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Chapter 1 Introduction

A cooperative relationship between collaborative companies is different from traditional one-time transactions. Two companies seeking mutual complement to enhance their survivability in the market form a collaborative organization (Huang and Wu 2003). A collaborative organization is formed by a group of partners based on mutual trust and/or strategic plans. Usually a company prefers to associate with an organization that can offer far more rewards than costs (Brinthaupt *et al.* 1991, Moreland *et al.* 1993). If most of the members in a collaborative organization cannot receive the expected rewards, the organization may dissolve. The relationship between the members in collaborative production is dependent on the alternatives available in a given situation.

Collaborative production needs flexible, reliable and quality production to increase advantage of market in a quickly change of customer requirement. Collaborative companies combines their individual energies and resources in joint activities aimed at reaching both individual and common goals (Zander 1985). Transaction between collaborative partners exist uncertainties. Gasser (1994) points out two approaches to reducing the control complexity. That is reducing the degree of uncertainty and the impact of uncertainty. Communication is used to reduce or at least cope with uncertainty (Weick 1979). The uncertainties of collaborative production include production planning and inventory management in manufacturer, difficult to acquire production information for distributer, complexities in different ordering from reseller, and unstable replenishment pattern and procurement cycle time from end-user (Park 2003). Causes of these uncertainties may be lack of information necessary to make a decision, the outcome of a decision or the perceived risk associated with a decision, or understanding of a problem's root causes in collaborative production (Balakrishnan *et al.* 1994). Minimization of uncertainties can be performed by information sharing of production and resource integrating between collaborators. Coordination is necessary among collaborative members in the collaborative production activities to reduce transaction uncertainties. Coordination require communication and the more the need for coordination, the greater the necessity for communication (Ceroni *et al.* 1999). Communication is the basis for cooperation and a successful factor in collaborative production.

1.1 Background and motivation

Production systems suffer the changing of globalization of market environment and improvement of production technology. Producers of today are seeking close relationships with their suppliers and customers to improve their survivability. In nineteenth century, one craftsman manufactured a customized car according to specific requirement of customer in the automotive industry (Womack *et al.* 1991). Taylor (1911) proposed scientific management leading to standardization of products and processes. Companies introduced scientific management, such as Ford Motor Company, organizing its assembly operations to mass manufacture large numbers of products at lowest possible cost per unit. Producers became to a large extent vertically integrated to standardize required for reducing costs. Vertically integrated companies become a large organization. They exposed a large number of incompatible activities that need to be coordinated when companies become larger. Companies begin to try to contracting out of noncore activities to an external provider. Outsourcing become a popular productive strategy to seek a realize benefits, such as cost savings, cost restructuring, capacity management, and risk management (Quinn and Hilmer 1994). Production becomes distributed in outsourcing production environment. However, distributed production and bilateral partnerships reveal wide ranges of complexity and requirement of coordination. Information and computation technologies change organizational structure of production network. Companies exhibit informatization of production processes. In the age of globalization and informatization leading to keen competition between companies, economies of scale is not guaranty of survivability. Companies aggregate their core-competition processes between upstream and downstream companies to reduce process time of transaction in the environment of internet cooperation. Companies come together to create a product or service, not to create an organization or corporation forming virtual enterprise (Goranson 1999). Groups of company recognize, create, or act upon business opportunities results in business networking.

ICT (IT and CT) technologies can be seen as major enable for modern enterprise collaborations (Jagdev and Thoben, 2001). Jagdev and Thoben (2001) also indicate that IT (Information Technology) deals with the sharing or exchange of information between two companies and CT (Communication Technologies) focuses on the tools required for the transfer of information between any two companies. ICT (Information and Communication Technology) became an important communication tool for the interaction within and between collaborative partners with the popular and rapid growth and development.

Conflicts occur between companies because of different specialty and values in outsourcing collaboration. The bargaining power in supplier-customer relationships depends on asymmetry of information. Authority to access information is different between collaborative partners of outsourcing. Communication with clear and sufficient information is almost impossible due to the privacy of internal (Jung and Jeong 2005). Complete information about a whole distributed collaborative organization is generally unavailable due to divisional boundaries defined by organizational structures and information privacy (Jeong and Leon 2002). Due to the various degrees of visibility of collaborative organizations, there exists different degree of network transparency of the collaboration (Tan and Harker 1997). Communication cannot handle exception because of lacking of horizontal communication in the vertically integrated collaboration. The results of Beer Game have indicated that ICT adds a degree of complexity to human decision-making that is difficult to cope with even if well-defined protocols are provided (Disney *et al.* 2004). Heavy process and high frequency of communication affect the update efficiency of information and accuracy of information content. There are too much information and too many calculations to manage. All of the above communication problems demonstrate that the transparency of information is important in collaborative organization. While ICT offers the opportunity for greater supply chain transparency, it creates an even more complex environment so that when people do have to take action, the decision-making is even more difficult. At the same time, with current technology, it is difficult for ICT systems to handle exceptions, such as absenteeism or factory shut downs.

ICT offer a good environment of communication between collaborative companies. Unfortunately, ICT could not offer solutions for resolving basic communication problems, willingness of communication and exceptions and conflicts between collaborative companies. However, few of papers to date propose what communication behavior of willingness of offering information and what a suitable communication between collaborative partners. No fundamental guidelines have been proposed for the design of collaborative production even though various designs have been investigated. This research will to develop a guideline of justification for suitable communication in collaborative organization and for designate communication method for a specific collaborative organization.

1.2 Research approach

Collaboration results when one or more companies confront an obstacle, a problem, or a task they wish to overcome, solve, or complete, and the companies recognize that the solution is beyond the reach of a single company. Collaboration among companies motivates effective communication. Communication is designed to coordinate their production activities and integrate resources among collaborators. Effective communication is the process of accurate and reliable message transmission and understanding by the receiver. The receiver responds to the message in the way that the message sender intends (Weston 1993). The extent and amount of information requirement and the communication frequency in the communication process among the collaborators are relevant to the complexity of the product itself. Market uncertainty is also relevant in the collaborative production process. Collaborative members establish communication and information exchange procedures according to the communication requirements of the individuals. Collaborators will communicate using different methods and tools to meet their communication needs. Various types of information exchange exist for different products, markets, and companies. Companies must develop a feasible communication procedure that allows fast, understandable, and efficient business transactions and information exchanges. Communication for collaborative production can be designated as three layers: data layer, syntax layer, and justification layer, as shown in Figure 1.1.

Data Layer: Communication for collaborative production requires a communication channel that allows fast, understandable and efficient data and message transmission between partners.

Syntax Layer: Collaboration must control the relationships between the communicating entities, the allocation of communicating resources, and the orderly flow of information that describes the coordination mechanism.

Justification Layer: Companies need to determine the relationship between communicating entities, the content of collaboration, and the resources of sharing to determine collaborative activities.

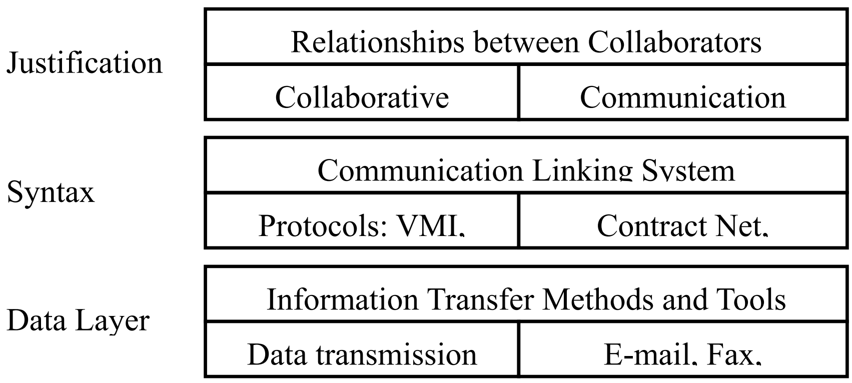

Figure 1.1 Communication Layering

Constructed communication is a nature extension of the behavior of communication in collaborative production. A company may send request message to partners, interpret information from multiple sources, negotiate allocation of resource, or measure communication performance. Organization can solve communication problems at each layer more easily by constructed infrastructure of communication if communication can be layered.

Data transmission in the data layer is the physical transfer of data over a point-to-point or point-to-multipoint transmission medium. The transmission medium includes communication and storage media. Communication between partners transmits data over telecommunication technology in a distributed organization.

Companies use different applications of computer systems. The various application systems present different data and file formats. Communication between different application systems usually requires complicated data format conversion. The data format conversion requires a common format for data transmission (syntax of communication). Blackboard, expectation-driven, and protocol are the solutions to data format conversion (Decker 1987) in the syntax layer.

The blackboard model where the place of information sharing is viewed as a blackboard on which to write messages, post partial results, and find information (Hayes-Roth 1988). The expectation-driven communication is an idea for minimizing communication, that only when need between collaborators. A protocol is a set of rules which is used by computers to communicate with each other across a network. A protocol is a convention or standard that controls or enables the connection, communication, and data transfer between computing endpoints. A protocol can be defined as the rules governing the syntax, semantics, and synchronization of communication (Gitlin *et al.* 1992). Protocols may be implemented by hardware, software, or a combination of the two. A protocol defines the behavior of a hardware connection at the lowest level. Protocols make it possible to establish and maintain a communication session by conveying appropriate messages among the units carrying out essential tasks between collaborative partners. The well designed protocol is not only rules for the exchange of information but also an agreement between the sender and the receiver about those rules.

