods is such that all resources are being used up. A particular agent wants to acquire goods but is limited by budget. Thus, it will make offers based on the current price of goods and its own preference. It has an internal utility function and its goal is to increase utility, which corresponds to the hypothesis of rational behavior. However, in the market-based approach using prices as a primary controlling mechanism, the convergence process may be slow when involving a large number of offers.

• *Game theory based negotiation*: Game theory based negotiation techniques have been widely used in agent systems. The key concepts in this game theory approach to negotiation are: utility functions, a space of deals, and strategies and negotiation protocols. Utility values are built into a payoff matrix which is typically common knowledge to both the parties involved in the negotiation. The negotiation process involves an interactive process of offers and counter-offers in which each agent chooses a deal which maximizes its expected utility value. There is an implicit assumption that each agent in the negotiation is an expected utility maximizer. At each step in the negotiation, an agent evaluates the other's offer in terms of its own negotiation strategy. The negotiation process depends heavily on the agents' goal of maximizing its utilities.

• *Plan based negotiation*: Plan based negotiation is based on cooperation strategies for resolving conflicts among plans of a group of agents. Agents need information from others to be able to plan and function effectively and efficiently. With this approach, agents know in advance exactly what actions they will take and what interactions will occur. By requiring such a complete specification of behavior, the plan can realistically only have a short-term horizon due to the unpredictability of events in the environment. Thus, the negotiation and planning are very tightly intertwined and inevitably suffers from limitations inherent in centralized or distributed multi-agent planning.

• *AI based negotiation*: It appears that almost every form of human interaction requires some degree of explicit or implicit negotiation. Hence, it is not surprising that many researchers draw from human negotiation strategies, which often leads to using AI techniques such as logic, case-based reasoning, and constraint-directed search.

• *Other approaches*: Negotiation strategies are more difficult to model in situations where conflicts arise between different sets of beliefs, and exchanged arguments then have to be taken into account. Extensive symbolic reasoning can be required at each stage and may depend closely on the context of the particular application. There are still many other approaches such as: time-limited, genetic algorithms based, socio-psychological theories based, argumentation-based and so on.

All methods have their own merits and demerits in solving related problems of SCN. However, when there are conflicts and decisions of agents affect each agent's payoff, game theory has advantages. That's because it is a powerful tool for analyzing interactive optimization problems. Therefore, this research introduces game theory into negotiation to solve conflicts between MAs and MSAs. A review on related works in this area will be discussed in next section. There are two main types of games applied in SC: non-cooperative game and cooperative game.

1.2.2.2 Game theory based negotiation

(a) Non-cooperative games in SCNs

There are many non-cooperative games in game theory, and Nash game and Stackelberg game are two main games which had been applied into SCNs. Nash game is a simultaneous move game where players concurrently make their decisions without any communication. Nash equilibrium [Nash, 1950] is the most central solution concept for games. It defines how rational agents should act in settings where an agent's best strategy may depend on what another agent does, and vice versa. In Stackelberg game, the Stackelberg leader player chooses a strategy firstly and then the Stackelberg follower player observes this decision and makes its own strategy choice. Since in many SCN models the upstream firm possesses certain power over the downstream firm, the Stackelberg equilibrium concept has found many applications in SCM literatures.

[An et al., 2007] introduced Stackelberg game in SC analyses to solve potential conflicts between manufacturing partners at various process. A CNP-based negotiation protocol amongst enterprises with marketing science models was proposed in [Kaihara et al., 2006] and [Kaihara and Fujii, 2008]. N-person game theoretic is included in the horizontally specialized business model to realize the coordination amongst enterprise in the same business segment. The seller and buyer relationship was considered in [Esmaeili et al., 2009] by using non-cooperative structure, specially, regarded the interaction between buyer and seller as a Stackelberg game. [Leng and Parlar, 2010] analyzed both simultaneous-move and leader-follower games to respectively determine the Nash and Stackelberg equilibria and find the globally optimal solution that maximizes the system-wide expected profit. [Hezarkhani and Kubiak, 2010] derived coordinating transshipment prices that always give rise to a coordinating contract for the chain using the generalized Nash bargaining solution. [Kurata and Nam, 2010] formulated a Nash game model and a manufacturer-leader Stackelberg model to explore whether the equilibrium after-sales level that a manufacturer and a retailer decide upon is equivalent to the optimal after-sales service in terms of customer satisfaction. [Lovejoy, 2010] developed a bargaining-based solution to the negotiation between two adjacent multi-firm tiers and show its consistency with familiar solution concepts form the theories of Nash bargaining. [de Albeniz V. and G., 2011] modeled the situation where a profit-maximizing retailer who seeks to allocate its shelf space capacity to n products of the same category from competing suppliers as a Stackelberg game and then analyzing the Nash equilibrium resulting from the supplier's pricing decisions. [SeyedEsfahani et al., 2011] established Nash game model, Stackelberg-manufacturer game model and Stackelberg-retailer game model to study the effect of SC power balance on the optimal decisions of SC members. [Javid and Hoseinpour, 2011] use Nash model and Stackelberg model to investigate the coordination of cooperative advertising decisions in a SC with one manufacturer and one retailer. [Hu et al., 2011] introduced Nash game and Stackelberg game involving a fair internal price to reduce lead-time hedging and increase the firm's overall profit. [Yin and Nishi, 2011] applied Stackelberg game model into solve a decision making on purchased quantity of raw materials, price, inventory and production. [Xia, 2011] revealed the equilibrium prices, market segments and overall profits for the suppliers based on game theory. [Rezapour et al., 2011] applied Stackelberg game in SCNs design problem anticipating later competition with the existing rival chain in the markets. [Wu, 2011] investigated the equilibrium behavior of a two-echelon SC in vertical Nash, manufacturer's Stackelberg and retailer's Stackelberg strategies. [Lu et al., 2011] applied game theory in manufacturer Stackelberg, retailer Stackelberg and vertical Nash SC scenarios to obtain the equilibrium solutions for every entity.

(b) Cooperative games in SCNs

In light of cooperative game theory, a supply network can be modelled as a coalition of partners pooling their resources and sharing the same utility function. The Pareto efficient solutions of cooperative game was obtained by optimizing weighted sum of sellers's and buyer's objective functions in [Esmaeili et al., 2009] . [Zhao et al., 2010] took a cooperative game approach to consider the coordination issue in a manufacturer-retailer SC using option contracts. [SeyedEsfahani et al., 2011] established one cooperative game model to study the effect of SC power balance on the optimal decisions of SC members. [Renna and Argoneto, 2011] proposed a cooperative mechanism based on game theory for capacity sharing in a network of independent plants.

The key point of using game theory is to find equilibriums of the games. Methods, which are used to find equilibriums of Nash game and Stackelberg game, are investigated in follows.

(c) Methods of finding equilibrium

• *Nash game*: [Mckelvey and McLennan, 1996] reviewed the methods for numerical computation of Nash equilibria for general finite n-person games and [Stengel, 2002] surveyed the algorithms for computing Nash equilibria of two-person games. [Sjostrom, 1991] provided a constructive way of checking whether or not a social choice correspondence can be implemented in Nash equilibria. Nash equilibrium was found by finding the reaction functions in [Reyniers and Tapiero, 1995] and the Nash equilibrium occurs where reaction curves intersect. [Koller et al., 1996] computed the Nash equilibria of a two-person, non-zero-sum game by linear complementarity problem. [Jorgensen and Zaccour, 1999] identified the Markov perfect Nash equilibrium by the Hamilton-Jacobi-Bellman approach of dynamic programming. [Govindan and Wilson, 2003] combined the global Newton method and the homotopy method to compute Nash equilibria of finite games. [Govindan and Wilson, 2004] developed a algorithm for computing Nash equilibria of N-player games by iterated polymatrix approximation. [Sandholm et al., 2005] presented a mixed integer program formulations for finding Nash equilibria in games (specifically, two-player normal form games). [Littman and Stone, 2005] presented a polynomial-time algorithm for computing a Nash equilibrium for repeated two-player games under the average-payoff criterion. [Conitzer and Sandholm, 2006] presented a technique for reducing a normal-form game to a smaller normal-form game for the purpose of computing a Nash equilibrium. [Porter et al., 2008] presented a pair (2-player and n-player) of algorithms for finding a sample Nash equilibrium. [Leng and Parlar, 2010] found the Nash equilibrium by using the best response functions. The subgame perfect (Nash) equilibrium was obtained in [Xiao et al., 2010] by employing backward induction technique. [Hoda et al., 2010] developed first-order algorithms to approximate Nash equilibria of two-person zero-num sequential games by applying Nesterov's smoothing technique to the saddle-point formulation of the Nash equilibrium problem. [Sinha and Sarmah, 2010] calculated the Nash-Bertrand equilibrium by the intersection of the best response functions. [Hu et al., 2011] calculated the Nash equilibrium from the first order derivatives based on their strictly quasi-concave function. [SeyedEsfahani et al., 2011] calculated the Nash equilibrium by solving the first order equation and KKT first order necessary conditions of extreme value theorem. [Wu, 2011] used the first order condition and backward induction technique to determine Nash equilibrium.

• *Stackelberg game:* [Cachon and Netessine, 2003] found an equilibrium of a Stackelberg game by solving a dynamic two-period problem via backwards induction. [An et al., 2007] located the Stackelberg equilibrium by the best response function and the backward induction solutions. [Esmaeili et al., 2009] transformed the finding of the Stackelberg equilibrium into an unconstrained nonlinear function where the optimal solution can be found using a grid search. [Leng and Parlar, 2010] found the Stackelberg equilibrium by using the best response functions. [Kurata and Nam, 2010] calculated the equilibrium by solving first order condition. [Hu et al., 2011] calculated Stackelberg equilibrium from the first order derivatives based on their strictly quasi-concave function. [SeyedEsfahani et al., 2011] calculated the Stackelberg equilibrium by solving the first order equation and KKT first order necessary conditions of extreme value theorem. A new combinatorial Simulated Annealing and Branch & Bound meta-heuristic solving method was proposed by [Rezapour et al., 2011] to find the solution of the von-Stackelberg model. [Wu, 2011] used the first order condition and backward induction technique to determine Stackelberg equilibrium.

• *Other games:* [Owen, 1975] used the duality theory of linear programming to obtain equilibrium price vectors of the n-person game. [Bhat and Leyton-Brown, 2004] presented algorithms for computing both symmetric and arbitrary equilibria of Action-graph games using a continuation method. [Ganzfried and Sandholm, 2010] developed the first mixed-integer programming formulations for computing a ε-equilibrium in large games of imperfect information by solving an infinite approximation of the original game. [Yin and Nishi, 2011] proposed a solution algorithm based on embedding quantity discount policy into the manufacturing optimization algorithm and solved this problem by using an Outer Approximation technique. [Lu et al., 2011] calculated the equilibrium by solving the response function and first order condition.

1.2.3 Multi-agent based coalition formation of supply chain networks

Coalition formation problem considers techniques and criteria that might be used by a collection of (rational) agents to decide how they might group together to improve individual or social utility. It has been and continues to be studied in research field of multi-agent systems [Asselin and Draa, 2002]. There are a lot of work focused on coalition formation among organizations of SCNs. [Shenoy and Lawrence, 1979] emphasized on coalition formation, two models of coalition formation are proposed based on theory of n-person games. [Ketchpel, 1995] formalized coalition formation problem in decision theoretic and game theoretic terms and presents a fully distributed algorithm that can efficiently determine coalitions that will be approximately stable. [Gamson, 1961] presented a theory of coalition formation to apply to a full-fledged coalition situation. [Aumann et al., 1974] connected a given solution notion with the same solution notion applied to appropriately defined games on each of the coalitions. [Sandholm and Lesser, 1995] extended the game theory to a normative, domain-independent theory of coalitions in combinatorial domains. [Klusch and Shehory, 1996] presented an approach for cooperation and coalition formation among information agents for heterogeneous databases. [Nagarajan and Sosic, 2008] reviewed coalition formation models in a SC from the viewpoint of game theory. Feasibility and benefits of general approach of price and production coordination is investigated in [Granot and Yin, 2008] via alliance formation in a SC setting and show that alliance formation has a significant effect on inefficiency stemming from decentralization of suppliers in a push system, system's performance depends on the number of alliances.

Related works of application of coalition formation in SCNs are surveyed as follows:

1.2.3.1 Coalition formation of supply chain

[Hennet and Mahjoub, 2010] represented supply network design problems as problems of optimal coalition formation. [Lin and Hsieh, 2012] studied selection of chain partners using cooperative coalitional game and formation continues until a stable Cournot-Nash equilibrium is reached. [Yang and Fong, 2012] discussed on dynamic SC formation. [Kim and Cho, 2010] presented a concrete method as a solution to SC formation problem by using agent negotiation based on a Single Machine Earliness/Tardiness model.

1.2.3.2 Coalition formation of buyers

Coalition formation among buyers can be seen as a group-buying game. [Li et al., 2004] envisioned combinatorial coalition formation problem by forming coalitions buyers to enlarge quantity in each transaction and take advantage of price discounts. A negotiation protocol and decision mechanism for buyers to form coalition was provided in [Sombattheera et al., 2004] when appropriate. [Ito et al., 2002] proposed a new group buy scheme for agent-mediated electronic markets. [Yamamoto and Sycara, 2001] proposed a new buyer coalition formation scheme which enables a large number if buyers to form coalitions. [Hyodo et al., 2003] discussed optimal allocation of buyers in the group buying using a search algorithm based on GA. An alternative, physics-motivated mechanism for coalition formation of buyers that treats agents as randomly moving, locally interacting entities was proposed in [Lerman and Shehory, 2000]. [Tsvetovat et al., 2001] presented a flexible test-bed system to implement and test coalition formation of groups of customers. [He et al., 2003] surveyed the buyer coalition formation. [Asselin and Draa, 2002] designed a protocol for the formation of coalitions of consumers as buying groups, with which consumers could to negotiated their preferred values of attributes of products.

1.2.3.3 Coalition formation of sellers

[Sombattheera et al., 2004] provided a negotiation protocol and decision mechanism for sellers to form coalition when appropriate. [Jin and Wu, 2006] studied the formation of supplier coalitions in on-line reverse auctions. [Argoneto and Renna, 2010] proposed a coalition formation algorithm for small and medium suppliers not able to fully respond to the customer requests based on the Nash equilibrium concept. [Renna, 2010] carried out the coalition model by a coalition agent, which knows the current processing order and collects the supplier counter offers.

1.2.3.4 Other coalition formation

[Sombattheera et al., 2004] provided a negotiation protocol and decision mechanism for logistic provider to form coalition when appropriate. [Bonnevay et al., 2005] analyze the dynamic of negotiation to deal with the problem of dynamically form coalitions and the obtain of an equilibrium solution.

1.2.4 Negotiation Model

Automated negotiation provides an important mechanism for distributed decision makers, both human participants and autonomous agents, to reach agreements. With the support of an automated negotiation system, human participants can simply input their preferences, requirements, etc. into the system and the representative agents can help negotiate the contents automatically. Such a procedure not only simplifies but also accelerates the negotiation processes. Imagine a human coordinator in a large organization who may need to negotiate with many members in the group on different issues on the same day. A face-to-face, one-to-one negotiation approach would be extremely time consuming and thus impact the operational efficiency of the organization. Automated negotiation provides a mechanism for autonomous agents to reach multiple agreements on, e.g., task allocation, resource sharing, and surplus division more quickly and efficiently [Lai and Sycara, 2009].

1.2.4.1 Single-attribute negotiation and multi-attribute negotiation

Existing research on negotiation problems can largely be divided into two categories: single-attribute and multi-attribute negotiation. While single-attribute negotiation problem has been extensively studied, and researches on multi-attribute negotiation is still at an early stage. In this section, we mainly reviewed related works on multi-attribute negotiation.

Multi-attribute (multi-issue) negotiation is both necessary and ubiquitous in commerce, and therefore important. It is a useful mechanism in real life. There are numerous situations where agents have to negotiate multiple issues at the same time. For example, in the human environment, a supplier and a buyer may need to negotiate the quantity, price, and delivery time of a supply contract at the same time. Likewise, an employer and an applicant may need to negotiate the position, wage, and training opportunities simultaneously. In the agent world, two (or more) agents in an organization commonly need to decide how to allocate multiple tasks or share a set of resources. In these situations, lack of agreement on any one issue can bring the whole process to a halt. Second, besides being a necessary part of the business environment, multi-attribute negotiations may also benefit agents when they have different preferences among the issues. Because they can trade off one issue for another, the agents may reach an agreement that makes them mutually better off. For instance, when selling automobiles, dealers can simply sell them at a single price, but they often introduce financing, insurance, warranty, and spare parts packages into the contract. It might be cheaper for the dealers to discount these packages rather than directly lower the price of the automobile. The buyers are then more willing to accept the automobile price, as they may find that the price of buying those packages individually is much higher. Thus, by negotiating multiple issues together, they can achieve a "win-win" outcome that would not be possible by negotiating a single issue [Lai et al., 2008, Lai and Sycara, 2009].

Multi-attribute negotiation can be much more complicated than single attribute negotiation. The complexity arises from the following factors [Lai and Sycara, 2009]:

• First, in a multi-attribute negotiation, an agent's utility depends on all issues. As a result, making an appropriate offer becomes more complex, since in each step, an agent may find that a number of offers provide her with the same utility level, i.e., are equally advantageous to her. Which offer to propose at each juncture is usually nontrivial; this decision impacts the opponent's utility and thus his response. If an agent can select the offer that maximizes the opponent's utility in each step, the opponent is more likely to accept the offer. The agent is therefore able to concede less and consequently achieve more utility.

• Second, negotiations in practice often take place in environments where information is incomplete. The parties might be meeting for the first time and thus know nothing about each other. While it may be possible for the parties to deduce each other's utility function and strategy in a single-attribute negotiation, it becomes much more difficult when multiple issues are involved. Moreover, the negotiation context in practice may also vary over time. The agents might not even have a definitive sense of their own preferences before a negotiation. The traditional approach to this problem is to apply preference elicitation before a negotiation. However, preference elicitation is known to be a difficult and time-consuming procedure, especially when the preferences of the agents are complex.

• Third, in a multi-attribute negotiation, it is important to achieve a Pareto-optimal solution. Rational agents should not leave "extra money" on the table. But achieving a Pareto-optimal settlement between self-interested agents in an incomplete information environment is difficult.

Therefore, multi-attribute negotiation is a more challenging field of research than single-attribute negotiation. A multi-attribute negotiation system must enable agents to negotiate issues efficiently and robustly in a domain in which agents might not know each other's preferences or even have a complete picture of their own preferences.

Barbuceanu and Lo presented a generic negotiation architecture that uses multi-attribute utility theory principles to reach agreements that satisfy multiple interdependent objective [Barbuceanu and Lo, 2000]. Bui et al. proposed a number of heuristics that could be used to develop trading mechanism based on multi-attribute utility theory, and presented a number of algorithms that initially focus on the issues that divide the buyer and sellers [Bui et al., 2001]. Teich et al. described a multi-attribute e-auction mechanism for auctioning multiple units of good, primarily in B2B transactions [Teich et al., 2006]. Hemaissia et al. proposed a negotiation protocol suited for multiple agents with complex preferences and taking multiple interdependent issues and recommendations made by the agents into account at the same time to improve a proposal [Hemaissia et al., 2007]. Ito et.al proposed an auction-based multiple-issue negotiation protocol among nonlinear utility agents [Ito et al., 2008]. Lai and Sycara reviewed the existing research on multi-attribute negotiation and discussed the gap between the existing work and an applicable automated multi-attribute negotiation system, and finally presented a generic framework with two new mechanisms that consider incomplete information, Pareto optimality, and tractability [Lai et al., 2008, Lai and Sycara, 2009]. An agent-based multi-attribute soft-bargaining method for bilateral contracts in a multi-agent market was presented in [Kebriaei and Majd, 2009] to facilitate negotiation among agents, and a multi-dimensional fuzzy satisfaction set is proposed for the attributes. Petric and Jezic addressed a multi-attribute auction model for agent-based content trading in telecom markets [Petric and Jezic, 2010]. Rao et al. designed a multi-attribute auction mechanism for addressing the decision making problem of multi-attribute and multi-source procurement of a kind of homogeneous continuous divisible goods [Rao et al., 2012]. Kersten proposed typology of concession-making in multi-bilateral negotiation and multi-attribute auctions [Kersten et al., 2013]. Most of the above work focus on one to one negotiation, and few of them discuss negotiation between one buyer and multiple sellers. However, to the best of our knowledge, there is no research address multi-attribute negotiation between multiple buyers and multiple sellers.

1.2.4.2 Single-item negotiation and multi-item negotiation

In this dissertation, items are indicated for different kinds of products. Negotiation related to items can be divided into: single-item negotiation and multi-item negotiation.

Most of researches are focused on previous one, because it's the most common situation to discuss attributes (e.g. price) of one specific item (product). However, it's a common situation that a MA must buy multiple kinds of items to produce its product (like a bill of materials to specify raw materials and components that make up a product) and it's also general that some items can be supplied by the same supplier. For example, a car company needs to buy screws, valves, lamps, horns, and so on. There are different kinds of lamps such as headlamps, turn signal lamps, fog lights, tail lights, and emergency lights, but can be supplied by one lamp supplier. Therefore, the car company will negotiate multi-item (combine all lamps together) at the same time with lamp supplier rather than respectively negotiates on individual lamp. In that case, MAs and MSAs may reach agreements that make them mutually better off by trading off among items. Furthermore, it will be a heavy workload and waste time for MAs to negotiate each item when there are diversity items to be ordered.

Most works on multi-item auctions suppose two simplifying conditions: quantities of items to sell are fixed as well as quantities requested by buyers. However, these two hypotheses do not meet requirements of many situations where negotiations are used. Researchers try to relax these assumptions where available quantities are not fixed [Lengwiler, 1999] as well as quantities requested by buyer [Ben-ameur et al., 2002]. [Ito et al., 2002] focused on multi-item negotiation, where items are substitute and sellers exchange items when they do not have enough abilities. None of them focused on coalition formation among sellers (suppliers). Shi and Hu using evaluation mechanism and Nash solution to determine winner of negotiation in which items are combined as a set [Shi and Hu, 2006]. [Roh and Yang, 2008] proposed an iterative multi-item unit-demand and unit-supply double-auction mechanism, in which buyers want to buy at most one item out of the many available and each seller has a single item to sell. A structure of utility graphs in multi-item negotiation was constructed through collaborative filtering of aggregate buyer preferences [Robu and Poutré, 2008].

1.3 Research Objectives

Recent studies have tended to focus on completely open and highly uncertain environments that apply agent systems to the real world. Negotiation is done by exchanging messages among agents (often only two) and there are different kinds of negotiations among material supplier agents, manufacturer agents, distributor agents, retailer agents, and consumer agents. However, all negotiations can be concluded as negotiation between seller and buyer, where the seller has diversity products to sell and the buyer has money to buy. This research focuses on negotiation between manufacturer agents (buyer) and material supplier agents (seller) because it's an essential and important issue of negotiation for supply chain networks. All negotiation models mentioned in section 1.2.4 focus on simple situations, where attributes and items are considered respectively. However, in real cases, it's much more complicated some times. Thus, this research considers all possible combination of situations as shown in Figure 1.5, where four different types of negotiations (single-attribute single-item (SASI) negotiation, single-attribute multi-item (SAMI) negotiation, multi-attribute single-item (MASI) negotiation, and multi-attribute multi-item (MAMI) negotiation) between one-MA and multi-MSA and between multi-MA and multi-MSA are discussed, respectively. It is assumed in this dissertation that only MSAs are allowed to form coalitions when the order of MA is out of their abilities. No MA is allowed to form coalitions. That's because this dissertation focuses on the situation where large-sized MAs and small-and-medium-sized MSAs are involved. Furthermore, it is assumed that all MAs must be allocated to one MSA or coalition.

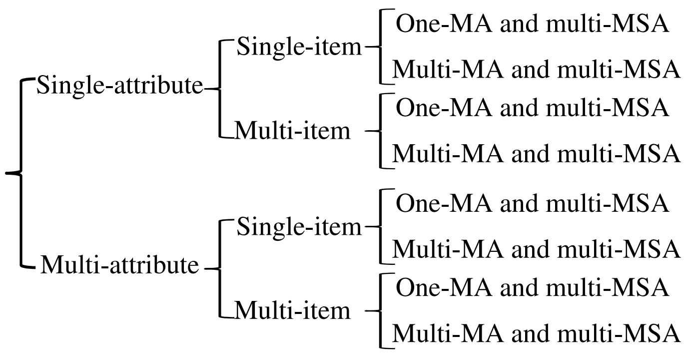


Figure 1.5: Negotiation model classification

SASI negotiation is the most common negotiation and has been extensively studied. However, MAs may need to buy multiple kinds of items to produce its product (like a bill of materials to specify raw materials and components that make up a product) and it's also general that some items can be supplied by the same MSA. In that case, MAs and MSAs may reach agreements that make them mutually better off by trading off among items. Thus, SASI negotiation is extended to SAMI negotiation.

Multi-attribute (multi-issue) negotiation is both necessary and ubiquitous in commerce, and therefore important. It is a useful mechanism in real life. There are numerous situations where agents have to negotiate multi-attribute at the same time. In the agent world, two (or more) agents in an organization commonly need to decide how to allocate multiple tasks or share a set of resources. In these situations, lack of agreement on any one issue can bring the whole process to a halt. Besides being a necessary part of the business environment, multi-attribute negotiations may also benefit agents when they have different preferences among the attributes. Because they can trade off one attribute for another, the agents may reach an agreement that makes them mutually better off. Thus, by negotiating multi-attribute together, they can achieve a "win-win" outcome that would not be possible by negotiating a single-attribute. Multi-attribute negotiation can be much more complicated than single-attribute negotiation, and it is a more challenging field of research than single-attribute negotiation. Both SASI negotiation and SAMI negotiation are generalized into MASI negotiation and MAMI negotiation in this research, respectively.

Furthermore, it is a common situation in manufacturing system that there exist large-sized MAs as well as small-and-medium-sized MSAs. In that case, the orders of MAs may be too big for the small-and-medium-sized MSAs to supply independently. MAs either select the large-sized MSAs or split the orders into pieces and then allocated to multiple small-and-medium-sized MSAs. MAs need to find the optimal MSA for each piece of the order if they want to split the orders into pieces, and also may need to pay for external fees (e.g. Transportation fee for each piece). It will be a hard work (waste time and with heavy workload) for MAs to split orders into pieces when there are diversity items with big quantity to place. MAs may choose the large-sized suppliers even with higher cost rather than the small-and-medium-sized MSAs with lower cost to reduce workload. In that case, both MAs and MSAs lose profits. MAs may need to pay more for the large-sized MSA. On the other hand, the small-and-medium-sized MSAs lose opportunities to compete for the orders because of their limited abilities. Therefore, it's important to find a reciprocal way for MAs to improve their profits and for small-and-medium-sized MSAs to increase their competitiveness. Thus, this dissertation tries to find another way to solve this problem. The proposed coalition formation based negotiation protocols provide effective and stable ways to solve the related problems. Main proposal is a hierarchical game based negotiation protocol. A cooperative game is introduced into finding coalitions among MSAs when it is necessary. Stackelberg game is used to find equilibrium of the negotiation between MA and MSA or coalition. Then, a two-person game is applied to find the final allocation scheme between MAs and MSAs based on the above acquired coalitions and equilibriums. Details of the hierarchical game will be discussed in Chapter 3.

Moreover, this research applies game theory into negotiation. Final objective of negotiation between multi-MA and multi-MSA is to determine allocation scheme of $I \times J$ game. Thus, an efficient way to solve $I \times J$ game will be another purpose of this research. It is solved by decomposing $I \times J$ game into J-person cooperative game to find coalition if necessary, two-person Stackelberg game to find equilibrium, and two-person game to determine final allocation scheme.

1.4 Thesis Outline

Remaining chapters of this dissertation are outlined as follows:

The second chapter gives a detail description of coalition formation mechanism. In this chapter, MSAs are allowed to find partners to establish coalitions when order of MA is out of their abilities. Both coalition formation determination for single-item involved negotiation and multi-item involved negotiation are discussed. Profit allocation among members of coalition is discussed after coalition is determined. Moreover, a modified coalition formation is proposed when multi-attribute is involved during negotiation.

In chapter 3, SASI negotiation between MA(s) and MSAs is presented. A two-stage negotiation protocol for SASI negotiation between one MA and multi-MSA is proposed. Stackelberg game is introduced to find equilibriums of negotiations between MA and MSAs or coalitions. Then, negotiation is extended between multi-MA and multi-MSA, where a hierarchical-game based negotiation protocol is presented. Simulations are provided to verify feasibility and effectiveness of proposed protocols. Finally, a compared protocol, in which MAs split orders into pieces and allocated to different MSAs, is provided. Internal comparisons of proposed protocols is provided to evaluate parameter settings and external comparison between proposed protocol and compared protocol is presented to verify effectiveness and superiority of the proposed protocols.

In chapter 4, SASI negotiation is generalized into SAMI negotiation when there is one MA and multi-MSA and when there are multi-MA and multi-MA, respectively. Coalition formation based negotiation protocols are provided, where coalition formations for complementary and substitution are combined together. Simulations and comparisons are provided as well.

In chapter 5, MASI negotiation is discussed. Three attributes including price, quantity and lead time are considered simultaneously. Concessions among attributes are addressed as well. Simulations when there is one-MA and multi-MSA and when there are multi-MA and multi-MSA are provided to illustrate feasibility of the proposed protocols, respectively. Finally, comparison protocols are presented and compared with the proposed protocols.

Chapter 6 focuses on MAMI negotiation between MA(s) and MSAs. A modified coalition formation mechanism is presented to get used to the changing of abilities of MSAs (coalitions). Not only is concessions among attributes, but also weights of attributes of MAs and MSAs are considered. MAs and MSAs can determine the weights according to their own preferences. Simulation and comparisons are provided as well.

Chapter 7 summarizes entire research work and concluding remarks as well as direction of future research activities are discussed.

Chapter 2 Coalition Formation Mechanism

2.1 Introduction

Coalition formation problem considers techniques and criteria that might be used by a collection of (rational) agents to decide how they might group together to improve individual or social utility. Coalitions are ubiquitous in real-life settings. Theoretical underpinnings of approaches to coalition formation lie in literature on multi-player games in game theory. Players negotiate among themselves about payoffs to decide which coalition to join. In reality, it is more complex than that. Self-interested agents, operating in dynamic environment such as supply chain (SC), are under heterogeneous constraints. Furthermore, each agent has its own strategies that increase or decrease the value of each constraint thus affects decision making of agents [Sombattheera et al., 2004]. While time is changing in dynamic environment, the value of a constraint varies thus affecting utility of agent. In contrast to traditional coalition formation study, where coalition value is predefined and thoroughly known among agents, an agent has to calculate, according to its constraints and strategies, for coalition that would give it maximum utility. The key components of successful coalition formation of self-interested agents are: quickly negotiating with other agents, and selecting the best possible coalition. Each agent, bounded by its own constraints, may negotiate with others to form a coalition, which is likely to yield maximum benefit. Such a coalition, however, may not be formed due to the constraints. So the agent has to look for the next best possible coalition by consulting with its internal utility mechanism. Negotiation and decision must be done in a timely fashion. In this chapter, collaboration among material supplier agents (MSAs) in SC is discussed. It includes two important components: a negotiation protocol and a decision mechanism. The negotiation protocol allows agents to exchange necessary information before deciding which coalition to join.

2.2 Cooperative Game based Coalition Formation Model

A coalition structure in a n-person game is a partition of the set of players. A game in characteristic function form, or simply a game, is a pair (N, v), where N is a finite set (the set of players), and v is a real-valued characteristic function on the family of subsets of N. A payoff vector for N is a real-valued function x on N; it may be thought of as a vector whose coordinates are indexed by the players. A coalition structure S on N is a partition of N. A game with coalition structure S is a triple (N, v, S) [Aumann et al., 1974].

Main assumption in cooperative game theory is that grand coalition will form. The challenge is then to allocate the payoff among players in some fair way. This assumption is not restrictive, because even if players split off and form smaller coalitions, we can apply solution concepts to the subgames defined by whatever coalitions actually form. A solution concept is a vector that represents the allocation to each player. Researchers have proposed different solution concepts based on different notions of fairness. Some properties to look for in a solution concept include:

- Efficiency: the payoff vector exactly splits the total value;
- Individual rationality: No player receives less than what he could get on his own;
- Existence: The solution concept exists for any game;
- Uniqueness: The solution concept is unique for any game;
- Computational ease: The solution concept can be calculated efficiently;
- Symmetry: The solution concept allocates equal payments to symmetric players;
- Additivity: The allocation to a player in a sum of two games is the sum of the allocations to the player in each individual game;
- Zero Allocation to Null Players: The allocation to a null player is zero.

Main solution concept for the cooperative game are: Core, Shapley value, Kernel, and Nucleolus. This research focuses on the core of the game. Let v be a game, the core of v is the set of payoff vectors: $C(v) = \{x \in \boldsymbol{R} : \sum_{i \in N} x_i = v(N); \sum_{i \in S} x_i \geq v(S), \forall S \subseteq N\}$. In words, the core is the set of imputations under which no coalition has a value greater than the sum of its members' payoffs. Therefore, no coalition has incentive to leave the grand coalition and receive a larger payoff.

In light of cooperative game theory, a supply network can be modelled as a coalition of partners pooling their resources and sharing the same utility function (profit). Partnership building problem can then be modelled as a cooperative game with transferable utilities (TU-game). A TU-game can thus be seen as a target model on which partners can agree to estimate the maximal value of chain and shares of global profit acceptable to all of them [Hennet and Mahjoub, 2010]. A coalition can be defined as a group of agents that have decided to cooperate in order to achieve a common goal. Let $S_j = (S_{j1}, \cdots, S_{jN})$ denotes all the partitions (coalition structure) for MSA j, $S_{ij} = (s_{ij1}, \cdots, s_{ijl}, \cdots)$ is one possible coalition of MSA j for MA i, l is index of the coalition. Let S^*_{ij} be the optimal coalition set of the game, which can maximize utility of MSA j. A supply network can be modeled as a coalition of partners pooling their resources and sharing the same utility function in light of cooperative game theory [Esmaeili et al., 2009]. For example, MSA j in Figure 2.1 is out of ability of order of MA i, thus, it needs to negotiate with other MSAs to find a coalition. s_{ijl} in Figure 2.1 is one of coalitions which consists of MSA j, MSA 1, and MSA $j+1$.

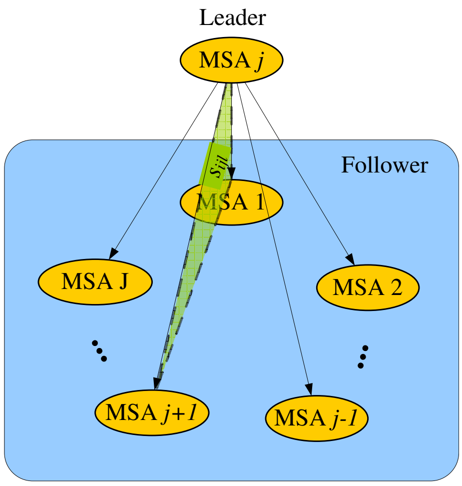


Figure 2.1: Coalition formation of MSA j

In real market, order happens frequently out of abilities of MSAs. MSAs will be compelled to reject order against their wills due to their limited abilities. In order to resolve this problem, researchers tend to decompose order into pieces and then allocate to multiple MSAs under this situation [Kraus, 1997, Chai et al., 2010]. However, it wastes time to decompose orders into pieces and allocate to different MSAs, and may cause external fee (e.g. transport fee) when MAs have diversified items (products) to order. Thus, this research tries to find another way to solve this problem which can maintain integrity of order. All MSAs in proposed model are allowed to make unions to increase their powers and share their tasks when orders are out of their abilities, and then compete for orders with the other MSAs or coalitions after coalition is successfully established.

Definitions, assumptions, and rules used in this chapter are given as follows:

Definition 2.1: *The MSA, which launches coalition formation mechanism and cannot finish order by itself, is defined as a leader-MSA (LMSA); and the other MSAs, which agree to establish a coalition, are defined as follower-MSAs (FMSAs).*

Definition 2.2: *Coalition formation of MSA j is called as a coalition for complementary if MSA j can supply item k but ability of item k is less than requested quantity ($0 < A_{ijk} < q_{ijk}^{M}$); while coalition formation is called as a coalition for substitution if MSA j cannot supply item k at all (A_{ijk}=0).*

Assumption 2.1: *If there are more than one MSAs agree to establish partnerships with MSA j, MSA j selects MSA with the lowest cost.*

Assumption 2.2: *FMSAs accept to establish a coalition if one of following conditions is satisfied: 1) they cannot finish the order by themselves but the order is profitable; 2) profit of belonging to a coalition is greater than that of completing the order by themselves.*

Assumption 2.3: *FMSAs can accept to be a member of coalition if and only if the order is in their abilities.*

Assumption 2.4: *If there are more than one MSAs invite MSA j to establish partnerships, MSA j accepts order with the highest profit.*

Rule 2.1: *When an order is out of ability of FMSA j_1, FMSA j_1 accepts to establish a coalition with LMSA j_2 if and only if combined price of coalition ($p_{ij_1lk}^{C}$) is greater than or equals to its minimum price ($p_{ij_1k}^{S}$); when order is in its ability, FMSA j_1 accepts to establish a coalition with LMSA j_2 if and only if combined price of coalition ($p_{ij_1lk}^{C}$) is greater than its initial price ($p_{ij_1k}^{SI}$).*

Rule 2.2: *An agreement can be obtained if and only if all members in coalition have positive profits.*

Rule 2.3: *Order is allocated according to contribution to the order of each item of each member.*

MSA j checks order to make sure whether the order is in its ability or not when MA i announces its order (p_{ijk}^{MI}, q_{ijk}^{M}, lt_{ijk}^{M}). Ability of MSA j for order of MA i is calculated by equation (2.1). Evaluate matrix can be got as $E = [e_{ijk}]$ according to A_{ijk} and q_{ijk}^{M}. The value of e_{ijk} equals to 1 if A_{ijk} is greater than or equals to q_{ijk}^{M}, and it equals to 0 if A_{ijk} is less than q_{ijk}^{M}. Coalition formation mechanism is triggered if e_{ijk} equals to 0. Combined price of coalition is calculated by equation (2.3), where the first multiplier is discount of coalition and the second multiplier is average price of all members in coalition which can supply item k. Payoff of coalition s_{ijl}, upper bound and lower bound of price of MSA j are calculated by equation (2.7), equation (2.8), and equation (2.9), respectively.

$$A_{ijk} = \gamma_{jk} LT^{MAX} - \sum_{i \in OL_j} QS_{ijlk},\ \forall i,\ \forall j,\ \forall k \tag{2.1}$$

$$LT_{jk}^{MAX} = \max\{lt_{i'jk^M}, |i' \in OL_j\}\},\ \forall j,\ \forall k \tag{2.2}$$

$$p_{ijlk}^{CI} = (1 + \sigma_{jk}) \frac{\sum_{j' \in s_{ijlk}} p_{ij'k}^{SI}}{N_{ijlk}},\ \forall i,\ \forall j,\ \forall l,\ \forall k \tag{2.3}$$

$$p_{ijlk}^{CL} = \frac{\sum_{j' \in s_{ijlk}} p_{ij'k}^{SL}}{N_{ijlk}},\ \forall i,\ \forall j,\ \forall l,\ \forall k \tag{2.4}$$

$$p_{ijlk}^{CU} = \frac{\sum_{j' \in s_{ijlk}} p_{ij'k}^{SU}}{N_{ijlk}},\ \forall i,\ \forall j,\ \forall l,\ \forall k \tag{2.5}$$

$$AC_{ijlk} = \sum_{j' \in s_{ijl}} A_{ij'k},\ \forall i,\ \forall j,\ \forall l,\ \forall k \tag{2.6}$$

$$\pi_{ijl}^{C} = \sum_{j' \in s_{ijl}} \sum_{k=1}^{K} (p_{ij'lk}^{C} - C_{j'k}) QS_{ij'lk},\ \forall i,\ \forall j,\ \forall l \tag{2.7}$$

$$p_{jk}^{SU} = (1 + \beta_{jk}^{U}) C_{jk},\ \forall j,\ \forall k \tag{2.8}$$

$$p_{jk}^{SL} = (1 + \beta_{jk}^{L}) C_{jk},\ \forall j,\ \forall k \tag{2.9}$$

Where

i: index of MA

j: index of MSA

l: index of coalition

k: index of item

t: index of iteration of negotiation

β_{jk}^{U}: upper bound of the percentage of profit of item k of MSA j

β_{jk}^{L}: lower bound of the percentage of profit of item k of MSA j

γ_{jk}: productivity of item k of MSA j

A_{ijk}: ability of item k of MSA $j$for MA i

AC_{ijlk}: ability of item k of coalition s_{ijl}

C_{jk}: cost of of item k MSA j

LT_{ijk}: lead time of item k of the order of MA i

N_{ijlk}: number of MSAs in coalition s_{ijl} can supply item k

OL_j: order list[1] of MSA j

p^{CI}_{ijlk}: initial price of item k of coalition s_{ijl}

p^{SI}_{ijk}: initial price of item k of MSA j

p^{SL}_{jk}: lower bound of price of item k of MSA j

p^{SU}_{jk}: upper bound of price of item k of MSA j

QS_{ijlk}: quantity of MSA j of item k obtained from s_{ijl}

s_{ijl}: l^{th} coalition of MSA j for MA i

$|s_{ijl}|$: number of members in s_{ijl}

π^{C}_{ijl}: profit of coalition s_{ijl}

2.3 Coalition Formation Protocol

Coalition formation protocol is concluded as follows based on rules and assumptions proposed in section **??**. Each MSA has a candidate list [2] to record all possible coalitions and sorts them by their combined price in descending order. Flowchart of coalition formation is shown in Figure 2.2 and protocols for LMSA and FMSA are shown as follows:

(a) For LMSA

- **Step L_1:** Updates its candidate list;

[1] The order list is used to record all accepted orders of MSA j.

[2] A candidate list of MSA j is used to record all coalitions which have sent a request to it, and then it selects the first one of candidate list with which it has maximum profit.

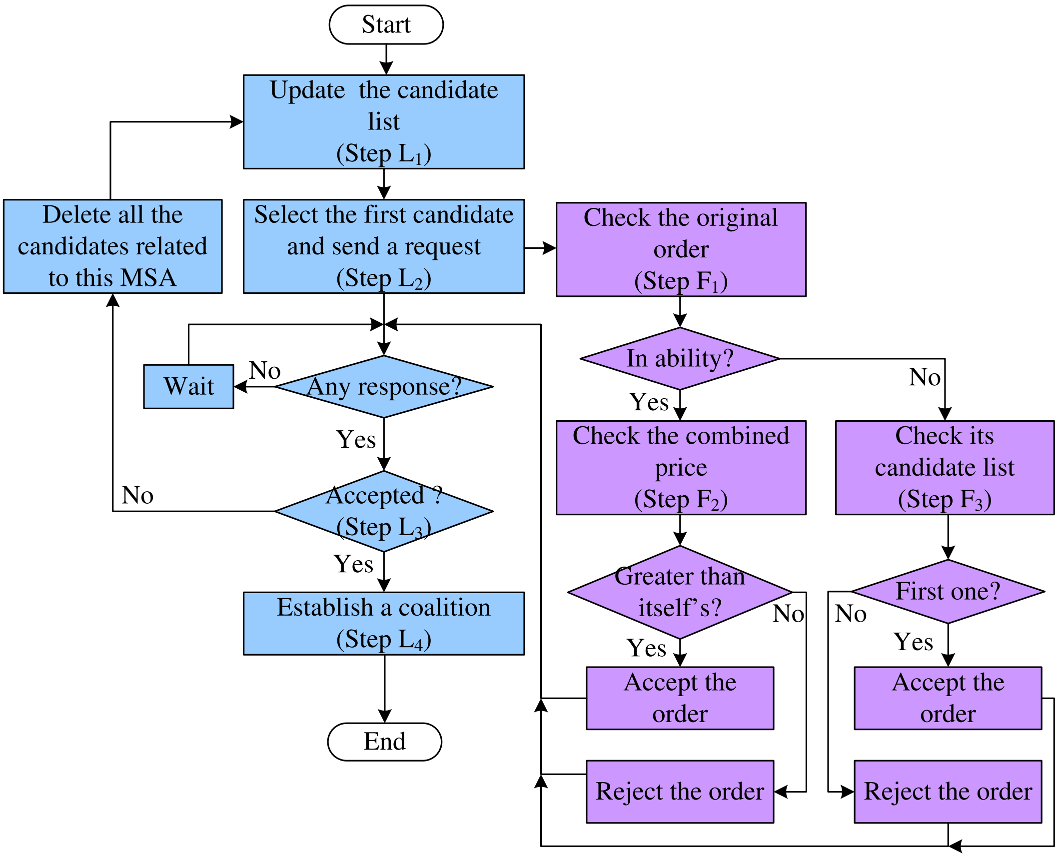


Figure 2.2: Flowchart of the coalition formation protocol

- **Step** L_2**:** Selects the first candidate, sends a request to it, and waits for its response;
- **Step** L_3**:** If candidate accepts the request, goes to step L_4, if candidate rejects the order, then deletes all candidates related to this MSA and goes back to step L_1;
- **Step** L_4**:** Establishes a coalition with this candidate and coalition formation ends.

LMSA makes decision according to ***Assumption 2.1*** when there are more than one FMSAs agree to establish partnerships.

(b) For FMSA

- **Step** F_1**:** Checks owner of the order. If it is in its ability, goes to step F_2; else goes to step F_3;
- **Step** F_2**:** Checks combined price of the coalition. If it is greater than its own price, accepts the request; else rejects the request;
- **Step** F_3**:** Checks its candidate list. If the LMSA is the first one, accepts the request;

else rejects the request.

2.3.1 Coalition formation determination

Each player $j \in J$ seeks to maximize its profit π_{ijlj}^{SC} by belonging to a coalition s_{ijl}. The coalition is determined only if all MSAs in s_{ijl} reach an agreement based on ***Rule 2.1*** and ***Rule 2.2***. All MSAs want to belong to coalitions with the highest profit.

2.3.1.1 Single-item involved coalition determination

Determination of final coalition of MSA j for MA i, in which there are only one item involved ($k = 1$), can be solved by finding solution of following problem [Yu et al., 2012b]:

$$SF_{ij}^{*} \quad = arg \max_{s_{ijl}} \{\pi_{ijlj}^{SC}\}, \ \forall i, \ \forall j \tag{2.10}$$

$$\text{s.t.} \quad AC_{ijlk} \geq q_{ijk}^{M}, \ \forall i, \ \forall j, \ \forall l, \ \forall k \tag{2.11}$$

$$\pi_{ijlj}^{SC} > 0, \ \forall i, \ \forall j, \ \forall l \tag{2.12}$$

where π_{ijlj}^{SC} is profit of MSA j by belonging to s_{ijl} and is calculated by equation (2.25). Equation (2.11) indicates determined coalition must be in ability of order of MA i. Equation (2.12) means profit of MSA j of belonging to s_{ijl} must be positive.

2.3.1.2 Multi-item involved coalition determination

When there are multi-item ($k > 1$) involved in coalition formation, MSA j which is out of ability of items will trigger coalition formation mechanism to find partners. For example, MSA j in Figure 2.3 is out of ability of item 1 and item K, thus, it needs to find partners to supply item 1 and item K, respectively. $s_{ijl1} = \{$MSA j, MSA $j-1$, and MSA $J\}$ and $s_{ijlK} = \{$MSA j, MSA 2, MSA $j+1$, and MSA $j-1\}$ in Figure 2.3 are one of possible coalitions for item 1 and item K.

Multi-item involved coalition determination is discussed in follows. The coalition formation can be divided into coalition formation for complementary and coalition formation for substitution according to ***Definition 2.2***. Hence, determination can be divided into two categories as well.

(a) Coalition for complementary

Coalition formation for complementary is negotiation among MSAs which supply the same item. MSA j wants to find partners which can supply item k for complementary

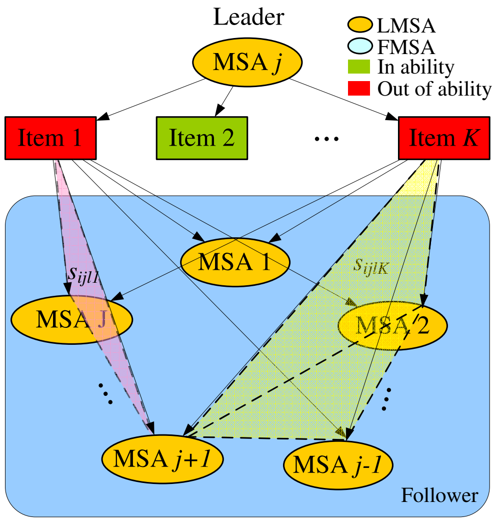


Figure 2.3: Multi-item involved coalition formation of MSA j

(e.g. The LMSA j in Figure 2.4 can supply item k but it is out of its ability. Thus, it selects MSA j' and MSA j^* which can supply item k but doesn't select MSA j" for it cannot supply item k). It selects coalition which can maximize its profit and total ability must be greater than or equal to requested quantity of MA as well.

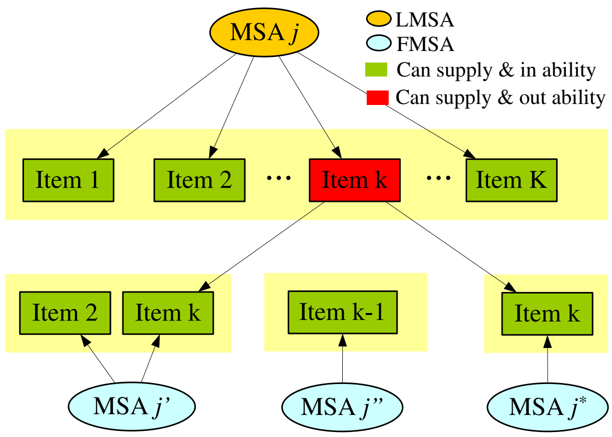


Figure 2.4: Coalition formation for complementary

Therefore, final coalition of MSA j for item k of MA i is determined as SFC^*_{ijk} by solving following problem:

$$SFC^{*}_{ijk} = arg\max_{s_{ijl}}\{(p^{CI}_{ijlk} - C_{jk})QS_{ijljk}\},\ \forall i,\ \forall j,\ \forall k \tag{2.13}$$

$$\text{s.t.} \quad AC_{ijlk} \geq q^{M}_{ijk},\ \forall i,\ \forall j,\ \forall l,\ \forall k \tag{2.14}$$

$$\prod_{j' \in s_{ijlk}} A_{ij'k} \neq 0,\ \forall k \tag{2.15}$$

where equation (2.13) is used to find coalition, in which it can get maximum profit. QS_{ijljk} is obtained quantity of item k of MSA j by belonging to s_{ijlk} and is calculated by equation (2.24). Equation (2.14) is used to ensure coalition s_{ijlk} has enough ability for order of MA i. Equation (2.15) is used to ensure that coalition is for complementary (each member in s_{ijlk} can supply item k).

(b) Coalition for substitution

Coalition formation for substitution is triggered when A_{ijk}=0, which means MSA j cannot supply item k at all and wants to find partners who can supply item k. It is assumed that MSA j in coalition formation for substitution only selects FMSAs which can supply item k but cannot supply the items that are in abilities of LMSA j in order to ensure its profit will not be shared by the other MSAs (e.g. The LMSA j in Figure 2.5 cannot supply item k. Thus, it selects MSA j'' which can supply item k, but doesn't select MSA j' and MSA j^*, because MSA j' cannot supply item k at all and MSA j^* can supply item k but also can supply item 2 which is in ability of LMSA j).

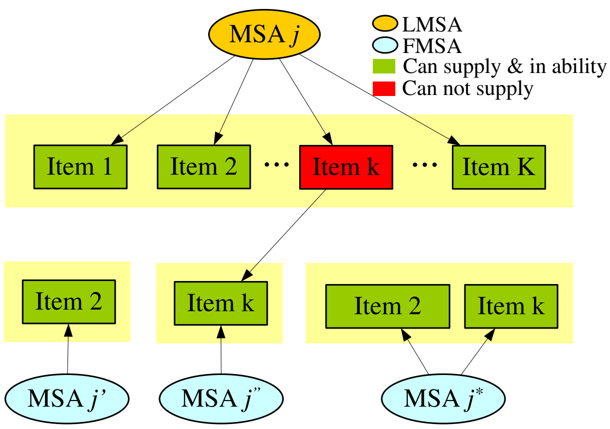


Figure 2.5: Coalition formation for substitution

As we know, LMSA j wants to enhance its competitiveness as well. Therefore, it has prone to selecting partners which has minimum price of item k. Thus, final coalition of MSA j for item k is determined as SFS^*_{ijk} by solving following problem:

$$SFS^*_{ijk} = arg\min_{s_{ijl}}\{\frac{\sum_{j'\in s_{ijlk}} p^{SI}_{ij'k}}{N_{ijlk}}\},\ \forall i,\ \forall j,\ \forall k \tag{2.16}$$

$$\textbf{s.t.}\quad AC_{ijlk} = \sum_{j'\in s_{ijlk}} A_{ij'k} \geq q^M_{ijk},\ \forall i,\ \forall j,\ \forall l,\ \forall k \tag{2.17}$$

$$\sum_{j'\in s_{ijlk}, A_{ijk'}\geq q^M_{ijk'}} A_{ij'k'} = 0,\ \forall i,\ \forall j,\ \forall j'\neq j,\ \forall k'\neq k \tag{2.18}$$

where equation (2.16) is used to find coalition, which has minimum price of item k, to enhance possibility to win the order. Equation (2.17) is used to ensure the selected coalition s_{ijlk} has enough ability for order of MA i, and equation (2.18) is used to ensure the selected coalition is for substitution.

(c) Combined coalition formation

Both coalition formation for complement and coalition formation for substitution are in ideal situations. In the first one, it assumes that MSA j selects coalition in which all members supply the same item(s). In the later one, it assumes that MSA j selects coalition in which all members cannot supply item(s) which is(are) in its ability. However, in real case, it may be much more complex. The member MSA $j'\in s_{ijl}$ may not only can supply item(s) which is(are) out of MSA j's ability but also can supply item(s) which is(are) in MSA j's ability. Therefore, it's better to form a combined coalition for order of MA instead of forming a coalition for each item. Final coalition of MSA j for MA i can be determined as SF_{ij} by solving following problems:

$$SF_{ij} = arg\max_{s_{ijl}}\{\sum_{k=1}^{K}(p^{SFI}_{ijlk} - C_{jk})QF_{ijlk},\ \forall i,\ \forall j \tag{2.19}$$

$$\text{s.t. } AC_{ijlk} \geq q^M_{ijk},\ \forall i,\ \forall j,\ \forall l,\ \forall k \tag{2.20}$$

$$p^{SFI}_{ijlk} = (1 - Sign(A_{ijk}))\frac{\sum_{j'\in SFS^*_{ij'k}} p^{SI}_{ij'k}}{N_{ij'lk}} + Sign(A_{ijk})\frac{\sum_{j'\in SFC^*_{ij'k}} p^{SI}_{ij'k}}{N_{ij'lk}},\quad \forall i,\ \forall j,\ \forall l,\ \forall k \tag{2.21}$$

$$QF_{ijlk} = \frac{A_{ijk}q^M_{ijk}}{AC_{ijlk}},\ \forall i,\ \forall j,\ \forall l,\ \forall k \tag{2.22}$$

$$Sign(x) = \begin{cases} 1, & \text{if } x > 0 \\ 0, & \text{otherwise} \end{cases} \tag{2.23}$$

where equation (2.19) is used to find coalition which maximizes utility of MSA j. Equation (2.20) means coalition s_{ijl} must be in ability of each item k. Equation (2.21) is used to calculate final price of item k of coalition s_{ijl}, when MSA j can supply item k but out of ability, it equals to average price of coalition obtained from the coalition for complementary, and when MSA j cannot supply item k at all, it equals to average price of coalition obtained from the coalition for substitution. Equation (2.22) is used to calculate final acquired quantity of item k, and equation (2.23) is used to check whether MSA j' can supply k or not.

2.3.2 Profit allocation

The problem of profit allocation among members after coalition gets order is discussed in this section. Profit is allocated according to abilities of members when the order just meets supplies of all members. However, it is possible that total ability of coalition AC_{ijlk} is greater than q^M_{ijk}. In other words, the order is not enough to fulfill supply of the coalition. Each player in coalition mainly interests in its individual benefit and tries to maximize its own profit. [Hartman and Dror, 1996] proposed three necessary criteria for good cost allocation: stability, justifiability, and computability. It can applied to allocation of profit as well, since during coalition formation no participants should be enticed by reward system to secede. All members in coalition should perceive that what they are obtained is fair, and they will resist imposition of profits they find unfair or unjustified. Profit allocation policies that do not reflect profit benefits to members nor provide a level field will cause dissention. Thus, profit should be assigned impartially in order to maintain stability of coalition. Allocation rule has been presented in section **??** for this purpose as ***Rule 2.3***.

Let π^{SC}_{ijl} be profit of player $j \in s_{ijl}$. According to ***Rule 2.3***, we have equation (2.24), which means the order is allocated according to abilities of members. Then, profit is allocated as equation (2.25).

$$QS_{ijlk} = \frac{A_{ijk} q^M_{ijk}}{\sum_{j' \in s_{ijl}} A_{ij'k}}, \ \forall i, \ \forall j, \ \forall l, \ \forall k \tag{2.24}$$

$$\pi^{SC}_{ijl} = \pi^{C}_{ij'l} \frac{QS_{ijlk}}{q^M_{ijk}}, \ \forall i, \ \forall j, \ \forall l \tag{2.25}$$

2.4 Modified Coalition Formation

A static coalition formation based negotiation protocol was proposed in section 2.3, where coalition is established at the first iteration of negotiation when MSAs are out of abilities of orders and it doesn't change once established. However, the coalition which is in ability at initial rounds may become out of ability during multi-attribute negotiation. That's because in multi-attribute negotiation not only price is changing but also lead time, which will lead to the change of ability of coalition. Therefore, a modified coalition formation protocol which takes change of lead time into account is required during multi-attribute negotiation.

A matrix $E[t] = [e_{ijk}[t]]$ is defined for MSA j to evaluate whether order of MA i at t is in its ability or not. $e_{ijk}[t]$ equals to 1 when item k of order of MA i at t is in ability of MSA j ($A_{ijk}[t] \geq q^M_{ijk}[t]$), and it equals to 0 if the order is out of MSA j's ability ($A_{ijk}[t] < q^M_{ijk}[t]$). Thus, order of MA i is said to be in ability of MSA j if and only if for all items are in ability ($A_{ijk}[t] \geq q^M_{ijk}[t]$, $\forall k$), and it is out of ability at least one of items is out of ability of MSA j ($A_{ijk}[t] \leq q^M_{ijk}[t]$, $\exists k$). At each iteration t, MSA j tries to negotiate with other MSAs to establish a coalition if there exists item k and $e_{ijk}[t]$ equals to 0.

2.4.1 Modified coalition determination

At each negotiation iteration t, coalition $SF_{ij}[t]$ which maximizes profit of MSA j at t is determined as final coalition by solving following problem [Yu et al., 2013a]:

$$SF_{ij}[t] = arg \max_{s_{ijl}[t]} \{ \sum_{k=1}^{K} [(pf_{ijlk}[t] - C_{jk}) QF_{ijlk}[t]], \ \forall i, \ \forall j, \ \forall t \tag{2.26}$$

$$\text{s.t.} \quad AC_{ijlk}[t] \geq q^M_{ijk}[t], \ \forall i, \ \forall j, \ \forall l, \ \forall k, \ \forall t \tag{2.27}$$

$$p^{SF}_{ijlk}[t] = (1 - Sign(A_{ijk}[t])) \frac{\sum\limits_{j' \in SFS^*_{ij'k}[t]} p^{SI}_{ij'k}}{N_{ij'lk}[t]} + Sign(A_{ijk}[t]) \frac{\sum\limits_{j' \in SFC^*_{ij'k}[t]} p^{SI}_{ij'lk}}{N_{ij'lk}[t]}, \ \forall i, \ \forall j, \ \forall l, \ \forall k, \ \forall t \tag{2.28}$$

$$QF_{ijljk}[t] = \frac{A_{ijk}[t] q^M_{ijk}[t]}{AC_{ijlk}[t]}, \ \forall i, \ \forall j, \ \forall l, \ \forall k, \ \forall t \tag{2.29}$$

where equation (2.26) is used to find coalition which can maximize profit of MSA j at t, and equation (2.27) indicates that final determined coalition must be in ability of each item k of MA i at t. Equations (2.28) - (2.29) are used to calculate final price and quantity of MSA j in $s_{ijl}[t]$.

2.4.2 Profit allocation

Another important issue of coalition formation is how to allocate profit among its members after coalition is determined. For single-attribute negotiation, profit was allocated according to contributions to coalition, and was finally reduce to allocation of quantity of the order. However, in multi-attribute negotiation, profit is evaluated according to all attributes. Therefore, profit of coalition must be allocated according to all attributes of its members. Thus, profit of each member j in $s_{ijl}[t]$ is calculated by

$$\pi^{SC}_{ijlj}[t] = \sum_{k=1}^{K} p^{M}_{ijk}[t] QS_{ijljk}[t] - \sum_{k=1}^{K} C_{jk} QS_{ijljk}[t] + (LT^{M}_{ijk}[t] - lt^{S}_{ijk}[0]) clt^{S}_{k}, \quad \forall i,\ \forall j,\ \forall l,\ \forall t \tag{2.30}$$

$$QS_{ijljk}[t] = \frac{A_{ijk}[t] q^{M}_{ijk}[t]}{\sum_{j' \in s_{ijl}[t]} A_{ij'k}[t]}, \ \forall i,\ \forall j,\ \forall l,\ \forall k,\ \forall t \tag{2.31}$$

where the first part of equation (2.30) is payment of MSA j received from coalition, the second part is cost of MSA j to supply received part, and the third part is profit or loss of extending or shortening lead time. Equation (2.31) is used to calculate obtained quantity of MSA j by belonging to $s_{ijl}[t]$.

Chapter 3 Coalition Formation Based Single-Attribute Single-Item Negotiation

3.1 Introduction

As we know, in real market, there are a lot of small-and-medium-sized companies. They may have to reject large order of MA due to their limited abilities. This research mainly focuses on situation when MSAs cannot finish orders independently. Researchers have prone to let MA split its order and then allocate to different MSAs when the order is out of abilities of MSAs [Kraus, 1997, Chai et al., 2010]. However, it wastes time to decompose orders into pieces and allocate to different MSAs when MAs have large quantity orders. Thus, this research tries to find another way to solve this problem which can maintain integrities of orders. All MSAs in proposed model are allowed to establish coalitions when orders are out of their abilities, and then compete for orders with other MSAs or coalitions after coalition is successfully established. Coalition formation based single-attribute single-item (SASI) negotiation will be discussed in this chapter to show how the proposed protocol solves negotiations between one-MA and multi-MA, and between multi-MA and multi-MSA.

3.2 Single-Attribute Single-Item Negotiation between One-MA and Multi-MSA

SASI negotiation between one-MA and multi-MSAs is discussed in this section. SASI negotiation model of SCNs is shown in Figure 3.1. MA broadcasts an order (p^{MI}, Q^M, LT^M) to all MSAs, where p^{MI} is initial price of MA, Q^M is quantity of the order, and LT^M is lead time of the order. Price of MA will be changed during negotiation, while quantity Q^M and lead time LT^M are constants and never change during negotiation. We assume that:

Assumption 3.1: *The negotiation environment is static*[1] *.*

Assumption 3.2: *MA has initiative and has more negotiation power.*

[1]Static means no new participant is allowed entering the negotiation after the negotiation starts

Assumption 3.3: *MSAs only can accept orders which are in their abilities.*

Assumption 3.4: *MSAs in negotiation model are allowed to trigger coalition formation mechanism (as Chapter 2) when the order is out of their abilities.*

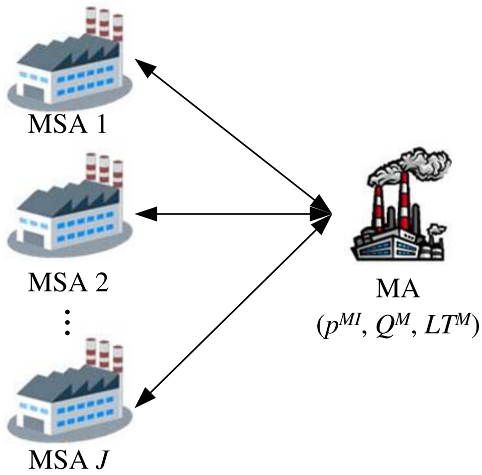


Figure 3.1: SASI negotiation model between one-MA and multi-MSA

3.2.1 Two-stage negotiation protocol

MA wants to find the optimal MSA with the lowest price. It has been assumed that MSAs only accept orders which are able to fulfill by themselves. A two-stage negotiation protocol is proposed as follows [Yu et al., 2012b]:

- **Stage 1:** Negotiation among MSAs. MSAs evaluate the order and check whether it can be finished by themselves. If they can do it, they can directly go to the second stage of negotiation; if they cannot, then they can negotiate with the other MSAs to build coalitions. A cooperative game is used for coalition formation. At the end, the final determined coalitions or MSAs enter into the second stage.

- **Stage 2:** Negotiation between MA and MSA or final coalition. MA negotiates with the final coalition to find the Stackelberg equilibrium.

Flowchart is shown in Figure 3.2. The first stage is used for preparation. There are MSAs which cannot complete the order by themselves. Thus, they should find partners to build coalitions. The final negotiation about price is started at the second stage.

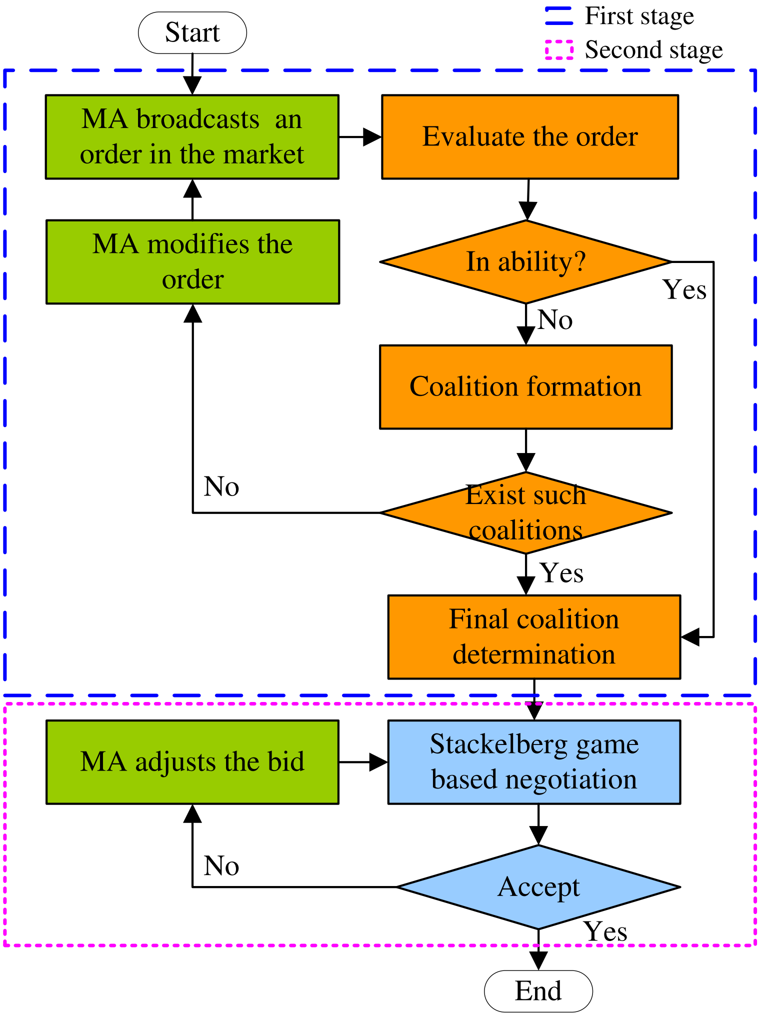


Figure 3.2: Flowchart of the two-stage negotiation protocol

3.2.2 Negotiations among MSAs

MSA starts to negotiate with other MSAs in SCNs to establish a coalition if it cannot complete the order by itself. The way to establish coalitions, determination of final coalition, and profit allocation have been discussed in section 2.3, section 2.3.1.1 and section 2.3.2, respectively. Thus, final determined coalition of MSA j for MA is indicated as:

$$SF_j = \begin{cases} arg \max_{s_{jl}} \{\pi_{jl}^{SC}\}, & \text{if } A_j < Q^M \\ j, & \text{if } A_j \geq Q^M \end{cases} \tag{3.1}$$

$$p_j^{SFI} = \frac{\sum_{j' \in SF_j} p_{j'}^{SI}}{N_j} \tag{3.2}$$

$$p_j^{SFL} = \frac{\sum_{j' \in SF_j} p_{j'}^{SL}}{N_j} \tag{3.3}$$

$$AF_j = \sum_{j' \in SF_j} A_{j'} \tag{3.4}$$

where equation (3.1) indicates final coalition of MSA j equals to itself if the order is in its ability and equals to the coalition s_{jl} which maximizes its profit when the order is out of its ability. The price, lower bound of price, and ability of final determined coalition SF_j equal to related price, lower bound of price, and ability of itself when the order is in its ability and equal to those of coalition s_{jl} which maximizes profit of MSA j when the order is out of its ability, and are calculated by equation (3.2), equation (3.3), and equation (3.4), respectively. And

A_j : ability of MSA j

AC_j : ability of s_{jl}

AF_j : ability of SF_i

N_j : the number of members in SF_i

π_{jl}^{SC} : profit of MSA j in coalition s_{jl}

p_{jl}^{CI} : initial price of s_{jl}

p_{jl}^{CL} : lower bound of price of s_{jl}

p_j^{SI} : initial price of MSA j

p_j^{SL} : lower bound of price of MSA j

p_j^{SFI} : initial price of SF_i

p_j^{SFL} : lower bound of price of SF_i

The profit π_{jl}^{SC} of MSA j of belonging to s_{jl} is calculated by

$$\pi_{jl}^{SC} = (p_{jl}^{CI} - C_j) QS_{jl} \tag{3.5}$$

$$QS_{jl} = \frac{A_j Q^M}{AC_{jl}} \tag{3.6}$$

where QS_{jl} is the acquired quantity of MSA j by belonging to coalition s_{jl}.

3.2.3 Negotiation between MA and MSA (coalition)

Negotiation between MA and final determined coalition SF_j of MSA j starts to reach an agreement on price after SF_j is determined. However, target of SF_j is contrary to the one of MA. MA aims to determine $p_j^M[t]$ as lower as possible to maximize its profit, while MSA wants to get the higher price the better. Moreover, it was assumed in ***Assumption 3.1*** that MA in proposed model has initiative and more negotiation power. Decision makings of MA and final coalition in this model are not simultaneously. MA announces an offer firstly, and then final coalition gives a counteroffer. Thus, interaction between MA and SF_j can be seen as a MA-Stackelberg game[2] [Esmaeili et al., 2009, Hu et al., 2011], where MA is considered to be the Stackelberg leader. Objective of the leader is to design its move to maximize its profit after considering all rational moves follower may devise. The solution of this structure is to find the Stackelberg equilibrium. MA chooses its strategy from low to high, and MSA chooses the strategy from high to low. Final strategy equals to the strategy $p_j^M[t]$ of MA which maximizes profit of MA and is accepted by SF_j.

Iteration of the negotiation is discussed in details in following sections.

3.2.3.1 Strategies without and with concession

(a) Strategies without concession

Strategies of MA and SF_j are defined as:

$$p_j^{SF}[t] = p_j^{SF}[t-1] - \frac{p_j^{SF}[t-1] - p_j^M[t]}{(TN - tTS)/TS} \tag{3.7}$$

$$p_j^M[t] = p_j^M[t-1] + \frac{p^{MU} - p_j^M[t-1]}{(TN - tTS)/TS} \tag{3.8}$$

$$p_j^{SF}[0] = p_j^{SFI} \tag{3.9}$$

$$p_j^M[0] = p^{ML} \tag{3.10}$$

where

$p_j^M[t]$: price of MA at t

$p_j^{SF}[t]$: price of SF_j at t

[2]The Stackelberg leadership model is a strategic game in economics in which the leader firm moves and then the follower firms move sequentially.

p^{ML} : lower bound of price of MA

p^{MU} : upper bound of price of MA

TN : Total negotiation time

TS : negotiation time of each iteration

(b) Strategies with concession

Sim et al. ([Sim and Wong, 2001, Sim, 2004]) proposed a MDA model for designing negotiation agents that make adjustable rates of concession for a given market situation by considering factors such as trading opportunity, competition, remaining trading time and eagerness. Effect of the remaining trading time is considered here and concession strategies are given as followings based on Sim's:

- **For MA:**

$$\Delta_p^M[t] = T_p^M(tTS, TN, \varepsilon)(p^{MU} - p^M[t-1]) \tag{3.11}$$

$$T_p^M(tTS, TN, \varepsilon) = (\frac{tTS}{TN})^{\frac{1}{\varepsilon}} \tag{3.12}$$

where

$\Delta_p^M[t]$: the spread of price of MA at iteration t

Different strategies in making concession related to the remaining trading time are classified as follows ([Ren et al., 2009]):

- $\varepsilon = 0$: means agent is totally not interested in negotiating;

- $\varepsilon = 1$: makes a constant rate of concession;

- $0 < \varepsilon < 1$: makes a smaller concession in early rounds and larger concession in later rounds.

- **For MSA j:**

$$\Delta_{jp}^S[t] = T_{jp}^S(tTS, TN, \varepsilon)(p_j^S[t-1] - p_j^{SL}) \tag{3.13}$$

$$T_{jp}^S(tTS, TN, \varepsilon) = (\frac{tTS}{TN})^{\frac{1}{\varepsilon}} \tag{3.14}$$

where

$\Delta_{jp}^{S}[t]$: the spread of MSA j of price at round t.

Thus, equation (3.7) and equation (3.8) are reduced to:

$$p_j^{SF'}[t] = p_j^{SF}[t-1] - (\frac{tTS}{TN})^{\frac{1}{\varepsilon}}(p_j^{SF}[t-1] - p_j^M[t]) \tag{3.15}$$

$$p_j^{M'}[t] = p_j^M[t-1] + (\frac{tTS}{TN})^{\frac{1}{\varepsilon}}(p^{MU} - p_j^M[t-1]) \tag{3.16}$$

3.2.3.2 Determination of equilibriums

Stackelberg strategy is applied when there is an asymmetry in power or in moves of players [Kogan and Tapiero, 2007]. Determination of the negotiation agreement between MA and SF_j is transformed into determining equilibrium PF_j of the Stackelberg game, where SF_j is final determined coalition from section 3.2.2. We give following rule to find equilibrium:

Rule 3.1: *The strategy of MA at t can be determined as the equilibrium if and only if profit of SF_j of taking this strategy is positive.*

Thus, determination of the Stackelberg equilibrium can be transformed into solving the following problem:

$$PF_j = arg \max_{p_j^M[t]} \{\pi_j^M = (psell - p_j^M[t])Q^M\} \tag{3.17}$$

$$\textbf{s.t.} \quad \pi_j^{SF} > 0 \tag{3.18}$$

$$AF_j > Q^M \tag{3.19}$$

where equation (3.17) indicates that the strategy of MA which maximizes its profit is determined as the equilibrium, equation (3.18) means the determined strategy of MA must be accepted by SF_j as well, and equation (3.18) means the order of MA must in ability of SF_j. $p_j^M[t]$ in equation (3.17) is calculated by equation (3.8) and equation (3.16) when MA takes concession into account and doesn't take the concession into account. The profit π_j^{SF} of MSA j by belonging to SF_j is calculated by equation (3.5) where p_{jl}^{CI} equals to $p_j^M[t]$ and QS_{jl} equals to $\frac{A_j Q^M}{AF_j}$.

3.2.3.3 Determination of final supplier

MA selects the MSA which maximizes its profit as final supplier:

$$arg \max_{SF_j} \quad \{\pi_j^M = (psell - PF_j)Q^M\} \tag{3.20}$$

$$\textbf{s.t.} \qquad PF_j = arg \max_{p_j^M[t]} \{\pi_j^M = (psell - p_j^M[t])Q^M\} \tag{3.21}$$

$$SF_j = arg \max_{s_{jl}} \{\pi_{jl}^{SC}\}. \tag{3.22}$$

3.2.4 Simulation and analysis

It is supposed that there are one MA and 5 MSAs distribute in SCNs. Initial values of MSAs are shown in Table 3.1 and the MA is price prior. Other parameters are set as: $\beta_{jk}^L = 0.2$, $\sigma_j = 0.2$, $TN = 60$s, $TS = 2$s, $p^{MU} = 11$, $psell = 15$, $Q^M = 3000$, and $LT^M = 10$.

Table 3.1: Parameter settings of MSAs

Supplier	γ_{jk}	C_{jk}	p_{jk}^{SU}
MSA 1	125	7.116	10.283
MSA 2	224	7.604	10.660
MSA 3	220	7.216	10.140
MSA 4	104	7.040	9.971
MSA 5	201	7.545	10.166

3.2.4.1 Verification

Feasibility of proposed protocol is verified in this part. All possible coalitions which are in abilities of MSAs and related equilibriums are shown in Table 3.2. Final supplier will be determined as coalition {314} with the lowest price 9.059 based on the results of Table 3.2.

3.2.4.2 Analysis

We can see from above that feasibility of proposed protocol was verified. The results indicate that proposed protocol is a good way to solve SASI negotiations between one-MA and multi-MSA.

(a) Calculation time

Then, simulation is executed by 1000 times to verify effectiveness of proposed protocol. Results are shown as Table 3.3, where average and standard derivation of calculation time

Table 3.2: All possible coalitions and related equilibriums for MSAs

Index	MSA1	MSA2	MSA3	MSA4	MSA5
s_{jl}					
1	{12}	{21}	{31}	{412}	{51}
2	{123}	{213}	{312}	{4123}	{512}
3	{1234}	{2134}	{3124}	{41235}	{5123}
4	{12345}	{21345}	{31245}	{4125}	{51234}
4	{1235}	{2135}	{3125}	{413}	{5124}
6	{124}	{214}	{314}	{4135}	{513}
7	{1245}	{2145}	{3145}	{415}	{5134}
8	{125}	{215}	{315}	{42}	{514}
9	{13}	{23}	{32}	{423}	{52}
10	{134}	{234}	{324}	{4235}	{523}
11	{1345}	{2345}	{3245}	{425}	{5234}
12	{135}	{235}	{325}	{43}	{524}
13	{145}	{24}	{34}	{435}	{53}
14	{14}	{245}	{345}	{45}	{534}
15		{245}	{35}		{54}
PF_{jl}					
1	9.218	9.218	9.087	9.146	9.198
2	9.186	9.186	9.186	9.140	9.260
3	9.140	9.140	9.140	9.180	9.225
4	9.180	9.180	9.180	9.195	9.180
5	9.225	9.225	9.225	9.059	9.195
6	9.146	9.146	9.059	9.130	9.172
7	9.195	9.195	9.130	9.133	9.130
8	9.260	9.256	9.172	9.192	9.133
9	9.087	9.252	9.252	9.169	9.363
10	9.059	9.169	9.169	9.212	9.282
11	9.130	9.212	9.212	9.243	9.212
12	9.172	9.282	9.282	9.061	9.243
13	9.133	9.192	9.061	9.155	9.232
14	9.198	9.243	9.155	9.172	9.155
15	9.363	9.232	9.172		

of proposed protocols with and without concessions to find solutions are presented. We can see the proposed protocols both with and without concession are effective and stable in solving SASI negotiation, and the protocol with concession is more superior than the protocol without concession.

Table 3.3: Calculation time of SASI negotiation between one-MA and multi-MSA

Calculation time (sec)	Without concession	With concession
Avg.	0.00089	0.00069
S.D.	0.00626	0.00321

(b) Comparisons of the protocols with & without concession

Comparisons between the protocols without concession and with concession are provided where $\varepsilon = 0.3$. We take negotiation between MA and $\{14\}$ as an example. Results are shown in Figure 3.3. We can see that the protocol with concession reaches the same agreement with the protocol without concession. However, it is faster than the protocol without concession to reach an agreement of the negotiation.

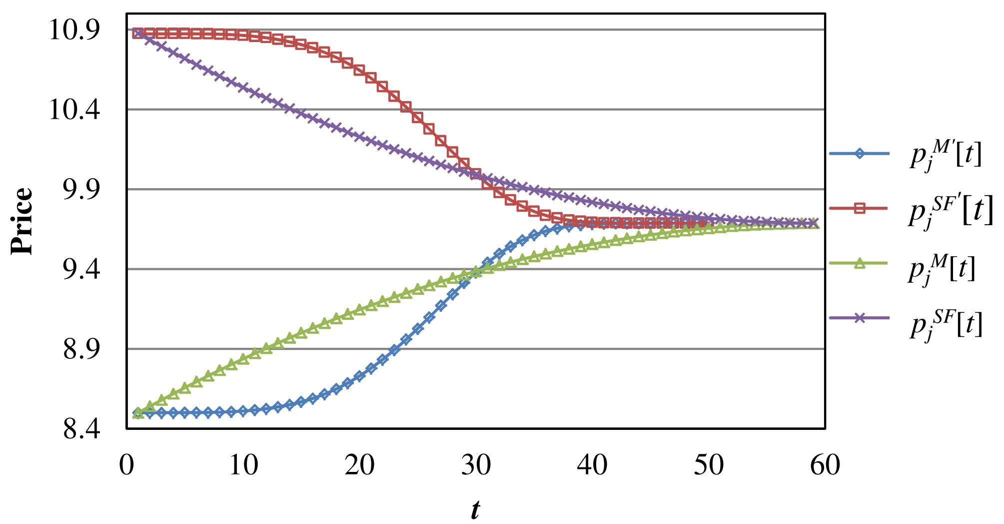


Figure 3.3: Comparisons of the protocol without concession and with concession

Furthermore, convergence rate of negotiation related to concession rate ε is discussed in follows. Negotiation is simulated under $\varepsilon = 0.1$, $\varepsilon = 0.2$, $\varepsilon = 0.3$, $\varepsilon = 0.3$, $\varepsilon = 0.4$, ε

= 0.6, ε = 0.7, ε = 0.8, ε = 0.9, ε = 1, and ε = 2, respectively.

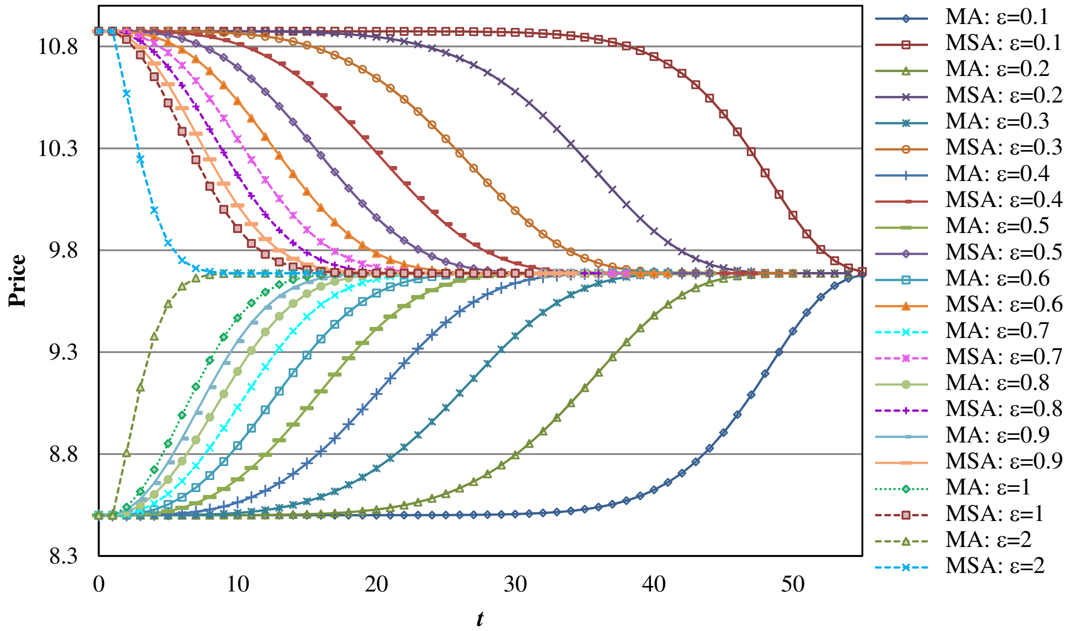


Figure 3.4: Negotiations under different concession rate ε

Results are shown in Figure 3.4, and we can see that convergence rate greatly depends on value of ε and the higher the value of ε the faster to reach an agreement.

3.3 Single-Attribute Single-Item Negotiation between Multi-MA and Multi-MSA

SASI negotiation between multi-MA and multi-MSA is discussed in this section. SASI negotiation model is shown in Figure 3.5, where I MAs and J MSAs are involved. Negotiation between multi-MA and multi-MSA can be seen as a $I \times J$ game. A game in normal form consists of: players, a set of strategies available to each player, and payoffs received by each player [Leng and Parlar, 2005].

All MAs should play with all MSAs to determine final trade partnerships. MSA should trigger coalition formation mechanism (see section 2.3) to find possible coalitions if the order is out of its ability. There are many strategies for MAs and MSAs (coalitions) to select during negotiation. Thus, MAs and MSAs (coalitions) should play with each other to determine final strategies. A hierarchical structure is proposed and is shown in

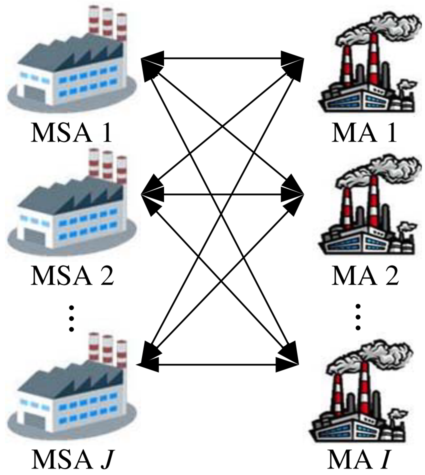


Figure 3.5: SASI negotiation model between multi-MA and multi-MSA

Figure 3.6. There are three layers in hierarchical structure: physic layer, logic layer for coalition, and logic layer for equilibrium. All MAs and MSAs (coalitions) are actually in the same physic layer. When the order of MA is out ability of MSA then the logic layer for coalition is triggered to find coalitions. It is a changeable hierarchical game. It is a two-layer game when all orders are in abilities of all MSAs. However, it is a three-layer game when there are some orders out of abilities of some MSAs. The first layer game is between multi-MA and multi-MSA (coalitions) and it aims to find the optimal allocation scheme to maximize total profit of SCNs. The second layer game is not necessary, and it is triggered to find coalitions among MSAs if and only if the order of MA i is out of ability of MSA j. The third layer game is between strategies of MA and MSA (coalition) to determine final equilibrium of product. These three layer games constitute the hierarchical-game.

3.3.1 Hierarchical-game based negotiation protocol

Protocol of hierarchical-game based negotiation is described in details as follows:

• **Step 1:** MAs announce orders to all MSAs and wait for responses. If there are some MSAs agree to start negotiation, and then go to Step 2; else go to Step 6.

• **Step 2:** The first layer game between MAs and MSAs (coalitions) starts and then each MSA evaluates each order and checks whether the order is in its ability or not. If it is in its ability, it agrees to start negotiation, and then goes to Step 4; if it is not in its

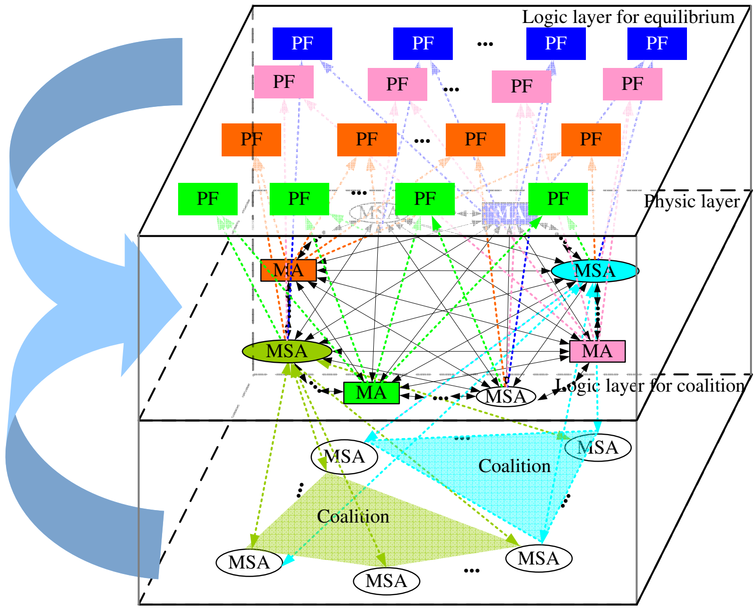


Figure 3.6: Hierarchical structure of SASI negotiation

ability, and then it goes to Step 3.

• **Step 3:** MSA tries to find partners to establish coalitions using cooperative game, and then checks whether there exists such coalitions. If there exists, it agrees to start negotiation, gives a response to MAs, and goes to Step 4; if there does not exist, then it rejects the order and gives a response to MAs.

• **Step 4:** The Stackelberg game between MA and MSA (or each possible coalition of MSA) is triggered to find the Stackelberg equilibrium of each game, and then checks whether equilibrium is found or not. If it is found, MSA feeds it back to the first layer game and goes to Step 5; if it is not found, and then both MA and MSA (coalition) modify their strategies and negotiation iterates until equilibrium is found or terminal condition is reached.

• **Step 5:** The first layer game tries to determine the optimal solution so as to determine final allocation scheme to maximize total profit of SCN.

• **Step 6:** MAs modify initial values of orders, and then go to Step 1 to re-announce the orders.

Flowchart of hierarchical-game based negotiation is described in Figure 3.7. The first layer game, which aims to find the optimal allocation scheme to maximize total profit of SCNs, is between multi-MA and multi-MSA. The second layer game is among MSAs to find all possible coalitions. The third layer game is between multi-strategy of MA and MSA (coalition) to determine final strategy. These three layer games constitute the hierarchical-game. There is a nested structure in hierarchical structure, where the second and the third layer games are nested inside the first layer game. The first layer game starts, and then the second and the third layer games are triggered if necessary. However, the first layer game can be finished if and only if the second and the third layer games have been finished. In other words, the first layer game is based on results of the second and the third layer games. Details of the protocol will be discussed in following sections.

3.3.1.1 First-layer game based negotiation

In the first layer game, it tries to determine final allocation scheme after all MSAs send their responses. It can be seen as a two-person game (see Figure 3.8), where all MAs are considered as player 1 and all MSAs are combined as player 2. Strategy of player 1 is allocation scheme $\bar{U}_w$ of assigning MAs to MSAs, where $\bar{U}_w = [\bar{u}_1, ..., \bar{u}_I]$, and $\bar{u}_i = j$ indicates that MA i is allocated to MSA j. Strategy of player 2 $\tilde{U}_v$ is allocation scheme of assigning obtained orders from MAs to coalitions of MSAs, where $\tilde{U}_v = [\tilde{u}_{ji}]_{J \times I}$, $\tilde{u}_{ji} = l$ indicates obtained order of MSA j from MA i is allocated to the l^{th} coalition $s_{ijl}[TF_{ijl}]$ of MSA j at TF_{ijl}, and $\tilde{u}_{ji} = \phi$ indicates MA i is not allocated to MSA j. Objective of the game is to decide strategies of players which can maximize total profit of SCNs. Therefore, allocation scheme can be called as an equilibrium of the game if none of members of the players can benefit by changing its strategy while the other player keep its strategy unchanging. The innovative point is the players in the two-person game actually consist of multiple players.

Profits of player 1 and player 2 are defined as:

$$\Pi_1 = \sum_{i=1}^{I} \pi_{ij}^M = \sum_{i=1}^{I} (psell_i - PF_{ij}) Q_i^M \tag{3.23}$$

$$\Pi_2 = \sum_{j=1}^{J} \pi_{ij}^S = \sum_{j=1}^{J} \sum_{i \in OL_j} (PF_{ij} - C_j) QS_{ijj'} \tag{3.24}$$

where

Π_1: profit of player 1

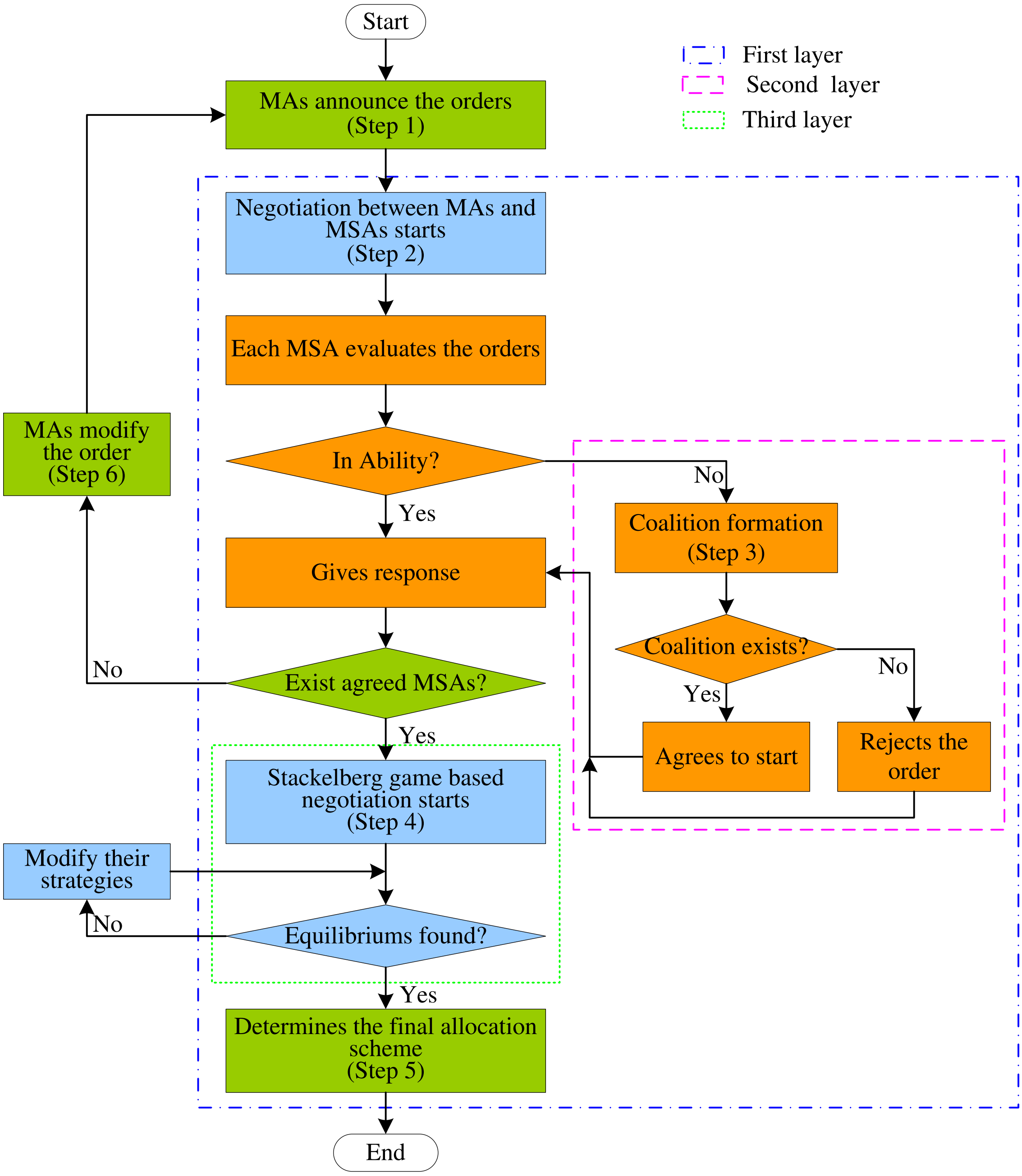


Figure 3.7: Flowchart of hierarchical-game based negotiation

Player 2

Player 1	$\tilde{U}_1$	$\tilde{U}_2$	$\cdots$	$\tilde{U}_v$
$\overline{U}_1$	π_{11}^{SCN}	π_{12}^{SCN}	$\cdots$	π_{1v}^{SCN}
$\overline{U}_2$	π_{21}^{SCN}	π_{22}^{SCN}	$\cdots$	π_{2v}^{SCN}
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
$\overline{U}_w$	π_{w1}^{SCN}	π_{w2}^{SCN}	$\cdots$	π_{wv}^{SCN}

Figure 3.8: Two-person game

Π_2: profit of player 2

π_{ij}^{M}: profit of MA i with MSA j

π_{ij}^{S}: profit of MSA j with MA i

C_j: cost of MSA j

OL_j: order list of MSA j

$psell_i$: selling price of MA i

PF_{ij}: final equilibrium of the negotiation between MA i and SF_{ij}

q_i^M: quantity of MA i

QS_{ij}^M: acquired quantity of MSA j' by belonging to SF_{ij}

PF_{ij} is final equilibrium determined in section 3.3.1.2. Then, strategy determinations of player 1 and player 2 are discussed in following. Both player 1 and player 2 aim to maximize their profits. Player 1 has prone to selecting supplier with the lowest price to increase its profit, and player 2 has prone to selecting manufacturer with the highest price to increase its profit. Following assumption is obtained:

Assumption 3.5: *MSA j chooses MAs according to their price from the highest to the lowest if there are more than one MAs want to select MSA j as final supplier, but MSA j cannot accept all of them.*

Final allocation scheme are determined according to M and N_{ij}. Matrixes $M = [m_{ij}]$ and $N_{ij} = [n_{ijl}]$ are given to show final schemes of order allocation, where m_{ij} and n_{ijl} equal to 1 or 0. There is only one matrix M to record final allocation of orders of MAs to MSAs. The value of m_{ij} equals to 1 means MA i is allocated to MSA j and m_{ij} equals to 0 means MA i is not allocated to MSA j. Matrix N_{ij} is used to record allocation of the order MSA j obtained from MA i to its coalitions. It exists only if e_{ij} equals to 0 and m_{ij} equals to 1. The value of n_{ijl} equals to 1 means the order is allocated to the l^{th} coalition of MSA j and n_{ijl} equals to 0 means the order is not allocated to the l^{th} coalition of MSA j.

Determination of final coalitions and final strategies are given in section 3.3.1.2 and 3.3.1.3, respectively. It leads to local optimal solution if we determine the optimal allocations after determining final coalitions and strategies. Thus, all three layers are combined together to find the optimal scheme to maximize total profit of SCNs. Thus, whole problem is:

$$\begin{aligned}
\max \quad & \{\Pi_1 + \Pi_2\} \\
& = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L} n_{ijl} Q_i^M (psell_i - PF_{ijl}) + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L} n_{ijl} QS_{ijlj'} (PF_{ijl} - C_j) \quad (3.25)\\
\textbf{s.t.} \quad & \sum_{j=1}^{J}\sum_{l=1}^{L} (n_{ijl} \sum_{j' \in s_{ijl}} A_{ij'}) \geq Q_i^M, \quad \forall i \quad (3.26)\\
& \sum_{i=1}^{I}\sum_{l=1}^{L} n_{ijl} QS_{ijlj'} \leq A_j^U, \quad \forall j \quad (3.27)\\
& \sum_{j=1}^{J}\sum_{l=1}^{L} n_{ijl} = 1, \quad \forall i \quad (3.28)\\
& n_{ijl} \in \{0, 1\}, \quad \forall i, \ \forall j, \ \forall l \quad (3.29)
\end{aligned}$$

where

$A_{ij'}$: ability of MSA j' for MA i

A_j^U: upper bound of the ability of MSA j

PF_{ijl}: final equilibrium of the negotiation between MA i and coalition s_{ijl}

$QS_{ijlj'}$: acquired quantity of MSA j' by belonging to coalition s_{ijl}

and n_{ijl} is a decision variable. In equation (3.25), what we should pay attention to are PF_{ijl} and $QS_{ijlj'}$, where PF_{ijl} and $QS_{ijlj'}$ respectively equal to PF_{ij} and Q_i^M when MA i negotiates with MSA j and the order is in ability of MSA j. Equations (3.28) - (3.29) mean that each order must and only can be allocated to one MSA or coalition.

Final trade allocation scheme M[3] and N are determined according to n_{ijl} after solving equations (3.25) - (3.29), where:

$$m_{ij} = \sum_{l=1}^{NC} n_{ijl}, \quad \forall i, \ \forall j \tag{3.30}$$

equation (3.30) indicates that if one of the coalition of MSA j gets order of MA i, then we can see MSA j gets order of MA i as well.

3.3.1.2 Second-layer game based negotiation

Negotiation among MSAs is to find coalitions when orders of MAs are out abilities of MSAs (see section 2.3). Final coalition of MSA j is determined as SF_{ij}.

3.3.1.3 Third-layer game based negotiation

Equilibrium of negotiation between MA i and SF_{ij} is determined in the third layer. Strategies in the third layer are prices of MA and MSA (coalition). MA firstly announces its strategy, and then SF_{ij} reacts by playing the best move based on strategy of MA. We give following rule to find equilibrium:

Rule 3.2: *The strategy of MA at t can be determined as the equilibrium if and only if the strategy of SF_j at t is less than this strategy.*

As we have mentioned in section 3.2.3 that problem of finding the Stackelberg equilibrium can be determined by solving equations (3.31) - (3.37).

$$PF_{ij} = arg \max_{p_{ij}^M[t]} \{(psell_i - p_{ij}^M[t]) Q_{ij}^M\}, \ \forall i, \ \forall j \tag{3.31}$$

$$\textbf{s.t.} \quad p_j^{SL} \le p_{ij}^S[t] \le p_{ij}^M[t], \ \forall i, \ \forall j \tag{3.32}$$

$$p_{ij}^M[t] \le p_i^{MU}, \ \forall i, \ \forall j, \ \forall t \tag{3.33}$$

$$p_{ij}^M[0] = psell_i/(1+\alpha_i^U), \ \forall i \tag{3.34}$$

$$p_i^{MU} = psell_i/(1+\alpha_i^L), \ \forall i \tag{3.35}$$

[3] If order of i is in ability of j, then all s_{ijl} equal to j. Thus, all n_{ijl} are allocations of i to j.

$$p_{ij}^{M}[t] = p_{ij}^{M}[t-1] + \frac{p_{ij}^{S}[t-1] - p_{ij}^{M}[t-1]}{(TN - tTS)/TS}, \ \forall i, \ \forall j, \ \forall t \tag{3.36}$$

$$p_{ij}^{S}[t] = p_{ij}^{S}[t-1] - \frac{p_{ij}^{S}[t-1] - p_{ij}^{M}[t]}{(TN - tTS)/TS}, \ \forall i, \ \forall j, \ \forall t \tag{3.37}$$

where

α_i^U: upper bound of profit of MA i

α_i^L: lower bound of profit of MA i

$p_{ij}^M[t]$: price of MA i for MSA j at t

p_i^{MU}: upper bound of price of MA i

$p_{ij}^S[t]$: price of MSA j for MA i at t

TN: total negotiation time

TS: negotiation time of each negotiation step

Thus, the problem is transformed into determination of $p_{ij}^M[t]$, which can maximize profit of MA in equation (3.31). Equation (3.32) indicates that final strategy PF_{ij} must be accepted by MSA j. Equation (3.33) indicates final price must be less upper bound of price of MA i. Equations (3.34) - (3.35) are initial value and upper bound of price of MA, respectively. Equations (3.36) - (3.37) are strategies of MA and MSA, respectively. Final strategy PF_{ij} is obtained by solving equations (3.31) - (3.37). Then, this final strategy PF_{ij} is fed back to the first layer game.

3.3.2 Simulation and analysis

It is supposed that there are 5 MA and 5 MSAs in SCNs. Initial values of MAs and MSAs are shown in Table 3.4. $\sigma_{jl} = 0.1$, $\alpha_i^{min} = 0.3$, $\alpha_i^U = 0.5$, $\beta_j^L = 0.2$, $\beta_j^U = 0.5$. ILOG CPLEX 12.0 is used to find solution of proposed protocol. Then, we verify proposed protocol for negotiation between multi-MA and multi-MSA.