Some of the studied protocols for distributed collaboration communication go back to the human organization metaphor. Contract net protocol is a communication process for seeking collaborative partners, according to the requirements of the task, and identifies the most appropriate ones (Smith and Davis 1981). RosettaNet protocol is a business-to-business electronic commerce standard consortium for the electronics industry, encompassing hundreds of companies from the domains of manufacturing, distribution, retail and end-user (RosettaNet 2000). New supply chain strategies, such as vendor managed inventory (VMI), collaborative planning, forecasting and replenishment (CPFR) and efficient consumer response (ECR), have begun to exploit these new communication channels, principally at the retail end of the supply chain (Disney *et al.* 2004). Protocols have become the trading patterns, processes, information content, and the industry standard of communication.

The development of different protocols is aimed at solving different communication requirements. Suppliers are authorized to manage inventories at locations of buyers such as VMI. Suppliers can rationalize inventory in the supply chain (Yao and Dresner 2008). Effective communication between collaborators requires various protocols for different collaborative organizations and specific environment. Vender need more amount of information to provide instruction for the product in a production of complex product. Collaborative organization must select and decide a feasible protocol for effective communication.

Communication benefits companies and incurs costs. The justification layer of communication determines the value of a communication method for a specific collaborative organization. Thus, the development of justification criteria is crucial for the evaluation of communication design in collaborative production. Corollaries or principles of communication have to be investigated to help build the justification criteria.

Amount of information between collaborative communications refers to production itself. Communication frequency between collaborators depends on requirement of coordination in collaborative activities. Some organizations need a regular exchange of information and message which is not urgent. The other organizations need to communicate frequently and speedily so that they could make decision or response for customer service with latest information. A collaborative organization needs to design suitable communication methods to increase communication efficiency and achieve production goals.

The diverse production requirement will form different patterns of collaborative organization in collaborative production (Balakrishnan *et al.* 1995). The collaborative organization requires communication to coordinate resource allocation and achieve a common goal (Villa *et al.* 1994). Three dimensions of collaborative production for communication are specified; production requirement, collaborative organization, and organizational communication. The three dimensions constitute the communication triangle, as shown in Figure 1.2.

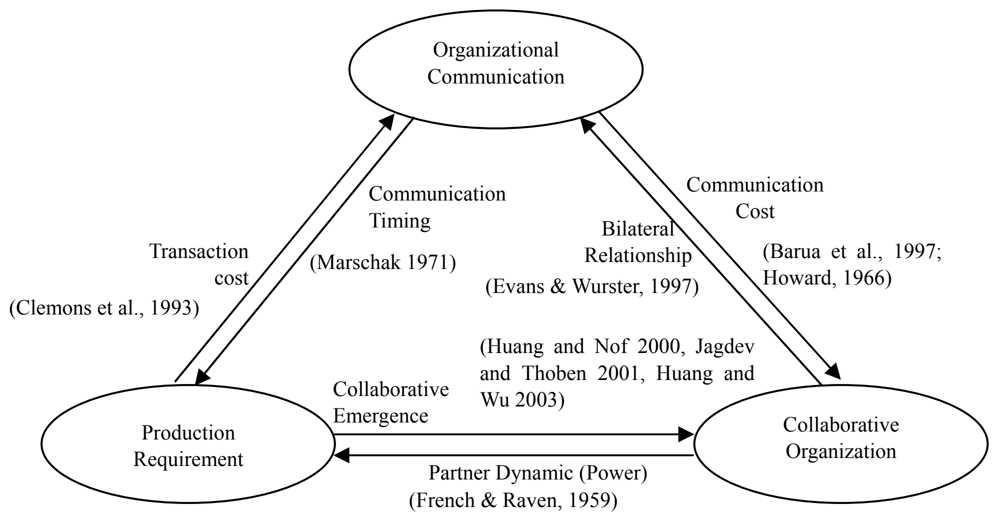

Figure 1.2 Communication Triangle

Some partners in the element of collaborative organization have influential power over other members (Clegg 1975). Influential power may come from the advanced know-how technology of the company or its size. The powerful company is clearly superior to the other members and rules the production behaviors. The behavior of production is one of the factors that influence the production requirement. Any collaborative organization is composed of a series of bilateral relationships. Multiple unique bilateral relationships may exist because various companies imply various relationships. The relationship between the collaborators affects the pattern of the communication networks (Forsyth 2006) and the selection of communication tools. Communication networks and tools will increase production cost in collaborative production. The willingness of communication which is the basis of coordination in the collaborative organization will diminish because of the increased communication cost. The collaborative organization may change or even collapse because the goal of the organization is not achieved because the cost is excessive.

Communication among companies in collaborative production is to reduce uncertainty (Goldhaber 1993). Information disclosure will decrease uncertainty of transaction (Williamson 1998). The greater the transaction cost the more companies communicate with each other. Transaction cost will affect organizational communication in collaborative production.

Batch communication or real-time communication is a type of information transmission for timing of organizational communication. Selection of information transmission type is a management requirement in collaborative production. The timing of communication will affect the operation of production. For example, a company can secure the capacity or materials from the suppliers on-line when it uses a real-time information system.

The three dimensions have distinct influences on communication for collaborative production. The production requirement and collaborative organization are different approaches to rearranging collaborative production.

The strength of collaboration as an organism, function and structure, is organizational communication. There are six elements which affect communication behavior; collaborative emergence, partner dynamics, bilateral relationship, communication cost, transaction cost, and communication timing. These elements are the building blocks for the communication principle of collaborative production.

1.3 Research objectives

Cooperation involves not only information exchange and alignment of activities, but also sharing resources for achieving compatible goals (Camarinha-Matos and Afsarmanesh 2007). Communication between collaborators is an activity not only a state of behavior. It is a process of transmitting or receiving information by means of information carriers in formats of data and syntax from one individual to another. The objective of this study was to establish guideline by means of corollaries and principles to indicate and determine suitable communication for collaboration. A case of collaborative production uses the guideline to develop a communication system for distributed manufacturing systems.

1.4 Research Methodology

The research methodology of this research is literature analysis and proposition reasoning to analyze phenomena of communication behavior. The reasoning process has four stages, as follow.

1. Induction of propositions

This stage collects literatures according to research approach and areas. The main literatures are application of information and communication technology, collaborative organization, organizational communication, and economics issue of communication. This research analyzes facts of communication behavior from collected literatures to induct propositions.

2. Development of corollaries

This stage reviews theories and supported by inducted propositions to deducted corollaries.

3. Discovery of principles

This stage combines inducted propositions, deducted corollaries and basic theories to discover communication principles.

4. Conclusions

This stage concludes results of research and application of the results.

1.5 Research areas and constrains

This research surveys theorems and literatures in economic issues, organizational communication, and organizational dynamic. These surveys explore necessary conditions for collaborative communication. The necessary conditions are presented in principles. Therefore, the discovered principles could be the guideline to establish effective communication system beyond information technology.

However, research process of this research require numerous of literatures to support inductive inference of communication principles. It is difficult to collect literatures completely. This research does not offer thorough communication principles for collaborative production. There may have more principles that could be added.

The methodology of this research cannot find out the methods to implement these necessary conditions. To find out how to establish these necessary conditions, the research requires other methodologies.

Information may be confused with data or information engineering. We denote information is message that take on a meaning which can be used to enhance knowledge.

1.6 Research contributions

This research finds out facts of communication behavior from literature analysis. According to these facts, this research proposes concepts related to communication. Then, the present approach obtains propositions from these concepts to developing corollaries under basic definitions and communication theories. Principles are discovered from deducted corollaries and propositions. Therefore, these principles provide a list of guideline for design communication system. However, these principles are not to explain the reasons of communication behavior, but describe what actions should be took during design of communication system.

1.7 Research structure

This research is organized as follows: Chapter 2 is literature reviews that summarize the information communication technologies for sharing and exchanging information. Then, this paragraph explores the power influence on bilateral relationships, describes the unique partnerships with varying strength of the inter-company bond, and presents hyperarchical organization communicating based on organizational power structures. Next, this paragraph illustrates how the cost of communication might influence organizational communication and discuses organizational communication and the benefit of horizontal bridge link communication. Chapter 3 presents the deduced communication principles for collaborative production based on the developed propositions and corollaries. Chapter 4 develops an algorithm for problem shaping of collaborative communication. We describe a case of application of communication principles in collaborative production and an order confirmation mechanism for this production networks. Network structure, protocols and messages have been designed and introduced. The core of the protocols, procedures is introduced. Based on the designed network structure, protocols, messages, and procedures, a system for distributed factory agents is developed and introduced. Finally, concluding remarks and future research are presented in chapter 5. Figure 1.3 shows the research framework of this research.