Table 3.4: Parameter settings of MAs and MSAs

	C_j	γ_j		$psell_i$	Q_i^M	LT_i^M
MSA 1	7.116	125	MA 1	13.131	4002	20
MSA 2	7.604	224	MA 2	13.712	5715	28
MSA 3	7.216	220	MA 3	13.416	675	3
MSA 4	7.040	104	MA 4	13.656	7427	37
MSA 5	7.545	201	MA 5	13.387	5000	80

3.3.2.1 Verification

Firstly, MAs announce their orders, and then MSAs check their abilities. The evaluation matrix can be obtained as: $E=\begin{pmatrix} 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{pmatrix}$. MSAs which cannot finish the order (e.g. $e_{14} = 0$ means order of MA 1 is out of ability of MSA 4) will try to find possible coalitions. All possible coalitions of MSAs for MAs are obtained by using coalition formation mechanism and are shown in Table 3.5, where {14} indicates coalition which consists of MSA 1 and MSA 4.

Then, related final strategies (equilibriums) are obtained by solving equations (3.31) - (3.37) and shown as Table 3.6. For example, 9.155 (the second line, second column of Table 3.6) means final price between MA 1 and coalition {14} (the second line and second column of Table 3.5) is determined as 9.155.

Finally, two-person game is used to determine final allocation scheme. Final allocation scheme is determined by solving equation (3.25) to find the optimal solution based on results of Table 3.5 and Table 3.6. Then, we can get the optimal allocation scheme according to equation (3.30) as:

$$M = \begin{pmatrix} 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{pmatrix}, N_{31} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}.$$

We can see from matrix M that MA 1 is allocated to MSA 5 ($m_{15} = 1$), MA 2 is

Table 3.5: All possible coalitions for each MSA

	Index	MSA1	MSA2	MSA3	MSA4	MSA5
MA1	1	{14}	{2}	{3}	{41}	{5}
MA2	1	{14}	{2}	{3}	{41}	{51}
	2	{145}			{415}	{514}
	3	{15}			{45}	{54}
MA3	1	{12}	{21}	{31}	{41}	{51}
	2	{123}	{213}	{312}	{412}	{512}
	3	{1234}	{2134}	{3124}	{4123}	{5123}
	4	{12345}	{21345}	{31245}	{41235}	{51234}
	5	{1235}	{2135}	{3125}	{4125}	{5124}
	6	{124}	{214}	{314}	{413}	{513}
	7	{1245}	{2145}	{3145}	{4135}	{5134}
	8	{125}	{215}	{315}	{415}	{514}
	9	{13}	{23}	{32}	{42}	{52}
	10	{134}	{234}	{324}	{423}	{523}
	11	{1345}	{2345}	{3245}	{4235}	{5234}
	12	{135}	{235}	{325}	{425}	{524}
	13	{14}	{24}	{34}	{43}	{53}
	14	{145}	{245}	{345}	{435}	{534}
	15	{15}	{25}	{35}	{45}	{54}
MA4	1	{14}	{2}	{3}	{41}	{5}
MA5	1	{1}	{2}	{3}	{4}	{5}

allocated to MSA 2 ($m_{22} = 1$), MA 3 is allocated to MSA 1 ($m_{31} = 1$), MA 4 is allocated to MSA 3 ($m_{43} = 1$), and MA 5 is allocated to MSA 4 ($m_{54} = 1$). However, MA 3 is out of ability of MSA 1, for e_{31} equals to 0. Thus, there exists a matrix N_{31} to record allocation among coalitions of MSA 1 of the order MA 3. $n_{3,1,13}$ equals to 1 means order of MA 3 is allocated to the thirteenth coalition of MSA 1 (see the second column of Table 3.5, there are fifteen possible coalitions of MSA 1 for MA 3). Therefore, final supplier of MA 3 is coalition {14} (the seventh column and fourth row of Table 3.7). Order allocation of each MSA or coalition, which maximizes total profit of SCNs, is shown in Table 3.7. The column FS is final supplier of each MA. Final profit of each agent under determined allocation scheme (as M) is shown in Table 3.8, where the number is index of MA or

Table 3.6: Final strategy between MA and MSA (coalition)

	MSA1	MSA2	MSA3	MSA4	MSA5
MA1	9.155	10.079	9.789	8.605	10.036
MA2	9.348	10.274	9.983	9.348	9.519
	9.454			9.454	9.453
	9.519			9.519	9.493
MA3	9.440	9.440	9.309	9.249	9.420
	9.408	9.408	9.408	9.368	9.482
	9.362	9.362	9.362	9.362	9.447
	9.402	9.402	9.402	9.402	9.402
	9.447	9.447	9.447	9.417	9.417
	9.368	9.368	9.281	9.281	9.395
	9.417	9.417	9.352	9.352	9.352
	9.482	9.482	9.394	9.355	9.355
	9.309	9.473	9.474	9.414	9.585
	9.280	9.391	9.391	9.391	9.504
	9.352	9.434	9.434	9.434	9.434
	9.394	9.504	9.504	9.461	9.465
	9.250	9.414	9.284	9.284	9.454
	9.355	9.465	9.378	9.377	9.377
	9.420	9.585	9.454	9.394	9.394
MA4	8.949	10.255	9.964	8.949	10.211
MA5	9.275	9.640	9.349	9.217	9.596

MSA.

3.3.2.2 Analysis

We can see from above results that feasibility of proposed protocol was verified. Results indicate that proposed protocol is a good way to solve SASI negotiations between multi-MA and multi-MSA.

(a) Calculation time

Simulation is executed by 1000 times to verify effectiveness of proposed protocol in solving SASI negotiation between multi-MA and multi-MSA as well. Results are shown as Table 3.9, where average and standard derivation of calculation time are presented. We

Table 3.7: Final trade partnerships and order allocation

	MSA1	MSA2	MSA3	MSA4	MSA5	FS
MA 1	0	0	0	0	4002	{5}
MA 2	0	5715	0	0	0	{2}
MA 3	368	0	0	307	0	{14}
MA 4	0	0	7427	0	0	{3}
MA 5	0	0	0	5000	0	{4}

Table 3.8: Final profit under the optimal allocation

	MA	MSA	SCN
1	12386.52	9967.69	
2	19651.43	15257.82	
3	2812.25	3865.22	
4	27416.66	20407.72	
5	20848.04	10886.69	
Total	83114.90	60385.14	143500.04

can see the proposed protocol is effective and stable in solving SASI negotiation between multi-MA and multi-MSA as well.

Table 3.9: Calculation time of SASI negotiation between multi-MA and multi-MSA

	Calculation time (sec)
Avg.	0.000906
S.D.	0.003653

(b) Comparisons related to average time (AT) and success rate (τ)

Performances of proposed protocols are discussed in this section. Impacts of upper bound of productivity γ^{Up} on performances of average time (AT) and success rate (τ) as the changing of upper bound of quantity Q^{Up} of the order are discussed in follows. Figure 3.11.

We compare performances of proposed protocol under γ^{Up} equals to 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000 and 1100. Fluctuations of AT and τ are shown in Figure 3.9, Figure 3.10, and we can get:

- **For** AT**:** (see Figure 3.9):

- There is a turning point of Q^{Up}, before which AT increases as Q^{Up} increases, and after which it decreases as Q^{Up} increases, and finally asymptotic converges to a certain region. AT increases because it takes much more time to reach an agreement among coalitions when L increases. Increase of L is due to increase of number of the members in coalition. AT decreases because L decreases when Q^{Up} keeps increasing. Decrease of L is because of symmetry of L.

- Final converged value of AT deceases as γ^{Up} increases, and there are only a few improvement when γ^{Up} is greater than or equals to 900.

- **For** τ**:** (see figures 3.10 and 3.11)

- There is a turning point of Q^{Up}, before which τ decreases as Q^{Up} increases, and after which it increases as Q^{Up} increases, and finally converges to a certain region.

- Final converged value of τ deceases as γ^{Up} increases and it is much higher when γ^{Up} is greater than or equals to 200 than $\gamma^{Up} = 100$. However, there are no improvements at all when γ^{Up} is greater than or equals to 900.

Analysis: As we known that productivity γ^{Up} is an important factor for MSAs. It takes cost to enhance γ^{Up}. γ^{Up} for MSA is the smaller, the better. Therefore, we can get conclusion that there is no need to set γ^{Up} greater than 900 in order to improve performance of the algorithm under any Q^{Up} from above analysis. In other words, the optimal setting of γ^{Up} equals to 900. We have verified that there are the same tendencies under both situations of changing numbers of MA and MSA. Other results of fluctuations of AT and τ related to numbers of MA and and MSA are presented in **Appendix A2** and **A3** of this dissertation.

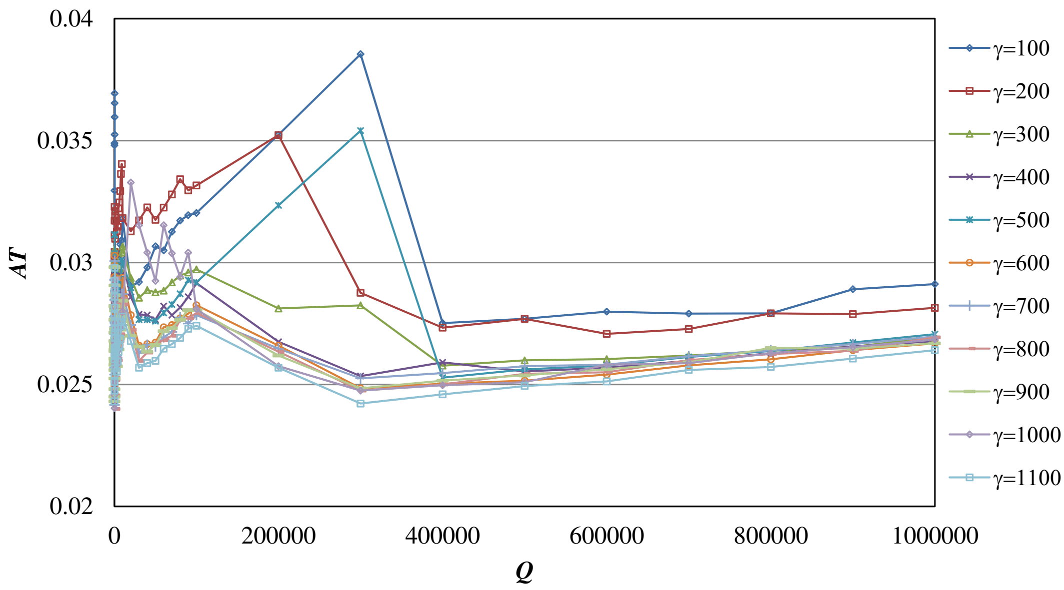


Figure 3.9: Fluctuation of AT related to Q

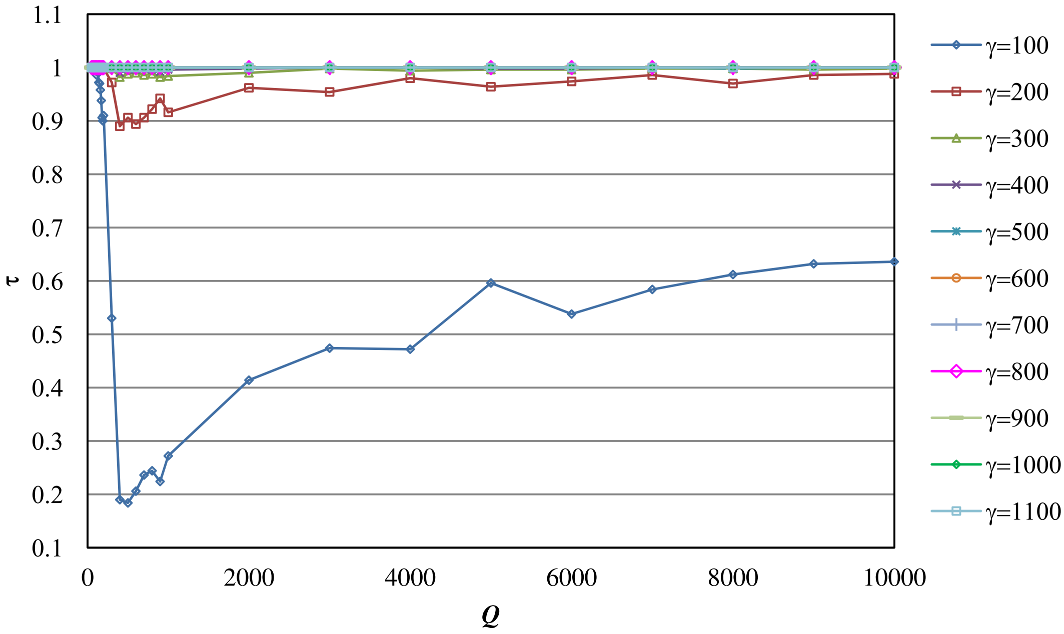


Figure 3.10: Fluctuation of τ related to Q

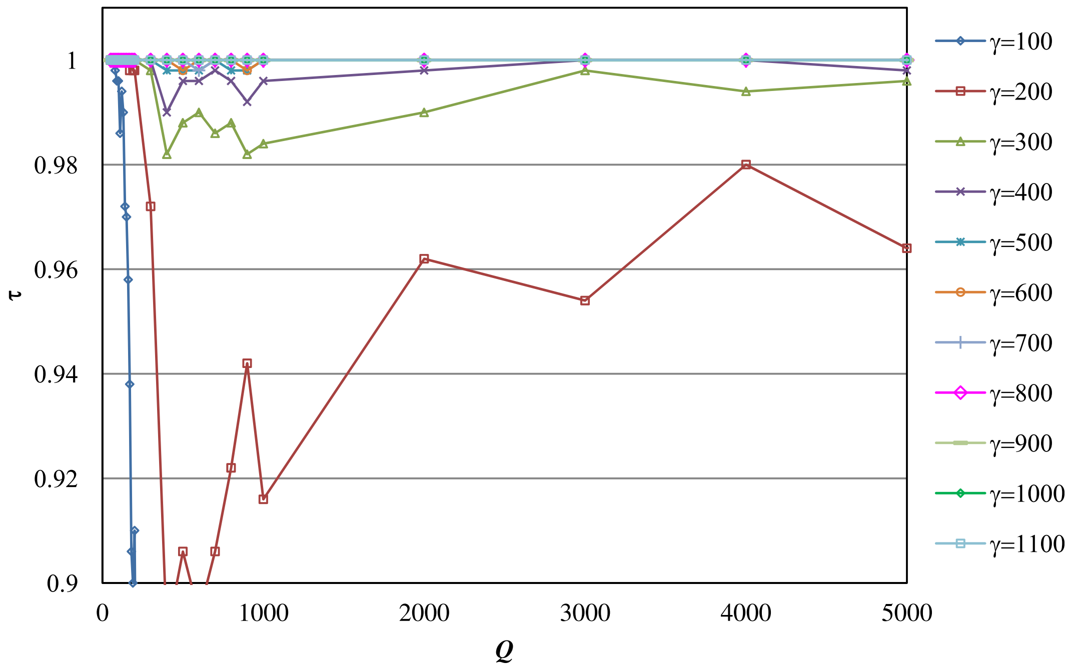


Figure 3.11: Enlargement of the fluctuation of τ related to Q

3.4 Comparison protocol

3.4.1 Greedy protocol

In this chapter, coalition formation mechanism is introduced for MSAs to establish coalitions when order(s) of MA(s) is(are) out of abilities of MSAs. However, it is a possible way for MA(s) to decompose its(their) order(s) into pieces and then allocated to different MSAs. It is defined as a **greedy protocol** in which MA selects MSA with the lowest price as supplier. If the selected MSA cannot complete the order by itself, then MA splits the order and allocates remaining quantity to MSA with the second lowest price and so on.

3.4.2 Comparisons and analysis

3.4.2.1 Comparison of equilibriums

Negotiation protocols proposed in section 3.2 and section 3.3 are compared in this section. Equilibriums are obtained according to ***Rule 3.1*** and ***Rule 3.2*** in section 3.2 and section 3.3, respectively. Results are shown in Table 3.10, where SF, PF, π^M, π^C, and π^T are final determined coalition, final determined equilibrium, profit of MA, profit of SF, and total profit of SCNs, respectively.

Table 3.10: Results according to Rule 3.1 and Rule 3.2

	Rule 3.1	***Rule 3.2***
SF	{314}	{314}
PF	8.52	9.07
π^M	19443.18	17795.49
π^C	4175.99	7602.90
π^T	23619.17	25398.39

Analysis: We can see ***Rule 3.1*** is better than ***Rule 3.2*** for MA, however, it's more realistic to take ***Rule 3.2***, because MSAs want to maximize their profits as well. Moreover, ***Rule 3.2*** is better from the view of total profit of SCNs.

3.4.2.2 Comparison of protocols with and without coalition

Proposed protocol is compared with greedy protocol under three cases to verify superiority of using coalition formation mechanism.

• *Case 1:* MA submits an Order (1000, 8.5, 10), which means that in this case all MSAs can complete order by themselves;

• *Case 2:* MA submits an Order (2000, 8.5, 10), we can see from Table 3.1 that some MSAs cannot complete order by themselves, thus, they need to find partners;

• *Case 3:* MA submits an Order (3000, 8.5, 10), we can see from Table 3.1 that no MSA can complete order by itself.

Comparisons are shown in Table 3.11. We can see that:

- In *Case 1*: All MSAs in both protocols can complete order by themselves, and MSAs don't need to form coalitions. However, if MSAs are allowed forming coalitions, final coalition for MA will be {14}, and all profits of MA, MSAs, and total SC increase.

- In *Case 2*: The order is out of abilities of some MSAs. Final suppliers for greedy algorithm is {4, 1} which means MA first allocates its order to MSA 4 with quantity $QS_4 = A_4 = 1040$ and then allocates remain parts $QS_1 = 2000 - QS_4 = 960$ to MSA

1. Final supplier for the proposed protocol is {14} which indicates the order is allocated to coalition consists of MSA 1 and MSA 4. All profits of MA, MSAs, and total SCNs in proposed protocol are higher than that of greedy algorithm.

- In *Case 3*: All MSAs in SCNs cannot finish the order by themselves. Final suppliers for greedy algorithm is {4, 1, 3} which means MA first allocates its order to MSA 4 with the quantity $QS_4 = A_4 = 1040$, then allocates its order to MSA 1 with quantity $QS_1 = A_1 = 1250$, and finally allocates remain parts $QS_3 = 3000$ - QS_4 - QS_1 = 710 to MSA 3. Final supplier for proposed protocol is {134} which indicates the order is allocated to coalition consists of MSA 1, MSA 3 and MSA 4. All profits of MA, MSAs, and total SCNs in proposed protocol are higher than that of greedy algorithm.

Table 3.11: Comparisons of greedy algorithm and proposed protocol under three cases

	Case 1		*Case 2*		*Case 3*	
	Greedy	Proposed	Greedy	Proposed	Greedy	Proposed
Final suppliers	{4}	{14}	{4,1}	{14}	{4,1,3}	{314}
Profit of MA	5470.00	5963.41	10885.28	11926.81	16245.03	17795.49
Profit of MSAs	2490.00	2523.94	4961.76	5047.88	7415.01	7602.90
Total profit	7960.00	8487.35	15847.04	16974.69	23660.04	25398.39

Analysis: We can see from above results that greedy algorithm adopts method of splitting the order and allocating it to multiple MSAs. It increases workload of MA. Proposed protocol solves this problem from side of MSAs. It tries to build coalitions and MA just announces order and waits for responses. Proposed protocol is much more superior to greedy algorithm. It doesn't only maintain integrity of the order, but also reduces workload of MA and increases profits of MA, MSAs, and total SCNs (see profit of MA, MSAs and total profit in Table 3.11)

Chapter 4 Coalition Formation Based Single-Attribute Multi-Item Negotiation

4.1 Introduction

It was assumed that there is only one kind of product (item) in Chapter 3. However, in real manufacturing system, it is a common situation that a MA must buy multiple kinds of items to produce its product. For example, a car company must buy screws, valves, lamps, bumpers, horns and so on to produce a car. Therefore, the research is extended into more general cases in this chapter, where the focus is fixed on single-attribute multi-item (SAMI) negotiation between MA(s) and MSAs.

Most works on multi-item auctions suppose two simplifying conditions: quantities of items to sell are fixed as well as quantities requested by buyers. However, these two hypotheses do not meet requirements of many situations where negotiations are used. Researchers try to relax these assumptions where available quantities are not fixed [Lengwiler, 1999] as well as quantities requested by buyer [Ben-ameur et al., 2002]. [Roh and Yang, 2008] proposed an iterative multi-item unit-demand and unit-supply double auction mechanism, in which buyers want to buy at most one item out of the many available and each seller has a single item to sell. [Ito et al., 2002] focused on multi-item negotiation, where items are substitute and sellers exchange items when they do not have enough abilities. None of them focused on the coalition formation among sellers (suppliers). As we have mentioned, this research tries to let MSAs combine together as a coalition when the order is out of their abilities and then compete for the order of MA. It is not uncommon in real-world that coalitions of complementary component-suppliers selling kits are formed [Nagarajan and Sošić, 2009]. The reasons for forming supplier alliances in SCs are manifold: potential cost savings, risk pooling, improve capacity utilization, and increase bargaining power. [Greys, 2011] and [Nagarajan and Sošić, 2009] have studied an assembly SC in which n suppliers sell complementary components to a downstream assembler. They assumed that suppliers can form alliances among themselves. However, all of these researches were assumed that MSAs supply the same item and only single-item negotiation was discussed. In this chapter, we try to extend coalition formation among

MSAs which can supply different items.

4.2 Single-Attribute Multi-Item Negotiation between One-MA and Multi-MSA

Consider a SAMI negotiation with one MA and J MSAs. The negotiation model is shown in figure 4.1, where p_k^{MI} is initial price of item k of MA, $\mathbf{Q^M} = (Q_1^M,...,Q_K^M)$ is quantities of items of MA, and LT^M is lead time of the order of MA. It is assumed in this section that only single-attribute (price) is discussed for simplification. MA wants to buy K items to produce its product. We assume that quantity Q_k^M of each item k is fixed, but there are some constraints of quantity of each item from the point of inventory. The quantity of each item must be in proportion (e.g. a car needs one steering wheel and four tyres, therefore, it's better for car company to buy quantities of steering wheel and tyre in proportion of $1:4$). The abilities of MSAs in this model are not identical. Some of them may only be able to afford one item while the others may be able to supply different kinds of items. Moreover, we assume that MSA j in this model is allowed to establish a coalition with other MSAs when the order of MA is out of its ability.

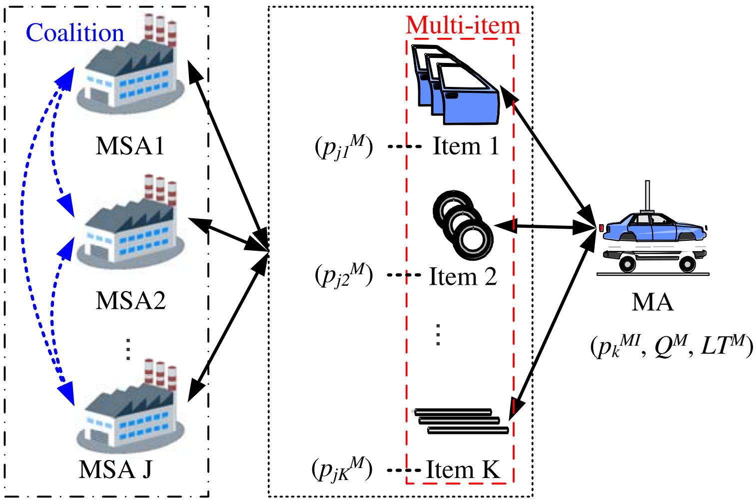


Figure 4.1: SAMI negotiation model between one-MA and multi-MSA

4.2.1 Single-attribute multi-item negotiation protocol

The protocol can be divided into two parts. The first part is for MSAs which cannot finish the order by themselves to find coalitions, and the second part is negotiation between MA and MSA (coalition) to decide final equilibrium. It can be concluded as follows:

- **Step 1:** MA announces its initial strategies about how many items, how many quantities of items and what price it wants to buy;
- **Step 2:** Each MSA evaluates the order, if it is in its ability, it gives a response to start negotiation and goes to Step 5, if it is out of its ability, then goes to Step 3;
- **Step 3:** Combined coalition formation is triggered to find a coalition which can maximize profit of MSA, and goes to Step 4;
- **Step 4:** MSA checks whether it can establish a coalition, if it can establish, it gives a response to start negotiation and goes to Step 5, if it cannot establish, then rejects the order, gives a response and negotiation goes to Step 5;
- **Step 5:** MA negotiates with MSA (coalition) to find agreement of prices of items, if it succeeds in finding the equilibrium, goes to Step 7, if it doesn't succeed in finding the equilibrium, then goes to Step 6;
- **Step 6:** Checks terminal condition, if terminal condition is satisfied, goes to Step 7, if it is not satisfied, then two partners of negotiation try to modify their strategies and negotiation goes to Step 5;
- **Step 7:** Checks whether all MSAs have replied, if all MSAs have replied, goes to Step 8, if not, then wait until all MSAs give responses and goes to Step 8;
- **Step 8:** Determines final supplier which maximizes its profit and negotiation ends.

Flowchart of multi-item negotiation is shown in figure 4.2, and details of the negotiation such as how does MSA establish a coalition and how does the negotiation find equilibrium are discussed in following sections.

4.2.2 Negotiation among MSAs

MSA starts to negotiate with other MSAs in SCNs to establish a coalition if it cannot complete the order by itself. Multi-item involved coalition formation has been discussed in section 2.3.1.2. Thus, the final determined coalition of MSA j for MA is indicated as

$$SF_j = \begin{cases} arg\max_{s_{jl}}\{\pi_{jl}^{SC}\}, & \text{if } A_{jk} < Q_k^M \\ j, & \text{if } A_{jk} \geq Q_k^M \end{cases} \tag{4.1}$$

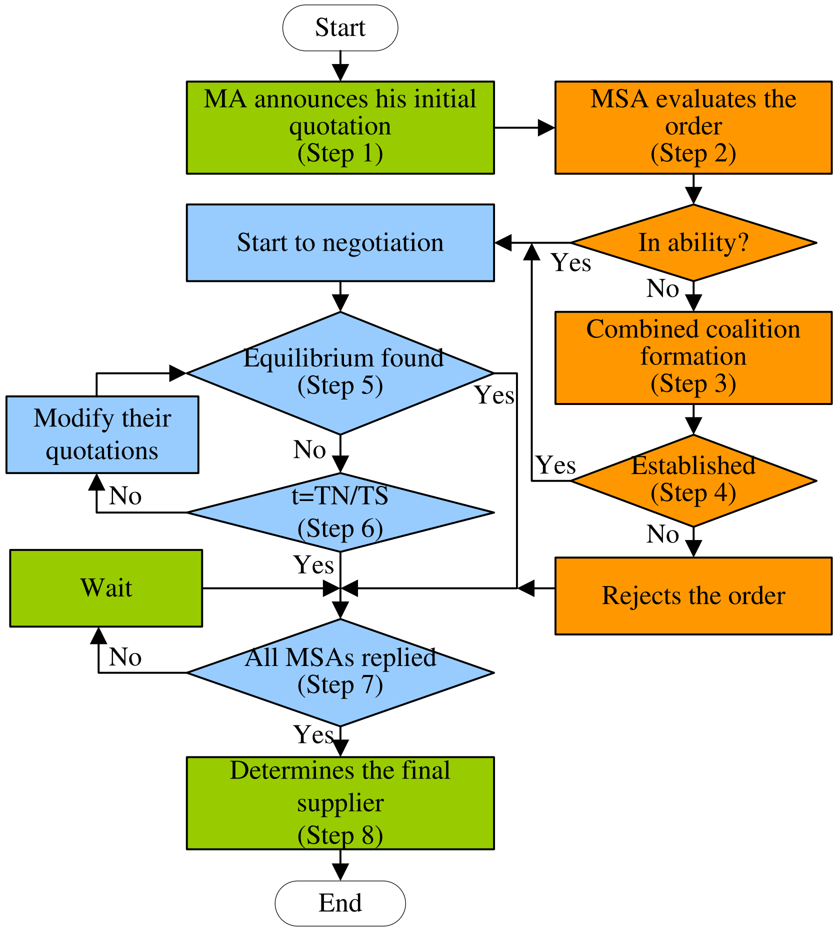


Figure 4.2: Flowchart of SAMI negotiation protocol

$$p_{jk}^{SFI} = \frac{\sum_{j' \in SF_j} p_{j'k}^{SI}}{N_{jk}} \tag{4.2}$$

$$p_{jk}^{SFL} = \frac{\sum_{j' \in SF_j} p_{j'k}^{SL}}{N_{jk}} \tag{4.3}$$

$$AF_{jk} = \sum_{j' \in SF_j} A_{j'k} \tag{4.4}$$

where equation (4.1) indicates the final coalition of MSA j equals to itself if the order is in its ability and equals to the coalition s_{jl} which maximizes its profit when the order is out of its ability. The price, lower bound of the price, and ability of the final determined coalition SF_j equal to the related price, lower bound of the price, and ability of itself when the order is in its ability, and equal to those of coalition s_{jl} which maximizes the profit of MSA j when the order is out of its ability, and are calculated by equation (4.2), equation (4.3), and equation (4.4), respectively. The profit $\pi_{jlj'}^{SC}$ of MSA j' of belonging to s_{jl} is calculated by

$$\pi^{SC}_{jlj'} = \sum_{k=1}^{K} (p^{CI}_{jlk} - C_{j'k}) QS_{jlj'k} \tag{4.5}$$

$$QS_{jlj'k} = \frac{A_{j'k} Q^M_k}{AC_{jlk}} \tag{4.6}$$

and

$A_{j'k}$: ability of item k of MSA j'

AC_{jlk} : ability of item $k$of s_{jl}

AF_{jk} : ability of item k of SF_i

N_{jk} : the number of member in SF_i which can supply item k

$\pi^{SC}_{jlj'}$: profit of MSA j' in coalition s_{jl}

p^{SFI}_{jk} : initial price of item k of SF_i

p^{SFL}_{jk} : lower bound of price of item k of SF_i

p^{SI}_{jk} : initial price of item k of MSA j

p^{SL}_{jk} : lower bound of item k of price of MSA j

$QS_{jlj'k}$: acquired quantity of item k of MSA j' by belonging to coalition s_{jl}.

4.2.3 Negotiation between MA and MSA (coalition)

4.2.3.1 Determination of strategies

Negotiation of price starts after SF_j is determined. Strategies of MA and SF_j are calculated by:

$$p^M_{jk}[t] = p^M_{jk}[t-1] + (p^{MU}_k - p^M_{jk}[t-1])(\frac{tTS}{TN})^{\frac{1}{\varepsilon}} \tag{4.7}$$

$$PM_j[t] = \sum_{k=1}^{K} p^M_{jk}[t] Q^M_k \tag{4.8}$$

$$p^M_{jk}[0] = p^{MI}_{jk} \tag{4.9}$$

$$p^S_{jk}[t] = p^S_{jk}[t-1] - (p^S_{jk}[t-1] - p^M_{jk}[t])(\frac{tTS}{TN})^{\frac{1}{\varepsilon}} \tag{4.10}$$

$$PS_j[t] = \sum_{k=1}^{K} p_{jk}^{S}[t] Q_k^M \tag{4.11}$$

$$p_{jk}^{S}[0] = p_{jk}^{SFI} \tag{4.12}$$

where

$p_{jk}^{M}[t]$: price of item k of MA at t

$PM_j[t]$: total price of all items of MA at t

$p_{jk}^{S}[t]$: price of item k of SF_j at k

$PS_j[t]$: total price of all items of SF_j at t

q_k^M :quantity of item k of MA

4.2.3.2 Determination of equilibriums

As we have mentioned before, the interaction between MA and SF_j can be seen as a MA-Stackelberg game and the strategy of MA which maximizes MA's profit and is accepted by SF_j will be determined as the final equilibrium. As we have analyzed in section 3.4.2.1 that it's better to adopt ***Rule 3.2***. Thus, the equilibrium can be obtained by solving:

$$PF_j = arg \max_{PM_j[t]} \{ \sum_{k=1}^{K} psell_k Q_k^M - PM_j[t] \} \tag{4.13}$$

$$\text{s.t. } PS_j[t] \leq PM_j[t] \tag{4.14}$$

$$PM_j[t] \leq \sum_{k=1}^{K} p_k^{MU} Q_k^M \tag{4.15}$$

where equation (4.13) indicates that $PM_j[t]$ which maximizes the profit of MA will be determined as the final equilibrium (price) PF_j, equation (4.14) means all the members in SF_j must be profitable by choosing the determined price, and the profit of each member in SF_j is calculated by equation (4.16). Equation (4.15) means the final determined price must be profitable for MA as well.

$$\pi_{jlj'}^{SFC}[t] = \sum_{k=1}^{K} (p_{jk}^{M}[t] - C_{j'k}) QSF_{j'k} - CS_j, \forall j' \in SF_j \tag{4.16}$$

$$QSF_{j'k} = \frac{A_{j'k} Q_k^M}{AF_{jk}} \tag{4.17}$$

And

$\pi^{SFC}_{jlj'}[t]$: profit of MSA j' by belonging to SF_j at t

CS_j : setup cost of MSA j per order

$QSF_{j'k}$: acquired quantity of item k of MSA j' by belonging to SF_j

4.2.3.3 Determination of final supplier

SF_j, with which MA has the maximum profit, is selected as final supplier of MA after all final equilibriums are determined:

$$arg \max_{SF_j} \quad \{\pi^M_j = \sum_{k=1}^{K} psell_k Q^M_k - PM_j[t]\} \tag{4.18}$$

$$\textbf{s.t.} \quad PF_j = arg \max_{p^M_j[t]} \{\pi^M_j = \sum_{k=1}^{K} psell_k Q^M_k - PM_j[t]\} \tag{4.19}$$

$$SF_j = arg \max_{s_{jl}} \{\pi^{SC}_{jl}\}. \tag{4.20}$$

4.2.4 Simulation and analysis

In this section, we consider SAMI negotiation between one MA and 5 MSAs. In order to consider all possible situations, we assume that MSA 1 can supply all items by itself; MSA 2 cannot supply some items but the others are in its ability; MSA 3 cannot supply some items but one of the others, which can be supplied, is out of its ability; MSA 4 can supply all items but all of them are out of its ability; and MSA 5 only can supply one item. The data settings are shown in Table 4.1, Q^M_k =(1000, 4000, 2000, 2000), and LT^M =10.

Table 4.1: Parameter settings of MSAs

	C_{j1}	C_{j2}	C_{j3}	C_{j4}	γ_{j1}	γ_{j2}	γ_{j3}	γ_{j4}
MSA 1	26	36	20	22	150	400	300	200
MSA 2			16	21	0	0	300	250
MSA 3	35	40			150	300	0	0
MSA 4	34	35	18	19	50	300	150	100
MSA 5	28				500	0	0	0

Table 4.2: All possible coalitions

l	s_{jl}	π_j^S	l	s_{jl}	π_j^S	l	s_{jl}	π_j^S
1	1	12437.4	17	{21}	2385.9	33	{412}	64899.1
2	{12}	10972.6	18	{213}	4819.8	34	{413}	101288.1
3	{13}	70391.0	19	{214}	13921.8	35	{415}	79367.6
4	{14}	121190.3	20	{215}	5252.6	36	{4123}	93734.1
5	{15}	14653.7	21	{2134}	12540.5	37	{4125}	73495.9
6	{123}	77199.7	22	{2135}	5625.2	38	{4135}	116513.9
7	{124}	104573.6	23	{2145}	16141.0	39	{41235}	109406.1
8	{125}	24166.1	24	{21345}	14059.2	40	{51}	779.1
9	{134}	159378.9	25	{31}	12540.5	41	{512}	1388.3
10	{135}	90386.6	26	{314}	75516.8	42	{513}	-725.8
11	{145}	123785.3	27	{315}	49779.5	43	{514}	6413.0
12	{1234}	140561.1	28	{3124}	85134.5	44	{5123}	-1473.9
13	{1235}	99467.7	29	{3125}	62217.3	45	{5124}	7257.9
14	{1245}	107596.2	30	{3145}	81705.5	46	{5134}	-1526.6
15	{1345}	179419.9	31	{31245}	93999.6	47	{51234}	-2168.4
16	{12345}	159265.1	32	{41}	72569.3			

We can see that coalition formations of MSA 2 and MSA 5 are for substitution, because items which can be supplied by MSA 2 and MSA 5 are in ability, and they wants to find partners which can supply the items which cannot be supplied by themselves. The coalition formation of MSA 3 is for both of complementary and substitution, and the coalition formation of MSA 4 is for complementary.

4.2.4.1 Verification

Result of all possible coalitions are shown in Table 4.2, where l is index of coalitions, s_{jl} (the second, fifth, and eighth columns of Table 4.2) are possible coalitions for each MSA which have enough ability for the order of MA, π_j^S is acquired profit of MSA j of belonging to s_{jl}, and {12} is a coalition of MSA 1, which consists of MSA 1 and MSA 2.

All coalitions, which are not shown in Table 4.2, mean they do not have enough ability for the order. However, coalitions which are shown in this table do not mean they are formed coalitions. That's because coalition can be determined if and only if all members in the coalition reach an agreement. In Table 4.2, although all coalitions have enough abilities, some of them have negative profits (e.g. when $l = 42$, MSA 5 gets negative profit (-725.3) if it agrees to establish a coalition with MSA 1 and MSA 3). MSAs which have negative profits absolutely reject to belong to these coalitions.

As we have mentioned above that MSA 1 can supply the whole order by itself and it agrees to form a coalition if and only if profit of belonging to a coalition is greater than that of completing by itself (according to ***Rule 2.1***). Therefore, MSA 1's best choice is belonging to coalition {1345} ($l = 15$), in which MSA 1 has the highest profit 179419.96. However, profit of MSA 5 in coalition {5134} is -1526.59 ($l = 46$). Thus, it rejects to belong to this coalition. That means members of coalition {1345} failed to reach an agreement. Then, MSA 1 selects the second best choice of belonging to coalition {134} with profit 159378.88 ($l = 9$). MSA 3 and MSA 4 cannot finish the order by themselves, and they accept to form a coalition if profits of belonging to a coalition are positive. We can see from Table 4.2 that profit of MSA 3 by belonging to {134} is 75516.8 ($l = 26$) and profit of MSA 4 by belonging to {134} is 101288.1 ($l = 34$), and both of them are positive. Therefore, all members of {134} reach an agreement and the coalition is formed. According to above analysis, the final coalition for MSA 1 is determined as {134}.

After the final coalition is determined as {134}, negotiation between MA and {134} starts. It tries to find equilibrium which can maximize profit of MA. We can get results as Table 4.3, where PF is final equilibrium of price of the order, π^S is total profit of {134}, π^M is profit of MA, and π^T is total profit of SCNs.

Table 4.3: Final equilibrium and profits

PF	π^S	π^M	π^T
458288.45	266077.45	229144.22	495221.67

The order is allocated according to equation (4.17) among members of coalition {134} and is shown as table 4.4, where 430 means the quantity of MSA 1 of item 1 acquired from coalition {134} equals to 430. Quantities of MSA 3 of item 3 and 4 equal to 0 because it cannot supply item 3 and item 4 at all.

Table 4.4: Order allocation among the members of coalition {134}

	Item			
	1	2	3	4
MSA 1	430	1600	1334	1334
MSA 3	428	1200	0	0
MSA 4	142	1200	666	666

4.2.4.2 Analysis

We can see from above results that feasibility of the proposed protocol was verified. Results indicate that proposed protocol is a good way to solve SAMI negotiations between multi-MA and multi-MSA. Simulation is executed by 1000 times to verify the effectiveness as well. Results are shown as Table 4.5, where average, standard derivation of calculation time, and success rate are presented. We can see the proposed protocol is effective and stable in solving SAMI negotiation between multi-MA and multi-MSA as well.

Table 4.5: Calculation time of SAMI negotiation between one-MA and multi-MSA

	Calculation time (sec)
Avg.	0.00327
S.D.	0.00636

4.3 Single-Attribute Multi-Item Negotiation between Multi-MA and Multi-MSA

Consider multi-item negotiation with I manufacturers and J material suppliers. Multi-agent system is utilized for modeling and analyzing SC, where each entity of SC is modeled as an agent. Thus, there are two different kinds of agents involved in this research: manufacturer agent (MA) and material supplier agent (MSA). K items are involved in the negotiation. Multi-agent based negotiation model is shown in figure 4.3, where MAs announce orders (expected price, quantity of each item, lead time) to all MSAs and then MSAs give responses (price, ability). MAs and MSAs negotiate with each other to determine final prices and allocation scheme. We can see from figure 4.3 that negotiations not only exist between MAs and MSAs, but also exist amongst MAs and amongst MSAs. MSAs coordinate with each other to establish a coalition when an order is out of their abilities and cooperate to decide final allocation of all orders when there are conflicts among MSAs. MAs cooperate to decide final selection of all suppliers when there are conflicts as well.

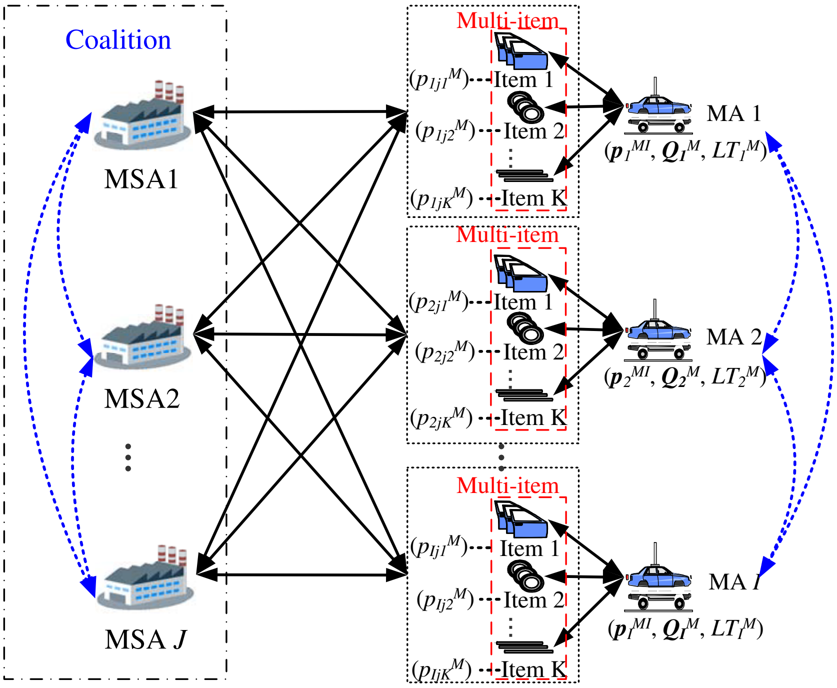


Figure 4.3: SAMI negotiation model between multi-MA and multi-MSA

4.3.1 Coalition formation based negotiation protocol

In real manufacturing system, it is a common situation that a MA must buy multi-item to produce its product. However, it wastes time for MAs to find a supplier for each item when there are diversity items to buy. Furthermore, due to the limited abilities of MSAs, MA may need to find more than one suppliers for each item. Thus, it will be a very heavy workload for MAs to find suppliers for all items they want to buy. This research tries to find another way to solve this problem, which can greatly reduce workloads of MAs and maximally maintain integrities of orders. A coalition formation protocol is proposed, where MSAs are allowed to find partners to establish coalitions when orders of MAs are out of abilities of MSAs. After coalitions are determined, MAs negotiate with MSAs to determine final allocation scheme. Protocol for the multi-item negotiation is proposed as follows:

- **Step 1:** MA i announces its order to all MSAs and waits for their responses.
- **Step 2:** Each MSA j evaluates each order and checks whether the order is in its ability. If the order is in its ability, agrees to start negotiation and goes to Step 7; if the order is out of its ability, then goes to Step 3.
- **Step 3:** MSA j checks each item k of the order. If item k is in ability ($A_{ijk} \geq Q_{ik}^{M}$), goes to Step 5; if the item is out of ability, then goes to Step 4.
- **Step 4:** MSA j checks which coalition formation is needed for item k. If MSA j cannot supply item k at all ($A_{ijk} = 0$), the coalition formation for substitution is triggered; if MSA j can supply item k with limited ability, then the coalition formation for complementary is triggered. After coalition formation is decided then goes to Step 5.
- **Step 5:** MSA j checks whether all items have been checked. If all items have been checked ($k = K$), MSA tries to determine final coalition and goes to Step 6; if not yet, goes back to Step 3 until all items are checked.
- **Step 6:** MSA j checks whether a coalition is successfully established. If all members of the coalition reach an agreement, MSA j agrees to start negotiation with MA i and then goes to Step 7; if not succeed, then rejects the order and negotiation goes to Step 7.
- **Step 7:** MA i checks whether exists MSAs agree to start negotiation. If there are some MSAs agree to start, then goes to Step 8; if there doesn't exist any MSA agrees to start negotiation, then MA i modifies its order and goes back to Step 1.
- **Step 8:** MA i negotiates with MSA j to find equilibrium and checks whether an equilibrium is found or not. If they are succeed in finding equilibrium, negotiation goes to Step 10; if they are failed to find equilibrium, and then goes to Step 9.
- **Step 9:** MA i and MSA j modify their strategies according to equations (4.37) - (4.40) and then go back to Step 8.
- **Step 10:** MA i checks whether all MSAs have replied or not. If all MAs have received replies from all MSAs, goes to Step 11; if not all MSAs have replied, then goes back to Step 7 and negotiation repeats until all MSAs give replies to all MAs.
- **Step 11:** Final allocation scheme is determined based on results of equilibriums and

coalitions, and negotiation ends.

Flowchart of multi-item negotiation is shown in figure 4.4, where the processes in the dashed area are the combined coalition formation.

4.3.1.1 Determination of coalitions

In multi-item negotiation, both coalition formation for complementary and coalition formation for substitution are involved. The final coalition will be determined as SF_{ij} according to section 2.3.1.2:

$$
\begin{aligned}
SF_{ij} \quad & = arg \max_{s_{ijl}} \{\pi^{SC}_{ijlj}\}, \quad \forall i, \ \forall j && (4.21)\\
\text{s.t.} \quad & AC_{ijlk} \geq Q^M_{ik}, \quad \forall k && (4.22)\\
& IF_j = IF_{j'}, \quad \forall j' \in s_{ijl} && (4.23)\\
& \pi^{SC}_{ijlj'} \begin{cases} > 0, & \text{if } \exists k, \ e_{ij'k}{=}0 \\ > \pi^S_{ij'}, & \text{if } \forall k, A_{ijk} \geq Q^M_{ik} \end{cases} , \forall j' \in s_{ijl}, j' \neq j && (4.24)
\end{aligned}
$$

where

$$
\pi^{SC}_{ijlj'} = \sum_{k=1}^{K} (p^C_{ijlk} - C_{j'k}) QS_{ijlj'k}, \quad \forall j' \in s_{ijl} \tag{4.25}
$$

$$
\begin{aligned}
p^C_{ijlk} = {} & e_{ijk} p^{SU}_{jk} + (1 - e_{ijk})(1 - Sign(A_{ijk})) \frac{\sum_{j' \in SFS_{ijk}} (1 + \beta^U_{j'k}) C_{j'k}}{NS_{ijlk}} \\
& + (1 - e_{ijk}) Sign(A_{ijk}) \frac{\sum_{j' \in SFC_{ijk}} (1 + \beta^U_{j'k}) C_{j'k}}{NC_{ijlk}}, \ \forall i, \ \forall j, \ \forall k
\end{aligned} \tag{4.26}
$$

$$
AC_{ijlk} = \sum_{j' \in s_{ijl}} \gamma_{j'k} LT^M_i, \quad \forall i, \ \forall j, \ \forall l, \forall k \tag{4.27}
$$

$$
QS_{ijlj'k} = \frac{\gamma_{j'k} LT^M_i Q^M_{ik}}{AC_{ijlk}}, \quad \forall i, \ \forall j' \in s_{ijl}, \ \forall l, \ \forall k \tag{4.28}
$$

$$
Sign(A_{ijk}) = \begin{cases} 0, & \text{if } A_{ijk}{=}0 \\ 1, & \text{if } 0 < A_{ijk} < Q^M_{ik} \end{cases} \tag{4.29}
$$

and

π^{SC}_{ijlj}: profit of MSA j by belonging to coalition s_{ijl}

$\pi^S_{ij'}$: profit of MSA j' with MA i

$\beta^S_{j'k}$: percentage of profit from item k of MSA j'

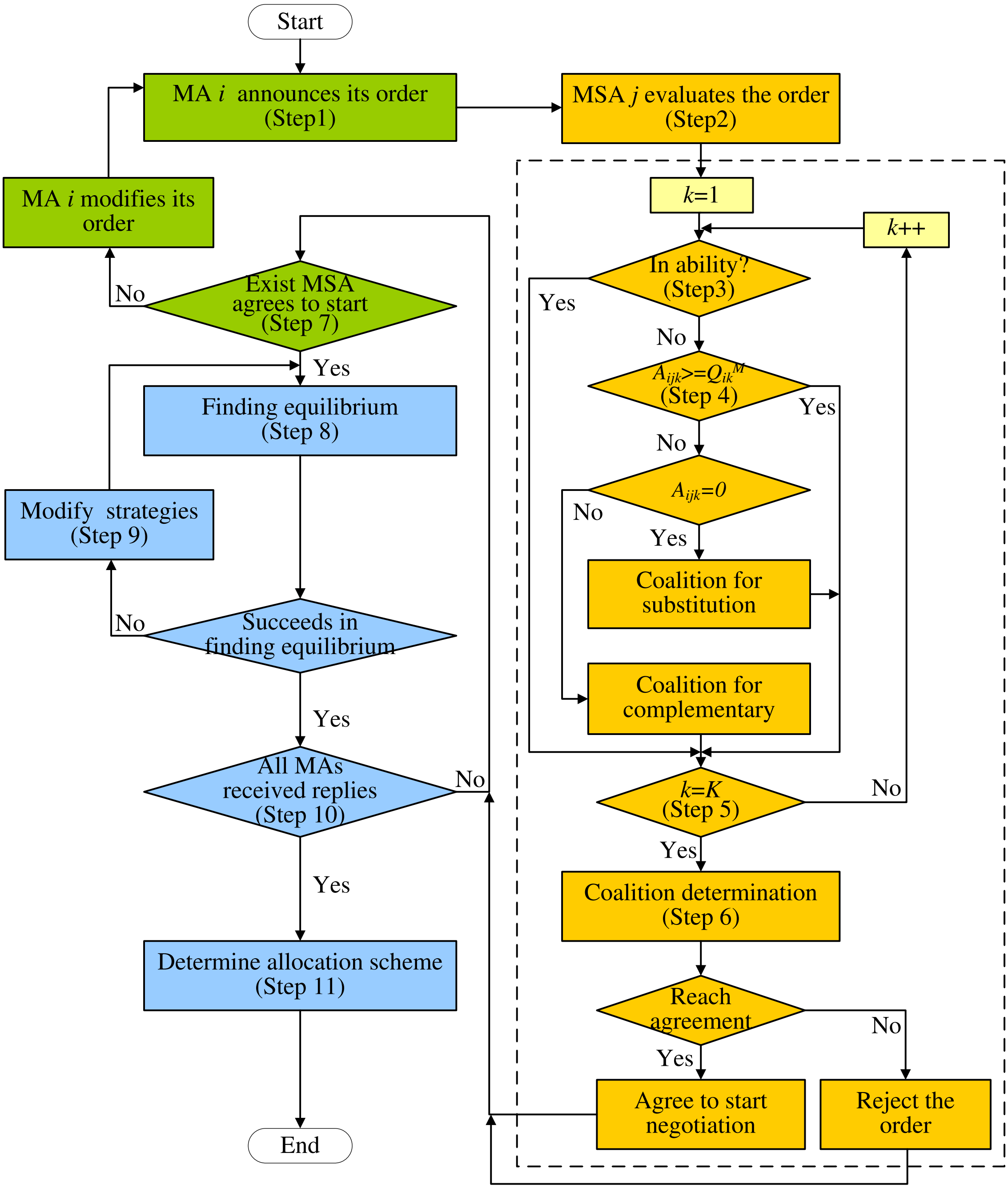


Figure 4.4: Flowchart of SAMI negotiation between multi-MA and multi-MSA

A_{ijk}: ability of item k of MSA j for MA i

AC_{ijlk}: ability of item k of coalition s_{ijl}

C_{jk}: cost of item k of MSA j

LT_i^M: lead time of the order of MA i

IF_j: index of final coalition of MSA j

NS_{ijlk}: number of members in SFS_{ijk} who can supply item k

NC_{ijlk}: number of members in SFC_{ijk} who can supply item k

p_{ijlk}^C: price of item k of coalition s_{ijl}

p_{jk}^{SU}: upper bound of price of item k of MSA j

Q_{ik}^M: quantity of item k of MA i

$QS_{ijlj'k}$: acquired quantity of item k of MSA j' by belonging to coalition s_{ijl}

C_{jk} and $QS_{ijlj'k}$ are decision variables. We can see from equation (4.21) that LMSA j wants to find the coalition s_{ijl}, in which it has the lowest cost and can get the highest quantity of the order. Equation (4.22) means the coalition s_{ijl} must be in ability of all the items. IF_j in equation (4.23) is the index of the coalition of MSA j expected to belong to, and equation (4.23) means all the members of the final determined coalition must reach an agreement. In other words, the final selected index $IF_{j'}$ of each $j' \in s_{ijl}$ must be the same. What should we pay attention to is the indexes of all the coalitions of all the MSAs are the same. Thus, the negotiation can decide whether the members reach an agreement by matching these indexes. Equations (4.26) - (4.28) are the upper bound of the price of LMSA j, the combined ability of s_{ijl}, and the order allocation among the members of s_{ijl}, respectively. e_{ijk} is the evaluation of MSA j for item k of MA i, and if MSA j can supply item k independently ($A_{ijk} \geq Q_{ik}^M$), then e_{ijk} equals to 1, otherwise it equals to 0. SFS_{ijk} and SFC_{ijk} are the coalitions for substitution and complementary of item k of MSA j, respectively. The details have been discussed in section 2.3.1.2. Thus, equation (4.26) means that the final price of the combined coalition will equal to the price of MSA j if MSA j can supply item k by itself, it will equal to the price of SFS_{ijk} if MSA j cannot supply item k at all, and it will equal to the price of SFC_{ijk} if MSA j can supply item k but cannot supply the whole amount.