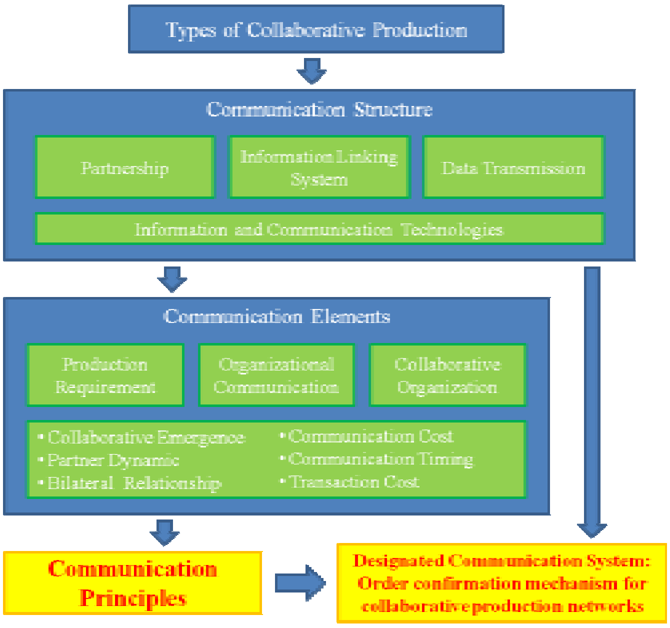

Figure 1.3 Research framework

Chapter 2 Literature review and Reasoning fundamentals

The various parts of the collaborative organization are supposed to act in a coordinated manner. Coordination depends on effective communication which is a process of sending and receiving messages. Effective communication involves two conditions: (1) the processes of message sending and receiving are accurate and reliable; (2) the message receiver understands and responds to the message in the way that the message sender intends (Weston 1993). Many apparently are convinced that there is a strong connection between communication effectiveness and organizational effectiveness (Nof *et al.* 2004). Classical and scientific approaches to organizations considered communication primarily as a tool for managerial control and coordination. Although organization managers often understand “organizational effectiveness” only in terms of increased productivity, improved work performance, or higher morale, the belief that effective communication is essential to these conditions in organizational communication.

Members of collaborative production is an association of independent organizations that come together and share resources and skills to achieve a common goal (Camarinha-Matos and Afsarmanesh 2007). Each member of collaborative production is an autonomous individual. The individual member may have its own goals. Assuming that individual member is egoism, who pursue their own maximum benefit and avert any possible risk. Individual member may hide important information, such as quality information, to obtain more benefits when their goals conflict with the common goal of collaborative production. Collaborative organization consequently could not get complete information to make decision. The incomplete information leads to inefficiencies for collaboration increasing uncertainty, risk, and information asymmetry.

The conflict must be resolved through communication. There is a major change in the allocation of resources, where conflicts might occur, when collaborative organization is formed. Conflict is inevitable and even necessary aspect of group and organizational processes (Janis 1972, Robbins 1977, Goldhaber 1993). It should not be suppressed and avoided but confronted, managed and resolved. It can bring to the surface issues that require resolution, relieve tensions, and lead to the development of new channels of communication (Koehler *et al.* 1981). The collaborative production organization must be based on open communication, accurate disclosure of objectives and sharing of information so that the conflicts could be minimized and the integrative bargaining could be reach.

Companies are intents to reduce risk, by accessing to additional information. Complete information is one of the theoretical preconditions of an efficient collaboration. The individual companies would not be able to predict the effect that their actions would have on the others collaborators if a transaction is not in complete information.

Uncertainty need not lead to inefficiency when both sides of a transaction have the same limited knowledge concerning the future, but it can lead to inefficiency when one side has better information (Nicholson and Snyder 2008). The side with better information have private information or equivalently, asymmetric information. Information asymmetry creates an imbalance of power in transactions which can sometimes cause the transaction to go awry. The market of lemons showed incomplete information lead to cost of operation risk when buying products (Akerlof 1970).

A collaborative production is an alliance constituting a variety of organizations that are largely autonomous, geographically distributed, and heterogeneous in terms of their operating environment, culture, social capital, and goals (Camarinha-Matos and Afsarmanesh 2007). Communication activities are affected by factors of organizational structure and communication process in collaborative production. Communication throughout the organizational structure exist message distortion or filtering problems between collaborators (Daniels and Spiker 1994). The greater the number of steps or linkages in a serial reproduction chain and the greater the perceptual differences among participants in that chain, the more likely it is that some form of message distortion or filtering will occur. More communication does not necessarily lead to greater efficiency. The key communication process within the organization is to identify the right people at the right time to obtain the adequate information. Communication will become easier if the organization, membership, and environment are stable. The communication process is dynamic, accompanied by new actors, new media, and new events. The dynamic of communication process leads to a situation of ambiguity and conflict.

Collaborative members desired to receive adequate information that has enough amount related to solving productive problem of collaboration since it is the key to reduce uncertainty (Daniels and Spiker 1994). Collaborative members consider themselves to be inadequately informed on many important topics in collaboration, too much or too little information. (Farace *et al.* 1977) assumed that inadequate information usually results from distribution problems. The collaborator manages the inputs of information and interactions of the group in the collaborative production when a collaborative member is working on a problem, exchanging information, and making a decision. A saturation point can be reached at which the individual can no longer efficiently monitor, collate or route incoming and outgoing messages as work progresses and the number of communications being routed through collaborative members increase. That is because "the greater the saturation the less efficient the performance of performance" (Shaw 1964).

2.1 Information and communication technologies in collaborative production

Collaborative partners need to communicate in order to solve task problems (Decker 1987). The WWW usage is associated with a reduction in search costs. WWW electronic communication and brokerage effects help corporate buyers quickly and easily to identify potential suppliers (Malone *et al.* 1987, Benslimane *et al.* 2005).

Information technology (IT), ERP and agent technology, become critical tools to enable autonomous and distributed enterprise to move toward agility, distribution, and mass customization (Huang *et al.* 2000). IT deals with the sharing or exchange of information between two collaborative members. Communication Technologies (CT) focuses on the tools required for the actual transfer of information between two parties. Important production-related information is available and manageable in a controlled user-dependent way by using Information and Communication Technologies (ICT) (Ishii *et al.* 2005). The manufacturing world is moving from a highly data-driven environment to a more cooperative information/knowledge-driven environment under ICT. This environment takes into account enterprise know-how and application semantics. The enabling technologies of computer communication increase the human ability to share and exchange information; among team members, among distributed machines, robots, tele-operations, and sensors. These technologies also increase the ability of producers, suppliers, distributors and customers to exchange information (Nof 2003).

Collaborative and information integration in manufacturing systems are characterized by autonomy, distribution, communication, and collaboration (Nof 1994). Those characteristics are enabled by ICT. Communication between collaborators is increased in regard to the amount of information and frequency of interaction if there is an increase of coordination and cooperation. Communication protocols keep this communication to a minimum through structures of dialogues and protocols to enhance the effectiveness and efficiency of communication (Huang and Nof 2000).

The development of IT and communication protocols allows communication between collaborative partners to resolve structural problems. Agent based communication and electronic messaging protocols such as RosettaNet (RosettaNet 2000) has been developed to automate the asynchronous exchange of business documents or messages between collaborating trading partners over the Internet between collaborative members.

Such protocols commonly employ mechanisms such as retries, time-outs, and fault handling to overcome uncertainty in the timing and reliability of message transmission, receipt, and processing.

The role of agents is to enable efficient information exchanges at the work application level, and perform tasks, under protocol control, to ensure smooth, efficient interactions, collaboration, and communication, which augment the natural human work abilities. An agent has been defined as a computing hardware and/or software system, that is able to (nonautonomously, or autonomously) interact with other agents and its environment, act, and respond reflexively to external impacts in accordance with its given goals (Nof 2003). It is important to integrate software tool based on protocols for integration and coordination between companies to have advantage of flexibility, reliability, and quality (Eberts and Nof 1993). A distributed scheduling algorithm has been developed to meet the need of communication and coordination between members in the collaborative production in which the negotiation mechanisms are adopted to resolve the conflicts (Anussornnitisarn *et al.* 2005b). Types of protocol are developed to achieve various communication functions in collaboration. Communication protocol can be defined as a set of rules governing the exchange of messages through interactions of communication software modules (Kakuda and Saito 1991). Coordination protocol guides the interaction among the independent entities via communication channel to exchange information and decision for communication of agents. Task protocols, sometimes called task administration protocols (Nof 2000) are similar to communication protocols but serve at the application level and obtain information via the communication protocols.

Electronic messaging protocols such as RosettaNet (RN) automate the asynchronous exchange of business documents between collaborating trading partners over the Internet. Such protocols commonly employ mechanisms such as retries, time-outs, and fault handling to overcome uncertainty in the timing and reliability of message transmission, receipt, and processing. RosettaNet is a business-to-business electronic commerce standard consortium for the electronics industry, encompassing hundreds of companies from the domains of manufacturing, distribution, retail and end-user (RosettaNet 2000). Process Flow Controller (PFC) is developed to design, interpret, and control the business messages based on RosettaNet standards (Park 2003). PFC will define transaction procedure, control and monitor transaction flow (RosettaNet 2000). The business process is divided into private and public processes in RosettaNet, whether the target is located inside or outside of the enterprise (RosettaNet 2000). The object of the public process is to communicate with external entities in PFC, and the private object to communicate with other systems inside the enterprise.

Collaborative organization can apply advanced ICT linking collaborative members to speed up communication and enhance autonomous decision-making. A disadvantage of the autonomous collaboration system is its uncertainty controls. The uncertainty occurs when the distribution of control information differs from where the control decisions are actually made (Lesser and Corkill 1981). Other types of uncertainties are more severe including the reliability of information, the imprecision of representation of that information, the incompleteness of the information, and the aggregation of information from multiple sources (Bonissone 1986, Bonissone and Decker 1986). Some of these communication problems occur because the collaborative members lack motivation to expend the additional effort that is required to resolve the problems. Effective communication for collaborative production consequently requires a fundamental guideline to develop a communication environment among collaborative members.

Definition 1 We denote communication with IT is using modern electric technologies for communication rather than traditional visual or audio or mail messages in data transmission.

Data transmission between partners is the physical transfer of data over a point-to-point or point-to-multipoint transmission medium in the data layer. The transmission medium includes communication media, and storage media. Communication between partners can transmit data over telecommunication technology in the distributed organization. Telecommunications involved the use of visual signals, such as smoke, semaphore telegraphs, signal flags, and optical heliographs, or audio messages via coded drumbeats, lung-blown horns, or sent by loud whistles in earlier times (Holzmann 1991), for example. Telecommunications has typically involved the use of electric means such as the telegraph, the telephone, the teletype, the fax, and the e-mail, the use of microwave communications, the use of fiber optics and their associated electronics, and/or the use of the Internet in the modern age of electricity and electronics. In general, data transmission belongs to telecommunications and electrical engineering.

Communication between partners requires transmitting speedy, reliable, and real-time information for satisfying its needs of clients and fulfilling its cooperative agreements. Collaborative partners could connect their computers or devices to each other with the ability to exchange data as a computer networking so that the communication can transmit information and share resource automatically. The three types of networks are: the Internet, the intranet, and the extranet.

2.1.1 Agent-based communication system

An agent is able to (nonautonomously, or autonomously) interact with other agents and its environment and respond reflexively to external impacts in accordance with its given goals, which has been defined as a computing hardware and/or software system (Nof 2003). A distributed scheduling algorithm could adopt agent-based negotiation mechanisms to resolve the conflicts and meet the need of communication and coordination between members in the collaborative production (Anussornnitisarn *et al.* 2005a).

2.1.2 Multi-agent systems

Huang and Nof (2000) specify four key characteristics of agent: autonomy, communicative capability, goal orientation, and reactivity. In terms of design, agents and protocols are the two most important elements in a multi-agent system. Protocols ensure inter-agents' communication into a complete state. Besides, a protocol should be associated with tasks. That is, agents do not communicate in vain. They communicate to collaborate with other agents to accomplish tasks. Hence, protocols in agent-based production systems are also specified as task administration protocols (Huang and Nof 2001).

Protocols define acts between agents. Each act embraces messages. Knowledge Query and Manipulation Language (KQML) (Labrou and Finin 1997) specifies a widely used message format, as shown in Figure 2.1. KQML message format include three layers: message layer, communication layer, and content layer. This research defines messages by following the format and will be explained later.

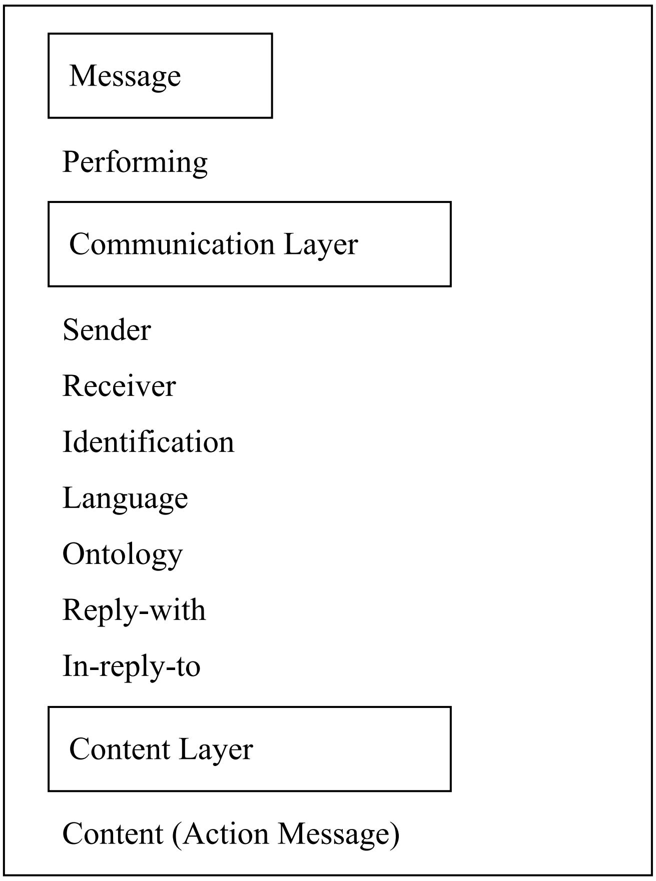

Figure 2.1 KQML message structure (Sun *et al.* 2001)

2.2 Organization issues in collaborative production

Collaborative organization can be different in types and bilateral relationships. Production requirement leads collaboration into types, while influential powers between collaborators lead collaboration into different bilateral relationships. Different types and bilateral relationships between collaborators have different communication behavior and requirement. Therefore, design of communication in collaborative organization need to consider these communication factors of organization issue at the same time.

2.1.1 Power in collaboration

The formation of a strategic coalition in collaborative production is based on pursuing maximal or long-term benefit. A collaborative production environment is constructed of units belonging to different companies. Each company has its own goal. The companies have to negotiate with each other to create consensus.

Bilateral relationships exist between collaborative organizations. Differences in the status and power of collaborative members are present in every collaborative relationship. The bases of power in groups is traced to six key sources (French and Raven 1959), Table 2.1.

Each company uses its own power to influence the partners. These powers will eventually reach equilibrium, a form of collaboration. The relationship among collaborative members changes when the power of a member changes. The change will result in a new equilibrium or dissolution of the relationship. Expert power, referent power, and reward power are important in improving the normative relationship commitment of the manufacturers. Reward and coercive power enhance instrumental relationship commitment (Zhao *et al.* 2008).

The powers in the organization influence the bilateral relationship. The different relationships will require different communication requirements and behaviors.

1. Reward power:

Power is closely tied to the control of valued resources in many cases. Reward power bases on controlling over the distribution of resources given or offering organization members. For example, customer can decide to give more business to a specific manufacturer. Rewards are more likely to augment its power that a company controls exclusively (Pfeffer and Salancik 1978). Collaborative members who rely on others for a reward will likely comply with the requests of individual.

Table 2.1 Analysis of power in organizational relationships

Power Base	Definition	Using power in collaborative production
Reward	The capability of controlling the distribution of rewards given or offered to the target.	A company, which controls exclusively is more likely to augment its power, for collaborative members who depend on others for a reward will likely comply with the requests of that individual (Pfeffer and Salancik 1978).
Coercive	The capacity to threaten and punish those who do not comply with requests or demands.	Powerless members tend to use coercive threats, punishments, and abuse more than do empowered authorities (Bugental and Lewis 1999).
Legitimate	Authority that derives from the powerholder's legitimate right to require and demand obedience.	Coercive power always seeks to clothe itself in the garments of legitimacy (Wrong 1979).
Referent	Influence based on the identification of the target attraction to, or respect for the powerholder.	The company with referent power lies at the organizational center of the collaborative production (Forsyth 2006).
Expert	Influence based on the belief of the target that the power holder possesses superior skills and abilities.	Collaborative members often defer to and take the advice of those who seem to possess superior technologies and knowledge.
Informational	Influence based on the potential use of informational resources, including rational argument, persuasion, or factual data.	Some companies achieve informational power by deliberately manipulating or obscuring information, or at least making certain that the information remains a secret shared by only a few group members (Messick 1999).

2. Coercive power:

Coercive power derives from ability of a company to punish or threaten others who do not comply with requests or demands. For example, Customer can cancel business or reduce the volume of business with manufacturer. Company use coercion to influence other collaborative members. They influence others by threatening customers with not offering materials or parts for them or threatening suppliers with not to use their products. They tend to use coercive threats, punishments, and abuse more than do empowered authorities when some members fell relatively powerless (Bugental and Lewis 1999). In contrast, they often avoid the use of their power when companies that are equal in coercive power interact (Lawler *et al.* 1988, Lawler and Yoon 1996).

For example, Wal-Mart, the world's largest retailer, has a power derived from their size. Wal-Mart does more business than Target, Sears, Kmart, J.C. Penney, Safeway, and Kroger combined. The size advantage of Wal-Mart becomes coercive power to squeeze profit concession from suppliers. Wal-Mart forces supplier offering goods 'everyday low prices'.

3. Legitimate power:

Legitimate power is recognition of right to ask other collaborative members to obey their orders. Some manufacturer believes that customer has the right to request and expect things to be done according to its requirements, as part of the manufacturer–customer relationship. Consent is a necessary condition of a stable system of power. Legitimacy is important because it gives rise to consent (Zelditch and Walker 1984). Legitimate power could minimize the need for maintaining means of coercion in constant readiness, continual surveillance of the power subjects, and regular supplies of economic or non-economic rewards. Coercive power always seeks to clothe itself in the garments of legitimacy (Wrong 1979).