The coalition can be determined if and only if all the members reach an agreement. FMSAs need to decide whether to accept to be a member of the coalition for there are multi-MA in the SCNs. They have the prone to selecting the coalition which can maximize their profits. What should we pay attention to is although only one coalition is determined as the final coalition, it is allowed that the member of the coalition is a coalition.

4.3.1.2 Determination of equilibriums

The negotiation, in which price of order is determined, is discussed in this section. As we know that MA wants to buy items at the lower price the better, while MSA wants to sell items at the higher price the better. MAs in proposed model are assumed have initiatives and have more negotiation powers. Thus, interaction between MA and MSA can be seen as a Stackelberg game, where MA is considered to be the Stackelberg leader. Determination of negotiation agreement between MA i and SF_{ij} is transformed into determining the equilibrium PF_{ij} of the Stackelberg game, where SF_{ij} is final determined coalition from section 4.3.1.1.

We assume final determined strategy is the strategy of MA which can maximize its profit and is accepted by SF_{ij}, because in this research we focus on situation where MAs have more negotiation powers. For SF_{ij}, it accepts the strategy of MA at t according to ***Rule 4.1***.

Rule 4.1*: When there are still much negotiation time, SF_{ij} accepts the strategy of MA at t if and only if profit of taking the strategy of MA is greater than that of taking its own strategy; when there are no negotiation time, SF_{ij} accepts the strategy of MA at t if and only if profit of taking the strategy of MA is positive.*

Thus, final equilibrium PF_{ij} can be obtained by solving following problem:

$$PF_{ij} = arg \max_{p_{ij}^M[t]} \{\pi_{ij}^M[t]\}, \quad \forall i, \ \forall j \tag{4.30}$$

$$\text{s.t.} \quad p_{ij}^M[t] \leq \sum_{k=1}^{K} p_{ik}^{MU} Q_{ik}^M \tag{4.31}$$

$$\pi_{ij}^{SM}[t] \geq \pi_{ij}^S[t], \quad \text{if } t < TN/TS \tag{4.32}$$

$$\pi_{ij}^{SM}[t] > 0, \quad \text{if } t = TN/TS \tag{4.33}$$

where

$\pi_{ij}^{M}[t]$: profit of MA i with MSA j at t

$\pi_{ij}^{SM}[t]$: profit of MSA j takes strategy of MA i at t

$p_{ij}^{M}[t]$: price of all items of MA i for MSA j at t

p_{ik}^{MU}: upper bound of price of item k of MA i

PF_{ij}: final determined price of the negotiation between MA i and MSA j

and equation (4.31) is used to ensure strategy belongs to the acceptable region of MA. Equations (4.32) - (4.33) are used to ensure that the strategy is profitable for SF_{ij}, equation (4.32) means SF_{ij} accepts the strategy of MA at t if it can get much more profit than its own strategy when there are still some negotiation time, equation (4.33) means SF_{ij} accepts the strategy of MA at $t = TN/TS$ if the profit of taking strategy of MA is positive, because for SF_{ij} it's better to reach an agreement than without reaching an agreement, and $\pi_{ij}^{SM}[t]$ and $\pi_{ij}^{S}[t]$ are calculated by equations (4.35) and (4.36), respectively.

$$\pi_{ij}^{M}[t] = psell_{ij}[t] - p_{ij}^{M}[t], \quad \forall i, \ \forall j \tag{4.34}$$

$$\pi_{ij}^{S}[t] = p_{ij}^{S}[t] - \sum_{k=1}^{K} C_{jk} Q_{ik}^{M} - CS_j, \quad \forall i, \ \forall j \tag{4.35}$$

$$\pi_{ij}^{SM}[t] = p_{ij}^{M}[t] - \sum_{k=1}^{K} C_{jk} Q_{ik}^{M} - CS_j, \quad \forall i, \ \forall j \tag{4.36}$$

$$p_{ij}^{M}[t] = p_{ij}^{M}[t-1] + (p_{ij}^{S}[t-1] - p_{ij}^{M}[t-1])(\frac{tTS}{TN})^{\frac{1}{\varepsilon}}, \quad \forall i, \ \forall j \tag{4.37}$$

$$PM_{ij}[t] = \sum_{k=1}^{K} p_{ik}^{M}[t] Q_{ik}^{M}, \quad \forall i, \ \forall j \tag{4.38}$$

$$psell_{ij}[t] = (1 + \alpha_i) p_{ij}^{M}[t], \quad \forall i, \ \forall j \tag{4.39}$$

$$p_{ij}^{S}[t] = p_{ij}^{S}[t-1] - (p_{ij}^{S}[t-1] - p_{ij}^{M}[t])(\frac{tTS}{TN})^{\frac{1}{\varepsilon}}, \quad \forall i, \ \forall j \tag{4.40}$$

$$p_{ij}^{S}[0] = \sum_{k=1}^{K} p_{jk}^{SU} Q_{ik}^{M}, \quad \forall i, \ \forall j \tag{4.41}$$

where

α_i: percentage of profit of MA i

CS_j : setup cost of MSA j per order

p_{ik}^{ML}: lower bound of price of item k of MA i

$p_{ij}^{S}[t]$: price of MSA j for MA i at t

p_{ij}^{SU}: upper bound of price of MSA j for MA i at t

$psell_{ij}[t]$: selling price of MA i with MA i at t

and equation (4.35) is the profit of SF_{ij}, equation (4.36) is the profit of SF_{ij} of taking the strategy $p_{ij}^{M}[t]$ of MA i, and equation (4.37) is the strategy of MA i at t, and it related to the strategies of itself and SF_{ij} at $t-1$, and the remaining negotiation time. Equation (4.38) is the initial price of MA, and it's the sum of the best strategies of all the items MA wants to buy. Equation (4.40) is the strategy of SF_{ij} at t, and it related to the strategy of itself at $t-1$, the strategy of MA at t, and the remaining negotiation time. Equation (4.41) is the initial price of SF_{ij} of all items. In addition, when it's the negotiation between MA and the coalition s_{ijl}, PF_{ij} and $p_{ij}^{M}[t]$ in equation (4.30) will be replaced by PF_{ijl} and $p_{ijl}^{M}[t]$. $\pi_{ijl}^{C}[t]$ and $\pi_{ijl}^{CM}[t]$, which are the total profit of all the members in the coalition, will instead of $\pi_{ij}^{S}[t]$ and $\pi_{ijl}^{SM}[t]$ of the constraints of equations (4.35) - (4.36). Moreover, Q_{ik}^{M} in equations (4.35) and (4.36) will be replaced by QS_{ijljk}.

4.3.1.3 Determination of final allocation scheme

Determination of final allocation scheme is discussed in this section. There are multi-MA and multi-MSA in SCNs negotiate with each other to determine final allocation scheme. Each MA wants to select the MSA with the lowest price to decrease its production cost, and each MSA wishes to select the MA with the highest price to increase its profit. We can see that all MAs or MSAs compete with each other for the partner with the highest profit. It can be seen as a two-person game, where all MAs are considered as player 1 and all MSAs are combined as player 2. Player 1 and player 2 make their strategies simultaneously. Strategy of player 1 in the first layer is the scheme to allocate orders of its members to MSAs. Strategy of player 2 is allocation of all orders from MAs to its members. The agreement is reached if and only if strategy of player 1 consists with strategy of player 2. Therefore, the optimal solution of the game in proposed protocol is the allocation scheme which can maximize total profit of whole supply chain. The innovative point is players in the two-person game consist of multi-players actually. Strategies of player 1 and player 2 consist of all strategies of their members. Thus, the final optimal solution can be got if none of members of players can benefit by changing player's strategies while the other one keep its strategy unchanging.

Matrix $M = [m_{ijl}]$, which is used to record final allocation of orders of MAs to MSAs or coalitions, is given to show final allocation scheme. The value of m_{ijl} equals to 1 or 0, and m_{ijl} equals to 1 means MA i is allocated to s_{ijl} of MSA j, m_{ijl} equals to 0 means MA i is not allocated to s_{ijl} of MSA j. Therefore, the allocation scheme, which maximizes total profit of SCNs, is determined to solve conflicts amongst agents, and the problem is transformed into finding solution of following optimal problem:

$$\max\{\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L} m_{ijl}(PsellF_{ijl} - PF_{ijl}) + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L} m_{ijl}(PF_{ijl} - \sum_{j' \in s_{ijl}}\sum_{k=1}^{K} QS_{ijlj'k}C_{j'k})\} \tag{4.42}$$

$$\textbf{s.t.}\ m_{ijl}AC_{ijlk} \geq m_{ijl}Q_{ik}^{M} \tag{4.43}$$

$$\sum_{j=1}^{J}\sum_{l=1}^{L} m_{ijl} = 1 \tag{4.44}$$

$$\sum_{i=1}^{I}\sum_{l=1}^{L} m_{ijl}QS_{ijlk} \leq AU_{jk} \tag{4.45}$$

$$PF_{ijl} = arg \max_{PM_{ijl}[t]} \{\pi_{ijl}^{M}[t]\} \tag{4.46}$$

$$PsellF_{ijl} = arg \max_{psell_{ijl}[t]} \{\pi_{ijl}^{M}[t]\} \tag{4.47}$$

$$AU_{jk} = \gamma_{jk} \max_{i=1}^{I}\{m_{ijl}LT_{i}^{M}\} \tag{4.48}$$

$$m_{ijl} \in \{0, 1\} \tag{4.49}$$

where equation (4.42) aims to maximize total profit of the SCNs, the first part is profits of all MAs, and the second part is profits of all MSAs. Equation (4.43) is used to ensure that the order of each MA i must be in ability of the final determined supplier (MSA j or coalition s_{ijl}). Equation (4.44) indicates that each MA i must be allocated to one MSA j or coalition which is used to keep the integrity of the order of MA i. It can be loosen (≤ 1) if MAs are allowed not finding suppliers. However, this research assumes that all MAs must be allocated to one MSA or coalition. Equation (4.45) is used to ensure that all the received orders of each MSA must be in its ability, QS_{ijlk} is the acquired quantity of MSA

j in coalition s_{ijl} (see equation (4.28) in section (4.3.1.1). AU_{jk} is the maximum ability of MSA j according to all the orders it received and is calculated by equation (4.48). Equations (4.46) - (4.47) indicate that the price $PM_{ijl}[t]$ and selling price $psell_{ijl}[t]$ of MA, at which the profit of MA is maximized, are determined as the final price and final selling price of the negotiation between MA i and s_{ijl}. m_{ijl} is the decision variable and is defined in equation (4.49).

We can see from equations (4.42) - (4.49) that the determination of the final allocation scheme depends on PF_{ijl} and AC_{ijlk}, which are the final total price of MSA j or coalition s_{ijl} for the order of MA i and the final ability of each item k of MSA j or coalition s_{ijl} for the order of MA i, respectively. They are obtained from section 4.3.1.1 and 4.3.1.2, respectively. Furthermore, it is assumed in section 3.3.1.1 that all MAs must and only be allocated to one MSA or coalition. However, it's possible that exist MA(s) cannot find any MSA or coalition in real cases for the price(s) is too low or the lead time is too short, and so on. Therefore, we modified constraints of allocation of MAs as equation (4.44).

4.3.2 Simulation and analysis

A car company which wants to buy auto parts to produce cars is cited as an example, and the company wants to buy steering wheels, tyres, rear view mirrors and headlights to produce cars. Simulations are given in this section in order to illustrate and verify the proposed protocol when there are 5 MAs and 6 MSAs in SCNs, and the maximum number of items MA want to buy is 4. Parameter settings of MAs and MSAs are shown in table 4.6, where p^{ML}_{ik}, Q^{M}_{ik}, γ_{jk}, and C_{jk} obey the uniform distribution. Eclipse IDE for Java Developers and ILOG CPLEX 12.0 are used to execute simulations to verify the feasibility of proposed protocol.

4.3.2.1 Verification

Firstly, MSAs which are out of abilities try to find all possible coalitions. Details of all possible coalitions of each MSA are omitted. After the coalitions are found, MAs start to negotiate with in ability MSAs or coalitions to find equilibriums by solving equation (4.30). The details of equilibriums between MAs and all possible coalitions are omitted. The negotiation between MA 1 and coalition {246} is taken as an example to illustrate processes of how to reach equilibrium. Fluctuations of prices of MA 1 and coalition {246} is shown

Table 4.6: Parameter settings of MAs and MSAs.

Parameters	
P_{ik}^{ML}	U(0,100)
Q_{ik}^{M}	U(0,5000)
LT_{ik}^{M}	$Q_{ik}^{M}/300$
γ_{jk}	U(100,600)
C_{jk}	U(0,50)

in figure 4.5, where $PM_{ij}[t]$ is price of MA 1 at t, and $PS_{ij}[t]$ is price of coalition $\{246\}$ at t. The final equilibrium is reached if profit of coalition $\{246\}$ of taking the price of MA 1 ($\pi_{ij}^{SM}[t]$) is greater than that of taking its own price at t ($\pi_{ij}^{S}[t]$) according to equation (4.32). Therefore, we can see from figure 4.6 that at $t = 25$ the profit $\pi_{ij}^{SM}[25] = 304281.7$ is greater than $\pi_{ij}^{S}[25]$=298432.9. Hence, the equilibrium is reached at $t = 25$ where $PM_{ij}[t] = 503472.6$.

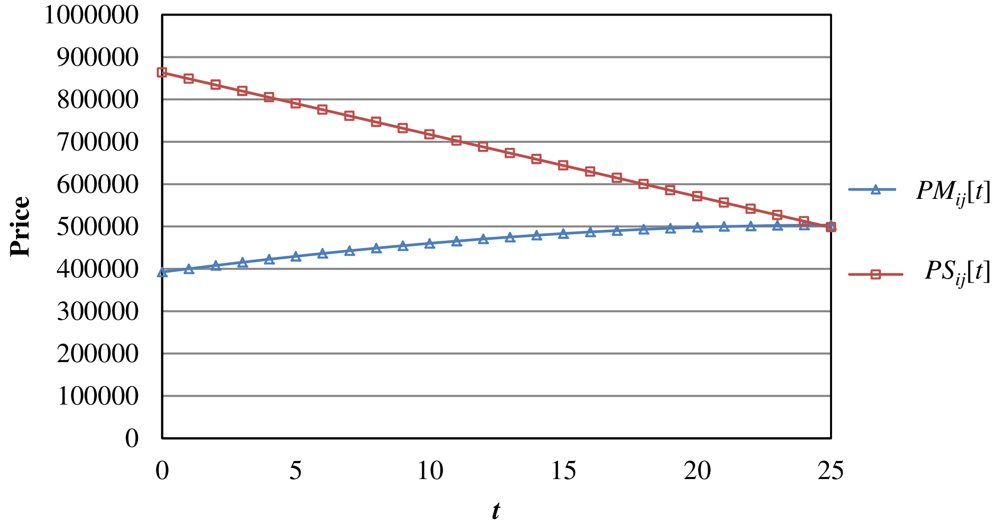


Figure 4.5: Fluctuation of prices of MA 1 and $\{246\}$

Difference of SIMA negotiation between multi-MA and multi-MSA and SIMA negotiation between one-MA and multi-MSA is that it needs to determine allocation scheme. Final allocation scheme of SIMA negotiation are as follows:

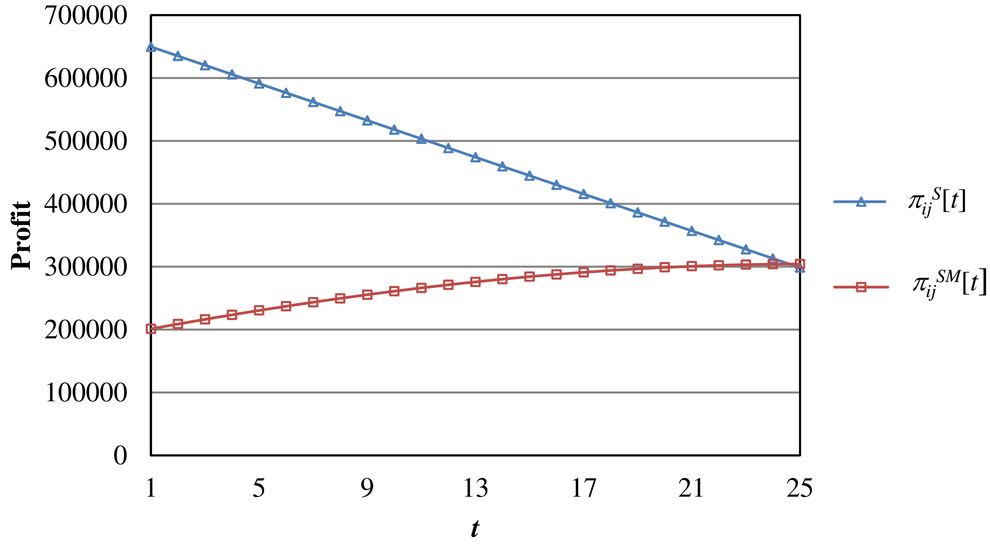


Figure 4.6: Fluctuation of profits of MA 1 and {246}

$$\bar{U} = \begin{pmatrix} 5 & 3 & 5 & 3 & 2 \end{pmatrix}, \tilde{U} = \begin{pmatrix} \phi & \phi & \phi & \phi & \phi \\ \phi & \phi & \phi & \phi & 1 \\ \phi & 11 & \phi & 11 & \phi \\ \phi & \phi & \phi & \phi & \phi \\ 2 & \phi & 6 & \phi & \phi \\ \phi & \phi & \phi & \phi & \phi \end{pmatrix},$$

where MAs are allocated to SF as shown in Table 4.7. MA 1 is allocated to the 2^{nd} coalition {52} of MSA 5; MA 2 is allocated to the 11^{th} coalition {325} of MSA 3; MA 3 is allocated to the 6^{th} coalition {512} of MSA 5; MA 4 is allocated to the 11^{th} coalition {325} of MSA 3; and MA 5 is allocated to the 1^{st} coalition {21} of MSA 2. Profits of MAs and final determined suppliers SF under the allocation scheme are shown as π^M and π^{SF} in Table 4.7.

Table 4.7: Profits of MAs and MSAs under the allocation scheme

	SF	π^M	π^{SF}	π^T
MA 1	{52}	400231.4	569227.3	6207644.0
MA 2	{325}	679473.4	808855.3	
MA 3	{512}	773130.7	869531.9	
MA 4	{325}	394876.0	490945.3	
MA 5	{21}	494559.9	726812.7	

4.3.2.2 Analysis

We can see from above results that the proposed protocol was feasible in solving SAMI negotiation. Nextly, we will discuss about effectiveness of proposed protocol in solving SAMI negotiation. The simulation is executed by 1000 times and the results are shown as Table 4.8, where the average and standard derivation of the calculation time are presented. We can see the proposed protocol is effective and stable in solving SAMI negotiation.

Table 4.8: Calculation time of SAMI negotiation between multi-MA and multi-MSA

	Calculation time (sec)
Avg.	0.0757
S.D.	0.0194

4.4 Comparison and analysis

Equilibriums obtained according to ***Rule 3.1***, ***Rule 3.2*** and ***Rule 4.1*** are compared in this section. We take negotiation between MA 1 and coalition {12} as an example. Results of comparison are shown in Table 4.9. We can see that:

- The negotiations has the same total profit under all three rules;
- It's the fastest to reach agreement under ***Rule 3.1***;
- ***Rule 3.2*** and ***Rule 4.1*** almost have the same performance and that's because we use total price of all orders rather than using each price of each item.

Table 4.9: Results according to three rules

	PF	π^M	π^C	π^T	TF
Rule 3.1	246631.89	179888.91	103.89	179992.80	18
Rule 3.2	295459.19	131061.61	48931.19	179992.80	56
Rule 4.1	295459.20	131661.60	48931.20	179992.80	57

Chapter 5 Coalition Formation Based Multi-Attribute Single-Item Negotiation

5.1 Introduction

Multi-attribute negotiation protocol has been widely studied and represents a promising field since most of negotiation problems in real-world are complex ones including multiple issues ([Choi et al., 2001, Ito et al., 2008]). In reality, attributes are constrained each other. It is a common situation that people must negotiate multi-attribute simultaneously, for example, quantity, price, and delivery time in a supply contract, and the position, wage, and training opportunity will be cared in labor market offer. Moreover, it is also beneficial for people to introduce multi-attribute into negotiation when they have different preferences on attributes, because they may achieve benefits by trading off multi-attribute. SASI negotiation has been discussed in Chapter 3. It was assumed that quantity of order of MA was fixed and only price is negotiated. However, in real market, quantity must be related to demand of market. Thus, in this chapter, the negotiation is extended to multi-attribute single-item (MASI) between MA(s) and MSAs, in which demand is not fixed and depends on selling price of MA. Three attributes (price of product, quantity of order, and lead time of order) are considered in MASI negotiation.

5.2 Multi-Attribute Single-Item Negotiation between One-MA and Multi-MSA

MASI negotiation between one-MA and multi-MSA will be discussed in this section [Yu et al., 2012a]. Negotiation model is shown in Figure 5.1, where $p_j^M[t]$, $q_j^M[t]$, and $lt_j^M[t]$ are price, quantity and lead time of MA at iteration t, respectively. We can see from Figure 5.1 that quantity and lead time of MA depends on demand of market, and market demand is affected by price of MA.

MA negotiates with MSAs to reach agreements on strategies of three attributes. We assume that demand of market is in an additive form as equation (5.1) and depends on

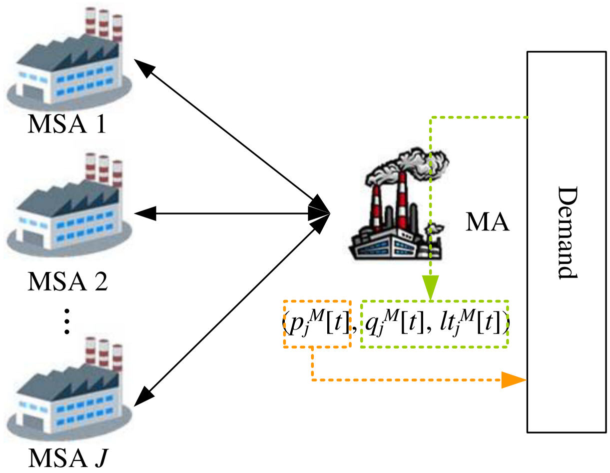


Figure 5.1: MASI negotiation model between one-MA and multi-MSA

selling price of MA.

$$D_j[t] = a - bpsell_j[t]. \tag{5.1}$$

where

a: maximum demand of market, and $a > 0$

b: coefficient of variation related to selling price, and $b > 0$

$D_j[t]$: market demand of MA at t

$psell_j[t]$: selling price of MA at t

5.2.1 Modified two-stage negotiation protocol

A modified two-stage negotiation protocol is proposed in this section based on two-stage negotiation protocol which was proposed in section 3.2.

- **Stage 1: Negotiation among MSAs**

- *Step 1:* MA forecasts demand of market, determines its initial price, quantity and lead time of the order which it wants to place, and then broadcasts the order to all MSAs.

- *Step 2:* MSAs evaluate the order and check whether the order can be finished by themselves. If they can do it, themselves will be determined as the final coalition

SF_j and fed back to MA; if they cannot do it, then they negotiate with other MSAs to build coalitions and feed back to MA. A cooperative game is used for coalition formation.

- *Step 3:* MA checks whether there exists any SF_j can fulfill the order, if there exists, goes to the second stage, if there does not exist, then MA modifies the order and re-broadcasts the order.

- **Stage 2: Negotiation between MA and** SF_j

- *Step 4:* MA starts to negotiate with SF_j. MA-Stackelberg game is introduced to find final solution.

- *Step 5:* MA checks whether an agreement is reached. If agreement is reached, negotiation ends, if agreement is not reached, then MA checks whether negotiation time is used up. If there are some negotiation time then MA modifies its strategies and goes back to Step 4, else negotiation ends and fails to find equilibrium.

Flowchart of modified two-stage negotiation is shown in Figure 5.2. Processes in left-hand side of the gray dash line are done by MA, and processes in right-hand side are done by MSA. Details of negotiation protocol will be discussed in following subsections.

5.2.2 Negotiation among MSAs

Negotiation among MSAs aims to find coalition when order is out of their abilities. Final determined coalition SF_j of MSA j and related ability is determined according to equation (2.10) and equation (2.6), respectively.

5.2.3 Negotiation between MA and SF_j

MA and SF_j make their decisions sequentially, and SF_j in multi-attribute negotiation wants to increase its price, quantity and lead time to improve its profit. However, MA wants to decrease price and lead time to increase its profit. Therefore, main point of this part is to find a balance between profits of SF_j and MA. Objective of negotiation is to find equilibrium of the MA-Stackelberg game.

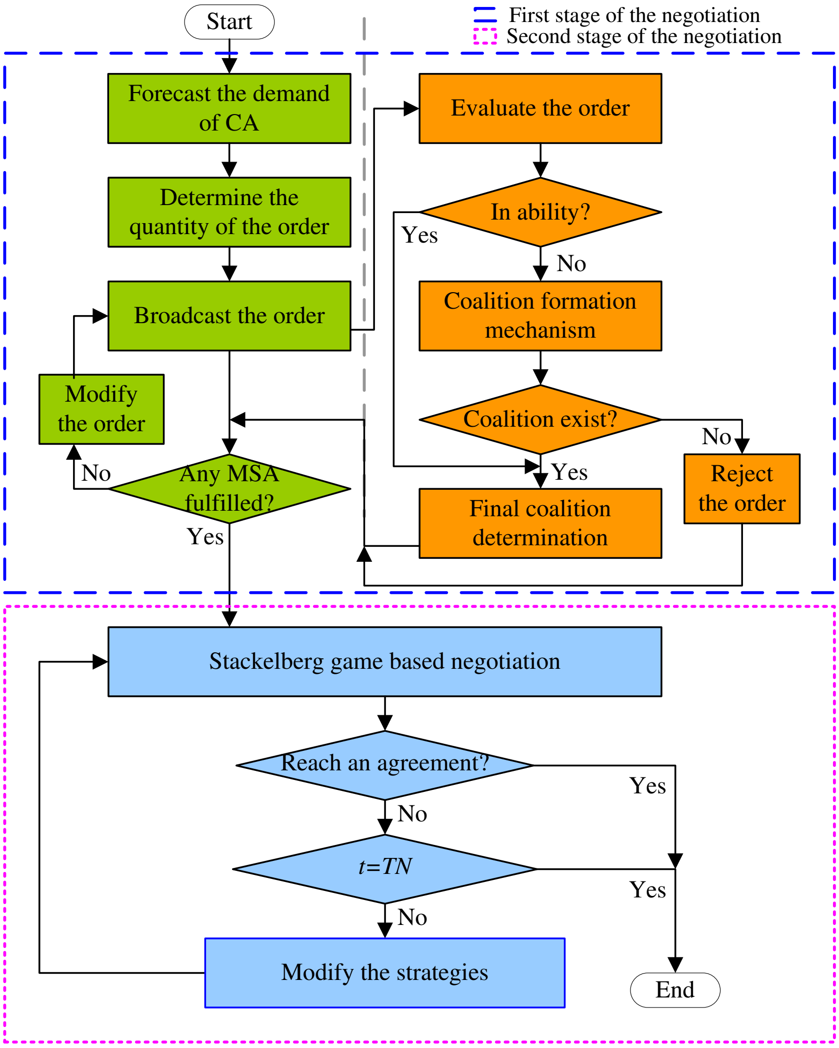


Figure 5.2: Flowchart of MASI negotiation protocol

5.2.3.1 Determination of the strategies

Concessions among attributes and strategies of three attributes of MA and SF_j are determined as:

(a) Concessions among attributes

As we known, for MA, it determines its strategies according to its own preferences. Concessions among attributes of MA are as follows:

- *Price:* It gives concession of price related to remaining time, and also give concession if MSAs shorten their lead time in order to reduce losses of potential profits.

- *Quantity:* It increases its quantity to buy if MSAs give discounts of prices.

- *Lead time:* It extends its lead time if MSAs give discounts of prices.

MSAs determine their strategies according to strategies of MAs at t, and make concessions as follows:

- *Price:* They give concessions of prices related to remaining time, and also give concessions if MA increases its quantity to buy or extends its lead time.

- *Quantity:* They reduce their minimum quantities to buy if MA increases its price or extends its lead time.

- *Lead time:* They shorten their lead time if MA increases its price.

We define $\delta^z_{x,y}(y)$ as concession rate of attribute x related to attribute y of z, and is calculated by equation (5.2), where $x, y \in \{p, q, lt\}$, and $z \in \{M, S\}$. p, q and lt indicate concession is respectively related to price, quantity and lead time. M and S indicate it's concession of MA and MSA, respectively. $\theta^{x,y}_g$ is threshold value of concession of attribute x related to attribute y, and y_g is piece-wise constant of attribute y. All these threshold values and piece-wise constants are defined as Table 5.1, where g is index of concession.

$$\delta^z_{x,y}(y) = \begin{cases} 0, & \text{if } y \leq y_1 \\ \theta^{x,y}_{g-1}, & \text{if } y_{g-1} < y < y_g \\ \theta^{x,y}_g, & \text{if } y \geq y_g \end{cases} \tag{5.2}$$

Table 5.1: Threshold values related to concession functions

z	x	y	$\theta^{x,y}_g$	$\delta^z_{x,y}(y)$
M	p	lt	$LT^{ML}_{ij} + g(LT^{MU}_{ij} - LT^{ML}_{ij})/G$	$(G-g)(P^{MU}_{ijk} - P^{ML}_{ijk})/G$
	q	p	$P^{ML}_{ijk} + g(P^{MU}_{ijk} - P^{ML}_{ijk})/G$	$(G-g)(Q^{MU}_{ijk} - Q^{ML}_{ijk})/G$
	lt	p	$P^{ML}_{ijk} + g(P^{MU}_{ijk} - P^{ML}_{ijk})/G$	$(G-g)(LT^{MU}_{ijk} - LT^{ML}_{ijk})/G$
S	p	q	$Q^{SL}_{ijk} + g(Q^{SU}_{ijk} - Q^{SL}_{ijk})/G$	$g(P^{SU}_{ijk} - P^{SL}_{ijk})/G$
		lt	$LT^{SL}_{ij} + g(LT^{SU}_{ij} - LT^{SL}_{ij})/G$	$g(P^{SU}_{ijk} - P^{SL}_{ijk})/G$
	q	p	$P^{SL}_{ijk} + g(P^{SU}_{ijk} - P^{SL}_{ijk})/G$	$t(G-g)(P^{MU}_{ijk} - P^{ML}_{ijk})/G^2$
		lt	$LT^{SL}_{ijk} + g(LT^{SU}_{ijk} - LT^{SL}_{ijk})/G$	$t(G-g)(P^{MU}_{ijk} - P^{ML}_{ijk})/G^2$

Figure 5.3 illustrates piece-wise functions of MA and MSAs. We can see from Figure 5.3 (a), (b), and (c) that MA will give higher concession of price if SF_j gives shorter lead

time, it will give higher concession of quantity if SF_j gives lower price, and it will give higher concession of lead time if SF_j gives lower price. On the other hand, we can see from Figure 5.3 (d), (e), and (f) that SF_j will give higher concession of price if MA buys higher quantity, and it will give higher concession of price if MA gives longer lead time.

(b) Strategies of MA:

Strategies of MA for SF_j at iteration t are ($p_j^M[t]$, $q_j^M[t]$, $lt_j^M[t]$), where:

$$p_j^M[t] = p_j^M[t-1] + \frac{p^{MU} - p_j^M[t-1]}{(TN - tTS)/TS} + \delta_{p,lt}^M(lt_j^S[t-1]) \tag{5.3}$$

$$q_j^M[t] = D_j[t] + \delta_{q,p}^M(p_j^S[t-1]) \tag{5.4}$$

$$lt_j^M[t] = lt_j^M[t-1] + \delta_{lt,p}^M(p_j^S[t-1]) \tag{5.5}$$

$$psell_j[t] = p_j^M[t](1 + \beta^U) \tag{5.6}$$

$$p_j^M[0] = p^{ML} \tag{5.7}$$

$$q_j^M[0] = D_j[t] \tag{5.8}$$

$$lt_j^M[0] = lt^{ML} \tag{5.9}$$

and

β^U: upper bound percentage of profit of MA

$lt_j^M[t]$: lead time of MA at t

lt^{ML}: lower bound of lead time of MA

$lt_j^S[t-1]$: lead time of SF_j at $t-1$

$p_j^M[t]$: price of MA at t

p^{ML} : lower bound of price of MA

p^{MU} : upper bound of price of MA

$p_j^S[t-1]$: price of SF_j at $t-1$

$q_j^M[t]$: quantity of MA at t

Equation (5.3) is used to calculate price of MA at t, the second part is concession related to remain negotiation time, and the third part is concession of price related to lead time

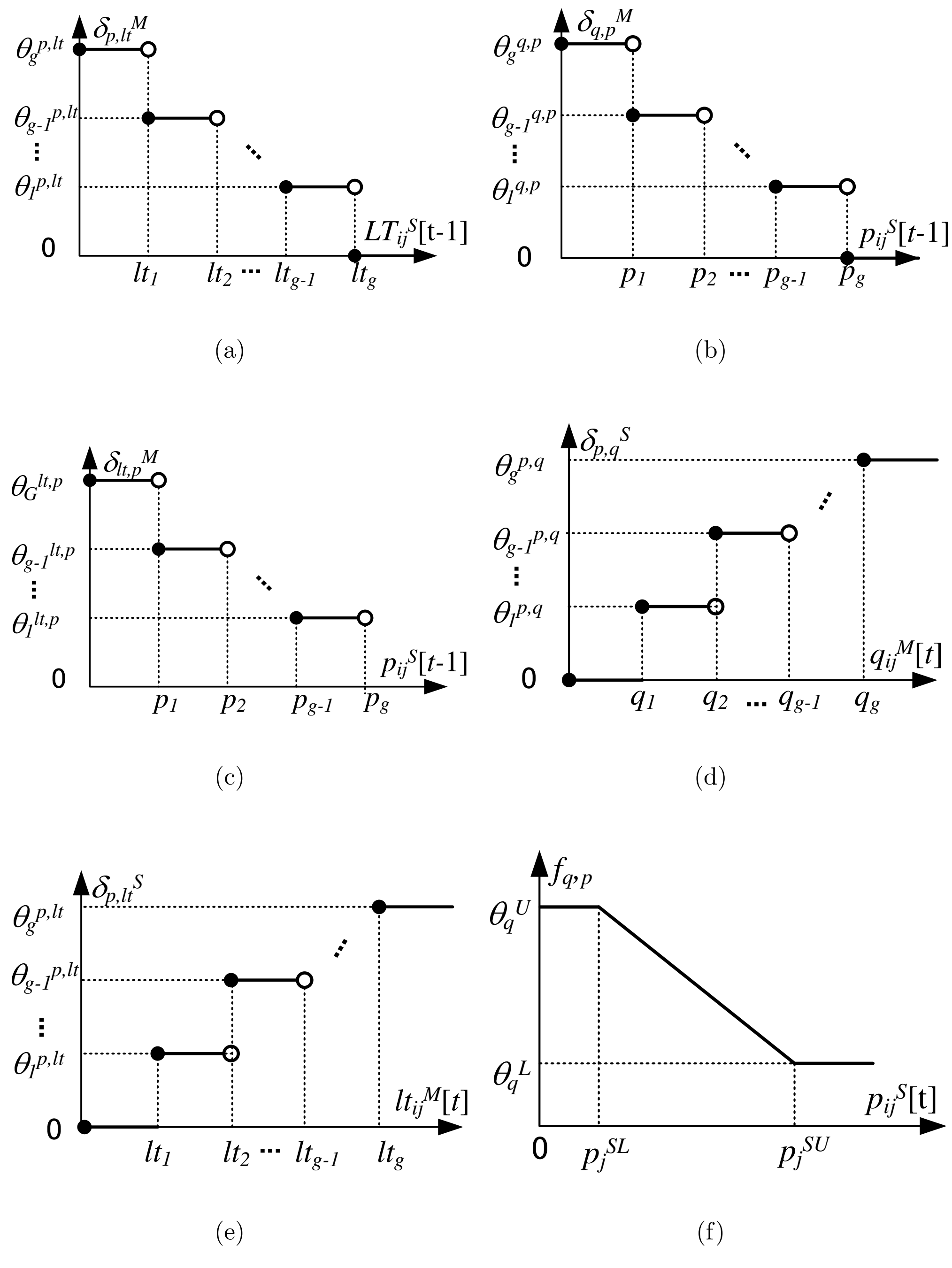


Figure 5.3: Piece-wise functions of MA and MSA related to attributes.

of SF_j at $t-1$. Quantity of MA depends on demand of market and is calculated by equation (5.4). The second part of equation (5.4) is concession of quantity of MA related to price of SF_j at $t-1$. Equation (5.5) is used to calculate lead time of MA at t, and the second part is concession related to price of SF_j at $t-1$. Equations (5.7) - (5.9) are used to calculate initial value of price, quantity, and lead time of MA, respectively.

(c) Strategies of SF_j:

Strategies of SF_j at t are ($p_j^S[t]$, $q_j^S[t]$, $lt_j^S[t]$), where:

$$p_j^S[t] = p_j^S[t-1] - \frac{p_j^S[t-1] - p_j^M[t]}{(TN - tTS)/TS} - \delta_{p,q}^S(q_j^M[t]) - \delta_{p,lt}^S(lt_j^M[t]) \tag{5.10}$$

$$q_j^S[t] = f_q(p_j^S[t]) \tag{5.11}$$

$$lt_j^S[t] = q_j^S[t]/\gamma_j \tag{5.12}$$

$$f_q(p_j^S[t]) = \begin{cases} \theta_q^U, & \text{if } p_j^S[t] \leq p_j^{SFL} \\ \theta_q[t], & \text{if } p_j^{SFL} < p_j^S[t] < p_j^{SFU} \\ \theta_q^L, & \text{if } p_j^S[t] \geq p_j^{SFU} \end{cases} \tag{5.13}$$

$$\theta_q[t] = AF_j - \frac{(\frac{cs_j}{p_j^S[0]-C_j} - AF_j)p_j^{SFL}}{p_j^{SFU} - p_j^{SFL}} + p_j^S[t]\frac{\frac{cs_j}{p_j^S[0]-C_j} - AF_j}{p_j^{SFU} - p_j^{SFL}} \tag{5.14}$$

$$p_j^S[0] = p^{SFI} \tag{5.15}$$

$$q_j^S[0] = AF_j \tag{5.16}$$

$$lt_j^M[0] = \frac{q_j^S[0]}{\gamma_j^F} \tag{5.17}$$

$$\gamma_j^F = \sum_{j' \in SF_j} \gamma_j' \tag{5.18}$$

and

γ_j: productivity of MSA j

γ_j^F: productivity of SF_j

AF_j: ability of SF_j

C_j: production cost of MSA j

cs_j: setup cost of MSA j

$p_j^{SFL}[t]$: lower bound of price of MSA j

$p_j^{SFU}[t]$: upper bound of price of MSA j

$q_j^S[t]$: quantity of SF_j

Equation (5.10) is used to calculate price of SF_j at t, the second part is concession related to remain negotiation time, the third part is concession related to quantity of MA at t, and the final part is concession related to lead time of MA at t. Equation (5.11) is used to calculate quantity of SF_j at t, and $f_q(p_j^S[t])$ is a piece wise function related to price of SF_j (see Figure 5.3(f)) and is defined as equation (5.13). Equation (5.14) is used to calculate threshold value of quantity, and equations (5.15) - (5.17) are used to calculate initial values of price, quantity, and lead time of SF_j, respectively. Equation (5.18) is used to calculate productivity of SF_j.

5.2.3.2 Determination of equilibriums

MA has its own preferences for price, quantity and lead time and it looks for offer that best satisfies these preferences. As we have mentioned above that objective of negotiation is to find equilibrium which can maximize profit of MA and accepted by SF_j at the same time. ***Rule 5.1*** is given for SF_j to check whether strategies of MA at t can be accepted.

Rule 5.1: *When there is still many remain negotiation time ($t < \frac{TN}{TS}$), SF_j accepts the strategies of MA at t if profit of taking the strategies of MA is greater than or equals to that of taking its own strategy; when there is no remain negotiation time ($t = \frac{TN}{TS}$), SF_j accepts the strategies of MA at t if profit of taking the strategies of MA is greater than 0* [1] .

Profits of MA and SF_j are summations of profits related to all three attributes and calculated by:

$$\pi_j^M[t] = psell_j[t]D_j[t] + Sign(q_j^M[t] - D_j[t])(q_j^M[t] - D_j[t])sv - Sign(D_j[t] - q_j^M[t])$$
$$(D_j[t] - q_j^M[t])cst - p_j^M[t]q_j^M[t] - \frac{cfD_j[t]}{q_j^M[t]} - \frac{h^M q_j^M[t]}{2} \tag{5.19}$$

$$\pi_j^{SM}[t] = \sum_{j' \in SF_j} (p_j^M[t] - C'_j)q_j^M[t] + clt_j^S(lt_j^S[0] - lt_j^M[t]) - cs_j - \frac{h_j^S q_j^M[t]}{2} \tag{5.20}$$

$$\pi_j^S[t] = \sum_{j' \in SF_j} (p_j^S[t] - C_j)q_j^S[t] + clt_j^S(lt_j^S[0] - lt_j^S[t]) - cs_j - \frac{h_j^S q_j^S[t]}{2} \tag{5.21}$$

[1] That's because for MSAs reaching an agreement is always better than without reaching an agreement if the order is profitable.

where

π_j^{SM}: profit of SF_j of taking the strategies of MA

π_j^{S}: profit of SF_j of taking its own strategies

sv : salvage value of unit unsold product of MA

cf : fixed cost per order of MA

clt_j^S: cost of saving or extending lead time per-day of SF_j

cst : shortage cost of MA

h^M : holding cost per unit of MA

h_j^S : holding cost per unit of SF_j

and the first part of equation (5.19) is profit of sold part of MA, the second part is salvage value of unsold part of MA, the third part is shortage loss, the fourth part is fix cost, and the last part is hold cost. Equation (5.20) is profit of SF_j at t by adopting strategies of MA, the first part is payment it can get from MA, the second part is profit or loss of SF_j by extending or shortening lead time, the third part is setup cost, and the last part is hold cost. Equation (5.21) is profit of SF_j at t by adopting its own strategies, and different parts are the same with equation (5.20).

Thus, equilibrium can be obtained by solving following problem according to ***Rule 5.1***:

$$PF_j \quad = arg \max_{p_j^M[t]} \{\pi_j^M[t]\} \tag{5.22}$$

$$\textbf{s.t.} \quad \pi_j^{SM}[t] \geq \pi_j^S[t], \text{if } t < \tfrac{TN}{TS} \tag{5.23}$$

$$\pi_j^{SM}[t] > 0, \text{if } t{=}\tfrac{TN}{TS} \tag{5.24}$$

$$q_j^M[t] \leq AF_j \tag{5.25}$$

where equation (5.22) indicates that price of MA which maximizes profit of MA will be determined as final equilibrium PF_j. Equations (5.23) and (5.24) indicate SF_j accepts strategies of MA at t if profit of taking the strategies of MA is greater than or equals to that of taking its own strategy when there is still many remain negotiation time ($t < \frac{TN}{TS}$), and SF_j accepts strategies of MA at t if profit of taking the strategies of MA is greater than 0 when there is no remain negotiation time ($t = \frac{TN}{TS}$), respectively. Equation (5.25) indicates the order must be in ability of SF_j.

5.2.3.3 Determination of final supplier

Finally, MA decides final supplier which can maximize its profit based on equilibriums acquired by solving equations (5.22) - (5.25):

$$\arg\max_{SF_j} \quad \{\pi_j^M\} \tag{5.26}$$

$$\textbf{s.t.} \quad PF_j = \arg\max_{p_j^M[t]}\{\pi_j^M = (psell - p_j^M[t])q_j^M[t]\} \tag{5.27}$$

$$SF_j = \arg\max_{s_{jl}}\{\pi_{jl}^{SC}\}. \tag{5.28}$$

5.2.4 Simulation and analysis

Firstly, we discuss about details of MASI negotiation between one MA and 5 MSAs. Parameter settings of MSAs are shown as Table 5.2.

Table 5.2: Parameter settings of MA and MSAs

MSA		MA	
γ_j	U(100,300)	α^{max}	0.5
β_j^{min}	0.2	α^{min}	0.3
β_j^{max}	0.5	a	U(1000,2000)
h_j^S	3	b	U(0,100)
cp_j	U(7,8)	cf^M	100
cs_j	U(200,300)	cst^M	5
J	5	h^M	3
		$psIn_i^M$	U(13,14)
		sv^M	2

5.2.4.1 Verification

All possible coalitions and related equilibriums are omitted. We take negotiation between MA and coalition {12} as an example to illustrate iteration of finding equilibriums during MASI negotiation. Fluctuations of three attributes are shown in Figure 5.4 - Figure 5.7.

We can see that:

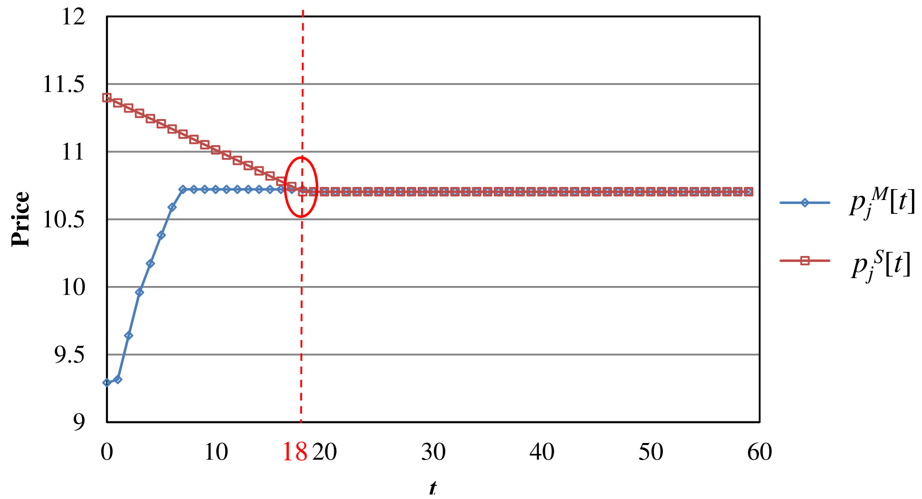


Figure 5.4: Fluctuation of prices of MA and SF_j in SIMA negotiation

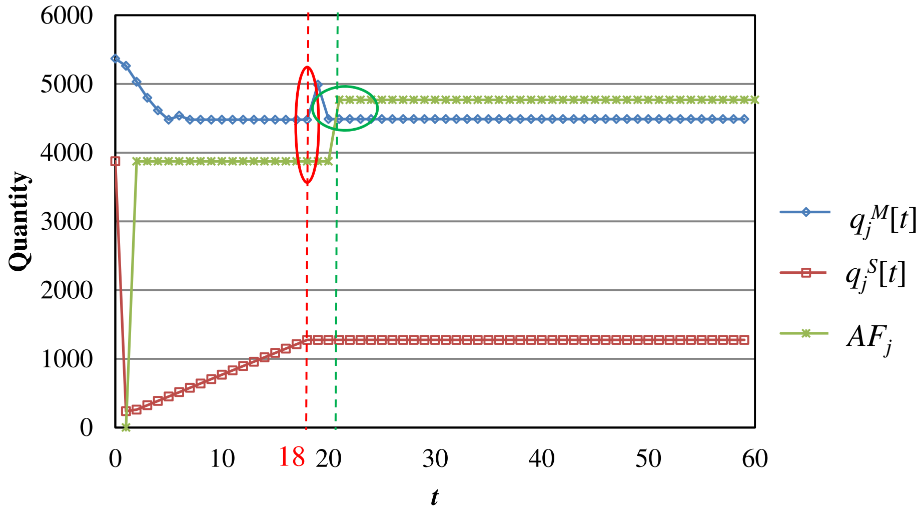


Figure 5.5: Fluctuation of quantities of MA and SF_j in SIMA negotiation

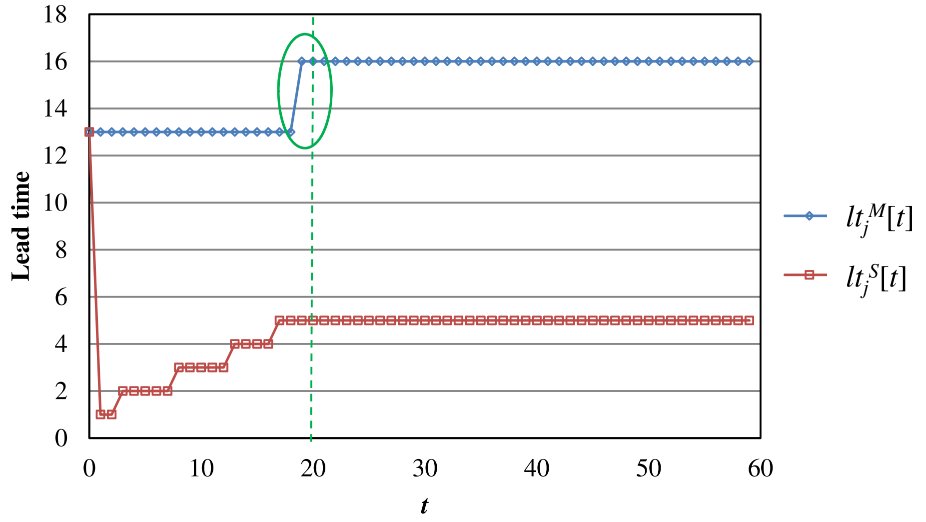


Figure 5.6: Fluctuation of lead time of MA and SF_j in SIMA negotiation

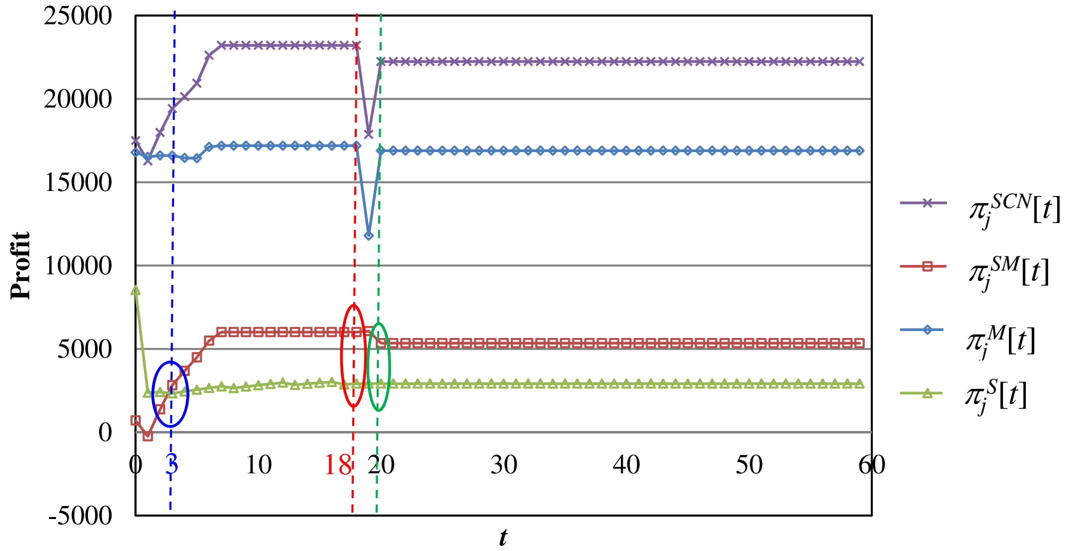


Figure 5.7: Fluctuation of profits of MA, SF_j and SCNs in SIMA negotiation

• At $t = 3$: Profit of coalition {12} takes strategies of MA is greater than takes his own strategies (see Figure 5.7, where $\pi_j^{SM}[3] > \pi_j^S[3]$), that means equation (5.23) is satisfied. However, quantity of MA is greater than ability of coalition {12} (see quantity at k=3 of Figure 5.5, where $q_j^M[3] > AF_j[3]$), that means equation (5.25) is not satisfied. Therefore, the agreement is not reached and negotiation goes by.