4. Referent power:

Company A has referent power with company B to the extent that B wish to collaborate with A. Referent power depends on identification. Identification occurs when a company adopts attitudes and values with other company. Kelman (1961) believes that identification involves a desirable, satisfying, and self-defining relationship with another company. A company with referent power lies at the organizational center of the collaborative production (Forsyth 2006). Companies identify with and seek close association with respected/attractive group members such as brand, design, and sales channel, when they seek out membership in selective/desirable partners. For example, a customer has power over the manufacturer, based on positive emotional ties, if the customer has developed a strong bond through its demonstrated concern, management style and organizational personality (Goodman and Dion 2001).

For example, Wal-Mart is one of the world's largest retailers. Wal-Mart has managed to eliminate supplier power and become referent power. Wal-Mart has dominant force and become an important account for their suppliers. Wal-Mart has twenty-three per cent of sales of Clorox and Revlon and twenty per cent of sales of RJR tobacco (Useem 2003). They would lose out on nearly a quarter of their revenue if these companies choose to expire on their supplier relationship with Wal-Mart. These suppliers know that their Wal-Mart account is one that they cannot afford to lose. The power of Wal-Mart derives from size becomes referent power.

5. Expert power:

A company holds expert power with others if they possess some special knowledge that is required to solve a problem, perform a task, designing or distributing new products to the final consumers. Collaborative members often defer to and take the advice of those who seem to possess superior technologies and knowledge. Patents authorization and technology transfer of production can transform their special knowledge into expert power.

6. Informational power:

Collaborative members can turn information into power by providing it to others who need it, by keeping it from others, by organizing it, increasing it, or even falsifying it. Collaborative leaders often know more about the group, its tasks, and its members than anyone else, because their role requires substantial communication and coordination. Some companies achieve informational power by deliberately manipulating or obscuring information, or at least making certain that the information remains a secret shared by only a few group members (Messick 1999).

For example, Wal-Mart is one of the largest retailers of world. Wal-Mart has customer requirement information. Wal-Mart has employed computers, network, and internet to connect to suppliers to share information of customer requirement and delivery time. Suppliers can reduce inventory and cost, and speed deliveries when access to these information so that the suppliers can achieve dramatic cost savings. The lower inventory allow Wal-Mart to produce inventory turnover rate around seventy per cent which is really high (Bateman and Snell 2003). Information sharing not only achieves substantial cost saving for entire supply chain, but also improves supplier's manufacturing processes. Wal-Mart has built enough power with suppliers that they can dictate the prices. The power of Wal-Mart is derived from their information and the influence that come with it. Wal-Mart turns information into power by organizing it. Wal-Mart has become the leader of collaborative organization.

Definition 2 We denote the forming of collaborative production follows the five bases power of and information power of organizational communication in forming organization.

Each organization has one or two more power influencing bilateral relationship between collaborative members. Each company in collaborative organization uses its own powers to influence other members. These powers will eventually reach equilibrium, a form of collaboration. The relationship among collaborative members will change when the power of a member is changed. The relation between collaborative partners will reach a new equilibrium which a new form of collaboration. Expert power, referent power and reward power are important in improving normative relationship commitment of manufacturers, while reward power and coercive power enhance instrumental relationship commitment (Zhao *et al.* 2008).

The powers in organization influence bilateral relationship. The different relationship between collaborators will have different communication requirements and communication behavior.

Definition 3 The choice of collaborative partners follows minimal costs and maximum benefits.

Companies are eager to seek collaborative partners for innovation and market opportunities to enhance their advantage of competition in the market (ability to quickly respond to the market, and reduce production costs) in collaborative production. Cooperation between companies that is followed by positive consequences will occur more frequently. Cooperation that is followed by negative consequences will become less frequent. These principles are based on the law of effect (Blau 1964, Foa and Foa 1971, Homans 1974, La Gaipa 1977).

Collaborative production incurs costs, such as negotiations, information sharing, and operation and opportunism risks. Individual companies will strive to maximize their rewards and minimize their costs based on social exchange theory (Thibaut and Kelley 1959).

A company will join collaborative organizations and remain in organizations that provide them with the maximum number of valued rewards while incurring the minimum amount of costs (Thibaut and Kelley 1959, Kelley and Thibaut 1978, Moreland and Levine 1982).

2.2.2 Strength of inter-company bond

Inventory and delivery problems are two major concerns in collaborative production. Collaborative production pursues the value of the organization as a whole. A company has a choice when it enters into a collaborative organization. The company will enter into the virtual concept, finding the best partner group. Jagdev and Thoben (2001) illustrate the strength of the inter-company bond between collaborators as three types: supply chain , extended enterprise, and virtual enterprise.

The supply chain type of collaboration entails coordination with customers and suppliers. In order to operate efficiently all collaborators across the supply chain must operate in a synchronous mode, providing rapid and quality response to the events. The extended type of collaboration can be regarded as a kind of organization which is represented by all those organizations or parts of organizations, customers, suppliers and subcontractors, engaged collaboratively in the design, development, production and delivery of a product to the end user (Browne *et al.* 1996). The virtual type of collaboration is one manifestation of organizational response to the dynamic and globalization of market demand. The baseline for a virtual enterprise is the customer needs. These needs can be extensive and unique or small but with numerous variations.

1. Partnership between organizations

One of the important terms of collaboration is partnership. Four factors are considered to determine partnership: the format of the relationship with suppliers, the number of suppliers, the type of service provided by suppliers, and the method of service delivery from suppliers (Huang and Wu 2003). The developed partnership defines enterprise collaboration in a broader perspective. A transaction between two companies performed over a telephone line is a type of collaboration. A co-design project among companies over the Internet is another type of collaboration.

2. Virtual organization

Huang and Nof (2000) propose a society of autonomous agents called the autonomous agent network (AAN). Autonomous agents are loosely coupled within the AAN. The tasks of the System are accomplished by the autonomous agents collaboratively through the communication and information exchange definitions protocols. A collaborative production includes more than two companies. The communication requirements of any two companies in the network could be different, co-replenish an inventory versus co-design a product.

'Loosely coupled' means the agents are not necessarily cooperating closely on any particular task according to Tsukada and Shin (1996), but they may affect one another, and in particular, the action of one may hinder another from achieving its goal. There could be more than two companies involved in any collaborative production network. The communication requirement between any two companies in the network could be uniquely different. The collaboration may just replenish inventory or co-design products. Each type of collaborative organization requires various communications to meet its production requirement and goal.

2.2.3 Bilateral relationships of collaborative production

Collaborative organization has specific communication requirement in different organization. Collaborative organization can be either hierarchical or nonhierarchical (Evans and Wurster 1997, Jagdev and Thoben 2001). Relationship between organizations will affect the mode of communication. Evans and Wurster (1997) and Jagdev and Thoben (2001) illustrate the network organization of inter-company interactions and interdependencies in their 'hyperarchy' model. Each member depends on one superior company in a hierarchy type, which has access to information that is not available for its subordinates. The communication links can be complex and can take any direction in a hyperarchy type of collaborative networks.

1. Hierarchical organization type

Companies outsource the non-core functions while retaining full strategic control in a hierarchical organization. Those non-core functions could be manufacturing or logistics. The organization is actually a central hub surrounded by networks of outside suppliers. The advantages of this kind of alliance type are to decrease overall costs, to quicken new product development, and to focus scarce resources on the areas where they hold a competitive advantage.

The central company has more hegemony in the hierarchical organization type. The other company should cooperate with it. Hegemony involves "the ability of one class to articulate the interests of other social groups to its own" (Mouffe 1981). Ideological hegemony therefore involves "effective self identification with the hegemonic forms" (Williams 1977). Thus ideology functions as control through active consent rather than through passive acceptance of pre-given social formations (Mumby 1987).

The control power of central company is because of the core-function ability that it own such as reputation, knowledge and technology within the organization, type and uniqueness of products, brand names and patents. Power is most successfully exercised by those who can structure their interests into the organizational framework itself (Mumby 1987). Power is achieved by establishing an organization's mode of rationality through controlling the deep structure rules of organizations (Mumby 1987).

2. Hyperarchical organization of collaborative production

Collaborative production involves tasks, projects, plans, and goals. Collaborative members exchange information, negotiate planning, and make decisions. The members must coordinate their various schedules, resources, and motivations so that the group can make a decision, generate a product, and achieve a common goal. Any collaborative organization has specific communication requirements. The relationship between different companies will affect the mode of communication. Each collaborative organization in these bilateral relationships can be either hierarchical or nonhierarchical (Evans and Wurster 1997, Jagdev and Thoben 2001). Evan and Wurster (1997) and Jagdev and Thoben (2001) illustrate the network organization of inter-company interactions and interdependencies in their ‘hyperarchy’ model.

The hyperarchical organization consists of a network of independent companies, suppliers, customers, competitors, linked together to share skills, costs, and access to a market. This network comprises a group of units of different firms that have joined in an alliance to exploit complementary skills in pursuing common strategic objectives. Hyperarchical organizations need not be permanent. Participating companies may be involved in multiple alliances at any one time. The hyperarchical organization has two categories, vertical and horizontal collaboration.

Vertical collaboration involves different companies performing complementary value activities. Horizontal collaboration involves different companies involved jointly in the same value activities such as production, research development, advertising, and distribution. The hyperarchical organization type has no central company to maintain full strategic control. Participating companies give up part of their control and accept interdependent destinies. The objectives of this type organization are enhanced capacity or competitiveness. This organization does not need a hierarchy (Dess *et al.* 1995). Participating companies pursue a group strategy that enables them to cope with uncertainty in the supply chain through cooperative efforts.

A well defined communication protocol is necessary to coordinate resource allocation because there is no central company. Communication structuring is a privilege enjoyed by some of the organizational members (Mumby 1987). Communication among collaborative members is constrained by organizational power structures. These constraints provide the medium through which members can act strategically in organizations (Conrad 1985). The companies in alliance will develop a unique collaborative model. The collaborative production network will be complicated if a company has various alliances. Optimum collaborative production is difficult to achieve in the real world.

Weick (1979) points out that organizational activity is often made sense of according to collaborative production model that the alliance developed, i.e., made to seem rational, only in retrospect; there is frequently organizational power. Thus "the structural framework is not an abstract chart but one of the crucial instruments by which groups perpetuate their power and control in organizations: groups struggle to constitute structures in order that they may become constituting" (Ranson *et al.* 1980).

2.3 Economic issues of collaborative production

Companies intend to increase communication frequency and data exchange between collaborators when transaction cost is high. However, frequent communication and large amount of data exchange increase communication cost, which will reduce willingness of communication. Therefore, how to reduce communication cost and transaction cost are important in collaborative communication.

2.3.1 Cost of communication

The company must assess many attributes of decision variables to reduce the transaction cost and maximize profit in determining a collaborative partner. Barua *et al*. (1997) propose effective supplier selection strategies that complement information technologies to lower the expected cost to the buyer, to evaluate more suppliers, and to selecting better suppliers. They divide the supplier selection cost into three basic elements including (1) supplier-search cost is customer looking for a new supplier, (2) cost of communication between supplier and customer, and (3) evaluation cost for the customer. Communication cost of collaborative production in this chapter will be discussed based on this model.

Supplier-search cost for each potential company is assumed to be equal and denoted by S_c on the Internet and the use of IT environment. Supplier-search cost is product of the unit cost of search, S_c, and the number of suppliers, N_s; $S_c \times N_s$.

Communication cost is the cost of data transmission between the collaborators. Each message attributes is denoted by N_a, such as delivery time, quality, and reliability. The acquiring cost of each attribute is assumed to be constant, A_c, in the use of IT technology. Communication cost is equivalent to $A_c \times N_a$. The communication cost becomes $A_c \times N_a \times N_s$ for searching new suppliers.

Evaluation costs include the cost of resources used to assess the capability of each and compare prices and other aspects of the proposals. If the evaluation cost of each potential supplier is E_c, the evaluation cost is $E_c \times N_s$. The supplier selection cost is the sum of supplier searching, communication, and evaluation cost, $S_c \times N_s + A_c \times N_a \times N_s + E_c \times N_s$.

Proposition 1 Supplier-search cost may be reduced by the adoption of IT in an open market.

Illustration:

1. Searching for companies, which have a better opportunity of finding the best price, quality, and other key product attributes, is expensive. Malone *et al.* (1987) point out that IT reduces the unit cost of coordination and the transaction specificity of investment in inter-firm interactions.
2. The coordination cost of the search process is reduced with IT (Clemons *et al.* 1993).

Corollary 1 Supplier-search cost increases as the amount of information being collected increases.

Proof. Supplier-search cost is equal to unit supplier-search cost multiply by the number of supplier searched. The number of supplier-search represents the amount of information that is collected. When the amount of information increased the cost of search is increased. As the unit cost of search is constant in the use of IT, the supplier-search cost increases as the amount of information collected.

Corollary 2 The profit of a supplier increases as it eliminates uncertainty by obtaining worthy information.

Proof. Information sharing at the inventory level by a retailer can reduce the uncertainty for the vender of the forecasted demand and variation. Inventory cost saving results from information sharing in the supply chain (Lee and Whang 2000, Xu *et al.* 2001). Yao and Dresner (2008) also demonstrate that inventory cost saving can be achieved through sharing of real-time inventory data by the retailer, no matter what the customer demand is stable or highly variant. However, the retailer does not receive any benefit from sharing either the projected net requirement or future planned order information with the supplier (Zhao and Xie 2002), because the retailer does not eliminate uncertainty through the sharing of information. Besides, clairvoyance of uncertainties has synergy effect. Howard (1966) proves that we have a basis for investing in uncertainty reduction when we know the benefit of reducing uncertainty.

Proposition 2 IT reduces communication cost among collaborative partners than without IT.

Illustration:

1. Many researchers agree that IT can decrease the costs accumulation, communication, and processing of information (Malone *et al.* 1987, Bakos 1991a, Bakos 1991b, Clemons and Row 1992, Strader and Shaw 1997).
2. The IT investment cost among collaborators is mainly the hardware and

software costs of the Internet (Garcia-Dastugue and Lambert 2003). A fundamental economic characteristic of IT investment is that fixed costs are high and marginal costs are low. (Clemons and Row 1992).

3. Because IT is able to increase information availability and processing capacity (Clemons *et al.* 1993), as the amount of information increases the unit cost of communicating and information processing is consequently reduced.

Corollary 3 Communication between companies requires a connected information system with IT to reduce communication cost and increase the efficiency of information transmission.

Proof. The uncertainties of collaborative production between companies may cause (1) a lack of information necessary to make a decision, (2) a lack of knowledge for the perceived risk associated with a decision, or (3) a lack of understanding the root cause of a problem in collaborative production (Balakrishnan *et al.* 1994). Communication reduces or at least copes with uncertainty (Weick 1979). However, communication also increases the cost of production. An individual collaborative member pursues its own maximal benefit and averts any possible risk based on Definition 3. Communication with IT reduces communication cost between companies, Proposition 2. Therefore, collaborative companies require IT to reduce communication cost and increase efficiency of information transmission.

Proposition 3 A company establishes a pool of candidate partners with a good reputation for future collaborative production. A company could reduce selection cost if a partner was selected from the pool that the partners have been qualified because the evaluation cost is reduced.

Illustration:

1. The evaluation cost for supplier selection is the product of the number of suppliers to be evaluated (*N*), and the number of attributes (*A*). A pool of candidate partners will help reduce *N* by ruling out the unqualified suppliers which do not pass the requirements. These requirements include delivery time, service backup, maintenance requirements, and a minimum level of expertise.
2. A smaller number of *N* will lead to a lower transaction cost for the buyer and will speed up the selection process. The company incurs less search cost if it searches for a new supplier in the pool.
3. The company may incur some risk (cost) that the supplier overcharges if the company directly negotiates the change with existing suppliers in the pool. However, the cost may be less expensive if there is a high levels of explicit coordination (Clemons *et al.* 1993).
4. Therefore, a company selects its partners from the pool of good reputation because it can reduce selection cost.

Corollary 4 Companies of customized products intend to select collaborators with goodwill and a good reputation based on their previous transactions.

Proof. Customers feel insecure when they are not certain about the capability of the producers to produce their customized products, because customers themselves may not be able to clearly define the product specifications. Complete information does not mean that there is no uncertainty for the customer. The uncertainty inherent in the collaborative design process remains (Terwiesch and Loch 2004).

Collaborative producers will require frequent communication for a complicated product and will collect more product attributes, *A*. High communication and evaluation cost, *E* result from a complicated product. The ability to customize important product or service characteristics inherent in explicit coordination decreases the benefits of the search (Clemons *et al.* 1993).

The customer has uncertainty about the capability of the customizing producer because of unfamiliar with the company in design process of collaborative production. On the other hand, the success of customized product is judged by customer. The customer itself may unable to clearly define the specification of product. Full information does not mean that there is no uncertainty for the customer, since there still exists the "regular" uncertainty inherent in the collaborative design process (Terwiesch and Loch 2004).

Communication cost during production is the actual cost of establishing contact with partners and communication detail of production activities. The cost also includes the costs of preparing the documentation that transmit these details. Communication cost will be increased when product is complex, such as customized product which require to collect more attributes, *A*, and communicate frequently. The evaluation cost, *E*, is also increased. The ability to customize important product or service characteristics inherent in explicit coordination decreases the benefits of search (Clemons *et al.* 1993).

The supplier selection cost of customized or complex products may much higher than standard product. Select supplier from the qualified pool that has been established could reduce supplier selection cost. Consequently, the selection of partner for customized product intends to select from the pool.

2.3.2 Transaction cost economics

Collaborative production attempts to increase resource utilization and value through higher explicit coordination of productive activities. Coordination of collaborative activities requires organizational communication among all participants. Communication is supported by information sharing such as resource allocation, market change, or new opportunity. However, increased explicit coordination creates transaction risks, exposure to opportunistic behavior by the other party. Researchers have proved that increasing the coordination of resources involves transactions costs for managing the interactions. The transaction costs include costs of searching for an appropriate partner, negotiating the contract, which implements the processes for the coordination, and monitoring performance of the relationship (Clemons and Row 1992).