• At $t = 18$: MA reaches an agreement with coalition {12} on price (see Figure 5.4) and equation (5.23) is satisfied. However, equation (5.25) is still not satisfied because $q_j^M[18] > AF_j[18]$ from Figure 5.5. Therefore, the agreement is not reached and negotiation goes by.

• At $t = 20$: Price of MA keeps unchanging, but it makes a concession of its lead time (see Figure 5.6) and then equation (5.25) is satisfied (see Figure 5.5, where $q_j^M[20] < AF_j[20]$). Therefore, both constraints of equation (5.23) and equation (5.25) are satisfied.

Thus, we can see that final equilibrium between MA and coalition {12} is the strategies of MA at $t = 20$ where the strategies are (10.704, 4489, 16). Similarly, we can get all equilibriums and then MA decides the final supplier which can maximize his profit. In this case, final supplier for MA is coalition {32} with final strategies (10.703, 6735, 16) and profit equals to 25501.295.

5.2.4.2 Analysis

What should we pay attention to are:

• The equilibrium not always exists;

• The order of MA may become out of ability of SF_j even it was in ability at the first time.

Simulation is executed by 1000 times and results are shown as Table 5.3, where average and standard derivation of calculation time are presented. We can see that the proposed protocol is effective and stable in solving MASI negotiation between one-MA and multi-MSA.

5.3 Multi-Attribute Single-Item Negotiation Between Multi-MA and Multi-MSA

MASI negotiation between multi-MA and multi-MSA will be discussed in this section, where MAs try to negotiate with MSAs about strategies of product they want to buy. We

Table 5.3: Calculation time of MASI negotiation between one-MA and multi-MSA

	Calculation time (sec)
Avg.	0.02384
S.D.	0.01032

can see from Figure 5.8 that quantities and lead time of MAs are affected by demand of market, while demand of market depends on prices of MAs.

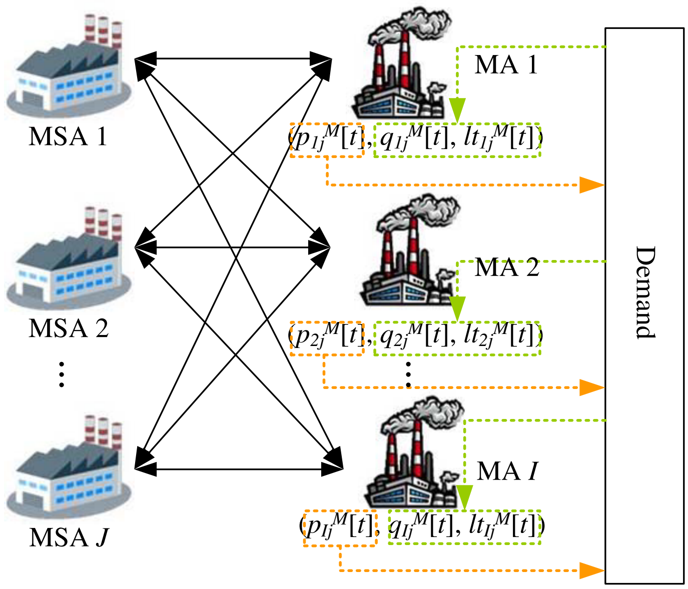


Figure 5.8: MASI negotiation model between multi-MA and multi-MSA

Market demand of MA i at certain lead time is in an additive form as equation (5.29) without upper bound, which means demand decreases as selling price increases.

$$D_{ij}[t] = a_i - b_i psell_{ij}[t], \ \forall i, \ \forall j, \ \forall t \tag{5.29}$$

where

a_i: maximum demand of MA i

b_i: coefficient of variation related to selling price of MA i

$D_{ij}[t]$: demand of MA i with MSA j at t

$psell_{ij}[t]$: selling price of MA i with MSA j at t

It is assumed that MAs and MSAs mainly care three attributes: price of product, quantity of order, and lead time of order.

5.3.1 Modified hierarchical-game based negotiation protocol

A hierarchical-game based negotiation protocol was proposed in section 3.3.1, where quantity of MA was fixed. In this section, a modified hierarchical-game based negotiation protocol is proposed, where quantity of MA depends on market demand. Protocol of the modified hierarchical-game based negotiation is described in details as follows:

- **Step 1:** MAs calculate market demand, determine their strategies, broadcast to all MSAs and goes to Step 4.
- **Step 2:** MSAs evaluate orders, if the order is in their abilities, determine their strategies, if the order is out of their abilities, then trigger coalition formation mechanism and goes to Step 3.
- **Step 3:** MSAs check whether exist coalitions, if there exists, try to determine coalition which maximize its profit and determine their strategies, if there doesn't exist, then reject the order and give a response to MAs.
- **Step 4:** MAs check whether exist any MSAs or coalitions which can fulfill their orders. If there exists, go to Step 5, if there doesn't exist, then modify their strategies and go back to Step 1.
- **Step 5:** Stackelberg game is introduced to find final strategies between MAs and MSAs or coalitions. If equilibrium is found, go to Step 6, if equilibrium is not found, then both MAs and MSAs or coalitions modify their strategies and negotiation repeats until an equilibrium is found or terminal condition is reached.
- **Step 6:** MAs check whether all MSAs give responses. If all MSAs give responses, go to Step 7, else wait until all MSAs give replies.
- **Step 7:** MAs negotiate with MSAs or coalitions to determine final allocation scheme.

Flowchart of the modified hierarchical-game based negotiation is shown in Figure 5.9. There is a nested structure in the hierarchical structure, where the second and third layer games are nested inside the first layer game. The first layer game starts and then the second and third layer games are triggered if necessary. But the first layer game can be finished only if the second and third layer games have been finished. In other words, the first layer game is based on results of the second and third layer games. Details of the protocol are discussed in following sections.

5.3.1.1 Determination of coalitions

In the second layer game (see the area marked by dotted line in Figure 5.9), MSAs negotiate with each other to find partners to establish coalitions when orders of MAs are profitable but out of their abilities. Matrix $E = [e_{ij}]$ is used to evaluate order of MA i for MSA j, where e_{ij} equals to 1 means order of MA i is in ability of MSA j, and e_{ij} equals to 0 means order of MA i is out of ability of MSA j. The second layer game is triggered to find coalitions when $e_{ij} = 0$. Coalition formation and determination mechanisms have been discussed in details in section 2.3, and final coalition of MSA j for MA i is determined as SF_{ij}

5.3.1.2 Determination of equilibriums

In the third layer game (see the area marked by dot-dashed line in Figure 5.9), MA negotiates with SF_{ij} to determine final equilibrium. MA firstly announces its strategies, and then SF_{ij} reacts by playing the best move based on strategies of MA. Both MA and SF_{ij} want to maximize their profits by choosing their preferential strategies. Interaction between MA and SF_{ij} can be seen as a MA-Stackelberg game as we have discussed before. Following rule is provided for SF_{ij} to decide whether accept strategies or not:

Rule 5.2 *When there are still much negotiation time, SF_{ij} accepts strategy of MA at t if and only if profits of all members in SF_{ij} are greater than their minimum expected profits; when there are no negotiation time, SF_{ij} accepts strategy of MA at t if and only if profits of all members in SF_{ij} are positive.*

Therefore, equilibrium of MA-Stackelberg game can be solved by tackling following problem:

$$PF_{ij} = arg \max_{p_{ij}^M[t]} \pi_{ij}^M[t],\ \forall i,\ \forall j \tag{5.30}$$

$$\textbf{s.t.}\ \pi_{ijlj'}^{SCM}[t] \geq \pi_{ij'}^{Min},\ \forall t < \frac{TN}{TS},\ \forall j' \in SF_{ij} \tag{5.31}$$

$$\pi_{ijlj'}^{SCM}[t] > 0,\ \forall t = \frac{TN}{TS},\ \forall i,\ \forall j' \in SF_{ij} \tag{5.32}$$

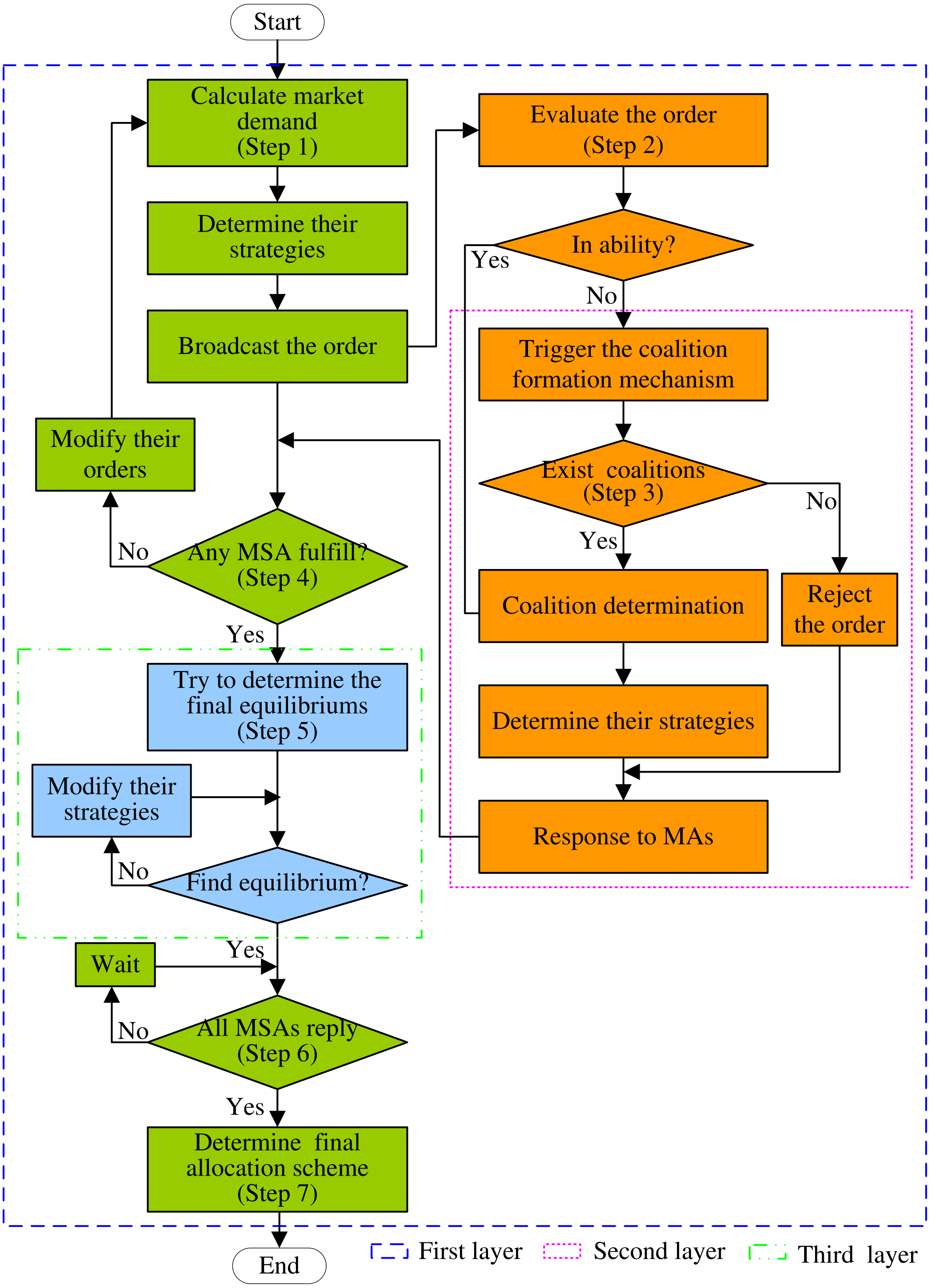


Figure 5.9: Flowchart of MASI negotiation protocol

$$AC_{ijl}[t] \geq q_{ij}^{M}[t],\ \forall i,\ \forall j,\ \forall l,\ \forall t \tag{5.33}$$

where

$\pi_{ij}^{M}[t]$: profit of MA i with MSA j at t

$\pi_{ijlj'}^{SCM}[t]$: profit of MSA j' in SF_{ij} takes the strategy of MA i

$\pi_{ij'}^{Min}$:minimum expected profit of MSA j'

$AC_{ijl}[t]$: ability of coalition s_{ijl} at t

q_{ij}^{M}: quantity of MA i for MSA j

SF_{ij}: coalition of MSA j for MA i

and PF_{ij} is final decided equilibrium (price) of negotiation. Equations (5.31) - (5.32) are used to ensure that final strategies must be profitable, and equation (5.33) indicates the order must be in ability of MSA j or coalition s_{ijl}.

In order to solve equation (5.30), we should know profits of MA and MSA (coalition). Specially, profit of MSA (coalition) takes strategies of MA and that of takes its own strategies. We define profits of MA and MSA (coalition) at t as follows:

$$\begin{aligned}\pi_{ij}^{M}[t] = &(psell_{ij}[t] - p_{ij}^{M}[t])D_{ij}[t] - clt_{i}^{M}(lt_{ij}^{M}[t] - lt_{ij}^{M}[0]) + Sign(q_{ij}^{M}[t] - D_{ij}[t])\\ &(q_{ij}^{M}[t] - D_{ij}[t])sv_i - Sign(D_{ij}[t] - q_{ij}^{M}[t])(D_{ij}[t] - q_{ij}^{M}[t])cst_i - p_{ij}^{M}[t]q_{ij}^{M}[t]\\ &-\frac{cf_i D_{ij}[t]}{q_{ij}^{M}[t]} - \frac{h_i^M q_{ij}^{M}[t]}{2},\ \forall i,\ \forall j,\ \forall t\end{aligned} \tag{5.34}$$

$$\pi_{ij}^{S}[t] = (p_{ij}^{S}[t] - C_j)q_{ij}^{S}[t] + clt_j^S(lt_{ij}^{S}[0] - lt_{ij}^{S}[t]) - cs_j - \frac{h_j^S q_{ij}^{S}[t]}{2},\ \forall i,\ \forall j,\ \forall t \tag{5.35}$$

$$\begin{aligned}\pi_{ij}^{SM}[t] = &(p_{ij}^{M}[t] - C_j)q_{ij}^{M}[t] + clt_j^S(lt_{ij}^{S}[0] - lt_{ij}^{M}[t]) - cs_j - \frac{h_j^S q_{ij}^{M}[t]}{2},\\ &\forall i,\ \forall j,\ \forall t\end{aligned} \tag{5.36}$$

$$\pi_{ijlj'}^{C}[t] = \pi_{ij'}^{S}(p_{ij}^{S}[t], QS_{ijlj'}[t], lt_{ij}^{S}[t]),\ \forall i,\ \forall j,\ \forall l,\ \forall t \tag{5.37}$$

$$\pi_{ijlj'}^{SCM}[t] = \pi_{ij'}^{S}(p_{ij}^{M}[t], QS_{ijlj'}[t], lt_{ij}^{M}[t]),\ \forall i,\ \forall j,\ \forall l,\ \forall t \tag{5.38}$$

where

$\pi_{ij}^{S}[t]$: profit of j at t

$\pi_{ij}^{SM}[t]$: profit of j takes the strategies of MA i at t

$\pi_{ijl}^{C}[t]$: profit of s_{ijl} at t

C_j: cost of MSA j

cf_i: fixed cost per order of i

clt_i^M: cost of MA i to shorten or extend the lead time per day

clt_j^S: cost of MSA j to shorten or extend the lead time per day

cs_j: set-up cost per order of MSA j

cst_i: shortage cost of MA i

h_i^M: holding cost of MA i

h_j^S: holding cost of MSA j

$lt_{ij}^M[t]$: lead time of MA i at t

$lt_{ij}^S[t]$: lead time of MSA j at t

$p_{ij}^M[t]$: price of MA i at t

$p_{ij}^S[t]$: price of MSA j at t

$q_{ij}^M[t]$: quantity of MA i at t

$q_{ij}^S[t]$: quantity of MSA j at t

sv_i: salvage value per unit of unsold product of MA i

The first item of equation (5.34) is profit of sales, the second item is increased or reduced profit by shortening or extending lead time, the third item is salvage values of unsold parts, the fourth item is shortage cost, the fifth item is purchase cost, the sixth item is fixed cost per order, and the last item is holding cost. The first items of equations (5.35) - (5.36) are net profits, the second items are increased or reduced profits by extending or shortening lead time, the third parts are setup costs per order, and the last items are holding costs.

Equations (5.37) - (5.38) are used to calculate profits of members in s_{ijl}, where $QS_{ijlj'}[t]$ is order allocation when total order equals to $q_{ij}^M[t]$.

Determination algorithm of final equilibrium are defined as follows and flowchart is shown in Figure 5.9.

• **Step 1:** MA i defines its initial strategies of product it wants to buy as equations (5.39) - (5.41) and then announces to j. If MSA j is in ability, goes to Step 2, if it is out of its ability, then triggers coalition formation to find coalition SF_{ij} and then goes to Step 2.

$$p_{ij}^M[0] = p_i^{ML} \tag{5.39}$$

$$q_{ij}^M[0] = a_i - b_i p_i^{ML}(1 + \alpha_i^U) \tag{5.40}$$

$$lt_{ij}^M[0] = \frac{q_{ij}^M[0]}{\gamma^U} \tag{5.41}$$

where

α^U: upper bound of profit of MA i

γ^U: upper bound of productivity

p_i^{ML}: lower bound of price of MA i

• **Step 2:** SF_{ij} evaluates strategies of MA i. If it agrees, negotiation ends; if it doesn't agree, then it makes a counter quote as equations (5.42) - (5.44) based on strategies of MA i and then feeds back counter quote ($p_{ij}^S[t]$, $q_{ij}^S[t]$, $lt_{ij}^S[t]$) to MA i, and negotiation enters into Step 3.

$$p_{ij}^S[t] = p_{ij}^S[t-1] - \frac{p_{ij}^S[t-1] - p_{ij}^M[t]}{(TN - tTS)/TS} - \delta_{p,q}^S(q_{ij}^M[t]) - \delta_{p,lt}^S(lt_{ij}^M[t]) \tag{5.42}$$

$$q_{ij}^S[t] = f_{q,p}(p_{ij}^S[t]) \tag{5.43}$$

$$lt_{ij}^S[t] = q_{ij}^S[t]/\gamma_j \tag{5.44}$$

$$p_{ij}^S[0] = p_j^{SU} \tag{5.45}$$

$$f_{q,p}(p_{ij}^S[t]) = \begin{cases} \theta_q^{SU}, & \text{if } p_{ij}^S[t] \le p_j^{SL} \\ \theta_q^S[t], & \text{if } p_j^{SL} < p_{ij}^S[t] < p_j^{SU} \\ \theta_q^{SL}, & \text{if } p_{ij}^S[t] \ge p_j^{SU}. \end{cases} \tag{5.46}$$

$$\theta_q^{SU} = q_{ij}^S[0] \tag{5.47}$$

$$\theta_q^{SL} = cs_j/(p_{ij}^S[0] - C_j) \tag{5.48}$$

$$\theta_q^S[t] = \theta_q^{SU} - \frac{(\theta_q^{SU} - \theta_q^{SL})p_j^{SL}}{p_j^{SL} - p_j^{SU}} + \frac{(\theta_q^{SU} - \theta_q^{SL})p_{ij}^S[t]}{p_j^{SL} - p_j^{SU}} \tag{5.49}$$

$$p_j^{SU} = (1 + \beta_j^{SU})C_j \tag{5.50}$$

$$p_j^{SL} = (1 + \beta_j^{SL})C_j \tag{5.51}$$

where

β_j^{SL}: lower bound of profit of MSA j

β_j^{SU}: upper bound of profit of MSA j

γ_j: productivity of MSA j

p_j^{SL}: lower bound of price of MSA j

p_j^{SU}: upper bound of price of MSA j

$\delta_{p,q}^S$ and $\delta_{p,lt}^S$ are concession functions of price of MSA related to quantity and lead time of MA i. They are piece-wise function as shown in Figure 5.3. All threshold values y_g can be defined by MSA j according to its preferential strategies. Equation (5.46) is piece-wise function of quantity of MSA j related to its price. Equations (5.47) - (5.49) are upper bound of concession, lower bound of concession, and concession rate at t, respectively. Equations (5.50) - (5.51) are upper bound and lower bound of price of MSA.

- **Step 3:** MA i evaluates counter quote from SF_{ij}. If it agrees with the strategies, negotiation ends; if it doesn't agree, then it makes a counter quote based on strategies of its own and SF_{ij} at round $t-1$ as follows and then re-announces the counter quote:

$$p_{ij}^M[t] = p_{ij}^M[t-1] + \frac{p_i^{MU} - p_{ij}^M[t-1]}{(TN - tTS)/TS} + \delta_{p,lt}^M(lt_{ij}^S[t-1]) \tag{5.52}$$

$$q_{ij}^M[t] = D_{ij}[t] + \delta_{q,p}^M(p_{ij}^S[t-1]) \tag{5.53}$$

$$lt_{ij}^M[t] = lt_{ij}^M[t-1] + \delta_{lt,p}^M(p_{ij}^S[t-1]) \tag{5.54}$$

$$psell_{ij}[t] = p_{ij}^M[t](1 + \alpha_i^U) \tag{5.55}$$

where p_i^{MU} is upper bound of price of MA i, and equations (5.52) - (5.54) are price, quantity, and lead time of MA i at t. Equation (5.55) is selling price of MA i based on strategies at round t.

Negotiation iterates until an agreement is reached.

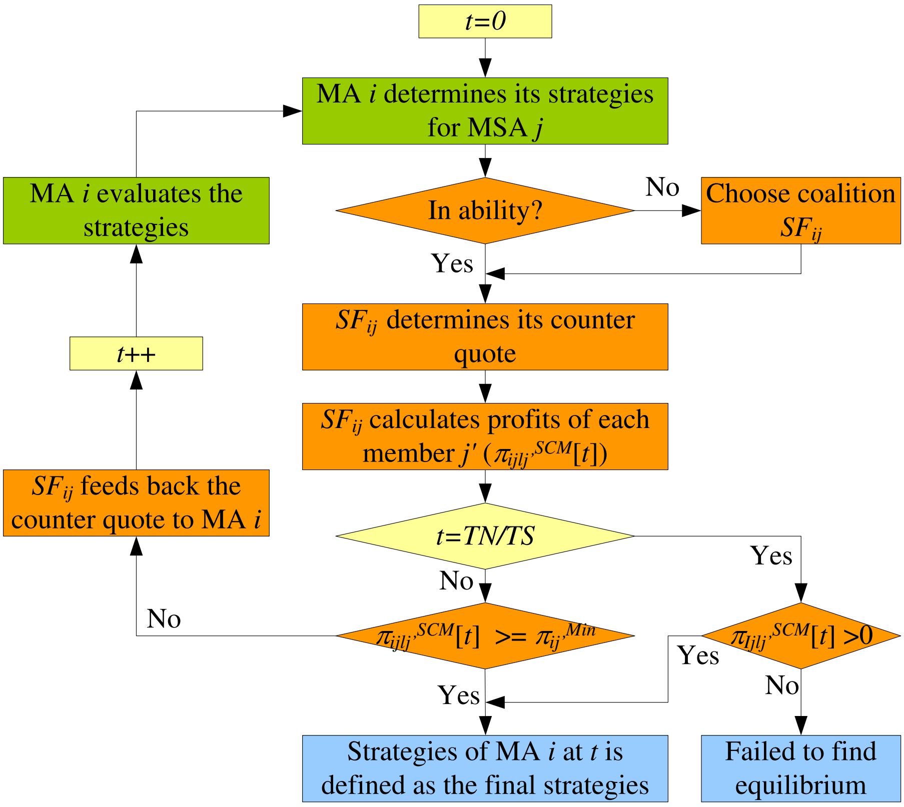


Figure 5.10: Flowchart of the determination of the final equilibrium

5.3.1.3 Determination of final allocation scheme

There are multi-MA and multi-MSA in SCNs, and not only MSAs have competitors, but also MAs have contestants. All MAs and MSAs have rights to select trade partners to maximize their profits. All MAs have prone to selecting supplier with the lowest price to increase their profits and all MSAs want to select manufacturer with the highest price to increase their profits. Therefore, main point is transformed into how to allocate orders among MSAs. A two-person like game was proposed in previous work [Yu et al., 2013b] to solve this problem. We generalize it to multi-attribute negotiation. All MAs are considered as player 1 and all MSAs are combined as player 2. Player 1 and player 2 make their strategies simultaneously. Strategies of player 1 in the first layer are scheme to allocate orders of its members to MSAs. Strategies of player 2 is allocation of all orders from MAs to its members. The agreement is reached only if strategy of player 1 consists with strategy of player 2. Final allocation scheme is determined as matrixes M and N_{ij}, where $M = [m_{ij}]$ is allocation of orders of MAs among MSAs and $N_{ij} = [n_{ijl}]$ is order allocation among coalitions of MSA j when order of MA i is out of ability of MSA j. There is only one matrix M to record final allocation of orders of MAs to MSAs. The value of m_{ij} equals to 1 means MA i is allocated to MSA j and m_{ij} equals to 0 means MA i is not allocated to MSA j. N_{ij} exists only if e_{ij} equals to 0 and m_{ij} equals to 1. The value of n_{ijl} equals to 1 means the order is allocated to the lth coalition of MSA j (s_{ijl}) and n_{ijl} equals to 0 means the order is not allocated to the lth coalition of MSA j. Matrixes M and N_{ij} can be got by solving following problem:

$$\max \quad \{\Pi_1 + \Pi_2 = \sum_{i=1}^{I}\sum_{j=1}^{J} m_{ij}\pi_{ij}^{M} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L} n_{ijl}\pi_{ijl}^{C}\} \tag{5.56}$$

$$\sum_{i=1}^{I} n_{ijl} QS_{ijl}^{F} \leq A_j^{FU}, \ \forall j \tag{5.57}$$

$$A_j^{FU} = \gamma_j \max\{LT_{ij}^{F}\}, \ \forall j \tag{5.58}$$

$$\sum_{j=1}^{J} m_{ij} = 1, \ \forall i \tag{5.59}$$

$$\sum_{l=1}^{L} n_{ijl} = 1, \ \forall i, \ \forall j, \text{if } m_{ij} = 1 \tag{5.60}$$

where

QS_{ijlj}^{F}: final acquired quantity of MSA j by belonging to SF_{ij}

A_j^{FU}: final upper bound of ability of MSA j

LT_{ij}^{F}: final determined lead time between MA i and MSA j

Final allocation scheme is determined according to M and N after solving equations (5.56) - (5.60), where the first part and second part of equation (5.56) are profits of player 1 and player 2, respectively. Equation (5.57) is used to ensure that all allocated orders to MSA j must be in its ability, equation (5.58) is used to calculate maximum ability at the longest lead time of all accepted orders, and equations (5.59) - (5.60) mean that each order must and only can be allocated to one MSA or coalition.

5.3.2 Simulation and analysis

Simulations are provided to illustrate proposed protocol and verify feasibility of the proposed protocol in MASI negotiation between multi-MA and multi-MSA. All settings of parameters of MAs and MSAs are shown in Table 5.4.

Table 5.4: Parameter settings of MAs and MSAs

MSA		MA	
J	5	I	5
γ_j	U(100,300)	h_i^M	3
cs_j^S	U(200,300)	α_i^{min}	0.3
C_j	U(7,8)	α_i^{max}	0.5
β_j^{min}	0.2	cf_i^M	100
β_j^{max}	0.5	cst_i^M	5
h_j^S	3	$ps_{ij}[0]$	U(13,14)
		sv_i^M	2
		a_i	U(1000,2000)
		b_i	U(0,100)

5.3.2.1 Verification of the proposed protocol for MASI negotiation

Evaluation matrix can be get as: $E = \begin{pmatrix} 1 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 \end{pmatrix}$, and we can see all orders are out of the abilities of MSA 2 and MSA 3. Thus, MSA 2 and MSA 3 should trigger coalition formation mechanism to find coalitions.

Take negotiation between MA 1 and coalition {21} as an example. Fluctuations of three attributes as t goes by are shown in Figure 5.11 - Figure 5.13, we can get:

- $p_{ijl}^M[t]$ increases as t increases and $p_{ijl}^C[t]$ decreases as t increases. We can see that $p_{ijl}^M[t]$ keeps unchanging from $t = 7$ to $t = 33$. That's because $p_{ijl}^M[t]$ must be greater than p_1^{ML}. Furthermore, both $p_{ijl}^M[t]$ and $p_{ijl}^C[t]$ keep unchanging after $t = 34$. That's because $p_{ijl}^C[33]$ is less than $p_{ijl}^M[33]$ at $t = 33$ (see the area marked by ellipse in Figure 5.11). It means MA 1 and coalition {21} reach an agreement on the price.

- MA 1 makes a concession on lead time after price reaching an agreement (see the area marked by ellipse in Figure 5.13).
- The best choice for coalition {21} to reach an agreement is at situation where profit of taking strategies of MA 1 is greater than taking its own strategies. Therefore, final agreement should be reached at $t = 7$ (see the point which is marked by a dash line in Figure 5.14). However, final agreement is reached at $t = 35$ where strategies are (9.985, 9648, 28). That's because the agreement can be reached only if the order is in ability of coalition {21}. We can see from Figure 5.12 that the order is in ability of coalition {21} only after $t = 34$. Thus, final agreement is reached at $t = 35$, where the order is in ability of coalition {21}, $\pi_{ijl}^{SM}[35]$ equals to 6136.283 is greater than $\pi_{ijl}^{S}[35]$ equals to 5558.548, and total profit ($\pi_{ijl}^{M}[35] + \pi_{ijl}^{SM}[35]$) equals to 39430.73 (maximum value).

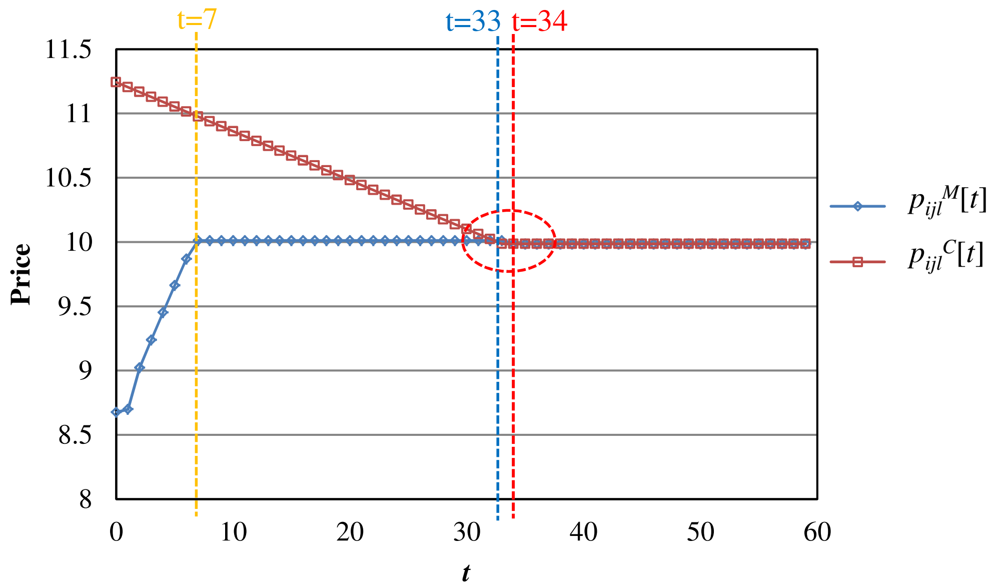


Figure 5.11: Fluctuation of prices of MA 1 and {21}

Final strategies of negotiations between MAs and MSAs (coalitions) are shown in Table 5.5, and MSAs (coalitions) which are not shown in Table 5.5 are failed to reach an agreement with MAs. Strategies (p^F, q^F, lt^F), which are determined in the third layer game, are final strategies of negotiation between related MA and MSA (coalition). π^F is related total profit of two partners of negotiation.

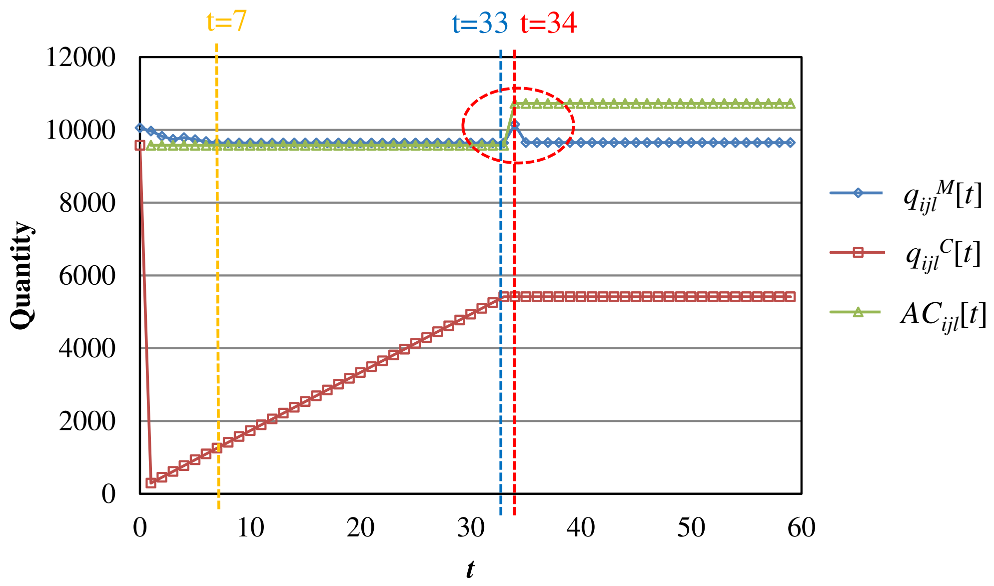


Figure 5.12: Fluctuation of quantities of MA 1 and {21}

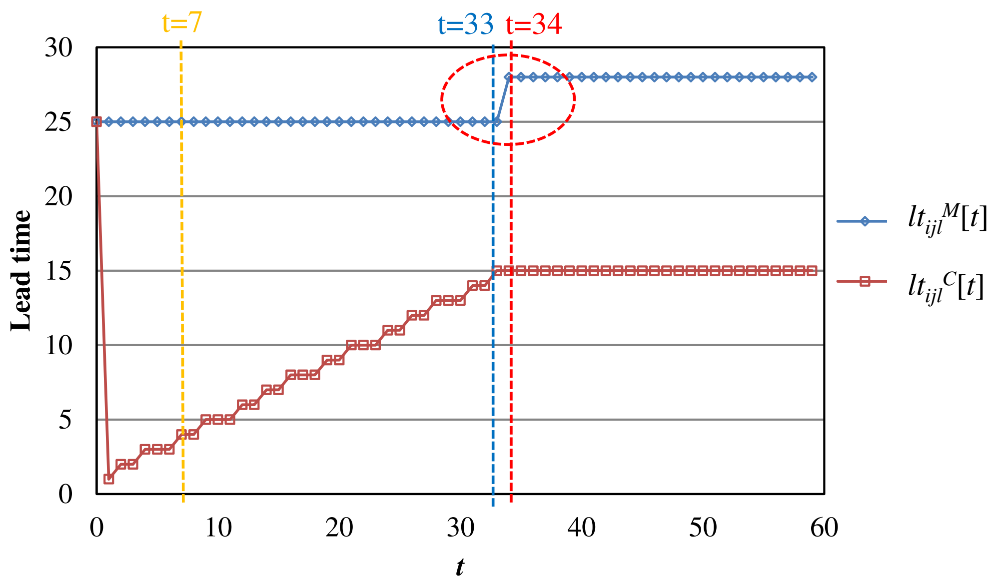


Figure 5.13: Fluctuation of lead time of MA 1 and {21}

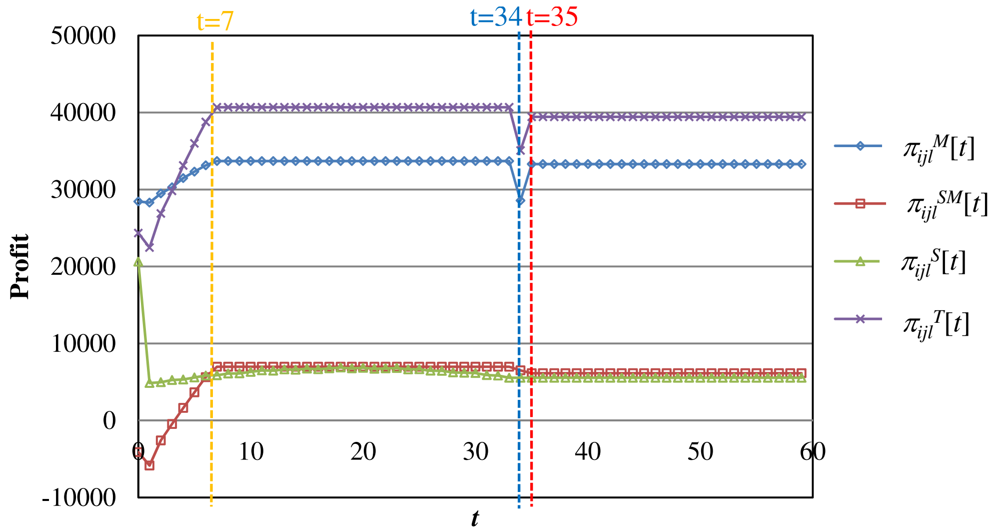


Figure 5.14: Fluctuation of profits of MA 1 and {21}

Then, the first layer game is used to find the optimal allocation scheme based on results above. We can get final allocation scheme by solving equation (5.56) as follows:

$$M = \begin{pmatrix} 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$$N_{22} = \begin{pmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$N_{32} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$N_{43} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

That's means that MA 1 is allocated to MSA 4, MA 2 is allocated to coalition {24} of MSA 2, MA 3 is allocated to coalition {214} of MSA 2, MA 4 is allocated to coalition {31} of MSA 3, and MA 5 is allocated to MSA 5. It's the optimal allocation scheme under constraints of three attributes, and total profit under above allocation scheme is 102956.86 by calculating equation (5.56).

5.3.2.2 Analysis

We can see from the verification that proposed protocol has characteristics as follows:

Table 5.5: Final strategies between MAs and MSAs (coalitions)

	SF_{ij}	p^F	q^F	lt^F	π^F	SF_{ij}	p^F	q^F	lt^F	π^F
MA 1	{1}	9.58	4791	25	15843.9	{4}	9.44	4827	25	15557.7
	{21}	9.99	9648	28	39430.7	{5}	9.44	4827	25	15557.7
MA 2	{1}	9.72	1361	9	4530.6	{31}	10.23	2559	9	10756.1
	{21}	10.23	2658	9	11654.6	{4}	9.62	1419	9	5327.1
	{24}	10.23	4845	12	22218.4	{5}	9.67	1391	9	4708.5
MA 3	{1}	9.79	1226	8	4175.9	{32}	10.44	2840	11	13837.8
	{21}	10.45	2080	8	9683.3	{34}	10.55	3609	11	17565.6
	{23}	10.44	3000	11	14697.2	{312}	10.53	5165	11	24521.9
	{24}	10.56	3766	11	18794.9	{314}	10.53	5945	11	27749.5
	{213}	10.53	5315	11	25292.8	{4}	9.47	1418	8	5006.0
	{214}	10.56	6082	11	29201.9	{5}	9.79	1226	8	4329.9
MA 4	{1}	9.725	3062	17	10627.9	{4}	9.60	3122	17	12087.4
	{21}	10.32	5947	17	27639.8	{5}	9.72	3062	17	10991.5
	{31}	10.31	6071	20	26132.4					
MA 5	{1}	9.77	2767	16	9799.9	{4}	9.56	2856	16	10824.6
	{21}	10.03	5784	16	24311.6	{5}	9.67	2811	16	9846.5
	{31}	10.00	5551	19	21195.6					

• An agreement can be reached as long as constraints (5.23) - (5.25) are satisfied, no matter MA cannot reach an agreement with SF_j on price or not.

• The agreement may not be reached even MA has reached an agreement with SF_j on price.

• Attributes may not be monotone changing.

During simulation, we found that MSAs (coalitions) failed to reach agreements with MAs because MAs decided their quantities based on demand of market. Demand increases as final price reduces. It may make MSAs (coalitions) finally cannot finish the order by themselves, which may be in their abilities at the first time.

Nextly, we will discuss about effectiveness of proposed protocol in solving MASI negotiation. Simulation is executed by 1000 times and results are shown as Table 5.6, where average and standard derivation of calculation time are presented. We can see that proposed protocol is effective and stable in solving MASI negotiation between multi-MA and multi-MSA.

Table 5.6: Calculation time of MASI negotiation between multi-MA and multi-MSA

	Calculation time (sec)
Avg.	0.4066
S.D.	0.0315

5.4 Comparison and analysis

5.4.1 Comparison of the proposed protocol with other protocols

We compare the proposed protocol with Kim's protocol ([Kim et al., 2007]) and Hindriks's protocol ([Hindriks et al., 2012]) under three cases, where $\gamma \sim$ [100, 300], $\gamma \sim$ [100, 250] and $\gamma \sim$ [100, 200], respectively. Main differences of three protocols are as follows:

• **Kim's:** the agreement is reached if $p_j^M[t] > p_j^S[t]$, the final price equals to $(p_j^M[t] + p_j^S[t])/2$;

• **Hindriks's:** the agreement is reached if $\pi_j^{SM}[t] > \pi_j^{min}$, and π_j^{min} is defined to ensure the order is profitable;

• **Proposed:** the agreement is reached only if equations (5.23) - (5.25) are satisfied, the final price equals to $p_j^M[t]$, and it is allowed to find coalitions when the order is out of ability of MSA.

Then, we can get results as Table 5.7, and Figure 5.15 - Figure 5.17, where the column Kim is results of Kim's protocol, the column Hind. is results of Hindriks's protocol, the column Prop. is results of proposed protocol, FS is final supplier of each protocol, π^M, π^S and π^T are profits of MA, MSA and total SCN, respectively, and E is evaluation of ability of selected final supplier of each protocol at the agreement point. E equals to 1 means the order is in ability of selected supplier FS, and E equals to 0 means the order is out of ability of selected supplier FS.

We can see that:

• **In Case 1:** Final suppliers for Kim's, Hindriks's and proposed protocol are {3}, {1}, and {4}, and all three protocol can finish the order independently. Kim's protocol gets the best profits for all parties (see Figure 5.15).

Table 5.7: Comparisons of three protocols in three cases.

	Case 1			Case 2			Case 3		
	Kim	Hind.	Prop.	Kim	Hind.	Prop.	Kim	Hind.	Prop.
FS	{3}	{1}	{4}	{5}	{5}	{5}	{1}	{2}	{213}
E	1	1	1	1	0	1	0	0	1

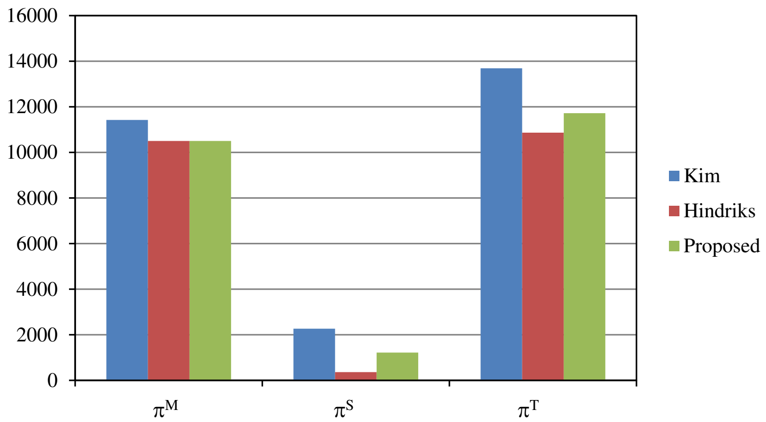


Figure 5.15: Comparisons of three protocols in Case 1

- **In Case 2:** Final suppliers for Kim's, Hindriks's and proposed protocol are {5}, {5}, and {5}. Profits of MA, MSA and overall profit are shown as Figure 5.16. Kim's protocol gets the best profits for MA, the proposed protocol gets the best profits of MSA and total SCN. Both Kim's protocol and the proposed protocol can finish the order independently. However, E of Hindriks's protocol equals to 0 (see the sixth column, fourth row of Table 5.7), which means the order is out of ability of final supplier {5} even at the agreement point of Hindriks's protocol. In other words, {5} cannot finish the order independently. Thus, we can see that Hindriks's protocol needs the coalition formation.
- **In Case 3:** Kim's protocol gets the best profits for MA and total SC (see π^M and π^T of Kim's in Figure 5.17); E equals to 0 which means the order is out of ability of final supplier {1} even at the agreement point. Thus, we can see that Kim's protocol needs the coalition formation as well. The proposed protocol only gets the best profit for MSA. However, it can ensure the order of MA is in ability of the final supplier at the agreement

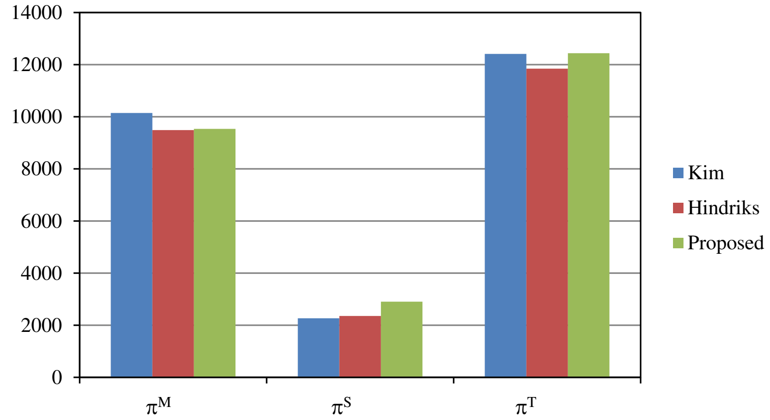


Figure 5.16: Comparisons of three protocols in Case 2

point.

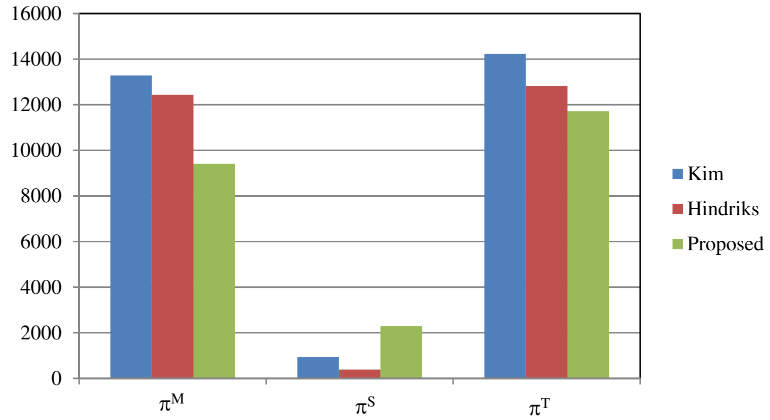


Figure 5.17: Comparisons of three protocols in Case 3

That's because both Kim's and Hindriks's protocols don't consider quantity. They have good performances when there is no need to take ability of MSA into account. However, it is crucial to consider the ability of MSA in multi-attribute negotiation. Thus, Kim's and Hindriks's protocols only suit for situation where all MSAs have big abilities. In real market, there are a lot of suppliers with limited abilities. The proposed protocol provides a good way for them to combine together as a coalition and then competed with other suppliers. It's a win-win protocol for both MA and MSA. For MA, it can find cheaper suppliers; and for MSAs, they can compete for the order by establishing a coalition which may be rejected for their limited abilities. Furthermore, it is good for increasing the competitiveness of the market.

Chapter 6 Coalition Formation Based Multi-Attribute Multi-Item Negotiation

6.1 Introduction

Both multi-attribute negotiation (discussed in literature [Bichler, 2000], [Kim et al., 2007], [Park and Yang, 2008], [Lai and Sycara, 2009], and [Hindriks et al., 2012]) and multi-item negotiation ([Lengwiler, 1999], [Ben-ameur et al., 2002], [Busch and Horstmann, 2002], and [Shi and Hu, 2006]) are crucial for negotiation of SCNs. Since MA has its own preferences for attributes of products, and looks for offer that best satisfies these preferences [Bichler, 2000]. On the other hand, it needs to buy multi-item to produce their products, and needs to negotiate with MSAs. MSAs in market consist of large companies as well as a large number of small-and-medium-sized enterprises. Thus, MA may need to negotiate and find a large number of MSAs to fulfill its order due to large number of items and quantities of its order, and limited abilities of MSAs. It will be a hard work for MA to split its order into pieces and allocate to different MSAs when there are diversity items to buy, and it also causes a lot of external fee (e.g. transport cost). Thus, MA would like to select MSAs with low price and high ability to reduce its cost. As a result, MA may have to give up MSAs with the lowest prices but limited abilities, and these MSAs may lose opportunities to compete for profitable orders. Therefore, in this chapter we try to solve multi-attribute multi-item (MAMI) negotiation.

6.2 Multi-Attribute Multi-Item Negotiation between One-MA and Multi-MSA

Considering negotiation between one MA and J MSAs, three attributes (price, quantity, and lead time), and K items are involved. Negotiation model is shown in Figure 6.1, in which a car company (defined as MA) is taken as an example. MA wants to buy K items (glasses, tiers, bearings and so on) from MSAs, and attributes of each item are defined as a triple (p^M, q^M, lt^M). We can see that determination of quantity q^M and lead time lt^M of MA depends on demand of market, and demand of market is affected by price p^M of MA. MSAs try to find partners to establish coalitions when order of MA is out of their abilities (the dotted arrows among MSAs indicate negotiations to establish coalitions).

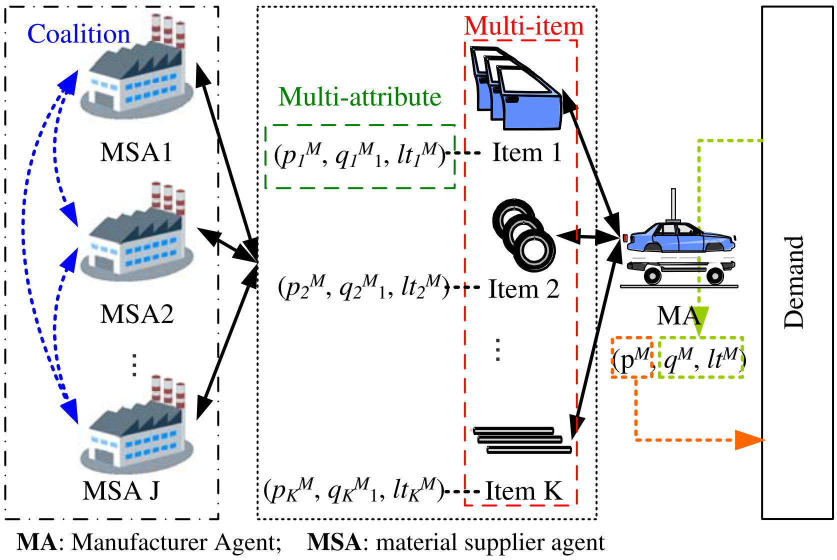


Figure 6.1: MAMI negotiation model between one-MA and multi-MSA

6.2.1 Modified coalition formation based negotiation protocol

Coalition formation of multi-attribute negotiation has been discussed in section 6.2 and it was assumed that coalition cannot be changed once established. However, it was found that final determined coalition may be out of ability of the order. That's because the searchings for coalitions are based on abilities of MSAs which are only calculated at initial step. Lead time and quantity may be changed during multi-attribute negotiation which of course lead to the change of abilities of MSAs. Therefore, a dynamic searching of all possible coalitions are required during multi-attribute negotiation. The MSAs, which are out of abilities, try to update their coalitions according to strategies of MA at each negotiation iteration t. A modified coalition formation based negotiation protocol is proposed as follows and flowchart of the protocol is shown in Figure 6.2.

- **Step 1:** MA calculates market demand and determines its strategies and broadcasts to all MSAs.

- **Step 2:** MSAs evaluate the order to check whether the order is in their abilities or not. If the order is in their abilities, go to Step 4, if the order is out of their abilities, then go to Step 3.

• **Step 3:** MSAs try to find coalitions, which can maximize their profits at t. If they succeed in finding coalitions, go to Step 4, if they failed in finding coalitions, then reject the order.

• **Step 4:** MSAs determine their strategies and go to Step 5.

• **Step 5:** MA negotiates with MSAs (coalitions) to determine equilibriums. If equilibriums are found, go to Step 8, and if they are not found yet, then go to Step 6.

• **Step 6:** Check whether terminal condition is reached or not. If it is not reached, go back to Step 1 and negotiation repeats until an agreement is reached or terminal condition is reached; if it is reached, then go to Step 7, and failed to reach an agreement.

• **Step 7:** MA checks whether all MSAs have given reply. If all MSAs have replied, go to Step 8, if not, then waits until all MSAs give responses.

• **Step 8:** MA determines final supplier according to these equilibriums and negotiations end.

6.2.2 Negotiation among MSAs

At each iteration t, MSAs which are out of abilities of MA will trigger the modified coalition formation to find coalitions (see section 2.4), and final determined coalition for MSA j is indicated as $SF_j[t]$ (see section 2.4.1):

$$SF_j[t] = \begin{cases} arg \max_{s_{jl}[t]} \{\pi_{jl}^{SC}[t]\}, & \text{if } A_{jk}[t] < q_{jk}^{M}[t] \\ j, & \text{if } A_{jk}[t] \geq q_{jk}^{M}[t] \end{cases} \tag{6.1}$$

$$AF_{jk}[t] = \sum_{j' \in SF_j[t]} A_{j'k}[t] \tag{6.2}$$

$$p_{jk}^{SFI}[t] = \frac{\sum_{j' \in SF_j[t]} p_{j'k}^{SI}}{N_{jk}[t]} \tag{6.3}$$

where

$A_{jk}[t]$: ability of item k of MSA j

$AF_{jk}[t]$: ability of item k of $SF_j[t]$

$N_{jk}[t]$: number of members in $SF_j[t]$ which can supply item k

p_{jk}^{SI}: initial price of item k of MSA j

$p_{jk}^{SFI}[t]$: initial price of item k of $SF_j[t]$

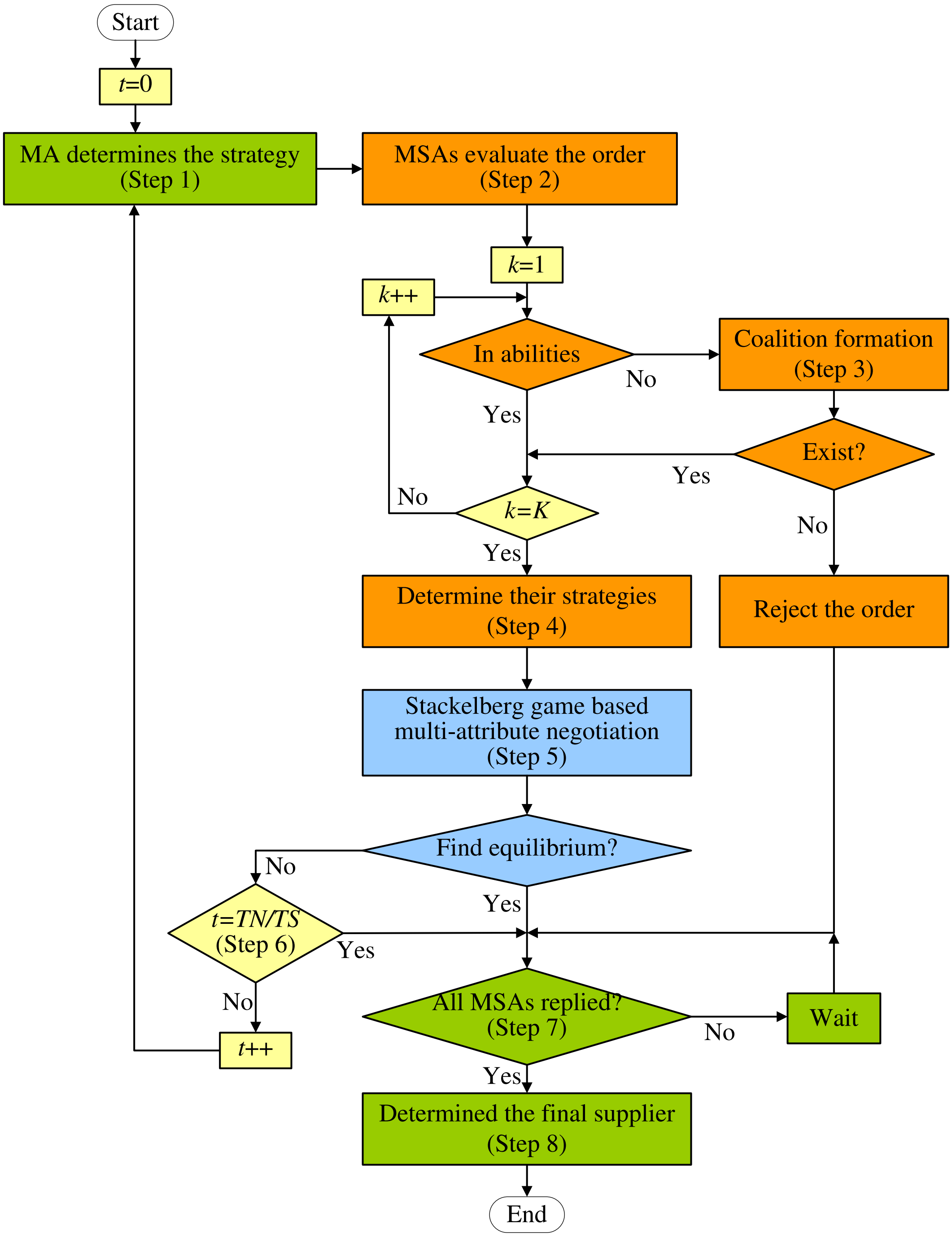


Figure 6.2: Flowchart of MAMI negotiation between one-MA and multi-MSA

$q_{jk}^M[t]$: quantity of item k of MA at t

$SF_j[t]$: coalition of MSA j at t

6.2.3 Negotiation between MA and MSA (coalition)

Negotiation between MA and $SF_j[t]$ starts after $SF_j[t]$ has been determined to find equilibrium of MIMA negotiation.

6.2.3.1 Determination of strategies

In section 5.2, MA makes concession of price according to current price $p_j^M[t]$, upper bound of price p^{MU}, and remain negotiation time. However, it takes longer time to find equilibrium if it always compare to its own upper bound of price. Therefore, we change the upper bound of price p^{MU} into price $p_{jk}^S[t-1]$ of SF_j at $t-1$.

(a) Strategies of MA

$$p_{jk}^M[t] = p_{jk}^M[t-1] + \frac{p_{jk}^S[t-1] - p_{jk}^M[t-1]}{(TN - tTS)/TS} + \delta_{p,lt}^M(lt_{jk}^S[t-1]) \tag{6.4}$$

$$q_{jk}^M[t] = d_{jk}^M[t] + \delta_{q,p}^M(p_{jk}^S[t-1]) \tag{6.5}$$

$$lt_{jk}^M = lt_{jk}^M[t-1] + \delta_{lt,p}^M(p_{jk}^S[t-1]) \tag{6.6}$$

$$LT_j^M = \max\{lt_{jk}^M[t]\} \tag{6.7}$$

$$d_{jk}^M[t] = \eta_k D_j[t] \tag{6.8}$$

$$D_j[t] = a - bPM_j[t] \tag{6.9}$$

$$PM_j[t] = (1+\alpha)\sum_{k=1}^{K} \eta_k p_{jk}^M[t] \tag{6.10}$$

where

α: expected percentage of profit of MA

η_k :proportion of item k in one final product

$D_j[t]$: demand of final product of MA at t

$d_{jk}^M[t]$: demand of item k of MA at t

$lt_{jk}^M[t]$: lead time of item k of MA at t

$p^M_{jk}[t]$: price of item k of MA at t

$PM_j[t]$: total price of one final product of MA at t.

Equation (6.4) is used to calculate price of item k of MA at t, the second part is concession related to price of $SF_j[t-1]$ and remaining negotiation time, and the third part is concession of price related to lead time of $SF_j[t-1]$. If $SF_j[t-1]$ can shorten lead time, MA will give a discount of price. Equation (6.5) is used to calculate quantity of item k of MA at t, the first part is demand of item k of MA at t which depends on demand of final product calculated in equations (6.8) - (6.9), and the second part is concession of quantity of MA related to price of $SF_j[t-1]$. If $SF_j[t-1]$ can give a discount of price, MA will buy more quantity of item k. Equation (6.6) is used to calculate lead time of item k of MA at t, the second part is concession of lead time of MA related to price of $SF_j[t-1]$. If $SF_j[t-1]$ can give a discount of price of item k, MA will agree to extend lead time of item k. Equation (6.7) is lead time for whole order include all items. Equation (6.10) is price of one final product, and it equals to summation of prices of all items which are needed in one final product.

(b) Strategies of $SF_j[t]$

$$p^S_{jk}[t] = p^S_{jk}[t-1] - \frac{p^S_{jk}[t-1] - p^M_{jk}[t]}{(TN - tTS)/TS} - \delta^S_{p,q}(q^M_{jk}[t]) - \delta^S_{p,lt}(LT^M_j[t]) \tag{6.11}$$

$$q^S_{jk}[t] = q^S_{jk}[t-1] - \frac{AF_{jk}[t] - q^{SFL}_{jk}}{(TN - tTS)/TS} - \delta^S_{q,p}(p^M_{jk}[t]) \tag{6.12}$$

$$lt^S_{jk} = \frac{q^S_{jk}[t]}{\gamma^F_{jk}} \tag{6.13}$$

$$q^{SFL}_{jk} = \sum_{j' \in SF_j[t]} q^{SL}_{jk} \tag{6.14}$$

$$\gamma^F_{jk} = \sum_{j' \in SF_j[t]} \gamma_{j'k} \tag{6.15}$$

$$p^S_{jk}[0] = p^{SFI}_{jk} \tag{6.16}$$

$$q^S_{jk}[0] = AF_{jk}[0] \tag{6.17}$$

where

γ^F_{jk}: productivity of item k of $SF_j[t]$

$lt^S_{jk}[t]$: lead time of item k of $SF_j[t]$

$p^S_{jk}[t]$: price of item k of $SF_j[t]$

$q^S_{jk}[t]$: quantity of item k of $SF_j[t]$

q^{SFL}_{jk}: lower bound of quantity of item k of $SF_j[t]$.

Equation (6.11) is used to calculate price of item k of MA at t, the second part is concession related to price of MA at t and remaining negotiation time, and the third part is concession of price related to quantity of MA at t. If MA buys more quantity of item k, $SF_j[t]$ will give a discount of price. The fourth part of equation (6.11) is concession of price related to lead time of MA at t. If MA extends lead time of order, $SF_j[t]$ will give a discount of price. Equation (6.12) is used to calculate quantity of item k of $SF_j[t]$, the second part is concession of quantity of $SF_j[t]$ related to its minimum required quantity of item k, and the third part is concession of quantity of $SF_j[t]$ related to price of MA at t. If MA increases price of item k, $SF_j[t]$ will give a discount of the minimum required quantity of item k. Equation (6.13) is used to calculate lead time of item k of $SF_j[t]$, and it depends on quantity and productivity of item k of $SF_j[t]$. Productivity of $SF_j[t]$ equals to summation of productivity of all members in $SF_j[t]$ and calculated by equation (6.15).

6.2.3.2 Determination of equilibriums

In section 5.2, strategies of MA at t is determined as equilibrium if these strategies maximize profit of MA and can be accepted by SF_j. Strategies can be accepted by SF_j if profit of taking the strategies is greater than that of taking its own strategies. However, we found that although overall profit of SF_j is greater than take its own strategies, members in coalition may have negative profits. Thus, following rule is proposed for SF_j to check whether accept strategies or not:

Rule 6.1: *Strategies of MA at t can be accepted by SF_j if and only if profits of all members in SF_j are greater than their minimum expected profits.*

Thus, determination of equilibrium between MA and $SF_j[t]$ can be obtained by solving:

$$\max \quad \pi^M_j[t], \forall j \tag{6.18}$$

$$\text{s.t.} \quad \pi^{SFC}_{jlj'}[t] \geq \pi^{Min}_{j'}, \forall j' \in SF_j[t] \tag{6.19}$$

where

$$\pi^M_j[t] = D_j[t]PM_j[t] - \sum_{k=1}^{K} p^M_{jk}[t]q^M_{jk}[t] + \sum_{k=1}^{K} (q^M_{jk}[t] - d^M_{jk}[t])sv_k$$

$$-(LT_j^M[t] - LT_j^M[0])clt^M \tag{6.20}$$

$$\pi_j^{SF}[t] = \sum_{k=1}^{K} p_{jk}^M[t] q_{jk}^M[t] - \sum_{j' \in SF_j[t]} \sum_{k=1}^{K} C_{j'k} QS_{j'lk}[t] + (LT_j^M[t] - lt_j^S[0])clt_k^S \tag{6.21}$$

$$\pi_{jlj'}^{SFC}[t] = \sum_{k=1}^{K} p_{jk}^M[t] QS_{j'lk}[t] - \sum_{k=1}^{K} C_{j'k} QS_{j'lk}[t]$$
$$+(LT_{jk}^M[t] - lt_{j'k}^S[0])clt_k^S, \quad \forall j' \in SF_j[t] \tag{6.22}$$

and

$\pi_j^M[t]$: profit of MA at t

$\pi_j^{SF}[t]$: profit of $SF_j[t]$

$\pi_{jlj'}^{SFC}[t]$: profit of MSA j' by belonging to $SF_j[t]$

π_j^{Min}: minimum expected profit of MSA j.

Equation (6.20) is used to calculate profit of MA at t, the first part is profit of sold quantity of final product, the second part is payment it should pay for $SF_j[t]$, the third part is salvage value of unsold quantity of item k, and the last part is profit or loss of shortening or extending lead time. Equation (6.21) calculates profit of $SF_j[t]$, the first part is payment it get from MA, the second part is cost of $SF_j[t]$ to produce all items, and the last part is profit or loss of $SF_j[t]$ by extending or shortening lead time. Equation (6.22) is used to calculate profit of MSA j' by belonging to $SF_j[t]$.

6.2.3.3 Determination of final supplier

After MA found all equilibriums between all $SF_j[t]$, it selects the supplier which can maximize its profit.

6.2.4 Simulation and analysis

We assume there is one MA and six MSAs in SCNs and four items are involved in negotiation. Experimental parameters are presented in Table 6.1, and $\alpha = 0.5$, $\eta_1 = 6$, $\eta_2 = 3$, $\eta_3 = 1$, $\eta_4 = 2$, $TN = 60$, $TS = 1$, and $clt = 100$.

Table 6.1: Parameter settings of MSAs

	k=1		k=2		k=3		k=4	
	γ_{jk}	C_{jk}	γ_{jk}	C_{jk}	γ_{jk}	C_{jk}	γ_{jk}	C_{jk}
MSA 1	500	1.5	0	0	200	5	0	0
MSA 2	0	0	350	10	0	0	0	0
MSA 3	350	1.7	200	12	150	5.5	0	0
MSA 4	0	0	0	0	220	4.9	200	80
MSA 5	250	1.65	200	10.5	100	5.1	100	90
MSA 6	0	0	0	0	0	0	300	75

6.2.4.1 Verification

After simulation, MA gets all profits by selecting equilibriums related to $SF_j[t]$. MA gets the highest profit by selecting {214}. {214} indicates the coalition consists of MSA 2, MSA 1 and MSA 4 (All equilibriums of all possible coalitions are presented in **Appendix A3** of this dissertation). Therefore, the final supplier of MA is decided as {214} and related profits of MA and {214} is shown in Table 6.2, where FS is final determined supplier, $\pi_j^M[11]$ is profit of MA of selecting {214} at $t = 11$, $\pi_j^{SF}[11]$ is profit of {214} at $t = 11$, $\pi_{j'}^{SFC}[11]$ is profit of MSA j' of belonging to {214} at $t = 11$, and $\pi_{j'}^{Min}$ is the minimum expected profit of related MSAs in {214}. Thus, we can see from Table 6.2 that profit of MA of selecting {214} equals to 401732.6454, and profit of {214} equals to 208384. According to equation (6.19), we can see that equilibrium can be reached if and only if all members in coalition are profitable. Thus, we check profits of all members of {214}. We can see from the fourth column and fifth column of Table 6.2 that profits of MSA 1, MSA 2, and MSA 4 of belonging to {214} equal to 2889, 28698, and 176797, respectively. All of them are greater than their minimum expected profits. Therefore, we can see that MSAs in {214} reach an agreement, and the final iteration of negotiation to reach equilibrium equals to 11.

Then, we take coalition {214} as an example to show how to find equilibrium during negotiation. Profits of all members of {214} are shown in Figure 6.3, where $\pi_1^{Min} = 2107.3$, $\pi_2^{Min} = 2324.4$ and $\pi_4^{Min} = 2168.4$ are the minimum expected profits of MSA 1, MSA 2 and MSA 4, respectively. Equilibrium can be reached if and only if profits of all

Table 6.2: Final supplier of MA and related profits

FS	$\pi_j^M[11]$	$\pi_j^{SF}[11]$	j'	$\pi_{j'}^{SFC}[11]$	$\pi_{j'}^{Min}[11]$
{214}	401732.6	208384	1	2889.0	2107.3
			2	28698.0	2324.4
			4	176797.0	2168.4

members are greater than π_1^{Min}, π_2^{Min} and π_4^{Min} according to ***Rule 6.1***. We can see that both profits of MSA 2 ($\pi_2^{SC}[5] = 7231$) and MSA 4 ($\pi_4^{SC}[5] = 30937$) at $t = 5$ are greater than their minimum expected profits, but profit of MSA 1 ($\pi_1^{SC}[5] =$ -4719) is negative. Therefore, the negotiation goes by and when $t = 11$ all profits of MSA 1 ($\pi_1^{SC}[11] = 2889$), MSA 2 ($\pi_2^{SC}[11] = 28698$), and MSA 4 ($\pi_4^{SC}[11] = 176797$) are greater than their minimum expected profits. Therefore, the negotiation between MA and {214} reach an equilibrium at $t = 11$.

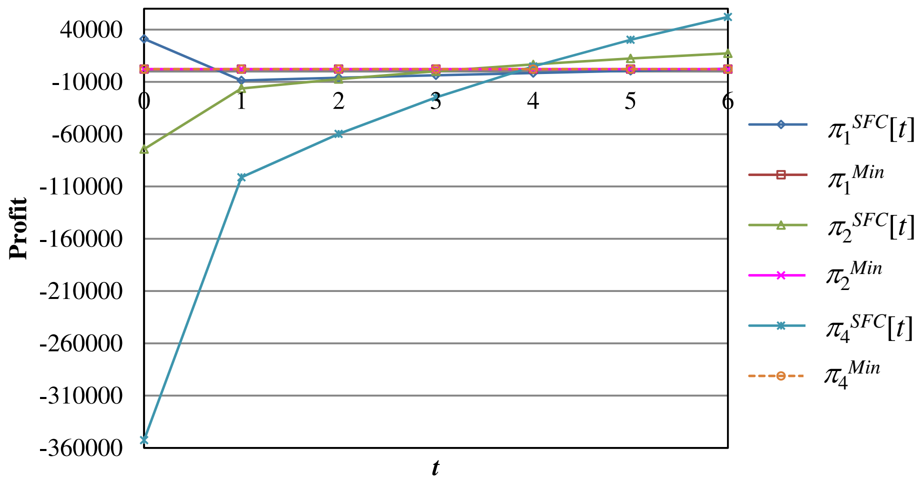


Figure 6.3: Fluctuation of profits of all members in {214}

Finally, iteration of MIMA negotiation is shown in Figure 6.4 - Figure 6.6 (Take coalition {214} as an example). Final equilibrium is reached at $t = 11$, where prices of items are (1.27, 13.84, 7.25, 108.80), quantities of items are (14770, 8862, 2954, 5908), and lead times of items are (40, 29, 29, 40). We can see from Figure 6.4 - Figure 6.6 that the equilibrium is reached even attributes haven't reached agreements. That's because each side of negotiation starts by selecting their most profitable strategies, and the final equilibrium is evaluated not only by one attribute, but on all three attributes.

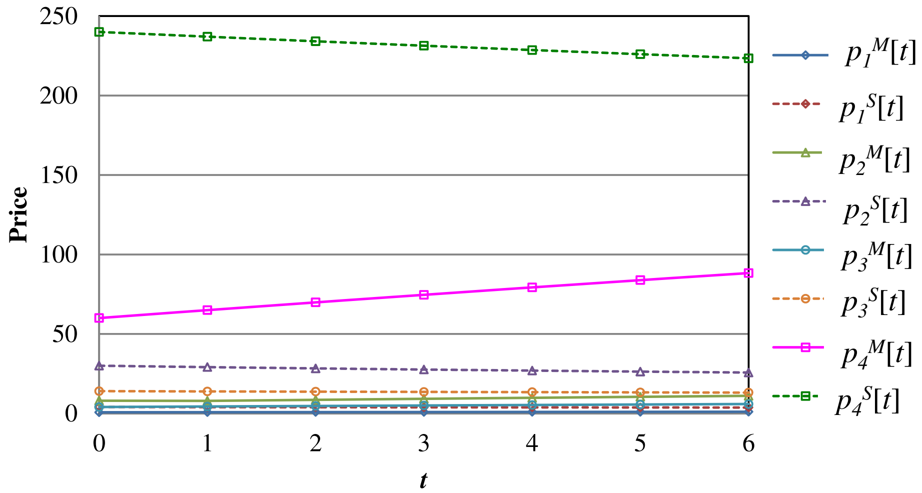


Figure 6.4: Fluctuation of prices of MA and {214} in MIMA negotiation

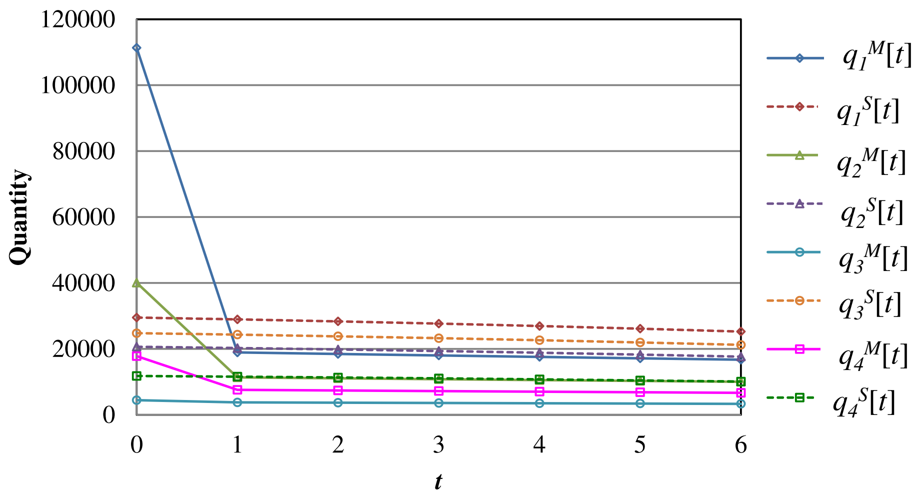


Figure 6.5: Fluctuation of quantities of MA and {214} in MIMA negotiation

6.2.4.2 Analysis

Simulation is executed by 1000 times and results are shown as Table 6.3, where average and standard derivation of calculation time are presented. We can see that the proposed protocol is effective and stable in solving MAMI negotiation between one-MA and multi-MSA.

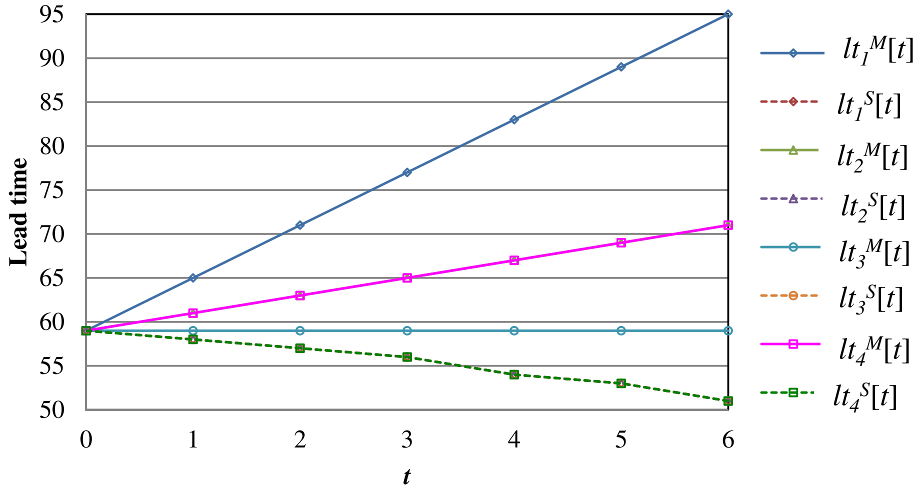


Figure 6.6: Fluctuation of lead time of MA and {214} in MIMA negotiation

Table 6.3: Calculation time of MAMI negotiation between one-MA and multi-MSA

	Calculation time (sec)
Avg.	4.3045
S.D.	0.0783

6.3 Multi-Attribute Multi-Item Negotiation between Multi-MA and Multi-MSA

Considering negotiation between I manufacturer agents (MAs) and J material supplier agents (MSAs). Three attributes (price, quantity, and lead time), and K items are involved. [Yu et al., 2012b] and [Yu et al., 2013b] discussed SASI negotiation between one MA and multi-MSA and SASI negotiation between multi-MA and multi-MSA, respectively. However, both of them assumed that only one item is ordered by MA(s). In this research, the results are generalized to more common situation where MAs want to buy multi-item at the same time and they want to maximally keep integrity of their orders. Negotiation model is shown in Figure 6.7, in which a car company (defined as MA) is taken as an example. MAs want to buy K items (glasses, tiers, bearings and so on) from MSAs, and attributes of each item are defined as a triple $(p_{ijk}^M, q_{ijk}^M, lt_{ijk}^M)$. Determination of quantity q_{ijk}^M and lead time lt_{ijk}^M of MA i depends on demand of market, and demand of market is affected by price p_{ijk}^M of MA i. It is assumed that MSAs try to find partners to establish coalitions when order of MA is out of their abilities (the dotted arrows among MSAs indicate negotiations to establish coalitions). We assume that the earlier for MAs to get material the better. That's because MAs may lose potential profits during waiting for materials.

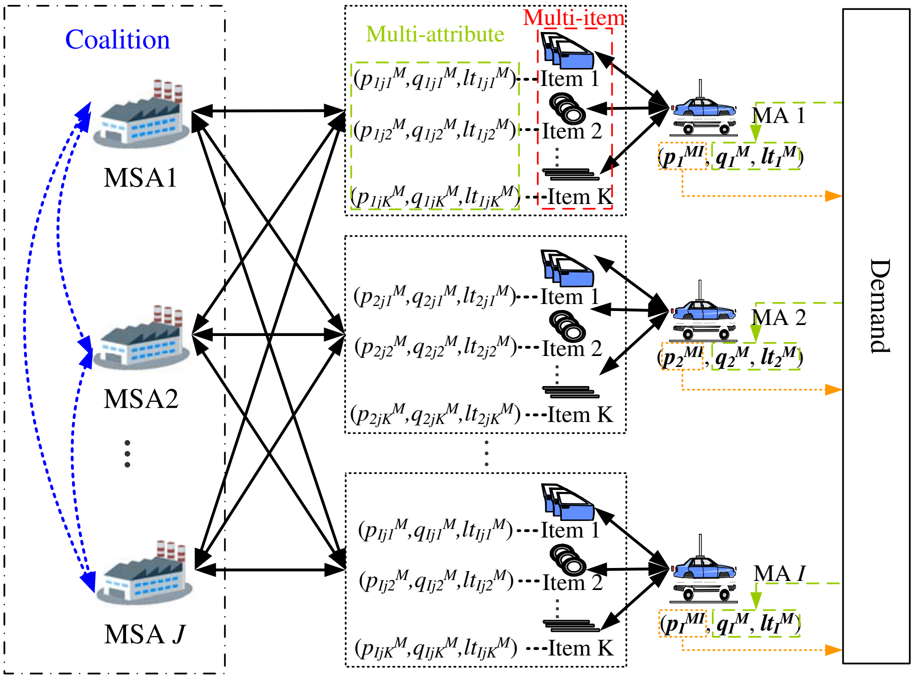


Figure 6.7: MAMI negotiation Model between multi-MA and multi-MSA

6.3.1 Coalition formation based negotiation protocol

As we have mentioned in section 6.2.1 that coalition which is in ability at initial rounds will become out of ability during multi-attribute negotiation. That's because in multi-attribute negotiation not only price is changing but also lead time, which will lead to change of ability of coalition. Therefore, a coalition formation which takes change of lead time into account is required. Coalition formation based negotiation protocol is proposed as follows:

- **Step 1:** At each negotiation iteration t, MAs calculate market demand and determine their strategies and broadcast to all MSAs.
- **Step 2:** At each negotiation iteration t, MSAs evaluate the order to check whether

the order is in their abilities or not. If al items are in their abilities, go to Step 4; if some items are out of their abilities, then go to Step 3.

• **Step 3:** MSAs try to find coalitions which can maximize their profits at t. If coalitions exist, check whether all items have been checked, if all items have been checked go to Step4 and if not then go back until all items have been checked. If coalitions does not exist, then check whether terminal condition has been arrived. If terminal condition has been arrived, reject the order and go to Step 7; if has not been arrived, then t plus one and go back to Step 1.

• **Step 4:** MSAs determine their strategies and go to Step 5.

• **Step 5:** MAs negotiate with MSAs (coalitions) to determine equilibriums, if equilibriums are found, go to Step 7, and if they are not found yet, then go to Step 6.

• **Step 6:** Check whether terminal condition is reached or not. If it is reached, negotiation ends and fails to reach an agreement and go to Step 7; if it is not reached, then t plus one, and go back to Step 1.

• **Step 7:** Check whether all MSAs have given responses. If all MSAs have given responses, go to Step 8; if not all MSAs have given responses, then wait until all MSAs give replies.

• **Step 8:** MA determines final allocation scheme according to equilibriums obtained from Step 5 and negotiation ends.

Flowchart of the protocol is shown in Figure 6.8. Details of related protocol are discussed in following sections.

6.3.2 Coalition formation mechanism

The coalition $SC_{ij}[t]$ which can maximize its profit will be determined as final coalition according to section 2.4 by solving following problems:

$$SC_{ij}[t] \quad = arg \max_{s_{ijl}[t]} (p^M_{ijk}[t] - C_{jk})QS_{ijljk}[t] \tag{6.23}$$

$$\text{s.t.} \qquad AC_{ijlk}[t] \geq q^M_{ijk}[t], \forall k \tag{6.24}$$

where

$$QS_{ijlj'k}[t] = A_{ij'k}[t]q^M_{ijk}[t]/AC_{ijlk}[t], \forall j' \in s_{ijl}[t], \forall k \tag{6.25}$$

$$AC_{ijlk}[t] = \sum_{j' \in s_{ijl}[t]} \gamma_{j'k} LT^M_{ij}[t] \tag{6.26}$$

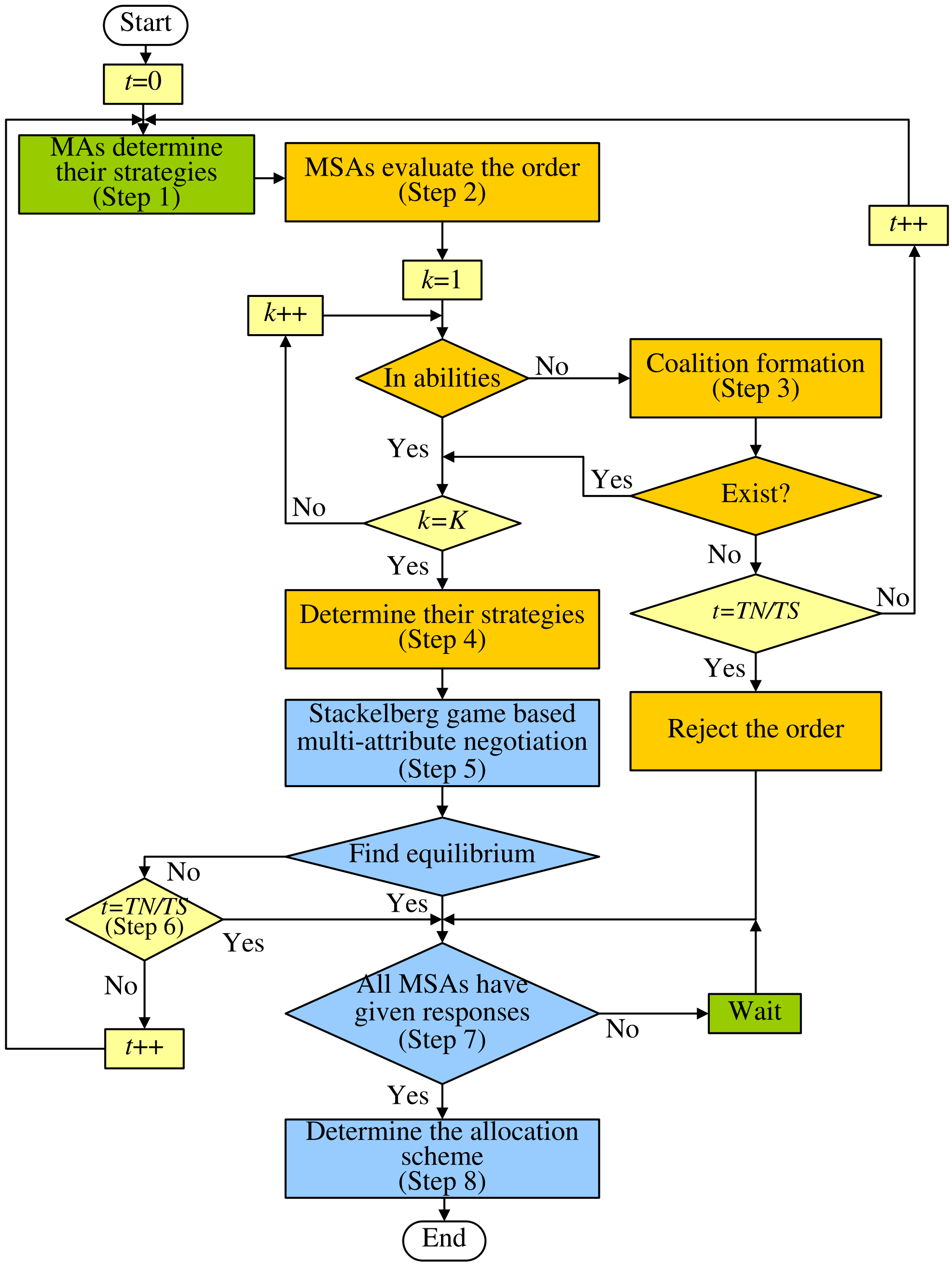


Figure 6.8: Flowchart of coalition formation based MAMI negotiation protocol

$$\pi^{SC}_{ijlj'}[t] = \sum_{k=1}^{K} p^M_{ijk}[t] QS_{ijlj'k}[t] - \sum_{k=1}^{K} C_{j'k} QS_{ijlj'k}[t] + \sum_{k=1}^{K} (lt^M_{ijlk}[t] - lt^S_{ij'k}[0]) clt^S_{j'} \tag{6.27}$$

and

$\pi^{SC}_{ijlj'}[t]$: profit of MSA j' by belonging to coalition $s_{ijl}[t]$

$\gamma_{j'k}$: productivity of item k of MSA j

$A_{ijk}[t]$: ability of item k of MSA j at t

$AC_{ijlk}[t]$: ability of item k of coalition $s_{ijl}[t]$

$clt^S_{j'}$: profit or loss of MSA j' by extending or shortening the lead time per day

C_{jk}: cost of item k of MSA j

$p^M_{ijk}[t]$: price of item k of MA i for MSA j at t

$lt^M_{ijlk}[t]$: lead time of item k of MA i for coalition $s_{ijl}[t]$

$LT^M_{ij}[t]$: lead time of MA i for MSA j at t

$q^M_{ijk}[t]$: quantity of item k of MA i for MSA j at t

$QS_{ijljk}[t]$: acquired quantity of item k of MSA j by belonging to $s_{ijl}[t]$

$AC_{ijlk}[t]$: coalition of MSA j for MA i at t.

Equation (6.23) is used to find coalition $s_{ijl}[t]$ in which profit of MSA j is maximized, equation (6.24) is used to ensure that determined coalition must in abilities of all items of MA i, and related acquired quantity $QS_{ijljk}[t]$ and total ability $AC_{ijlk}[t]$ are calculated by equation (6.25) and equation (6.26), respectively. Profit is allocated according to contributions of its members as equation (6.27) after coalition is formed, where the first part is payment of MSA j can receive by belonging to coalition $s_{ijl}[t]$, the second part is cost of MSA j to supply received part, and the last part is profit or loss of extending or shortening lead time.

6.3.3 Determination of equilibriums

Determination of equilibrium depends on strategies of MAs and MSAs (coalitions). Thus, determination of strategies of MAs, MSAs, and coalitions are discussed at first. They determine their strategies according to their own preferences. $\omega_{i,p}^M$, $\omega_{i,q}^M$, and $\omega_{i,lt}^M$ are respectively defined as weights of price, quantity and lead time of MA i, and $\omega_{j,p}^S$, $\omega_{j,q}^S$, and $\omega_{j,lt}^S$ are defined as weights of price, quantity and lead time of MSA j, respectively. Concessions, which are not only among attributes but also among items, are taken into account during determination of strategies. MAs and MSAs make concessions according to their related weight of each attribute. $\delta_{x,y}^z(y)$ is concession rate of attribute x related to attribute y of z and calculated by equation (5.2), where x, $y \in \{p, q, lt\}$, and $z \in \{M, S\}$. p, q, and lt indicate concession is related to price, quantity and lead time, respectively. M and S indicate it's concession of MA and MSA, respectively. $\theta_g^{x,y}$ is threshold value of concession of attribute x related to attribute y, and y_g is piece-wise constant of attribute y.

6.3.3.1 Strategies of MAs

It is assume that MAs in this research have more negotiation powers and initiatives. They announce their strategies firstly. Concessions among attributes have been discussed in section 5.2.3. Thus, we can get:

$$\begin{aligned} p_{ijk}^M[t] = p_{ijk}^M[t-1] + \omega_{i,p}^M(P_{ik}^{MU} - p_{ijk}^M[t-1])/(TN - tTS)/TS \\ +\omega_{i,p}^M \delta_{p,lt}^M(lt_{ijk}^S[t-1]) \end{aligned} \tag{6.28}$$

$$q_{ijk}^M[t] = d_{ijk}^M[t] + \omega_{i,q}^M \delta_{q,p}^M(p_{ijk}^S[t-1]) \tag{6.29}$$

$$lt_{ijk}^M[t] = lt_{ijk}^M[t-1] + \omega_{i,lt}^M \delta_{lt,p}^M(p_{ijk}^S[t-1]) + \omega_{i,lt}^M \delta_{lt,q}^M(q_{ijk}^M[t]) \tag{6.30}$$

$$LT_{ij}^M[t] = \max_{k=1}^{K}\{lt_{ijk}^M[t]\} \tag{6.31}$$

$$d_{ijk}^M[t] = \eta_{ik} D_{ij}^M[t] \tag{6.32}$$

$$D_{ij}^M[t] = a_i - b_i P_{ij}^M[t] \tag{6.33}$$

$$P_{ij}^M[t] = (1+\alpha_i)\sum_{k=1}^{K} \eta_{ik} p_{ijk}^M[t] \tag{6.34}$$

where

α_i: percentage of profit of MA i

η_{ik}: proposition of item k of MA i

$d^M_{ijk}[t]$: demand of item k of MA i for MSA j at t

$D^M_{ij}[t]$: demand of final product of MA i at t

P^{MU}_{ik}: upper bound of price of item k of MA i

$P^M_{ij}[t]$: total price of unit final product of MA i at t

$p^S_{ijk}[t-1]$: price of item k of MSA j for MA i at $t-1$.

Equations (6.28) - (6.30) are used to calculate price, quantity and lead time of MA i at t^{th} iteration of negotiation with MSA j. The second part of equation (6.28) is concession related to remain negotiation time, and the third part is concession related to lead time of MSA j at $t-1$. The second part of equation (6.29) is concession related to price of MSA j at $t-1$. The second part of equation (6.30) is concession of lead time related to price of MSA j at $t-1$, and the third part of equation (6.30) is concession of lead time related to its own quantity. Equation (6.31) is used to calculate final lead time of the whole order and it equals to the maximal lead time of all items. Equation (6.32) is used to calculate demand of each item k at t, and it depends on demand of final product $D^M_{ij}[t]$ at t. Demand of final product at t is calculated by equation (6.33), it is assumed in an additive form, and depends on price of final product $P^M_{ij}[t]$ at t. Equation (6.34) is used to calculate price of final product, and it equals to summation of prices of all needed items.

6.3.3.2 Strategies of MSAs

MSAs determine their strategies according to strategies of MAs at t, and make concessions as discussed in section 5.2.3. Thus, all three attributes are defined as follows:

$$p^S_{ijk}[t] = p^S_{ijk}[t-1] - \omega^S_{j,p}(p^S_{ijk}[t-1] - p^M_{ijk}[t])/(TN - tTS)/TS - \omega^S_{j,p}\delta^S_{p,q}(q^M_{ijk}[t]) - \omega^S_{j,p}\delta^S_{p,lt}(LT^M_{ij}[t]) \quad (6.35)$$

$$q^S_{ijk}[t] = A_{ijk}[t] - \omega^S_{j,q}\delta^S_{q,p}(p^M_{ijk}[t]) - \omega^S_{j,q}\delta^S_{q,lt}(LT^M_{ij}[t]) \quad (6.36)$$

$$lt^S_{ijk}[t] = lt^{SU}_{ijk}[t] - \omega^S_{j,lt}\delta^S_{lt,p}(p^M_{ijk}[t]) \quad (6.37)$$

$$lt^{SU}_{ijk}[t] = A_{ijk}[t]/\gamma_{jk} \quad (6.38)$$

$$A_{ijk}[t] = \gamma_{jk} LT^M_{ij}[t] \tag{6.39}$$

$$p^S_{ijk}[0] = P^{SU}_{jk} = (1 + \beta^{SU}_j) C_{jk} \tag{6.40}$$

where

β^{SU}_j: upper bound of percentage of profit of MSA j

$lt^S_{ijk}[t]$: lead time of item k of MSA j at t

lt^{SU}_{ijk}: upper bound of lead time of item k of MSA j

P^{SU}_{jk}: upper bound of price of item k of MSA j

$q^S_{ijk}[t]$: quantity of item k of MSA j for MA i at t.

Equations (6.35) - (6.37) are used to calculate price, quantity and lead time of MSA j at iteration t. The second part of equation (6.35) is concession of price of MSA j related to remain negotiation time, the third part is concession related to quantity of MA i at t, and the last part is concession related to lead time of MA i at t. The second part of equation (6.36) is concession of quantity of MSA j related to price of MA i at t, and the third part is concession related to lead time of MA i at t. Equation (6.37) is used to calculate lead time of MSA j at t, the first part is upper bound of lead time of MSA j for item k, and the second part is concession related to price of MA i at t. Equation (6.38) is to calculate upper bound of lead time of MSA j for item k. $A_{ijk}[t]$ in equation (6.36) is ability of MSA j of item k at t, and is calculated by equation (6.39). Initial price of MSA j equals to upper bound of its expected price, and is calculated by equation (6.40).

6.3.3.3 Strategies of coalitions

Strategies of coalition $s_{ijl}[t]$ of MSA j are calculated by

$$\begin{aligned} p^C_{ijlk}[t] = {} & p^C_{ijlk}[t-1] - \omega^S_{j,p}(p^C_{ijlk}[t-1] - p^M_{ijk}[t])/(TN - tTS)/TS - \omega^S_{j,p}\delta^S_{p,q}(q^M_{ijk}[t]) \\ & -\omega^S_{j,p}\delta^S_{p,lt}(LT^M_{ij}[t]) \end{aligned} \tag{6.41}$$

$$q^C_{ijlk}[t] = AC_{ijlk}[t] - \omega^S_{j,q}\delta^S_{q,p}(p^M_{ijk}[t]) - \omega^S_{j,q}\delta^S_{q,lt}(LT^M_{ij}[t]) \tag{6.42}$$

$$lt^C_{ijlk}[t] = lt^{CU}_{ijlk}[t] - w^S_{j,lt}\delta^S_{lt,p}(p^M_{ijk}[t]) \tag{6.43}$$

$$lt^{CU}_{ijlk}[t] = AC_{ijlk}[t] / \sum_{j' \in s_{ijl}[t]} \gamma_{j'k} \tag{6.44}$$

where

$lt^{C}_{ijlk}[t]$: lead time of item k of coalition $s_{ijl}[t]$

$lt^{CU}_{ijlk}[t]$: upper bound of lead time of item k of coalition $s_{ijl}[t]$

$p^{C}_{ijlk}[t]$: price of item k of coalition $s_{ijl}[t]$

$q^{C}_{ijlk}[t]$: quantity of item k of coalition $s_{ijl}[t]$.

Equations (6.41) - (6.44) are used to calculate price, quantity, lead time of item k, and upper bound of lead time of coalition $s_{ijl}[t]$, respectively. Calculations of concessions among attributes are the same with calculations of MSAs.

6.3.3.4 Determination of equilibriums

It has been assumed above that MAs in proposed model have more negotiation power. Thus, interaction between MA and MSA (coalition) can be seen as a MA-Stackelberg game, where MA is the leader. Objective of the leader is to design its move to maximize its profit after considering all rational moves follower may devise. Strategies of MAs which can maximize their profits are determined as final equilibriums. However, these equilibriums must be accepted by MSAs or coalitions as well. In order to maintain stabilities of coalitions, it is assumed that equilibriums are accepted by coalitions if and only if all members in coalitions are profitable. Profits of MAs and coalitions are defined as:

$$\pi^{M}_{ij}[t] = D^{M}_{ij}[t]P^{M}_{ij}[t] - \sum_{k=1}^{K} p^{M}_{ijk}[t]q^{M}_{ijk}[t] + \sum_{k=1}^{K} (q^{M}_{ijk}[t] - d^{M}_{ijk}[t])sv_{ik} \qquad (6.45)$$
$$-(LT^{M}_{ij}[t] - LT^{M}_{ij}[0])clt^{M}_{i}$$
$$\pi^{C}_{ijl}[t] = \sum_{k=1}^{K} p^{M}_{ijk}[t]q^{M}_{ijk}[t] - \sum_{k=1}^{K}\sum_{j'\in s_{ijl}} C_{j'k}QS_{ijlj'k} + (LT^{M}_{ij} - LT^{S}_{ij})clt^{S}_{j} \qquad (6.46)$$

where

$\pi^{M}_{ij}[t]$: profit of MA i with MSA j at t

$\pi^{C}_{ijl}[t]$: profit of coalition $s_{ijl}[t]$

clt^{M}_{i}: profit or loss of MA i by shortening or extending the lead time per day

sv_{ik}: salvage value of item k of MA i.

The first part of equation (6.45) is profit of sold parts of MA i, the second part is salvage value of unsold part, the third part is payment MA i should pay for coalition $s_{ijl}[t]$, and the last part is profit or loss of extending or shortening lead time. Equation (6.46) is used to calculate profit of coalition $s_{ijl}[t]$, the first part is payment got from MA i, the second part is total cost of members in coalition $s_{ijl}[t]$ to supply all items, and the last part is profit or loss of shortening or extending lead time.

Equilibrium of negotiation between MA i and coalition $s_{ijl}[t]$ can be obtained by solving following problem:

$$arg\max \quad \{\pi_{ij}^{M}[t]\} \tag{6.47}$$

$$\text{s.t.} \quad \pi_{ij}^{M}[t] > 0 \tag{6.48}$$

$$\pi_{ijlj'}^{SC}[t] > 0, \forall j' \in s_{ijl}[t] \tag{6.49}$$

$$AC_{ijlk}[t] \geq q_{ijk}^{M}[t], \forall k \tag{6.50}$$

where equation (6.47) indicates that strategies of MA i at t can be determined as equilibrium if it can maximize profit of MA i. Equations (6.48) - (6.50) are constraints, where equation (6.48) is used to ensure MA i is profitable at t by accepting this equilibrium, equation (6.49) is used to ensure all members in coalition $s_{ijl}[t]$ are profitable at t by accepting this equilibrium, and equation (6.50) is used to ensure that coalition $s_{ijl}[t]$ must be in ability at t.

What should we pay attention to is $s_{ijl}[t]$ equals to j and $AC_{ijlk}[t]$ equals to $A_{ijk}[t]$ if it's trying to find equilibrium of negotiation between MA i and MSA j rather than coalition $s_{ijl}[t]$.

6.3.4 Determination of final allocation scheme

The negotiation tries to determine final allocation scheme after all MSAs sending their responses. It can be seen as a two-person game as we have discussed in section 3.3.1.1, where all MAs are considered as player 1 and all MSAs are combined as player 2. Strategy of player 1 is allocation scheme $\bar{U}_w$ of assigning MAs to MSAs, where $\bar{U}_w = [\bar{u}_1, ..., \bar{u}_I]$, and $\bar{u}_i = j$ indicates that MA i is allocated to MSA j. Strategy of player 2 $\tilde{U}_v$ is allocation scheme of assigning obtained orders from MAs to coalitions of MSAs, where $\tilde{U}_v = [\tilde{u}_{ji}]_{J\times I}$, $\tilde{u}_{ji} = l$ indicates obtained order of MSA j from MA i is allocated to the l^{th} coalition $s_{ijl}[TF_{ijl}]$ of MSA j at TF_{ijl}, and $\tilde{u}_{ji} = \phi$ indicates MA i is not allocated to MSA j.