1. Transaction cost

Malone et al. (1987) suggest that IT reduces transactions costs will lead to greater degree of outsourcing and hence less vertically integrated firms (Malone *et al.* 1987). Outsourcing of production activities will rely more on searching in markets leading to emergence of electronic markets since search costs are decreased. Malone et al. (1987) also identified a phenomenon that they termed electronic hierarchies, which were inter firm relationships characterized by less use of search and market competition and more use of tightly coupled operations with a few long-term partners. The collaborative group may tend to dissolve and form a vertically integrated company in the group of collaborative production, likewise, when the transaction cost is high.

Clemons *et al.* (1993) and Clemons and Row (1992) separated transaction costs into coordination costs, operations risk, and opportunism risk. Their analytical approach to transaction cost involved determining the minimal total cost of the transaction cost. The acquisition of information and the effectiveness of coordination are the main factors that affect transaction cost. A certain degree of uncertainty occurs in any transaction. An optimal degree of uncertainty could be found when the marginal cost of searching for more information equals the marginal benefit of expected gains from the extra piece of information.

2. Reputation building and trust

The main aim of a collaborative organization is to enhance the survivability of the members in the markets. Collaborators are more likely to collaborate freely and productively when they trust each other. Companies are more likely to share intellectual property when they trust each other (Evans and

Wolf 2005). The main aspects, which influence trust among the members of a collaborative organization, are their roles, reputations, and membership level (Msanjila and Afsarmanesh 2008). Trust is based on reputation and reputation is acquired on the basis of observed behavior over time (Dasgupta 1988). The development of a reputation is important for the process of indirect reciprocity (Alexander 1987, Nowak and Sigmund 2005, Ohtsuki and Iwasa 2006, Brandt *et al.* 2007). Trust, reciprocity, and cooperation, are dependent on reputation building and the spread of information about the reputation of others in the industry (Bravo and Tamburino 2008).

Evans and Wolf (2005) point out that the information flow is important to the level of trust. The opportunity for one company to exploit the ignorance of another company is diminished. Fewer misunderstandings occur when there is a common vocabulary and mode of working. People are less likely to act opportunistically when their reputation is at stake. Companies that reciprocate often gain a reputation that result in greater perceived trustworthiness. These companies are more likely to be honored by other companies (Sommerfeld *et al.* 2008). These factors enhance trust, the fundamental requirement of collaborative production. Companies are tempted to break the commitment when they see a greater opportunity if there is no trust.

3. Trust reduces transaction cost

Trust is similar to decisions about taking risky choices in collaborative production (Msanjila and Afsarmanesh 2008). Collaborators are motivated to establish trust relationships with each other in order to either maximize the expected gains or minimize the expected losses from their transactions (Josang and Lo Presti 2004). The incentive of a retailer to coordinate order is less if there is a lack of trust (Mohtadi and Kinsey 2005). The knowledge by the supplier of the parameters and strategies of the retailer could lead to greater monitoring, timing of invoices and payments if there is no trust. The lack of trust reduces the incentive of the retailer to share its Point of Sale (POS) data with the supplier (Nakayama 2000).

Nakayama (2000) finds that information exchange plays a role in the power relationship between supermarkets and their suppliers, which impacts their mutual trust and the sharing of information technology among companies. The component suppliers of Toyota share process knowledge daily. They trust that Toyota will not use it to beat down prices. Linux hackers trust one another to make uncoordinated and simultaneous emendations in the code base (Evans and Wolf 2005). Agreements are enforced neither by the sanction of a legal contract nor by the authority of a boss but by mutual trust-lowering transaction costs in the Linux and Toyota communities (Evans and Wolf 2005). Large-scale trust drives down transaction costs. Low transaction costs enable many small transactions, which create a cumulatively deepening, self-organized network.

Corollary 5 Contracts dictate the engagement of collaboration and reciprocity strengthens the trust relationship.

Proof. Collaborative production relies on trust in governing the risk of transactions. Firms might build trust through contracts. Contracts contain gaps, which result from their inability to completely anticipate the future. Companies fear that their collaborative partners are solely seeking their self-interest. Contracts have a positive impact on trust but cannot avoid transaction cost. Some retailers fear that suppliers who learn of their inventory, sales, and ordering practices may somehow share this information with rivals or otherwise use it in ways that would diminish the profitability of the retailer (Kinsey and Ashman 2000). A lack of trust in collaborative production cannot guarantee success. Ford and Asea Brown Boveri build a $300 million paint-finishing plant in Oakville, Canada, which may outweigh the gain associated with lowering purchasing costs (Frey and Schlosser 1993). Ford decided to achieve a twenty to thirty per cent reduction in the cost of its capital investment projects relative to previous similar undertakings. Ford was disappointed in this plan, because no innovative technology was proposed and the estimated cost of the project (three hundred million dollars) did not fulfill its expectations of lowering previous costs by twenty to thirty per cent.

Information flows and coordination diminish and the willingness of collaborators to invest in information sharing is low if there is little or no trust between collaborators. The sharing of resources, knowledge, co-development, and information in collaborative production require a balanced level of trust between collaborative partners. A prerequisite to developing trustworthiness of a company is reputation. Reciprocity is important to reputation building. The act of reciprocity includes direct and indirect reciprocities (Trivers 1971). Cooperative behavior is required to develop a reputation (Sommerfeld *et al.* 2008). Repeated transactions and observation of norms of equity and reciprocity, may place greater reliance on parties not to act opportunistically when given access to proprietary information (Ring and Vandeven 1992). Collaboration involves the mutual engagement of participants to solve a problem. Collaboration requires strong mutual trust and thus takes time, effort, and dedication (Msanjila and Afsarmanesh 2008).

Corollary 6 It is value sharing to increase motivation of information sharing between collaborative companies.

Proof. Retailers connect to their suppliers and transmit data and information so that they know what and when the customer needs the product in a collaborative supply chain. Suppliers plan manufacturing time, product quality and inventory levels with shared information from the retailer. Zhao and Xie (2002) prove that suppliers can achieve dramatic cost savings when retailers share either the projected net requirement or future planned order information with a supplier. The profit of the supplier will increase as a result of the elimination of uncertainty, Corollary 2. Zhao and Xie (2002) also point out that the retailers usually do not receive any savings. The willingness of companies to share information by the retailer is low if a company reports that the reward is less than communication costs, Corollary 2. The trust between collaborators decreases and opportunism increases if a retailer feels the transaction is not equitable or there is a lack of reciprocity, Corollary 5. Companies expect to receive rewards in exchange for their investment of communication and other resources. A collaborative company will not offer any help if it cannot identify any personal benefit from helping others (Ratner and Miller 2001). The retailer will evaluate how well the collaborative relationship matches the collaborative goal. The collaborative organization seeks other relationships if the relationship does not fulfill its needs. The other company may provide a way of inducing changes in information sharing if the collaborative organization is valuable to continuous, financial incentive and bonuses (Domberger 1998). Hence, the collaborative members must share values obtained from the collaborative activities to increase motivation to share information.

2.4 Organizations communication of collaborative production

Collaborative production members need to communicate to reduce uncertainty during production. These uncertainties include facility changeovers in response to product design changes or urgent changes to orders (Huang *et al.* 2010). The communication structure between two companies is a system of pathways or channels of message flow connected with a common distinction between formal and informal systems of organizations communication. As task certainty increases, the group coordinates itself more through formal communication than through informal communication modes (Jablin 1990). Formal communication is a protocol governing the exchange of messages through interactions of communication software modules (Kakuda and Saito 1991). Informal communication is a substitute for an inadequate formal system. Informal communication systems arise when information transmitted through the formal system is either insufficient or ambiguous (Walton 1961). Communication is fast and more often accurate in informal communication systems, though much of the information is incomplete. The value of prompt information is not perfect but its value can be enhanced by the delayed information in the decision making process (Marschak 1971).

2.4.1 Formal communication

A company requires formal communication to ensure information flows effortlessly, precisely, and timely. Formal communication usually is described in terms of the three directions of message flow within a hierarchical system; downward communication, upward communication, and horizontal communication (Daniels and Spiker 1994).

1. Downward Communication

Downward communication involves the transmission of messages from upper levels to lower levels of the organization hierarchy. Communication is considered as a primary tool for managerial control and coordination between organizations. The movement of human relations stressed the use of downward-communication strategies that would promote morale in the belief that satisfaction would lead to compliance with authority (Miles 1965). Satisfaction of "need to know" is important to the successful assimilation of members into an organization. Koehler et al. (1981) argued that "The best integrated employees are those who are told what goals and objectives are, how their jobs fit into the total picture, and the progress they are making on the job".

Downward communication in formal communication is ineffective in many organizations, though the transmission of information has received. Problems with downward communication include inadequacy of information, inappropriate means of diffusing information, filtering of information, and a general climate of dominance and submission that pervades downward communication (Daniels and Spiker 1994). Inadequacy of information is referred to not enough information or too much information. Advanced IT could be used to manipulate information more efficiently but also to send more messages to more people. On the other hand, organization members might receive too much wrong information. It means that much of the information that members receive may not be relevant to their personal job and organizational concerns. Distortions occur because different people have different interpretations of the same information or because human beings simply have a limited capacity to process information (Daniels and Spiker 1994). The greater the number of steps or linkages in a serial reproduction chain or/and the greater the perceptual differences among participants in that chain, the more likely it is that some form of message distortion or filtering will occur (Daniels and Spiker 1994).