Objective of the game is to decide strategies of players which can maximize total profit of SCNs. Therefore, allocation scheme can be called as an equilibrium of the game if none of members of players can benefit by changing its strategy while the other player keep its strategy unchanging. The innovative point is players in the two-person game actually consist of multiple players. In order to reduce complexity to solve the problem, strategy of player 1 $\bar{U}_w$ and strategy of player 2 $\tilde{U}_v$ are combined together as m_{ijl}, where m_{ijl} equals to 1 if and only if $\bar{u}_i$ equals to j and $\tilde{u}_{ji}$ equals to l, and otherwise it equals to 0. Determination of m_{ijl} is done by a market mediator. Thus, final equilibrium which can maximize total profit of SCNs (π_{wv}^{SCN}) can be obtained by solving

$$\max \quad \pi_{wv}^{SCN} = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{l=1}^{L} m_{ijl}(\pi_{ijl}^{M}[TF_{ijl}] + \pi_{ijl}^{C}[TF_{ijl}]) \tag{6.51}$$

$$\text{s.t.} \quad m_{ijl}AC_{ijlk}[TF_{ijl}] \geq q_{ijk}^{M}[TF_{ijl}], \forall i, \forall j, \forall l, \forall k \tag{6.52}$$

$$\pi_{ijl}^{M}[t] > 0 \tag{6.53}$$

$$\pi_{ij}^{SC}[TF_{ijl}] > 0, \forall j \in s_{ijl}[TF_{ijl}] \tag{6.54}$$

$$\sum_{j=1}^{J}\sum_{l=1}^{L} m_{ijl} = 1, \forall i \tag{6.55}$$

$$\sum_{i=1}^{I}\sum_{l=1}^{L} m_{ijl}QS_{ijljk}[TF_{ijl}] \leq AU_{jk}[TF_{ijl}], \forall j, \forall k \tag{6.56}$$

$$AU_{jk} = \gamma_{jk} \max_{i=1}^{I}\{m_{ijl}LT_{ij}^{M}[TF_{ijl}]\}, \forall j, \forall k \tag{6.57}$$

$$TF_{ijl} = arg \max_{t}\{\pi_{ijl}^{M}[t]\} \tag{6.58}$$

$$m_{ijl} \in \{0, 1\}, \forall i, \forall j, \forall l \tag{6.59}$$

where

TF_{ijl}: final iteration index of reaching equilibrium between MA i and coalition $s_{ijl}[t]$

AU_{jk}: upper bound of ability of item k of MSA j.

Equation (6.51) is used to calculate total profit of whole SCNs, equation (6.52) is used to ensure final determined coalition is in ability of the related order, equation (6.53) is used to ensure all MAs are profitable, equation (6.54) is used to ensure that all members in final determined coalitions are profitable, equation (6.55) is used to ensure that each MA i must be allocated to only one coalition, equation (6.56) is used to ensure that each MSA j can only accept orders which are in its ability, and equation (6.57) is used to calculate upper bound of ability of MSA j at the longest lead time of all orders it received. TF_{ijl} is final iteration time to get equilibrium of negotiation between MA i and coalition $s_{ijl}[t]$ by solving equation (6.58).

6.3.5 Simulation and analysis

Simulations are provided in this section to imitate MAMI negotiation based on the proposed protocol. We assume there is five MAs and six MSAs in SCNs and four items are involved in negotiation. Experimental parameters are presented in Table 6.4. We also assume that a_i equals to 5000, b_i equals to 5, α_i equals to 0.3, β_j^U equals to 2, TN equals to 60, TS equals to 1, and both clt_i^M and clt_j^S equal to 100. η_{ik} equals to 5, 3, 1, and 2 for item 1, item 2, item 3 and item 4, respectively. sv_{ik} of item 1, item 2, item 3, and item 4 equals to 0.1, 0.5, 1, and 5, respectively. $\omega_p = 0.5$, $\omega_q = 0.25$ and $\omega_{lt} = 0.25$. Eclipse IDE for Java Developers and ILOG CPLEX 12.0 are used to execute simulations to verify feasibility of proposed protocol.

Table 6.4: Parameter settings of MSAs.

	k=1			k=2			k=3			k=4		
	γ_{jk}	C_{jk}	Q_{jk}^{SL}	γ_{jk}	C_{jk}	Q_{jk}^{SL}	γ_{jk}	C_{jk}	Q_{jk}^{SL}	γ_{jk}	C_{jk}	Q_{jk}^{SL}
MSA 1	500	1.5	240	0	0	0	200	5	169	0	0	0
MSA 2	0	0	0	350	10	22	0	0	0	0	0	0
MSA 3	350	1.7	350	200	12	17	150	5.5	152	0	0	0
MSA 4	0	0	0	0	0	0	220	4.9	178	200	80	10
MSA 5	250	1.65	250	200	10.5	22	100	5.1	152	100	80	10
MSA 6	0	0	0	0	0	0	0	0	0	300	75	11

6.3.5.1 Verification

Details of coalitions and equilibriums are omitted, and final strategies of player 1 and player 2 are as follows:

$$\bar{U}_{w1} = \begin{pmatrix} 2 & 6 & 3 & 2 & 3 \end{pmatrix}, \tilde{U}_{v1} = \begin{pmatrix} \phi & \phi & \phi & \phi & \phi \\ 18 & \phi & \phi & 9 & \phi \\ \phi & \phi & 15 & \phi & 15 \\ \phi & \phi & \phi & \phi & \phi \\ \phi & \phi & \phi & \phi & \phi \\ \phi & 6 & \phi & \phi & \phi \end{pmatrix},$$

where $\bar{U}_{w1}$ and $\tilde{U}_{v1}$ are strategies of player 1 and player 2 in Case 1, respectively. $\bar{U}_{w1}$ and $\tilde{U}_{v1}$ indicate that MA 1 is allocated to the 18^{th} coalition {2136} of MSA 2, MA 2 is allocated to the 6^{th} coalition {612} of MSA 6, MA 3 is allocated to the 15^{th} coalition {356} of MSA 3, MA 4 is allocated to the 9^{th} coalition {216} of MSA 2, and MA 5 is allocated to the 15^{th} coalition {356} of MSA 3 in Case 1.

Table 6.5: Final allocation scheme in Case 1.

	s^F_{ijl}	π^{MF}_{ijl}	π^{CF}_{ijl}	TF_{ijl}	π^{SCN}_{wv}
MA 1	{2136}	603325.9	204248	20	4168005.2
MA 2	{612}	818285.6	63604.2	11	
MA 3	{356}	627854.4	163012.8	19	
MA 4	{216}	805315.6	72204.0	11	
MA 5	{356}	678699.5	131454.8	17	

6.3.5.2 Analysis

We can see from above verification that the proposed protocol was feasible in solving MAMI negotiation.

(a) Calculation time

Nextly, we will discuss about effectiveness of proposed protocol in solving MAMI negotiation. The simulation is executed by 1000 times and the results are shown as Table 6.6, where average and standard derivation of calculation time are presented. We can see the proposed protocol is effective and stable in solving MAMI negotiation between multi-MA and multi-MSA.

(b) Comparison of the proposed protocol under different weights

In this section, effects caused by weights of attributes are discussed. Nine cases are provided, where MAs and MSAs prefer to give the biggest concessions of their prices in

Table 6.6: Calculation time of MAMI negotiation between multi-MA and multi-MSA

	Calculation time (sec)
Avg.	1.5767
S.D.	0.0543

Case 1, Case 4, and Case 7, give the biggest concessions of quantities in Case 2, Case 5, and Case 8, and give the biggest concessions of lead time in Case 3, Case 6, and Case 9, respectively.

- Case 1: ω_p =0.5, ω_q =0.25,ω_{lt} =0.25;
- Case 2: ω_p =0.25,ω_q =0.5, ω_{lt} =0.25;
- Case 3: ω_p =0.25,ω_q =0.25,ω_{lt} =0.5;
- Case 4: ω_p =0.6, ω_q =0.2, ω_{lt} =0.2;
- Case 5: ω_p =0.2, ω_q =0.6, ω_{lt} =0.2;
- Case 6: ω_p =0.2, ω_q =0.2, ω_{lt} =0.6;
- Case 7: ω_p =0.8, ω_q =0.1, ω_{lt} =0.1;
- Case 8: ω_p =0.1, ω_q =0.8, ω_{lt} =0.1;
- Case 9: ω_p =0.1, ω_q =0.1, ω_{lt} =0.8.

(c) Relationship between the weights and the convergence rates

Equilibriums of the negotiations between MAs and MSAs or coalitions can be obtained by solving equations (6.47) - (6.50). Total numbers of in ability coalitions for MAs in 9 cases are shown in Table 6.7, where NS_i is total number of suppliers (include MAs and coalitions), with which MA i succeed to find equilibrium.

Details of all equilibriums are presented in **Appendix A4**, and after simulation we have:

• It's faster to find equilibriums when weight of price is the biggest: in Case 1, Case 4, and Case 7;

• Prices of items are higher when weight of price is the biggest: in Case 1, Case 4, and Case 7;

• Quantities of items are higher when weight of quantity is the biggest: in Case 2, Case 5, and Case 8.

Results are shown in Figure 6.9 - Figure 6.11, and we can see that:

Table 6.7: The number of in ability coalitions in different cases.

	NS_i								
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
MA 1	134	130	141	123	102	110	125	58	62
MA 2	130	130	138	125	109	109	125	94	111
MA 3	130	128	132	113	80	97	124	48	49
MA 4	130	125	134	125	112	112	125	94	114
MA 5	134	130	141	121	95	108	125	60	60

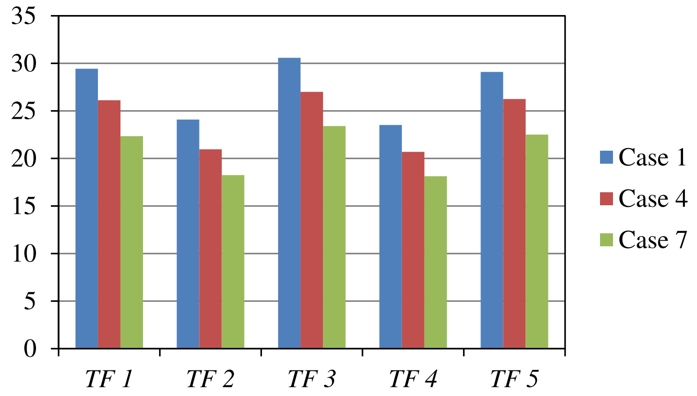


Figure 6.9: Comparison of TF related to ω_p.

- TF_i decreases as ω_p increases (see Figure 6.9);

- TF_i increases as ω_q increases (see Figure 6.10);

- TF_i increases as ω_{lt} increases (see Figure 6.11).

(d) Relationship between weights and iterations of attributes

The negotiation between MA 2 and coalition {612} is taken as an example to illustrate iteration of three attributes in nine cases. Final equilibriums in nine cases are shown in Figure 6.12 - Figure 6.14, where TF_i is final iteration to reach equilibriums, and p^F_{ijk}, q^F_{ijk}, and lt^F_{ijk} is price, quantity, and lead time of item k at TF. We can see from Figure 6.12 that p^F_{ijk} has the highest values in Case 1, Case 4, and Case 7, and from Figure 6.13 that

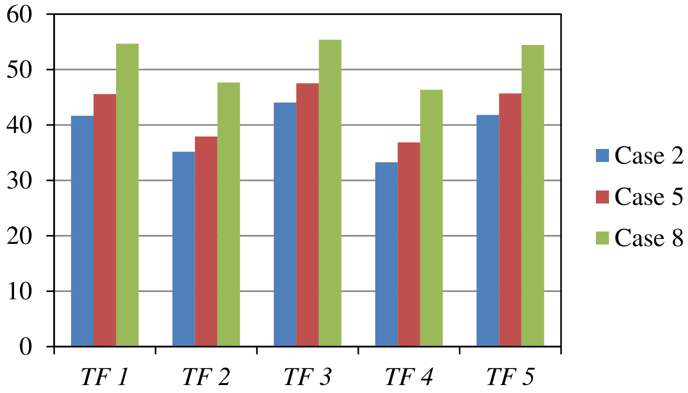


Figure 6.10: Comparison of TF related to ω_q.

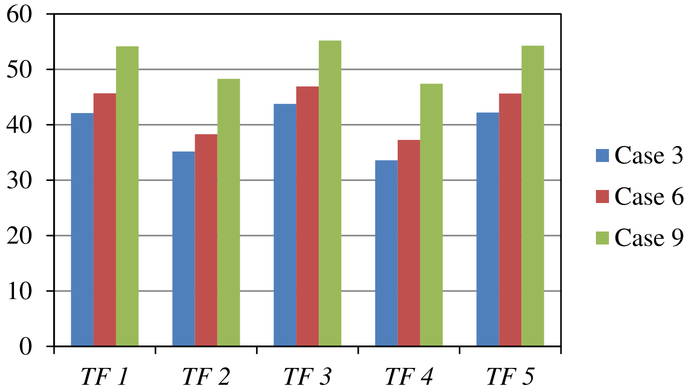


Figure 6.11: Comparison of TF related to ω_{lt}.

lt^F_{ijk} has the highest values in Case 3, Case 6, and Case 9. Moreover, it's faster to find equilibriums in Case 1, Case 4, and Case 7 (see TF_i in Figure 6.12), in which weight of price has the highest value.

Then, we take item 1 as an example to illustrate iteration of attributes in Case 1 - Case 3. Iteration of attributes are shown in Figure 6.15 - Figure 6.17, where $PM1$, $PM2$, and $PM3$, $QM1$, $QM2$, and $QM3$, and $LTM1$, $LTM2$, and $LTM3$ are prices, quantities, and lead time of MA 2 in Case 1, Case 2 and Case 3, respectively; $PC1$, $PC2$, and $PC3$, $QC1$, $QC2$, and $QC3$, and $LTC1$, $LTC2$, and $LTC3$ are prices, quantities, and lead time of coalition $\{612\}$ in Case 1, Case 2 and Case 3, respectively. We can get from Figure 6.15 - Figure 6.17 that:

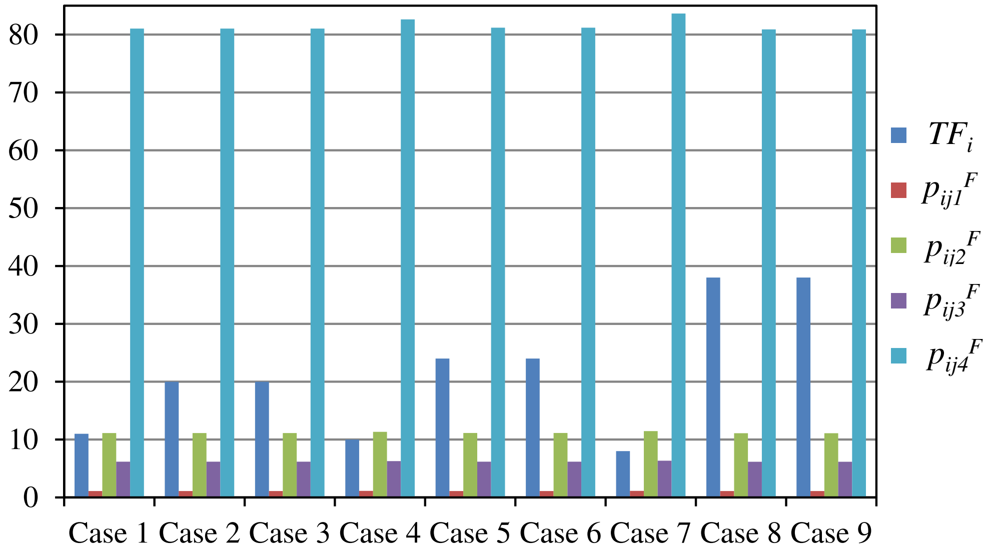


Figure 6.12: Final prices in nine cases.

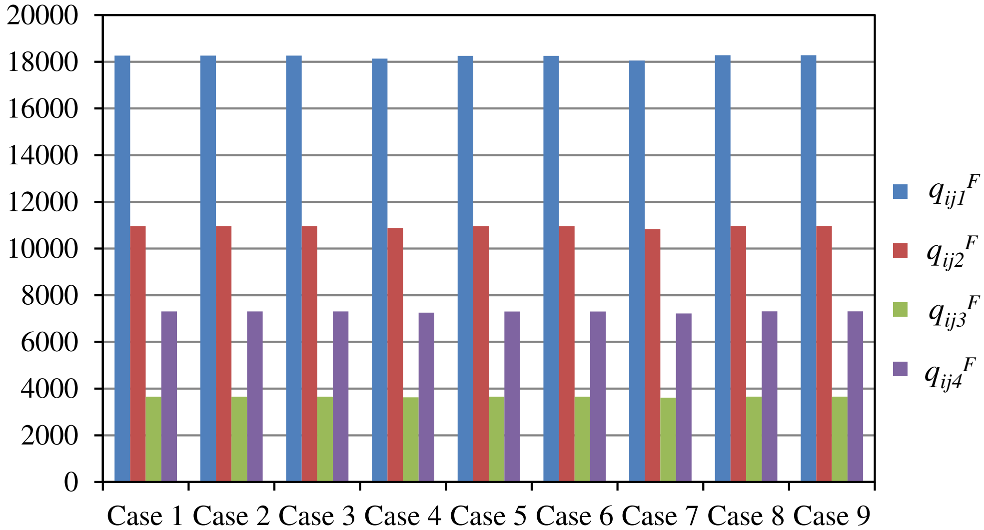


Figure 6.13: Final quantities in nine cases.

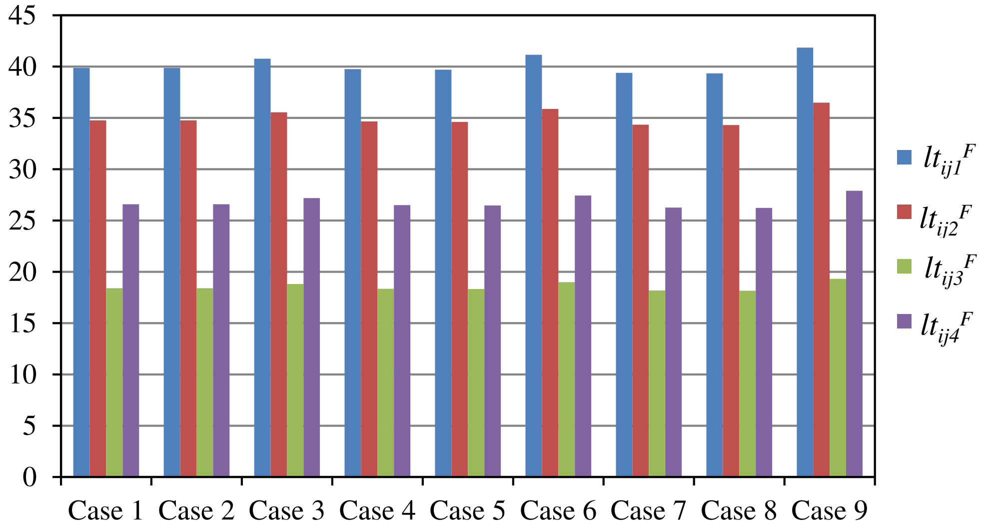


Figure 6.14: Final lead time in nine cases.

- In Case 1: weight of price has the highest value.

- $PM1$ gives the greatest concessions in Case 1 (e.g. $PM1[3]$ = 0.919 is greater than $PM2[3]$ = 0.887 and $PM3[3]$ =0.887 in Figure 6.15(a)). That's because concession rate (the second parts and third parts of equation (6.28)) is the greatest in Case 1.

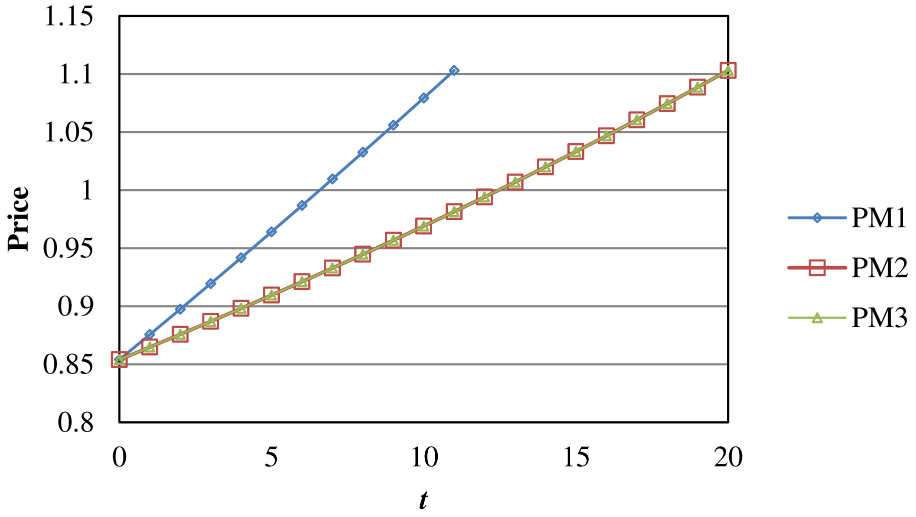
- $PC1$ gives the greatest concessions in Case 1 (e.g. $PC1[3]$ = 3.035 is less than $PC2[3]$ = 3.960 and $PC3[3]$ = 3.60 in Figure 6.15(b)). That's because concession rate (the second parts and third parts of equation (6.41)) is the greatest in Case 1.

- In Case 2: weight of quantity has the highest value.

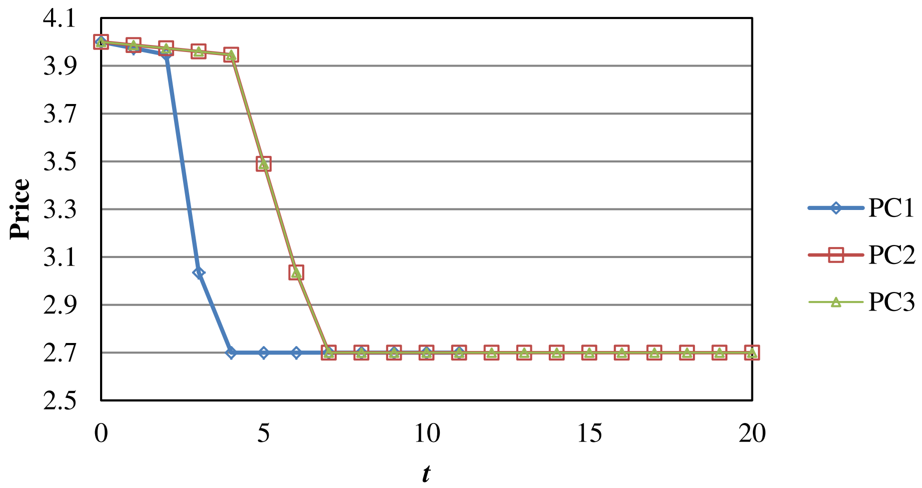
- $QM2$ has the highest value in Case 2 (e.g. $QM2[11]$ = 19095 is greater than $QM1[11]$ = 18265 and $QM3[11]$ = 19095 in Figure 6.16(a)). That's because concession rates (the second part of equation (6.29)) is the greatest in Case 2.

- $QC2$ has the lowest value in Case 2 (e.g. $QC2[11]$ = 19719.09 is less than $QC1[11]$ = 19937.70 and $QC3[11]$ = 19940.41 in Figure 6.16(b)). That's because concession rate (the second part and third part of equation (6.42)) is the highest in Case 2.

- In Case 3: weight of lead time has the highest value.

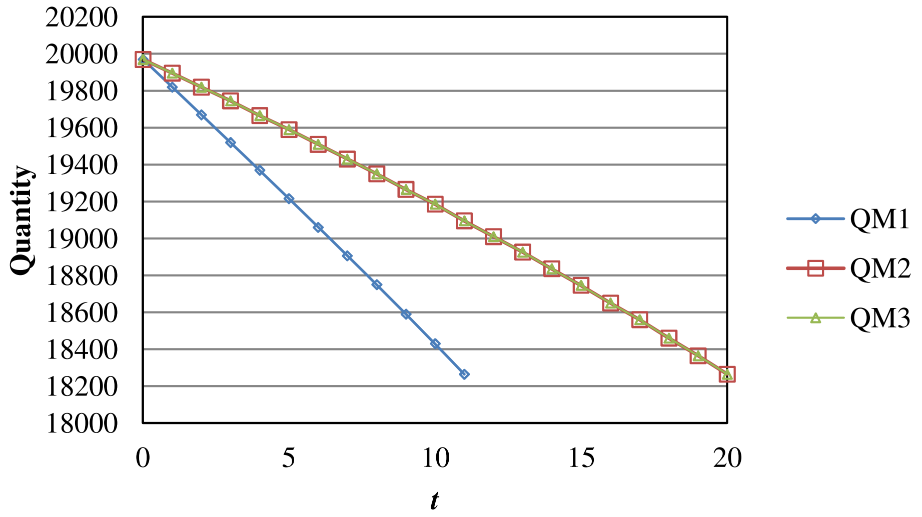


(a) Fluctuation of PM

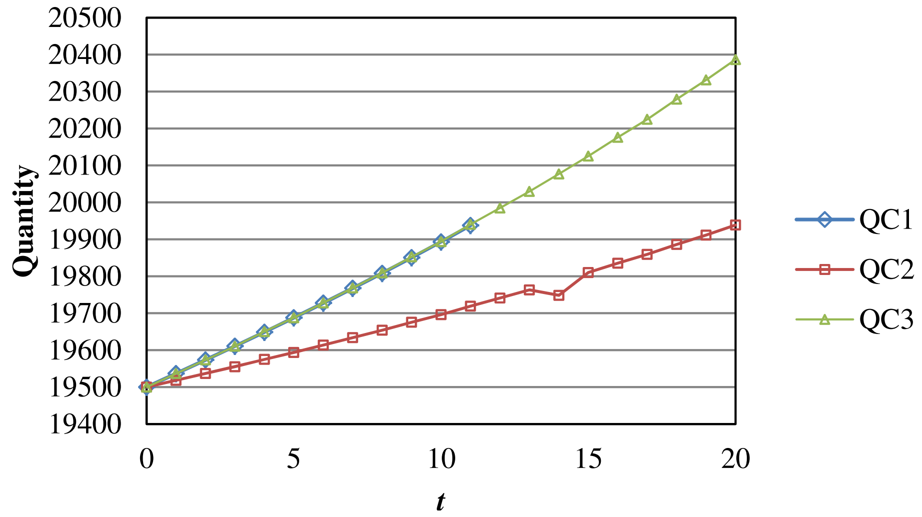


(b) Fluctuation of PC

Figure 6.15: Fluctuation of quantity in Case 1 - Case 3.



(a) Fluctuation of QM



(b) Fluctuation of QC

Figure 6.16: Fluctuation of quantity in Case 1 - Case 3.

- $LTM3$ has the highest value in Case 3 (e.g. $LTM3[11] = 39.881$ is greater than $LTM1[11] = 39.875$ and $LTM2[11] = 39.438$ in Figure 6.17(a)). That's because concession rate (the second part and third part of equation (6.30)) is the greatest in Case 3.

- $LTC3$ has the highest value in Case 3 (e.g. $LTC3[11] = 39.881$ is greater than $LTC1[11] = 39.875$ and $LTC2[11] = 39.438$ in Figure 6.17(b)). That's because concession rate (the second part of equation (6.30)) is the greatest in Case 3.

Finally, we compare attribute fluctuations under the same situations, where price has the highest weight (Case 1, Case 4, and Case 7), quantity has the highest weight (Case 2, Case 5, and Case 8), and lead time has the highest weight (Case 3, Case 6, and Case 9). Then, we have:

• ω_p related:

- From Figure 6.18(a), we can see that MA 2 has the highest value of price in Case 7, and concession of price increases as ω_p increases;

- From Figure 6.18(b), we can see that coalition {612} has the highest value of price in Case 7 as well, and concession of price increases as ω_p increases.

• ω_q related:

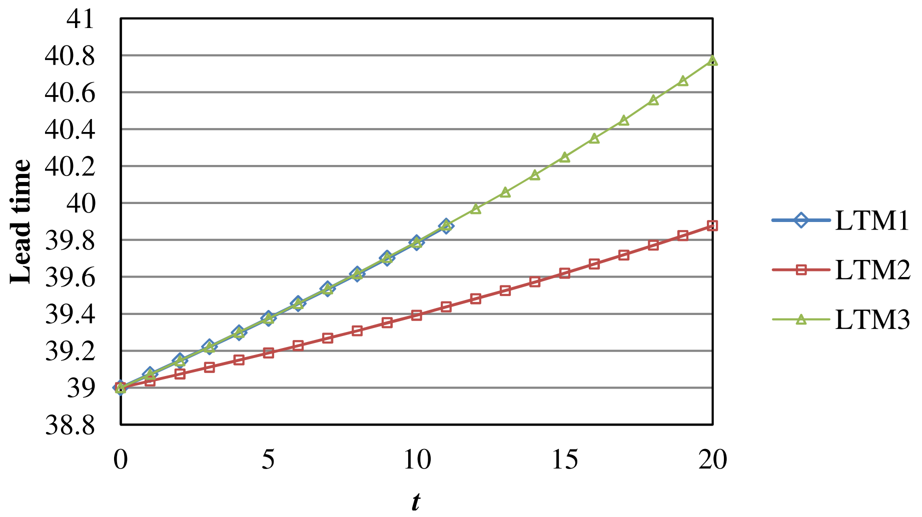
- From Figure 6.19(a), we can see that MA 2 has the lowest value of quantity in Case 8, and concession of quantity decreases as ω_q increases;

- From Figure 6.19(b), we can see that coalition {612} has the lowest value of quantity in Case 8 as well, and concession of quantity increases as ω_q increases.

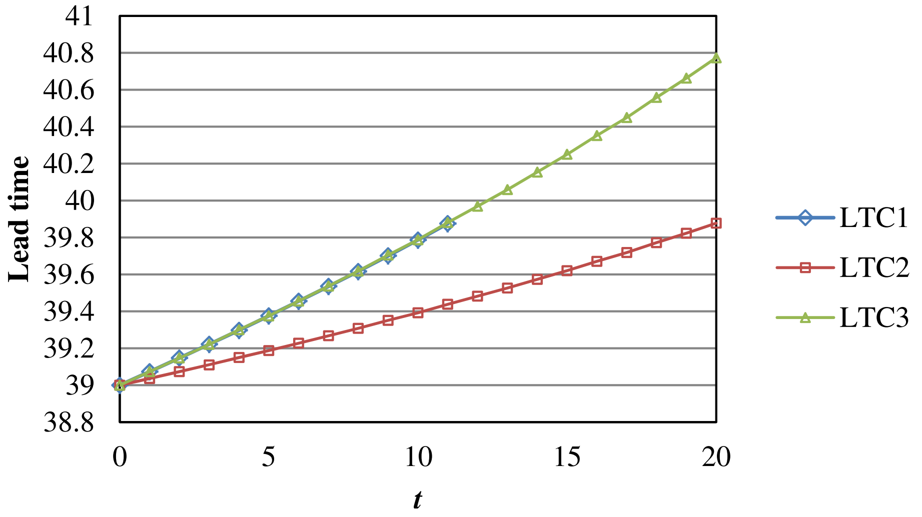
• ω_{lt} related:

- From Figure 6.20(a), we can see that MA 2 has the lowest value of lead time in Case 9, and concession of lead time decreases as ω_{lt} increases;

- From Figure 6.20(b), we can see that coalition {612} has the lowest value of lead time in Case 9 as well, and concession of lead time increases as ω_{lt} increases.

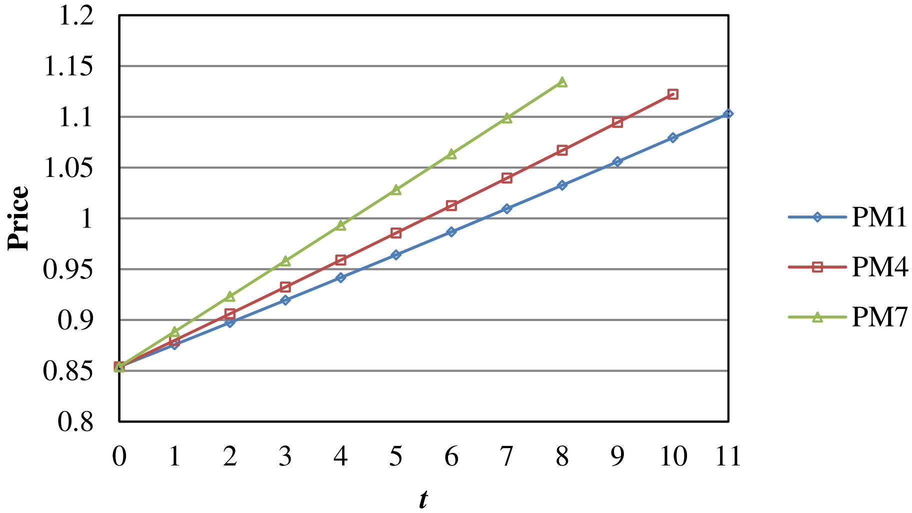


(a) Fluctuation of LTM

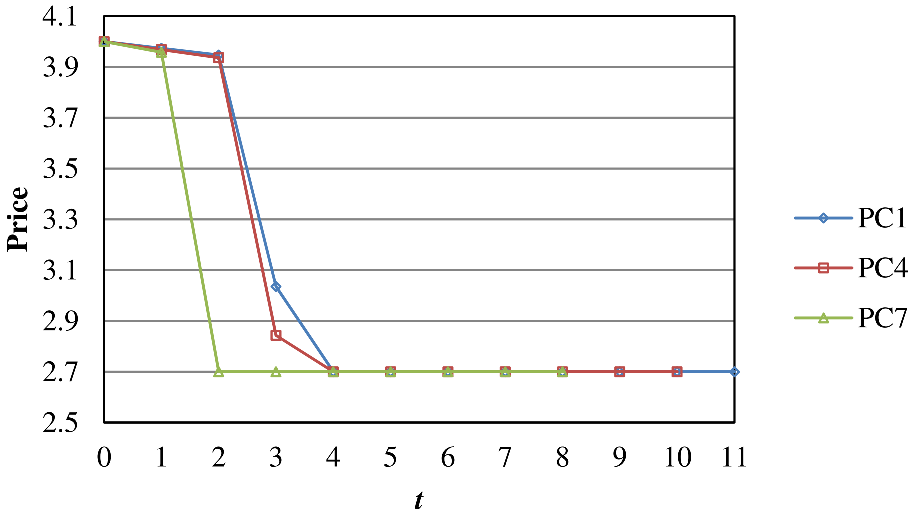


(b) Fluctuation of LTC

Figure 6.17: Fluctuation of lead time in Case 1 - Case 3.

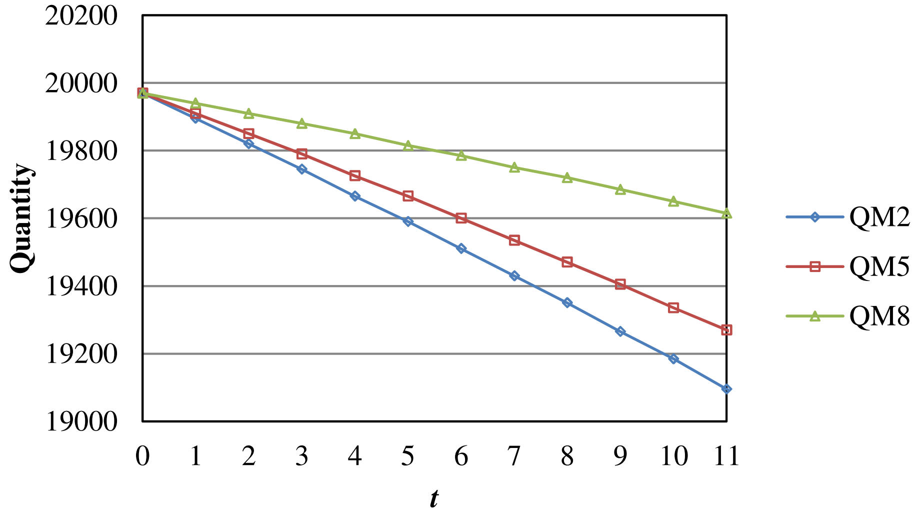


(a) Fluctuation of PM

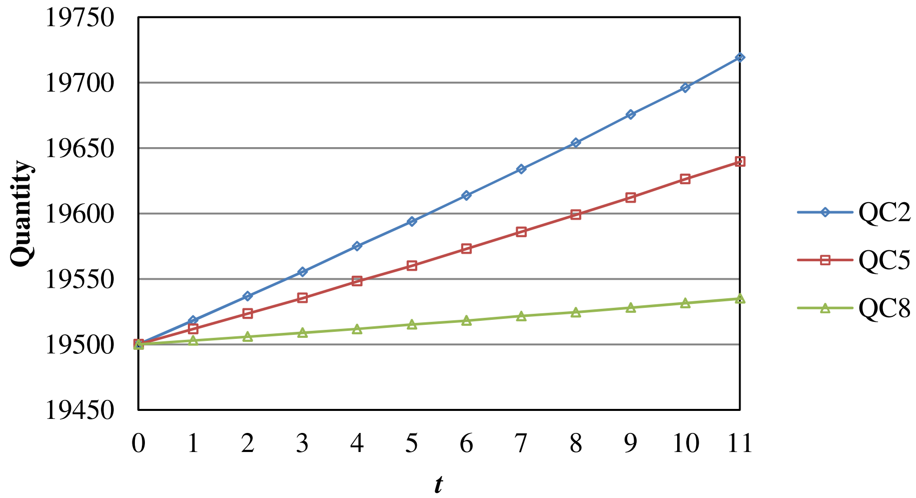


(b) Fluctuation of PC

Figure 6.18: Fluctuation of price in Case 1, Case 4, and Case 7.

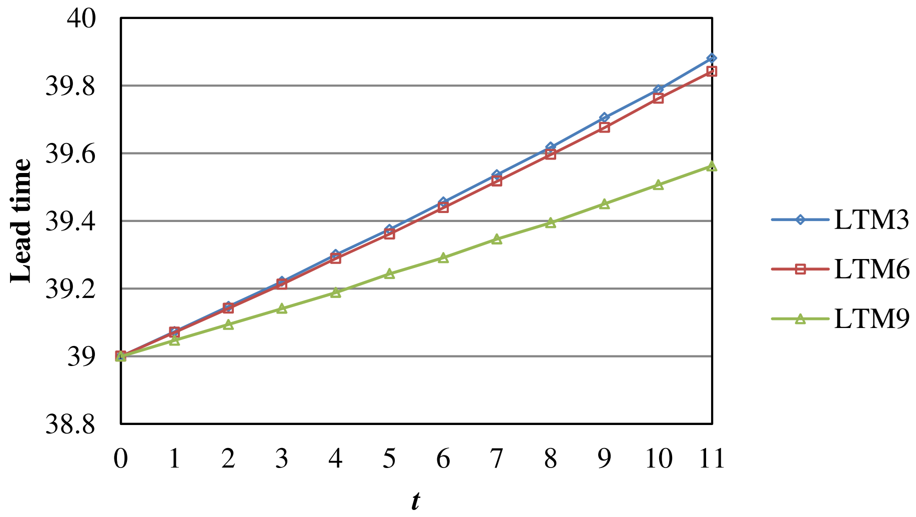


(a) Fluctuation of QM

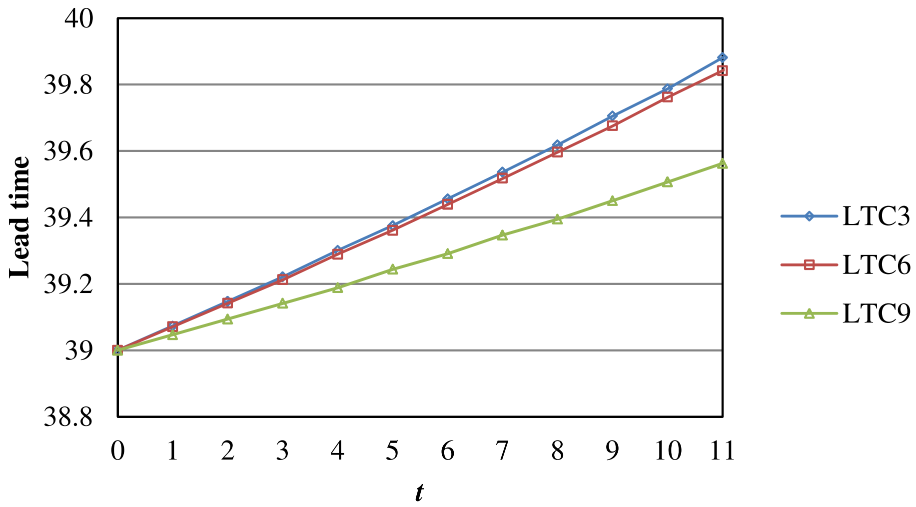


(b) Fluctuation of QC

Figure 6.19: Fluctuation of quantity in Case 2, Case 5, and Case 8.



(a) Fluctuation of LTM



(b) Fluctuation of LTC

Figure 6.20: Fluctuation of lead time in Case 3, Case 6, and Case 9.

Table 6.8: Parameter settings of MAs

	k	p_{ik}^{MU}	p_{ik}^{ML}	q_{ik}^{MI}	lt_{ik}^{MI}		k	p_{ik}^{MU}	p_{ik}^{ML}	q_{ik}^{MI}	lt_{ik}^{MI}
MA 1	1	3.86	0.08	24997	68	MA 3	3	18.42	4.12	4973	29
MA 1	2	36.79	8.38	14836	59	MA 3	4	272.22	60.66	9211	46
MA 1	3	18.34	4.49	4970	29	MA 4	1	3.73	0.79	24974	68
MA 1	4	272.89	60.44	9214	46	MA 4	2	36.84	8.95	14825	59
MA 2	1	3.41	0.85	24972	68	MA 4	3	18.84	4.95	4967	29
MA 2	2	36.90	8.33	14837	59	MA 4	4	272.13	60.79	9209	46
MA 2	3	18.87	4.80	4968	29	MA 5	1	3.54	0.07	24997	68
MA 2	4	272.47	60.34	9215	46	MA 5	2	36.82	8.74	14829	59
MA 3	1	3.12	0.040	24998	68	MA 5	3	18.89	4.37	4971	29
MA 3	2	36.65	8.33	14837	59	MA 5	4	272.20	60.15	9218	46

6.4 Comparison of Four Types of Negotiations

SASI, SAMI, MASI, and MAMI negotiations are compared in this section. Five MAs, six MSAs, and four items are involved in simulation. Parameters of MAs and MSAs are shown as Table 6.8 and Table 6.9, respectively. p_{ik}^{MU}, p_{ik}^{ML}, q_{ik}^{MI}, and lt_{ik}^{MI} are upper bound price, lower bound price, initial quantity, and initial lead time of item k of MA i. C_{jk}, γ_{jk}, and CS_{jk} are cost, productivity, and setup cost of item k of MSA j.

Table 6.9: Parameter settings of MSAs

	Item	C_{jk}	γ_{jk}	CS_{jk}		Item	C_{jk}	γ_{jk}	CS_{jk}
MSA 1	1	1.5	500	211	MSA 4	4	80	200	552
MSA 1	3	5	200	672	MSA 5	1	1.65	250	202
MSA 2	2	10	350	249	MSA 5	2	10.5	200	210
MSA 3	1	1.7	350	226	MSA 5	3	5.1	100	613
MSA 3	2	12	200	187	MSA 5	4	80	100	621
MSA 3	3	5.5	150	625	MSA 6	4	75	300	635
MSA 4	3	4.9	220	619					

Table 6.10: Results of SASI negotiation

MA	Item	MSA	SF_{ik}	π^M_{ijk}	π^S_{ijk}	π^T
1	1	5	{51346}	81724.18	54891.66	23812290.55
1	2	2	{21346}	527998.03	368445.72	
1	3	3	{3256}	89177.54	36270.69	
1	4	4	{41236}	2512728.94	937856.34	
2	1	3	{312456}	66585.47	44142.06	
2	2	3	{31456}	530726.31	284804.87	
2	3	4	{4256}	94477.32	38681.12	
2	4	4	{41236}	2509274.46	935565.65	
3	1	1	{12456}	58536.76	88758.01	
3	2	5	{51346}	526368.23	283385.35	
3	3	5	{5236}	90198.49	22719.81	
3	4	6	{61234}	2502794.62	1410893.66	
4	1	1	{12456}	78834.96	86946.60	
4	2	2	{21346}	528167.74	369574.74	
4	3	4	{4236}	92403.10	36388.90	
4	4	6	{61235}	2500127.44	1767860.86	
5	1	3	{32456}	70614.20	79111.96	
5	2	3	{312456}	530848.82	156782.29	
5	3	1	{126}	95454.76	52905.71	
5	4	5	{51234}	2508621.50	760641.71	

6.4.1 Results of SASI negotiation

In SASI negotiation, MAs negotiate with MSAs for each item, and only price is considered. Final allocation of SASI negotiation is shown as Table 6.10, where SF_{ik} is final determined coalition for item k of MA i, π^M_{ijk} and π^S_{ijk} are profits of MA and MSA related to item k, and π^T is total profit of supply chain networks.

We can see from Table 6.10 that item 1, item 2, item 3 and item 4 of MA 1 is allocated to coalition {51346}, {21346}, {3256}, and {41236}, respectively. Item 1, item 2, item 3 and item 4 of MA 2 is allocated to coalition {312456}, {31456}, {4256}, and {41236}, respectively. Item 1, item 2, item 3 and item 4 of MA 3 is allocated to coalition {12456}, {51346}, {5236}, and {61234}, respectively. Item 1, item 2, item 3 and item 4 of MA 4 is allocated to coalition {12456}, {21346}, {4236}, and {61235}, respectively. Item 1, item 2, item 3 and item 4 of MA 5 is allocated to coalition {32456}, {312456}, {126}, and {51234}, respectively. Total profit of SCNs under the allocation is 23812290.548.

6.4.2 Results of SAMI negotiation

In SAMI negotiation, MAs negotiate with MSAs for all items (items are combined together), and only price is considered. Final allocation of SAMI negotiation is shown as Table 6.11, where SF_i is final determined coalition for MA i, π_i^M, π_j^S, and π^T are profits of MA i, MSA j, and total profit of SCNs, respectively.

Table 6.11: Results of SAMI negotiation

		SF_i	π_i^M	π_j^S	π^T
MA 1	MSA 4	{412356}	3446470.98	3490330.50	34860420.35
MA 2	MSA 4	{412356}	3560963.04	3457656.73	
MA 3	MSA 1	{123456}	3433494.13	3457523.24	
MA 4	MSA 2	{213456}	3634729.86	3447554.22	
MA 5	MSA 2	{213456}	3456372.19	3475325.46	

We can see from Table 6.11 that MA 1 is allocated to coalition {412356}, MA 2 is allocated to coalition {412356}, MA 3 is allocated to coalition {123456}, MA 4 is allocated to coalition {213456}, and MA 5 is allocated to coalition {213456}. Total profit of SCNs under the allocation is 34860420.35.

6.4.3 Results of MASI negotiation

In MASI negotiation, MAs negotiate with MSAs for each item, and price, quantity and lead time are considered. Final allocation of MASI negotiation is shown as Table 6.12, where SF_{ik} is final determined coalition for item k of MA i, π_{ijk}^M and π_{ijk}^S are profits of MA and MSA related to item k, and π^T is total profit of supply chain networks.

We can see from Table 6.12 that item 1, item 2, item 3 and item 4 of MA 1 is allocated to coalition {246}, {5146}, {526}, and {6123}, respectively. Item 1, item 2, item 3 and item 4 of MA 2 is allocated to coalition {5246}, {2146}, {326}, and {6123}, respectively. Item 1, item 2, item 3 and item 4 of MA 3 is allocated to coalition {246}, {3146}, {526}, and {5123}, respectively. Item 1, item 2, item 3 and item 4 of MA 4 is allocated to

Table 6.12: Results of MASI negotiation

MA	Item	MSA	SF_{ik}	π_{ijk}^M	π_{ijk}^S	QF_{ijk}	LTF_{ijk}	π^T
1	1	2	{246}	80128.83	138514.36	24940	68.09	31706212.78
1	2	5	{5146}	540947.76	518295.22	14781	59.13	
1	3	5	{526}	85373.27	82095.94	4956	29.05	
1	4	6	{6123}	2300438.30	2609116.36	8790	47.27	
2	1	5	{5246}	73128.13	124729.79	24950	68.04	
2	2	2	{2146}	543718.82	510870.16	14781	59.13	
2	3	3	{326}	87057.68	80325.67	4954	29.05	
2	4	6	{6123}	2297548.23	2604575.65	8792	47.27	
2	1	2	{246}	52620.17	152372.74	24935	68.10	
3	2	3	{3146}	527766.65	535777.82	14766	59.17	
3	3	5	{526}	87456.34	77579.58	4958	29.05	
3	4	5	{5123}	2291617.80	2592365.28	8788	47.27	
4	1	3	{3246}	74820.54	146715.10	24940	68.06	
4	2	5	{5146}	533813.97	548653.51	14769	59.13	
4	3	3	{326}	86247.90	82146.03	4953	29.05	
4	4	5	{5123}	2289694.38	2595857.07	8788	47.26	
5	1	3	{3246}	68888.38	145658.30	24940	68.09	
5	2	5	{5146}	536505.63	537353.70	14772	59.14	
5	3	5	{526}	89019.98	81754.49	4957	29.05	
5	4	6	{6123}	2296707.03	2597956.26	8794	47.27	

coalition {3246}, {5146}, {326}, and {5123}, respectively. Item 1, item 2, item 3 and item 4 of MA 5 is allocated to coalition {3246}, {5146}, {526}, and {6123}, respectively. Total profit of SCNs under the allocation is 31706212.777.

6.4.4 Results of MAMI negotiation

In MAMI negotiation, MAs negotiate with MSAs for all items (items are combined together), and price, quantity, and lead time are considered. Final allocation of MAMI negotiation is shown as Table 6.13, where QF_{ik} is final determined quantity of item k of MA i, LTF_i is final lead time of MA i, SF_i is final determined coalition for MA i, π_i^M, π_j^S, and π^T are profits of MA i, MSA j, and total profit of SCNs, respectively.

Table 6.13: Results of MAMI negotiation

MA	Item	QF_{ik}	LTF_i	MSA	SF_i	π_i^M	π_j^S	π^T
1	1	10820	70.47	2	{23456}	281059.72	540571.86	4029959.84
1	2	6492						
1	3	2164						
1	4	4328						
2	1	12375	65.07	2	{2456}	286782.79	491698.65	
2	2	7425						
2	3	2475						
2	4	4950						
3	1	9255	76.53	1	{12346}	266186.00	562057.18	
3	2	5553						
3	3	1851						
3	4	3702						
4	1	12315	65.09	2	{2456}	286694.62	493805.57	
4	2	7389						
4	3	2463						
4	4	4926						
5	1	10855	70.32	2	{23456}	281289.41	539814.04	
5	2	6513						
5	3	2171						
5	4	4342						

We can see from Table 6.13 that MA 1 is allocated to coalition {23456}, MA 2 is allocated to coalition {2456}, MA 3 is allocated to coalition {12346}, MA 4 is allocated to coalition {2456}, and MA 5 is allocated to coalition {23456}. Total profit of SCNs under the allocation is 4029959.838.

6.4.5 Comparison and analysis

Results of SASI, SAMI, MASI, and MAMI negotiation are compared in this section.

6.4.5.1 Single-attribute negotiation and multi-attribute negotiation

Single-attribute negotiation is compared with multi-attribute negotiation in this section. What we should pay attention to is quantities and lead time of items will never be changed in single-attribute negotiation, they always equals to initial values of quantities and lead time. However, quantities and lead time will be changed during multi-attribute negotiation. We can get:

- Profits for MSAs and total SCNs are higher in MASI negotiation than in SASI negotiation (see π_j^S and π^T of MASI and SASI in Figure 6.21). We can say that multi-attribute negotiation is better for MSAs and SCNs.

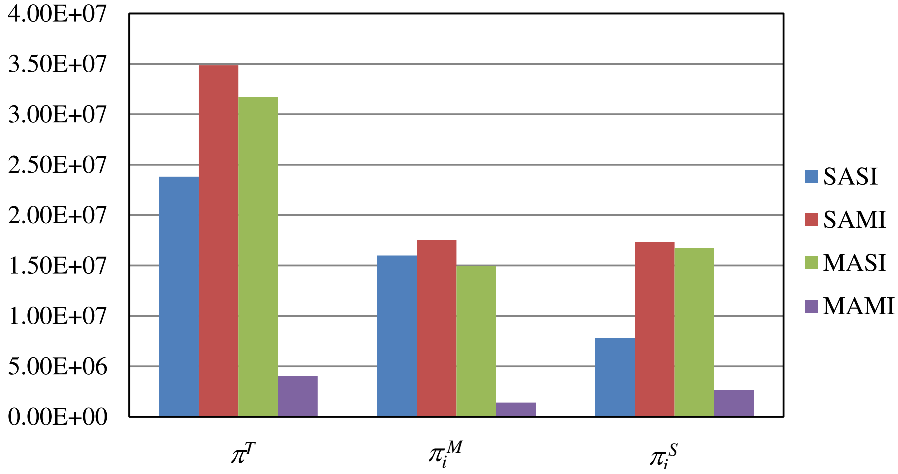


Figure 6.21: Comparison of profits of four negotiations.

- Profits of MAs are lower in MASI negotiation than in SASI (see π_i^M of MASI and SASI in Figure 6.21). However, it cannot be said that MAs get higher profits in SASI negotiation than in MASI negotiation. That's because the final reached equilibriums of quantities and lead time are different in MASI negotiation and SASI negotiation. We can see from Figure 6.22 and Figure 6.23 that the final quantities are lower in MASI negotiation than in SASI negotiation, and the lead time is higher in MASI negotiation than in SASI negotiation, which of course will lead to the decrease of profits of MAs. Furthermore, MAs and MSAs in MASI negotiation can make concession among attributes according to their own preferences.

- Profits of MAs, MSAs, and SCNs are lower in MAMI negotiation than in SAMI negotiation. As the same with above analysis, decreases of profits are because of the

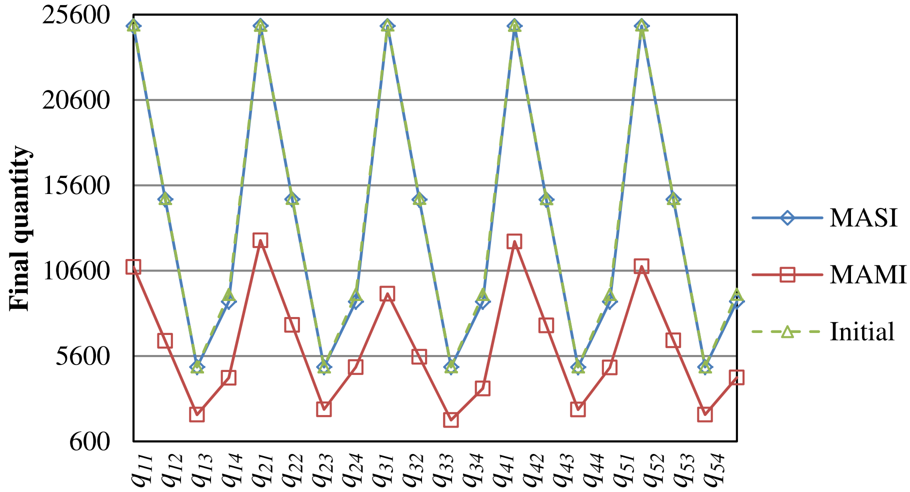


Figure 6.22: Final quantities of items in four negotiations.

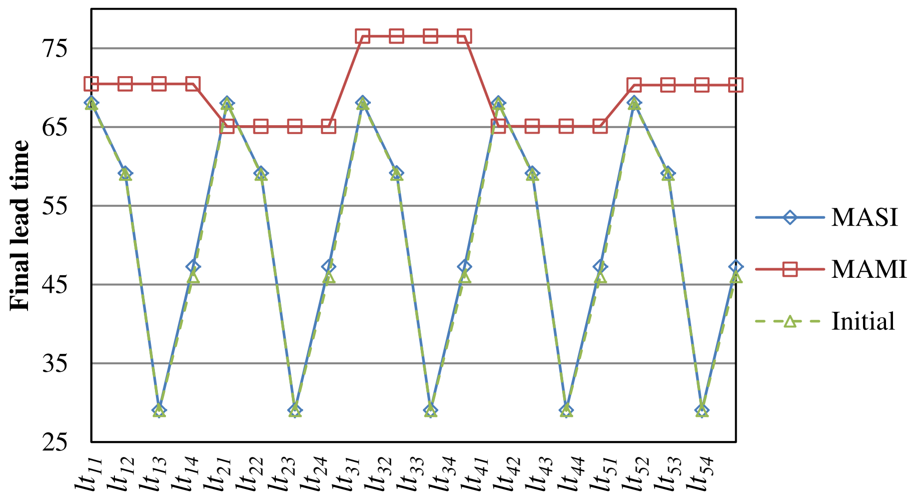


Figure 6.23: Final lead time of items in four negotiations.

differences of quantities and lead time in MAMI negotiation and SAMI negotiation. We can see from Figure 6.22 and Figure 6.23 that the quantities of items in MAMI negotiation are greatly lower than in SAMI negotiation, and the lead time is almost higher in MAMI negotiation than in SAMI negotiation. Furthermore, MAs and MSAs in MAMI negotiation can make concession according to their own preferences.

6.4.5.2 Single-item negotiation and multi-item negotiation

Single-item negotiation is compared with multi-item negotiation in this section, and we can get the results as:

- Profits of MAs, MSAs, and total SCNs are higher in SAMI negotiation than in SASI negotiation. We can see multi-item negotiation can improve profits of MAs and MSAs according to their own preferences.

- Profits of MAs, MSAs, and total SCNs are lower in MAMI negotiation than in MASI negotiation. However, it cannot be said that MASI negotiation is better than MAMI negotiations because the final reached equilibriums of quantities and lead time are different in MAMI and MASI negotiations. We can see from Figure 6.22 and Figure 6.23 that quantities in MAMI negotiation are greatly lower than in MASI, and lead time in MAMI negotiation is higher than in MASI. We can see that multi-item negotiation can give concessions among items according to their own preferences.

6.4.5.3 Analysis

According to analysis of section 6.4.5.1 and 6.4.5.2, we can get conclusion that multi-attribute negotiation is better than single-attribute negotiation when agents have different preferences on attributes, and multi-item negotiation is better than single-item negotiation when agents have different preferences on items. Moreover, it is profitable to combine items and(or) attributes during negotiation. MAs and MSAs can trade off items or attributes during negotiation according to their own preferences.

Chapter 7 Summary and Conclusion

7.1 Summary

This dissertation addresses the problem of negotiation of supply chain networks. Main purposes of this research are to find another way to solve problems when orders of MAs are out of abilities of MSAs, which can maximally keep integrities of orders of MAs; find another way to solve multi-to-multi game by decomposing multi-to-multi game into two-person Stackelberg game, J-person cooperative game, and two-person game.

The results obtained in this dissertation can be summarized as follows:

Chapter 1 presents background and motivation for this research, defines its purpose and presents a basic outline of the study problem. Literature reviews on multi-agent based supply chain networks, multi-agent based negotiation of supply chain networks, and multi-agent based coalition formation of supply chain networks are described. Finally, structure of dissertation is presented.

Chapter 2 addresses coalition formation mechanism for MSAs when order of MA is out of their abilities. Coalition formation protocols are proposed for single-item negotiation and multi-item negotiation, respectively. Determination of coalition and allocation of profit among members are discussed as well. Then, a modified coalition formation protocol which takes change of lead time into account, is presented to get used to dynamic changing during multi-attribute negotiation.

Chapter 3 is comprised of two main parts. In the first part, SASI negotiation between one-MA and multi-MSA is discussed. It is verified that the proposed two-stage negotiation protocol is effective and feasible in solving SASI negotiation between one-MA and multi-MSA. Comparisons are provided and verified that the proposed protocol with concession is faster to reach agreement than the protocol without concession. Furthermore, it is verified that convergence rate greatly depends on concession rate, and the higher the concession rate the faster to reach agreement. In the second part, SASI negotiation between multi-MA and multi-MSA is addressed. A hierarchical-game based negotiation protocol is proposed. Simulations are provided and verified efficiency and feasibility of the proposed protocol. It is proved that the proposed coalition formation based protocol is superior to greedy algorithm which splits the orders into piece. It doesn't only maintain integrity of the order, but also reduces workload of MA and increases profits of MA, MSAs, and total SCNs.

Chapter 4 is comprised of two main parts. In the first part, SAMI negotiation between one-MA and multi-MSA is discussed. It is testified that the proposed protocol is effective and stable in solving SAMI negotiation between multi-MA and multi-MSA. In the second part, SAMI negotiation between multi-MA and multi-MSA is addressed. A coalition formation based negotiation protocol is presented. It is certified that the proposed protocol have a good performance in solving SAMI negotiation between multi-MA and multi-MSA as well.

Chapter 5 discusses MASI negotiations between one-MA and multi-MSA, and between multi-MA and multi-MSA, respectively. A modified two-stage negotiation protocol and a modified hierarchical-game based negotiation protocol is proposed for two negotiations, respectively. It is verified that the proposed two protocols are effective and stable in solving MASI negotiations. They can better off agents by trade off one attribute for another according to their own preferences. Comparisons are provided and verified the necessity of using coalition formation mechanism. Moreover, the proposed protocol is good for increasing the competitiveness of the market.

Chapter 6 presents a modified coalition formation based negotiation protocols for MAMI negotiations between one-MA and multi-MSA, and between multi-MA and multi-MSA, respectively. It is verified that the proposed negotiation protocols are effective, stable, and flexible in solving MAMI negotiation problem. They can better off agents not only have tradeoff among attributes but also can have tradeoff among items according to their own preferences. Comparisons of SASI, SAMI, MASI, and MAMI negotiations are provided, and verified that multi-attribute negotiation is better than single-attribute negotiation when agents have different preferences on attributes, and multi-item negotiation is better than single-item negotiation when agents have different preferences on items.

In this dissertation, negotiation between MA(s) and MSAs of SCNs is discussed step-by-step. In chapter 3, SASI negotiation is discussed, and then result is extended to negotiation where multi-item is involved in chapter 4. The results of chapter 3 is generalized into MASI negotiation in chapter 5. Based on result of chapter 5, we popularize the proposed model into the most complex situation in chapter 6, where MAMI are involved.

7.2 Conclusion

This dissertation focuses on negotiation between MA(s) and MSAs when the order(s) of manufacture agent(s) is(are) out of abilities of MSAs. It tries to solve this problem using coalition formation mechanism which allows material supplier agents to find partners to establish coalitions when they cannot finish the order(s) independently.

Moreover, game theory is adopted to analyze interactive optimization problems exist in negotiation between MA(s) and MSAs. The $I \times J$ game is decomposed into two-person game (MA(s) negotiate with MSAs to decide final trade partnership), J-person cooperative game (all MSAs negotiate to establish coalitions), and two-person Stackelberg game (MA(s) negotiate(s) with MSAs coalitions to decide final equilibriums), which greatly reduces complexity to solve $I \times J$ game.

The proposed coalition formation based negotiation protocols are reciprocal protocols for both MAs and MSAs:

- MAs can reduce cost to divide orders into pieces and allocate to different MSAs by selecting coalitions to keep integrities of orders (e.g. they need to pay for transport fees for different suppliers when they split orders for different suppliers), and reduce cost to buy materials by selecting suppliers which have lower price but once have been abandoned due to their limited abilities.

- On the other hand, MSAs have more opportunities to win orders which were once out of their abilities by establishing coalition.

- In addition, the proposed protocol increases the competitiveness of MSAs in SCNs.

Furthermore, the proposed protocols are very flexible, because all MAs and MSAs can define weights of attributes and concession rates among different attributes or items according to their own preferences:

- They not only can tradeoff one attribute to another;

- but also can tradeoff one item to another in order to maximize their total profits of whole order according to their own preferences rather than maximize each attribute or item.

The proposed coalition formation based negotiation protocols are verified in different situations where SASI, SAMI, MASI, and MAMI are involved, respectively. It is shown that the proposed protocols are feasible and effective in solving real problems.

7.3 Future Research Direction

This dissertation focuses on negotiation between MA(s) and MSA(s), and only two echelons of supply chain networks are involved. The results can also be generalized into other negotiations between MA(s) and retailer agent(s), between retailer agent(s) and consumer agent(s), or generalized into multi-echelon negotiation. Furthermore, it is assumed that negotiation environment is static, no MAs or MSAs are allowed entering into negotiation after negotiation starts. For future work, the proposed protocol can be applied into the situation where negotiation environment is dynamic changing. In other words, new participates are allowed entering negotiation even negotiation has started. Moreover, in this dissertation it is assumed that MAs have more negotiation powers, and it can be extended to the situation where MSAs have more negotiation powers or where MAs have the same negotiation powers as MSAs. Only was concession related to deadline of negotiation considered in this research. Concession related to trading opportunity (related to the number of trading partner) and competition (related to the number of competitors) can be taken into account in future.

In this research only abilities of MSAs are considered. We just focus on finding the solution which can finish the order and don't consider of finishing the order just in time. Because the inventory cost of MSAs of finishing the orders before the due time is not taken into account. Next step of our research will take cost of finishing the order too early into account.

Another possible direction for this research can be focused on the scales of coalitions. In this dissertation, the scales of coalitions are not considered, however, it's impossible or unrealistic to establish huge-scale coalitions in real SCN. Furthermore, one objective of this dissertation is to keep integrity of the order of MA, while the degree of integrity is not discussed. It's assumed that the whole order is kept integrity in this dissertation, which is a hard assumption in real manufacturing system as well. Therefore, for future work, the degree of integrity should be considered as well.

References

[Alonso, 1998] Alonso, E. (1998). How individuals negotiate societies. In *In Proc. ICMAS-98*, pages 18–25. IEEE Computer Society Press.

[An et al., 2007] An, N., Lu, J.-C., Rosen, D., and Ruan, L. (2007). Supply-chain oriented robust parameter design. *International Journal of Production Research*, 45(23):5465–5484.

[Argoneto and Renna, 2010] Argoneto, P. and Renna, P. (2010). Production planning, negotiation and coalition integration: A new tool for an innovative e-business model. *Robotics and computer-Integrated Manufacturing*, 26:1–12.

[Asselin and Draa, 2002] Asselin, F. and Draa, B. C. (2002). Toward a Protocol for the Formation of Coalitions of Buyers. In Crainic, T. G. and Gavish, B., editors, *Proceedings of the Fifth International Conference on Electronic Commerce Research (ICECR-5).*

[Aumann et al., 1974] Aumann, R., Jerusale, Dreze, J., and Louvain (1974). Cooperative games with coalition structures. *International Journal of Game Theory*, 3(4):217–237.

[Barbuceanu and Lo, 2000] Barbuceanu, M. and Lo, W.-K. (2000). A multi-attribute utility theoretic negotiation architecture for electronic commerce. In *Proceedings of the fourth international conference on Autonomous agents*, AGENTS '00, pages 239–246, New York, NY, USA. ACM.

[Ben-ameur et al., 2002] Ben-ameur, H., Benameur, H., Chaib-draa, B., and Kropf, P. (2002). Multi-item auctions for automatic negotiation. *Journal of Information and Software Technology*, 44:291–301.

[Bhat and Leyton-Brown, 2004] Bhat, N. A. R. and Leyton-Brown, K. (2004). Computing nash equilibria of action-graph games. In *Proceedings of the 20th conference on Uncertainty in artificial intelligence*, UAI '04, pages 35–42, Arlington, Virginia, United States. AUAI Press.

[Bichler, 2000] Bichler, M. (2000). An experimental analysis of multi-attribute auctions. *Decision Support Systems*, 29(3):249 – 268.

[Bonnevay et al., 2005] Bonnevay, S., Kabachi, N., and Lamure, M. (2005). Agent-based simulation of coalition formation in cooperative games. In *International Conference on Intelligent Agent Technology*, pages 136–139.

[Bui et al., 2001] Bui, T., Yen, J., Hu, J., and Sankaran, S. (2001). A multi-attribute negotiation support system with market signaling for electronic markets. *Group Decision and Negotiation*, 10(6):515–537.

[Busch and Horstmann, 2002] Busch, L.-A. and Horstmann, I. J. (2002). The game of negotiations: ordering issues and implementing agreements. *Games and Economic Behavior*, 41(2):169 – 191.

[Cachon and Netessine, 2003] Cachon, G. P. and Netessine, S. (2003). Game theory in supply chain analysis. In Simchi-Levi, D., Wu, S. D., and Shen, Z.-J. M., editors, *Supply Chain Analysis in the eBusiness Era*. Kluwer.

[Chai et al., 2010] Chai, J. Y., Sakaguchi, T., and Shirase, K. (2010). A framework of multi objectives negotiation for dynamic supply chain model. *Journal of advanced mechanical design, systems and manufacturing*, 4(2):457–468.

[Chaib-draa and Müller, 2006] Chaib-draa, B. and Müller, J. P. (2006). Multiagent based supply chain management: a brief introduction. In Chaib-draa, B. and Müller, J. P., editors, *Multiagent based supply chain management*. Springer Berlin Heidelberg.

[Choi et al., 2001] Choi, S. P., Liu, J., and Chan, S.-P. (2001). A genetic agent-based negotiation system. *Computer Networks*, 37:195–204.

[Cloutier et al., 2001] Cloutier, L., Frayret, J.-M., D'Amours, S., Espinasse, B., and Montreuil, B. (2001). A commitment-oriented framework for networked manufacturing coordination. *International Journal of Computer Integrated Manufacturing*, 14(6):522–534.

[Conitzer and Sandholm, 2006] Conitzer, V. and Sandholm, T. (2006). A technique for reducing normal-form games to compute a nash equilibrium. In *Proceedings of the fifth international joint conference on Autonomous agents and multiagent systems*, AAMAS '06, pages 537–544, New York, NY, USA. ACM.

[de Albeniz V. and G., 2011] de Albeniz V., M. and G., R. (2011). Competing for shelf space. *Production and Operations Management*, 20(1):32–46.

[Esmaeili et al., 2009] Esmaeili, M., Aryanezhad, M.-B., and Zeephongsekul, P. (2009). A game theory approach in seller-buyer supply chain. *European Journal of Operational Research*, 195:442–448.

[Gamson, 1961] Gamson, W. A. (1961). A theory of coalition formation. *American Sociological Review*, 26(3):373–382.

[Ganeshan et al., 1999] Ganeshan, R., Jack, E., Magazine, M. J., and Stephens, P. (1999). A taxonomic review of supply chain management research. In Tayur, S., Ganeshan, R., and Magazine, M. J., editors, *Quantitative models for supply chain management*. Kluwer Academic Publishers.

[Ganzfried and Sandholm, 2010] Ganzfried, S. and Sandholm, T. (2010). Computing equilibria by incorporating qualitative models. In *Proceedings of the 9th International Conference on Autonomous Agents and Multiagent Systems*, volume 1, pages 183–190.

[Govindan and Wilson, 2003] Govindan, S. and Wilson, R. (2003). A global newton method to compute nash equilibria. *Journal of Economic Theory*, 110:65–86.

[Govindan and Wilson, 2004] Govindan, S. and Wilson, R. (2004). Computing nash equiliria by iterated polymatrix approximation. *Journal of Economic Dynamics & Control*, 28:1229–1241.

[Granot and Yin, 2008] Granot, D. and Yin, S. (2008). Competition and cooperation in decentralized push and pull assembly systems. *Management Science*, 54(4):733–747.

[Greys, 2011] Greys, S. (2011). Impact of demand uncertainty on stability of supplier alliances in assembly models. *Production and Operations Management*, 20(6):905–920.

[Hartman and Dror, 1996] Hartman, B. C. and Dror, M. (1996). Cost allocation in continuous-review inventory models. *Naval Research Logisics*, 43:549–561.

[He et al., 2003] He, M., Jennings, N. R., and fung Leung, H. (2003). On agent-mediated electronic commerce. *IEEE Transactions on Knowledge and Data Engineering*, 15:985–1003.

[Hemaissia et al., 2007] Hemaissia, M., El Fallah Seghrouchni, A., Labreuche, C., and Mattioli, J. (2007). A multilateral multi-issue negotiation protocol. In *Proceedings of the 6th international joint conference on Autonomous agents and multiagent systems*, AAMAS '07, pages 155:1–155:8, New York, NY, USA. ACM.

[Hennet and Mahjoub, 2010] Hennet, J.-C. and Mahjoub, S. (2010). Toward the fair sharing of profit in a supply network formation. *International Journal of Production Economics*, 127:112–120.

[Hezarkhani and Kubiak, 2010] Hezarkhani, B. and Kubiak, W. (2010). A coordinating contract for transshipment in a two-company supply chain. *European Journal of Operational Research*, 207:232–237.

[Hindriks et al., 2012] Hindriks, K., Tykhonov, D., and Weerdt, M. (2012). Qualitative one-to-many multi-issue negotiation: Approximating the qva. *Group Decision and Negotiation*, 21:49–77.

[Hoda et al., 2010] Hoda, S., Gilpin, A., Pena, J., and Sandholm, T. (2010). Smoothing techniques for computing nash equilibria of sequential games. *Mathematics of Operations Research*, 35(2):494–512.

[Hu et al., 2011] Hu, Y., Guan, Y., and Liu, T. (2011). Lead-time hedging and coordination between manufacturing and sales departments using nash and stackelberg games. *European Journal of Operational Research*, 210:231–240.

[Hyodo et al., 2003] Hyodo, M., Matsuo, T., and Ito, T. (2003). An optimal coalition formation among buyer agents based on a genetic algorithm. In *Proceedings of the 16th international conference on Developments in applied artificial intelligence*, IEA/AIE'2003, pages 759–767. Springer Springer Verlag Inc.

[Ito et al., 2008] Ito, T., Klein, M., and Hattori, H. (2008). A multi-issue negotiation protocol among nonlinear utility agents: A preliminary report. In Ito, T., Hattori, H., Zhang, M., and Matsuo, T., editors, *Rational, Robust, and Secure Negotiations in Multi-Agent Systems*, volume 89 of *Studies in Computational Intelligence*, pages 25–38. Springer Berlin Heidelberg.

[Ito et al., 2002] Ito, T., Ochi, H., and Shintani, T. (2002). A group buy protocol based on coalition formation for agent-mediated e-commerce. *International Journal of Computer & Information Science*, 3(1).

[Javid and Hoseinpour, 2011] Javid, A. A. and Hoseinpour, P. (2011). A game-theoretic analysis for coordinating cooperative advertising in a supply chain. *Journal of Optimal Theory Application*, 149:138–150.

[Jiao et al., 2006] Jiao, J. R., You, X., and Kumar, A. (2006). An agent-based framework for collaborative negotiation in the global manufacturing supply chain network. *Robotics and Computer-Integrated Manufacturing*, 22(3):239 – 255.

[Jin and Wu, 2006] Jin, M. and Wu, S. D. (2006). Supplier coalitions in on-line reverse auctions: Validity requirements and profit distribution scheme. *International Journal of Production Economics*, 100:183–194.

[Jorgensen and Zaccour, 1999] Jorgensen, S. and Zaccour, G. (1999). Equilibrium pricing and advertising strategies in a marketing channel. *Journal of Optimization Theory and Applications*, 102(1):111–125.

[Kaihara and Fujii, 2008] Kaihara, T. and Fujii, S. (2008). Game theoretic enterprise management in industrial collaborative networks with multi-agent systems. *International Journal of Production Research*, 46(5):1297–1313.

[Kaihara et al., 2006] Kaihara, T., Fujii, S., and Iwata, K. (2006). Virtual enterprise coalition strategy with game theoretic multi-agent paradigm. *CIRP Annals - Manufacturing Technology*, 55(1):513 – 516.

[Kebriaei and Majd, 2009] Kebriaei, H. and Majd, V. J. (2009). A simultaneous multi-attribute soft-bargaining design for bilateral contracts. *Expert Systems with Applications*, 36(3, Part 1):4417 – 4422.

[Kersten et al., 2013] Kersten, G. E., Vahidov, R., and Gimon, D. (2013). Concession-making in multi-attribute auctions and multi-bilateral negotiations: Theory and experiments. *Electronic Commerce Research and Applications*, (0):–.

[Ketchpel, 1995] Ketchpel, S. P. (1995). Coalition formation among autonomous agents. *Lecture Notes in Computer Science*, 957:73–88.

[Kim and Cho, 2010] Kim, H. S. and Cho, J. H. (2010). Supply chain formation using agent negotiation. *Decision Support Systems*, 49:77–90.

[Kim et al., 2007] Kim, W., Hong, J., and Song, Y. (2007). Multi-attribute-based agent negotiation framework under incremental information disclosing strategy. *International Journal of Information Technology & Decision Making*, 6:61–83.

[Klusch and Shehory, 1996] Klusch, M. and Shehory, O. (1996). Coalition formation among rational information agents. *Lecture Notes in Computer Science*, 1038:204–217.

[Kogan and Tapiero, 2007] Kogan, K. and Tapiero, C. S. (2007). *Supply chain games: operations management and risk valuation*. Springer Science+Business Media, LLC.

[Koller et al., 1996] Koller, D., Megiddo, N., and von Stengel, B. (1996). Efficient computation of equilibria for extensive two-person game. *Game and Economic Behavior*, 14:247–259.

[Kraus, 1997] Kraus, S. (1997). Negotiation and cooperation in multi-agent environments. *Artificial Intelligence*, 94:79–97.

[Kurata and Nam, 2010] Kurata, H. and Nam, S.-H. (2010). After-sales service competition in a supply chain: Optimization of customer satisfaction level or profit or both? *International Journal of Production Economics*, 127:136–146.

[Lai and Sycara, 2009] Lai, G. and Sycara, K. (2009). A generic framework for automated multi-attribute negotiation. *Group Decision Negotiation*, 18:169–187.

[Lai et al., 2008] Lai, G., Sycara, K., and Li, C. (2008). A decentralized model for multi-attribute negotiations with incomplete information and general utility functions. In Ito, T., Hattori, H., Zhang, M., and Matsuo, T., editors, *Rational, Robust, and Secure Negotiations in Multi-Agent Systems*, volume 89 of *Studies in Computational Intelligence*, pages 39–57. Springer Berlin Heidelberg.

[Leng and Parlar, 2005] Leng, M. and Parlar, M. (2005). Game theoretic applications in supply chain management: A review. *INFOR*, 43(3):187–219.

[Leng and Parlar, 2010] Leng, M. and Parlar, M. (2010). Game-theoretic analyses of decentralized assembly supply chains: Non-cooperative equilibria vs. coordination with cost-sharing contracts. *European Journal of Operational Research*, 204(1):96–104.

[Lengwiler, 1999] Lengwiler, Y. (1999). The multiple unit auction with variable supply. *Economic Theory Journal*, pages 373–392.

[Lerman and Shehory, 2000] Lerman, K. and Shehory, O. (2000). Coalition formation for large-scale electronic markets.

[Li et al., 2004] Li, C., Chawla, S., Rajan, U., and Sycara, K. (2004). Mechanism design for coalition formation and cost sharing in group-buying markets. *Electronic Commerce Research and Applications*, 3:341–354.

[Lin and Hsieh, 2012] Lin, C.-C. and Hsieh, C.-C. (2012). A cooperative coalitional game in duopolistic supply-chain competition. *Networks and Spatial Economics*, 12:129–146.

[Littman and Stone, 2005] Littman, M. L. and Stone, P. (2005). A polynomian-time nash equilibrium algorithm for repeated games. *Decision Support Systems*, 39:55–66.

[Lovejoy, 2010] Lovejoy, W. S. (2010). Bargaining chains. *Management Science*, 56(12):2282–2301.

[Lu et al., 2011] Lu, J.-C., Tsao, Y.-C., and Charoensiriwath, C. (2011). Competition under manufacturer service and retail price. *Economic Modelling*, 28:1256–1264.

[Maturana et al., 1999] Maturana, F., Shen, W., and Norrie, D. H. (1999). Metamorph: An adaptive agent-based architecture for intelligent manufacturing. *International Journal of Production Research*, 37:2159–2174.

[Mckelvey and McLennan, 1996] Mckelvey, R. D. and McLennan, A. (1996). Computation of equilibria in finite games. *Handbook of Computational Economics*, 1:88–139.

[Nagarajan and Sosic, 2008] Nagarajan, M. and Sosic, G. (2008). Game-theoretic analysis of cooperation among supply chain agents: Review and extensions. *European Journal of Operational Research*, 187:719–745.

[Nagarajan and Sošić, 2009] Nagarajan, M. and Sošić, G. (2009). Coalition stability in assembly models. *Oper. Res.*, 57(1):131–145.

[Nash, 1950] Nash, J. F. (1950). Equilibrium points in n-person games. In *Proceeding of the National Academy of Scoemces*, volume 36, pages 48–49.

[Owen, 1975] Owen, G. (1975). On the core of linear production games. *Mathematical Programming*, 9:358–370.

[Park and Yang, 2008] Park, S. and Yang, S.-B. (2008). An efficient multilateral negotiation system for pervasive computing environments. *Eng. Appl. Artif. Intell.*, 21(4):633–643.

[Petric and Jezic, 2010] Petric, A. and Jezic, G. (2010). Multi-attribute auction model for agent-based content trading in telecom markets. In *Proceedings of the 14th international conference on Knowledge-based and intelligent information and engineering systems: Part I*, KES'10, pages 261–270, Berlin, Heidelberg. Springer-Verlag.

[Porter et al., 2008] Porter, R., Nudelman, E., and Shoham, Y. (2008). Simple search methods for finding a nash equilibrium. *Games and Economic Behavior*, 63:642–662.

[Rao et al., 2012] Rao, C., Zhao, Y., and Ma, S. (2012). Procurement decision making mechanism of divisible goods based on multi-attribute auction. *Electronic Commerce Research and Applications*, 11(4):397 – 406.

[Ren et al., 2009] Ren, F., Zhang, M., and Sim, K. M. (2009). Adaptive conceding strategies for automated trading agents in dynamic open markets. *Decision Support Systems*, 46:704–716.

[Renna, 2010] Renna, P. (2010). Negotiation policies and coalition tools in e-marketplace environment. *Computers & Industrial Engineering*, 59:619–629.

[Renna and Argoneto, 2011] Renna, P. and Argoneto, P. (2011). Capacity sharing in a network of independent factories: A cooperative game theory approach. *Robotics and Computer-Integrated Manufacturing*, 27:405–417.

[Reyniers and Tapiero, 1995] Reyniers, D. J. and Tapiero, C. S. (1995). The delivery and control of quality in supplier-producer contracts. *Management Science*, 41(10):1581–1589.

[Rezapour et al., 2011] Rezapour, S., Farahani, R. Z., Ghodsipour, S. H., and Abdollahzadeh, S. (2011). Strategic design of competing supply chain networks with foresight. *Advances in Engineering Software*, 42:130–141.

[Robu and Poutré, 2008] Robu, V. and Poutré, H. (2008). Constructing the structure of utility graphs used in multi-item negotiation through collaborative filtering of aggregate buyer preferences. In Ito, T., Hattori, H., Zhang, M., and Matsuo, T., editors, *Rational, Robust, and Secure Negotiations in Multi-Agent Systems*, volume 89 of *Studies in Computational Intelligence*, pages 147–168. Springer Berlin Heidelberg.

[Roh and Yang, 2008] Roh, D. H. and Yang, H. S. (2008). Design of an iterative multi-item double-auction mechanism. *Computational Intelligence*, 24(1):62–75.

[Sandholm et al., 2005] Sandholm, T., Gilpin, A., and Conitzer, V. (2005). Mixed-integer programming methods for finding nash equilibria. In *Proceedings of the 20th national conference on Artificial intelligence - Volume 2*, AAAI'05, pages 495–501. AAAI Press.

[Sandholm and Lesser, 1995] Sandholm, T. W. and Lesser, V. R. (1995). Coalition formation among bounded rational agents. In *14th International Joint Conference on Artificial Intelligence*, pages 662–669.

[SeyedEsfahani et al., 2011] SeyedEsfahani, M. M., Biazaran, M., and Gharakhani, M. (2011). A game theoretic approach to coordinate pricing and vertical co-op advertising in manufacturer-retailer supply chains. *European Journal of Operation Research*, 211:263–273.

[Shen et al., 2001] Shen, W., Norrie, D. H., and paul A. Barthes, J. (2001). *Multi-Agent Systems for Concurrent Intelligent Design and Manufacturing*. Taylor & Francis.

[Shenoy and Lawrence, 1979] Shenoy, P. and Lawrence (1979). On coalition formation: A game-theoretical approach. *International Journal of Game Theory*, 8(3):133–164.

[Shi and Hu, 2006] Shi, M.-Y. and Hu, S.-L. (2006). Modeling negotiation in combinatorial auctions based on multi-agent. In Shi, Z.-Z. and Sadananda, R., editors, *Agent Computing and Multi-Agent Systems*, volume 4088 of *Lecture Notes in Computer Science*, pages 644–649. Springer Berlin Heidelberg.

[Sim, 2004] Sim, K. M. (2004). Negotiation agents that make prudent compromises and are slightly flexible in reaching consensus. *Computational Intelligence*, 20(4):643–662.

[Sim and Wong, 2001] Sim, K. M. and Wong, E. (2001). Toward market-driven agents for electronic auction. *IEEE Transaction on Systems, Man, and Cynernetics-Part A: Systems and Humans*, 31(6):474–484.

[Sinha and Sarmah, 2010] Sinha, S. and Sarmah, S. (2010). Coordination and price competition in a duopoly common retailer supplychain. *Computers and Industrial Engineering*, 59:280–295.

[Sjostrom, 1991] Sjostrom, T. (1991). On the necessary and sufficient conditions for nash implementation. *On the necessary and sufficient conditions for Nash implementation*, 8:333–340.

[Sombattheera et al., 2004] Sombattheera, C., Ghose, A., and Hyland, P. (2004). A framework to support coalition formation in supply chain collaboration. In *The Fourth International Conference on Electronic Business*, pages 1–6.

[Stengel, 2002] Stengel, B. V. (2002). Computing equilibria for two-person games. In Aumann, R. and Hart, S., editors, *Handbook of Game Theory*, volume 3, pages 1725–1756.

[Teich et al., 2006] Teich, J. E., Wallenius, H., Wallenius, J., and Zaitsev, A. (2006). A multi-attribute e-auction mechanism for procurement: Theoretical foundations. *European Journal of Operational Research*, 175(1):90 – 100.

[Tsvetovat et al., 2001] Tsvetovat, M., Sycara, K., Chen, Y., and Ying, J. (2001). Customer coalitions in electronic markets. In Dignum, F. and CortC)s, U., editors, *Agent-Mediated Electronic Commerce III*, volume 2003 of *Lecture Notes in Computer Science*, pages 121–138. Springer Berlin Heidelberg.

[Wooldridge, 2001] Wooldridge, M. (2001). *Introduction to Multiagent Systems*. John Wiley & Sons, Inc., New York, NY, USA.

[Wu, 2011] Wu, D. (2011). Joint pricing-servicing decision and channel strategies in the supply chain. *Central European Journal of Operations Research E*, 19(1):99–137.

[Xia, 2011] Xia, Y. (2011). Competitive strategies and market segmentation for suppliers with substitutable products. *European Journal of Operational Research*, 210:194–203.

[Xiao et al., 2010] Xiao, T., Jin, J., Chen, G., Shi, J., and Xie, M. (2010). Ordering, wholesale pricing and lead-time decisions in a three-stage supply chain under demand uncertainty. *Computers & Industrial Engineering*, 59:840–852.

[Yamamoto and Sycara, 2001] Yamamoto, J. and Sycara, K. (2001). A stable and efficient buyer coalition formation scheme for e-marketplaces. In *Proceedings of the fifth international conference on Autonomous agents*, AGENTS '01, pages 576–583, New York, NY, USA. ACM.

[Yang and Fong, 2012] Yang, H. and Fong, S. (2012). Optimizing dynamic supply chain formation in supply mesh using cset model. *Information Systems Frontiers*, pages 1–20.

[Yin and Nishi, 2011] Yin, S. and Nishi, T. (2011). Incorporating contract decision for supply chain optimization. In *Proceedings of the 44th CIRP Conference on Manufacturing Systems*.

[Yu et al., 2012a] Yu, F., Kaihara, T., and Fujii, N. (2012a). Game theory based multi-attribute negotiation between ma and msas. In *International Conference Advances in Production Management Systems*, Rhodes, Greece.

[Yu et al., 2012b] Yu, F., Kaihara, T., and Fujii, N. (2012b). A multi-agent based negotiation for supply chain network using game theory. In Frick, J. and Laugen, B., editors, *Advances in Production Management Systems. Value Networks: Innovation, Technologies, and Management*, volume 384 of *IFIP Advances in Information and Communication Technology*, pages 299–308. Springer Berlin Heidelberg.

[Yu et al., 2013a] Yu, F., Kaihara, T., and Fujii, N. (2013a). Coalition formation based multi-item multi-attribute negotiation of supply chain networks. In *46th CIRP Conference on Manufacturing Systems 2013*, Setubal, Portugal.

[Yu et al., 2013b] Yu, F., Kaihara, T., and Fujii, N. (2013b). Hierarchical-game based negotiation protocol for effective supply chain network. *Transactions of the Institute of Systems, Control and Information Engineers*, 26(4):138–146.

[Zhao et al., 2010] Zhao, Y., Wang, S., Cheng, T., Yang, X., and Huang, Z. (2010). Coordination of supply chains by option contracts: A cooperative game theory approach. *European Journal of Operational Research*, 207:668–675.

Appendix

A1. All equilibriums for MA with all SF_j

MSA	SF_j	TF	k	p_j^F	q_j^F	lt_j^F	π^M	π^S
0	{013}	12	0	1.256	14365	41	406108.244	2703.809
		12	1	15.004	8619	29		
		12	2	7.178	2873	29		
		12	3	112.535	5746	41		
	{015}	10	0	1.165	15085	39	397768.095	2568.992
		10	1	13.992	9051	29		
		10	2	6.658	3017	29		
		10	3	104.943	6034	39		
	{0245}	9	0	1.118	15460	38	392221.657	2565.025
		9	1	13.462	9276	29		
		9	2	6.386	3092	29		
		9	3	100.962	6184	38		
	{04}	20	0	1.558	11990	49	413841.232	9052.287
		20	1	18.341	7194	29		
		20	2	8.901	2398	29		
		20	3	137.556	4796	49		
1	{103}	11	0	1.269	14770	40	401732.645	28698.806
		11	1	13.845	8862	29		
		11	2	7.253	2954	29		
		11	3	108.801	5908	40		
	{105}	9	0	1.178	15515	38	391413.339	23492.118
		9	1	12.772	9309	29		
		9	2	6.731	3103	29		
		9	3	100.962	6206	38		

continued on next page

continued from previous page

MSA	SF_j	TF	k	p^F_{jk}	q^F_{jk}	lt^F_{jk}	π^M	π^S
	{14}	20	0	1.605	12035	49	414066.675	26115.827
		20	1	17.803	7221	29		
		20	2	9.170	2407	29		
		20	3	137.556	4814	49		
2	{213}	13	0	1.299	14095	42	408520.375	6125.880
		13	1	14.851	8457	29		
		13	2	7.425	2819	29		
		13	3	116.140	5638	42		
	{23}	14	0	1.341	13765	43	410978.854	19525.681
		14	1	15.328	8259	29		
		14	2	7.664	2753	29		
		14	3	119.615	5506	43		
	{234}	10	0	1.165	15160	39	396676.880	4454.742
		10	1	13.317	9096	29		
		10	2	6.658	3032	29		
		10	3	104.943	6064	39		
	{24}	53	0	1.056	16375	82	371112.879	2801.925
		53	1	12.073	9825	60		
		53	2	6.036	3275	38		
		53	3	91.167	6550	82		
	{245}	9	0	1.118	15540	38	391040.749	2526.7516
		9	1	12.772	9324	29		
		9	2	6.386	3108	29		
		9	3	100.962	6216	38		
3	{301}	11	0	1.269	15080	40	397707.494	150093.048
		11	1	14.507	9048	29		
		11	2	6.922	3016	29		
		11	3	103.836	6032	40		

continued on next page

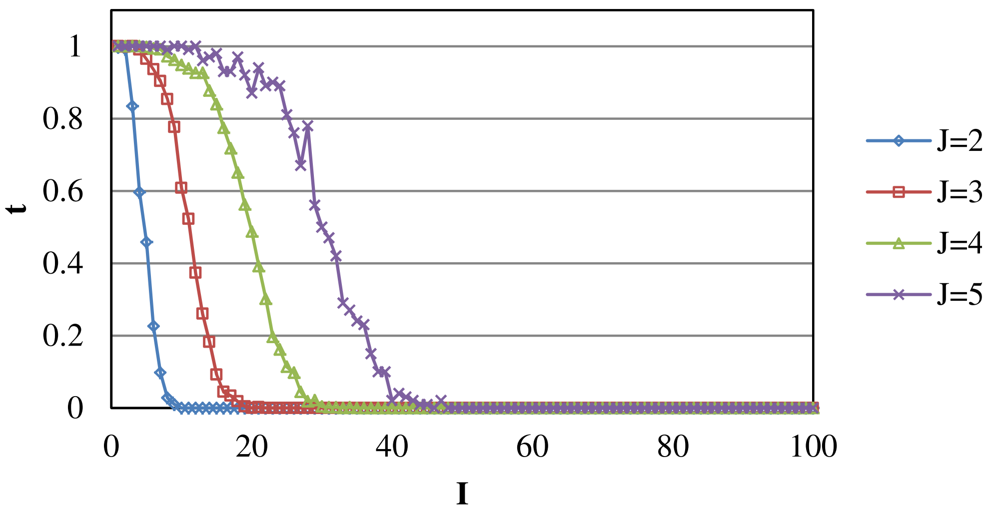
continued from previous page

MSA	SF_j	TF	k	p^F_{jk}	q^F_{jk}	lt^F_{jk}	π^M	π^S
	{32}	14	0	1.396	14030	43	408848.914	203606.661
		14	1	15.949	8418	29		
		14	2	7.664	2806	29		
		14	3	114.960	5612	43		
	{324}	8	0	1.130	16235	37	378566.145	55290.133
		8	1	12.915	9741	29		
		8	2	6.106	3247	29		
		8	3	91.586	6494	37		
	{34}	53	0	1.064	16415	82	370461.615	55548.139
		53	1	12.156	9849	60		
		53	2	6.036	3283	38		
		53	3	90.546	6566	82		
4		21	0	1.588	12110	50	414055.294	292723.887
		21	1	18.146	7266	29		
		21	2	9.073	2422	29		
		21	3	136.097	4844	50		
	{403}	14	0	1.341	14110	43	408177.642	78299.735
		14	1	15.328	8466	29		
		14	2	7.664	2822	29		
		14	3	114.960	5644	43		
	{423}	10	0	1.165	15540	39	390890.690	31747.103
		10	1	13.317	9324	29		
		10	2	6.658	3108	29		
		10	3	99.874	6216	39		
	{425}	9	0	1.118	15925	38	384276.855	19015.908
		9	1	12.772	9555	29		
		9	2	6.386	3185	29		
		9	3	95.790	6370	38		

continued on next page

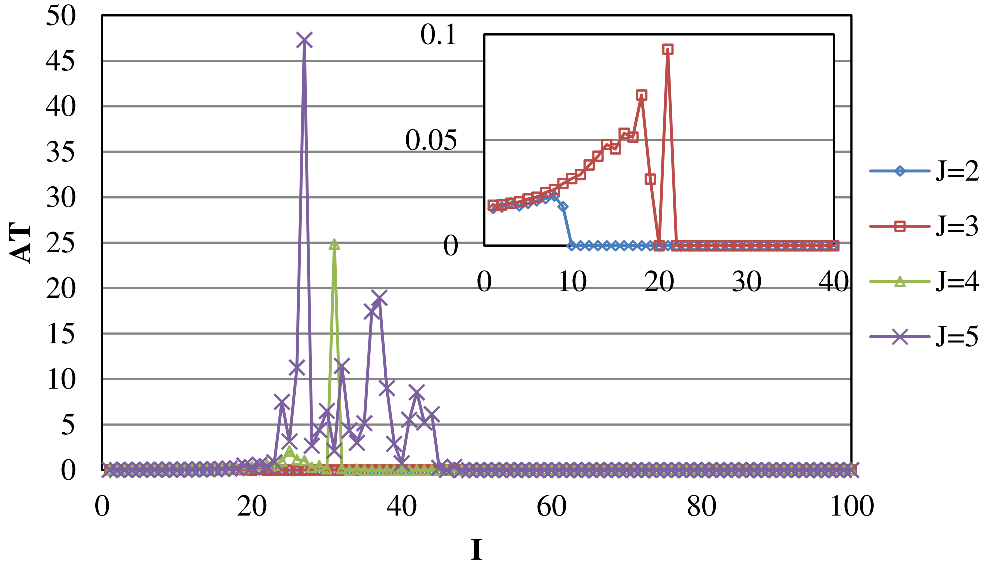
continued from previous page								
MSA	SF_j	TF	k	p^F_{jk}	q^F_{jk}	lt^F_{jk}	π^M	π^S
5	{501}	9	0	1.178	15825	38	386155.468	135399.564
		9	1	13.462	9495	29		
		9	2	6.731	3165	29		
		9	3	95.790	6330	38		
	{52}	14	0	1.396	14020	43	408991.609	228397.298
		14	1	15.949	8412	29		
		14	2	7.974	2804	29		
		14	3	114.960	5608	43		
	{524}	8	0	1.130	16220	37	378786.134	84405.612
		8	1	12.915	9732	29		
		8	2	6.457	3244	29		
		8	3	91.586	6488	37		

A2. Fluctuation of τ related to I and J



A3. Fluctuation of AT related to I and J

A4. Statistic results of the equilibriums of MAs in nine cases



MA	$\overline{TF_i}$	$\overline{p_{ijk}^M[TF_i]}$ $k=1$	$k=2$	$k=3$	$k=4$	$\overline{q_{ijk}^M[TF_i]}$ $k=1$	$k=2$	$k=3$	$k=4$
Case 1									
1	29.43	1.198	16.793	8.594	123.360	14867.7	8920.6	2973.5	5947.1
2	24.09	1.459	15.102	8.133	110.625	15833.0	9499.8	3166.6	6333.2
3	30.58	0.992	17.094	8.545	126.143	14693.3	8816.0	2938.7	5877.3
4	23.52	1.470	15.399	8.160	109.646	15865.3	9519.2	3173.1	6346.1
5	29.10	1.080	16.953	8.612	122.161	14948.8	8969.3	2989.8	5979.5
Case 2									
1	41.66	1.114	16.165	8.288	118.662	15257.8	9154.7	3051.6	6103.1
2	35.17	1.427	14.743	7.956	107.954	16052.5	9631.5	3210.5	6421.0
3	44.05	0.970	16.896	8.445	124.662	14814.8	8888.9	2963.0	5925.9
4	33.27	1.392	14.655	7.789	104.011	16328.6	9797.2	3266.7	6531.4
5	41.81	1.023	16.490	8.372	118.663	15238.0	9142.8	3047.6	6095.2
Case 3									
1	42.11	1.143	16.378	8.392	120.259	15125.0	9075.0	3025.0	6050.0

continued on next page

continued from previous page

MA	$\overline{TF}_i$	$k=1$	$k=2$	$k=3$	$k=4$	$k=1$	$k=2$	$k=3$	$k=4$
2	35.17	1.421	14.676	7.923	107.464	16093.0	9655.8	3218.6	6437.2
3	43.77	0.961	16.809	8.401	124.012	14868.6	8921.2	2973.7	5947.4
4	33.59	1.397	14.702	7.812	104.366	16299.4	9779.6	3259.9	6519.7
5	42.21	1.047	16.688	8.475	120.161	15114.1	9068.4	3022.8	6045.6
Case 4									
1	26.12	1.206	12.764	6.823	91.750	14828.2	10434.8	3478.3	6956.5
2	20.96	1.453	14.526	7.533	105.225	15872.2	9797.1	3265.7	6531.4
3	27.00	0.991	16.045	8.219	116.947	14697.3	9231.0	3077.0	6454.0
4	20.69	1.472	18.077	9.270	132.035	15856.8	8475.9	2825.3	65650.6
5	26.25	1.106	20.193	10.318	147.962	14814.4	7688.9	2563.0	5126.0
Case 5									
1	45.58	1.095	16.024	8.219	117.613	15345.4	9207.2	3069.1	6138.2
2	37.92	1.391	14.337	7.756	104.942	16300.5	9780.3	3260.1	6520.2
3	47.53	0.937	16.589	8.290	122.370	15003.8	9002.3	3000.8	6001.5
4	36.86	1.388	14.614	7.769	103.699	16354.7	9812.8	3270.9	6541.9
5	45.69	1.005	16.349	8.299	117.600	15326.4	9195.9	3065.3	6130.6
Case 6									
1	45.68	1.099	16.049	8.231	117.793	15330.5	9198.3	3066.1	6132.2
2	38.30	1.385	14.275	7.725	104.487	16337.8	9802.7	3267.6	6535.1
3	46.92	0.914	16.373	8.180	120.758	15137.1	9082.3	3027.4	6054.8
4	37.27	1.379	14.534	7.729	103.092	16404.6	9842.7	3280.9	6561.8
5	45.63	1.001	16.318	8.284	117.370	15345.5	9207.3	3069.1	6138.2
Case 7									
1	22.34	1.279	17.403	8.891	127.926	14488.6	8693.2	2897.7	5795.4
2	18.25	1.512	15.691	8.423	114.996	15473.4	9284.0	3094.7	6189.3
3	23.41	1.066	17.777	8.890	131.244	14270.6	8562.3	2854.1	5708.2
4	18.13	1.543	16.089	8.504	114.878	15434.8	9260.9	3087.0	6173.9
5	22.51	1.176	17.732	9.015	128.045	14461.4	8676.8	2892.3	5784.5

continued on next page

continued from previous page

MA	$\overline{TF_i}$	$k=1$	$k=2$	$k=3$	$k=4$	$k=1$	$k=2$	$k=3$	$k=4$
Case 8									
1	54.66	0.987	15.207	7.821	111.500	15852.4	9511.4	3170.5	6341.0
2	47.67	1.277	13.065	7.129	95.497	17077.8	10246.7	3415.6	6831.1
3	55.38	0.818	15.492	7.735	114.172	15682.1	9409.3	3136.4	6272.8
4	46.35	1.246	13.267	7.097	93.487	17194.8	10316.9	3439.0	6877.9
5	54.43	0.889	15.406	7.812	110.481	15916.0	9549.6	3183.2	6366.4
Case 9									
1	54.16	0.955	14.967	7.703	109.702	16001.9	9601.1	3200.4	6400.7
2	48.29	1.297	13.292	7.241	97.183	16939.1	10163.5	3387.8	6775.7
3	55.20	0.803	15.357	7.667	113.166	15765.2	9459.1	3153.0	6306.1
4	47.41	1.286	13.646	7.286	96.361	16958.3	10175.0	3391.6	6783.3
5	54.27	0.876	15.304	7.759	109.709	15979.9	9588.0	3196.0	6392.0

List of Publications

Journal

1. Fang Yu, Toshiya Kaihara, and Nobutada Fujii: Hierarchical-game based negotiation for effective supply chain network. *Transactions of the Institute of Systems, Control and Information Engineers*, 26(4), pp.138 - 146, 2013.

2. Fang Yu, Toshiya Kaihara, and Nobutada Fujii: Hierarchical-game based multi-attribute negotiation of supply chain network. SICE Journal of Control, Measurement, and System Integration, 6(2), pp.89 - 95, 2013.

3. Fang Yu, Toshiya Kaihara, and Nobutada Fujii: Multi-agent based multi-item negotiation of supply chain network using game theory. *IEEJ Transactions on Electronics, Information and Systems*, 133(9), 2013 (Accepted).

4. Fang Yu, Toshiya Kaihara, and Nobutada Fujii: An efficient multi-item multi-attribute negotiation protocol between multiple manufacturer agents and multiple material supplier agents. *European Journal of Operational Research*, 2013 (Submitted).

International Conference

1. Fang Yu, Toshiya Kaihara, and Nobutada Fujii: A multi-agent based negotiation for supply chain network using game theory. *Proceeding of the APMS 2011 International Conference Advances in Production Management Systems*, Norway, September, 2011.

2. Fang Yu, Toshiya Kaihara, and Nobutada Fujii: Hierarchical-game based negotiation for supply chain network. *The ASME 2012 International Symposium on Flexible Automation*, St. Louis, MO, USA, 18-20 June, 2012.

3. Fang Yu, Toshiya Kaihara, and Nobutada Fujii: Game theory based multi-attribute negotiation between MA and MSAs. *Proceeding of the APMS 2012 International Conference Advances in Production Management Systems*, Greece, September, 2012.

4. Fang Yu, Toshiya Kaihara, and Nobutada Fujii: Coalition formation based multi-item multi-attribute negotiation of supply chain networks. *Procedia CIRP, Forty Six CIRP Conference on Manufacturing Systems 2013*, 7, pp.85-90, 2013.

Book Chapter

1. Fang Yu, Toshiya Kaihara, and Nobutada Fujii: A multi-agent based negotiation for supply chain network using game theory. *J. Frick and B. Laugen (Eds): APMS2011, IFIP AICT 384*, pp.294-303, 2012 (Selected & Revised).

2. Fang Yu, Toshiya Kaihara, and Nobutada Fujii: Game theory based multi-attribute negotiation between MA and MSAs. *Emmanouilidis C., Taisch M. and Kiritsis D. (Eds): IFIP AICT 398*, pp.535-543, 2013.