2. Upward Communication

Upward communication involves transmission of messages from lower to higher levels of the organization. Upward communication is a prerequisite for employee involvement in decision making, problem solving, and development of policies and procedures (Smith *et al.* 1972). Planty and Machaver (1952) stated that upward communication can (1) provide valuable ideas from subordinates; (2) facilitate acceptance of downward messages; (3) generally facilitate decision making by fostering subordinates' participation and by providing a better picture of performance, perceptions, and possible problems at all levels of the organization.

Upward communication may be subject to the same filtering problems that affect downward communication on occurring. Most of organization members would rather receive information than provide information to others (Goldhaber 1993). Koehler and Huber (1974) found that managers tend to be more receptive to upward communication when the information is positive, is in line with current policy, and has intuitive appeal to the own biases of managers. Krivonos (1976) reported that subordinates tend to tell their superiors what they think the superiors want to hear or only what they want their superiors to hear. This reticence of low-status members means that good news travels quickly up the hierarchy, whereas the top of the ladder will be the last to learn bad news (Jablin 1979, Jablin 1982), the delay of transmitting bad information.

Studies of Read (1962), Maier *et al.* (1963), and Roberts and O'Reilly (1974) indicated that accuracy of upward communication is greater when subordinates trust their superiors. Studies of Read and Maier *et al.* found that upward mobility of aspirations of subordinates are negatively related to accuracy. Accuracy in upward communication decreases as mobility of aspirations of subordinates increase. Study of Read indicates that some people who want to move up may distort information to make themselves look good (Daniels and Spiker 1994).

3. Horizontal Communication

Horizontal communication refers to the flow of messages across functional areas at a given level of an organization. Fayol (1949) recognized that emergencies and unforeseen routine contingencies require flexibility in formal channels. Strict adherence to the chain of command would be too timely consuming in emergencies. Therefore, some provision has to be made for horizontal bridges that permit people at the same level to communicate directly without going through several levels of organization (Daniels and Spiker 1994).

Horizontal communication introduces flexibility in organizational structure. It facilitates problem solving, information sharing across different work groups, and task coordination between departments or project teams. It may also enhance morale and afford a means for resolving conflicts (Koehler *et al.* 1981).

Theorists of human resource development regard horizontal communication as an essential feature of participative decision making and organizational adaptiveness (French *et al.* 1983). Reliance on horizontal communication of an organization for decision making and problem solving does not mean that the process is more efficient than simple downward communication, but horizontal communication may be more effective. Decision making and problem solving usually occur through horizontal communication at lower levels in Japanese organizations. Nomura (1981), chairman of the board of Japan's Triyo Industries, observed that decision making under this system can be a lengthy and difficult process, but once a decision has been made, its implementation is swift and certain. Organization members are committed to the decision because difficulties have been resolved and opposing points of view reconciled through horizontal communication. Downward decision making is fast because it is centralized near the top of the organization according to Nomura. However, decisions at lower levels that is accepted and implemented by top management echelon is slow to develop. Conflicts over implementation arise at lower levels leading to lack of commitment to decisions where members have been excluded from the decision-making process.

Horizontal-communication problems occur because of territoriality, rivalry, specialization, and simple lack of motivation (Daniels and Spiker 1994). Organization members often regard involvement of others in that area as territorial encroachment. Organizations value their territory and strive to protect it. Organization members are competition for rewards and resources.

2.4.2 Horizontal Bridges Link communication

Communication between collaborators has to establish an information link as a communication channel. Bridge links communication is a pattern of horizontal communication between different collaborative members and organizational units (Albrecht and Ropp 1982). Bridge links seldom appears in formal organization communication. The link facilitates information sharing between collaborative members reducing the information filtering and distortion. The delay in the transmission of information occurs because of fewer levels of horizontal communication structure within a company. Research indicates that linkers identify more closely with the collaborator, have a stronger connection between their tasks and self-concepts, think of their tasks in terms of collaboration and effectiveness, see a closer connection between their tasks and their benefits, and are less frustrated than nonlinkers (Albrecht 1984).

Information in communication transmit from operational layer upward to enterprise layer sending by information link, then to enterprise layer of another company, and then downward to operational layer. The response information from another company transmits to the contrary path. The long-path channel of communication may lead to many communication problems, such as information distortions, information filtering between companies, inadequacy of information and inappropriate means of diffusing information in formal communication, and too timely consuming of information transfer. Figure 2.2 shows communication and information flow between companies.

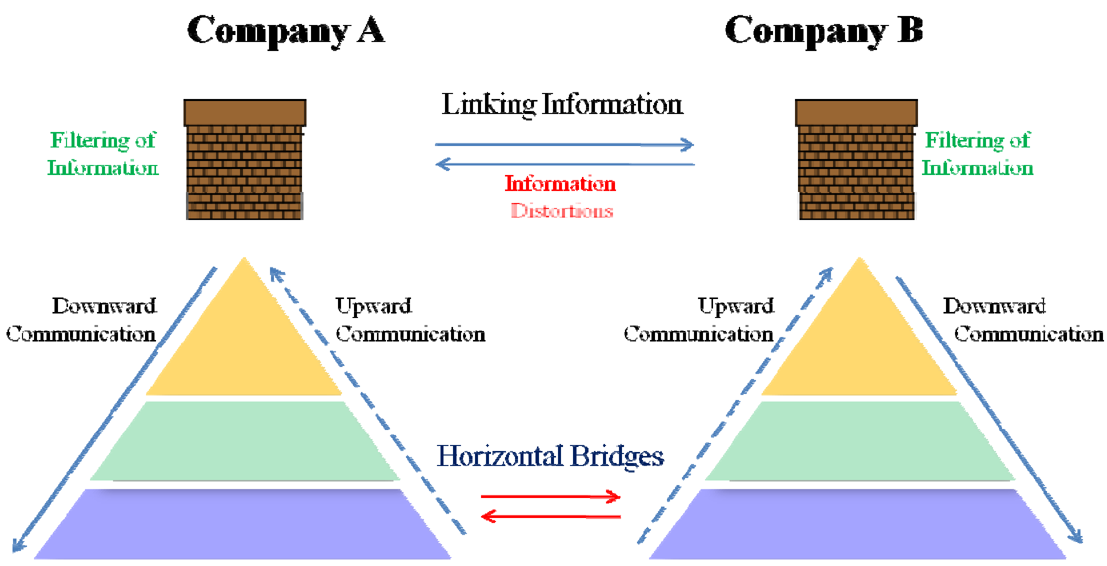

Figure 2.2 Communication and Information flow between companies

Proposition 4 Collaborators may establish horizontal bridge links to communicate directly for activities of timeliness.

Illustration:

1. Three major characteristics of communication content are described that affect coherence in the network; relevance, timeliness, and completeness (Durfee *et al.* 1987). These three are interdependent. A solution may be highly relevant but may not be timely. The information flow between the two companies passes a series of levels, including upward and downward communication processes of formal communication between companies.

Communication, which follows those formal communication steps, would be too time-consuming in emergencies.

2. The greater the number of steps or linkages in a serial reproduction chain and the greater the perceptual differences among participants in the chain, the more likely it is that some form of message distortion or filtering will occur. Distortions occur because different people have different interpretations of the same information. These differences occur because human beings have a limited capacity to process information (Daniels and Spiker 1994). The key is the limitation of unnecessary steps in information transfer which lead to time delay and information distortion.
3. Establishing horizontal bridge links between companies offer communication channels for the transfer of information at the same level directly without going through several levels of the organizations.

Chapter 3 Principles of communication for collaborative production

Collaborative production requires coordination (1) to carry out the alignment of production activities, (2) to exchange production information to enhance the production flexibility, agility, efficiency, and (3) to exchange quality information on products and services. Many obstacles exist as to the purpose of communication and to the efficiency and effectiveness of communication. A communication paradigm is required for communication, quick access to the semantic content of information to reduce uncertainty, and minimize the amount of information in communication (Decker 1987).

This research deduces the basic principles of communication by the basic communication theory and, the propositions and the corollaries obtained from the aforementioned discussion. Table 3.1 shows the deductive map. These principles provide a guideline for communication design for collaborative organizations.

1. Principle of linking information system

Communication in collaborative production requires effective information transfer and data exchange. Collaborators in a production network will seek a channel to relieve the burden of communication based on <u>Proposition 4</u>. One enterprise must link into the enterprise information system of another before sending information. One enterprise can send messages to another enterprise and obtain feedback to confirm the consciousness is consistent based on <u>Corollary 3</u>. The Principle follows from Definition 3. <u>Proposition 2</u> suggests that introducing information technology could reduce communication cost. The link of the information system between collaborators should connect with IT based on <u>Proposition 1</u>. Figure 3.1 shows the deductive map of Principle 1.

Table 3.1 Principle deductive map

Principle	Proposition	Corollary	Related theory
Principle of linking information system	1, 2, 4	3	
Principle of information sharing/exchange		2	
Principle of integrating information system	1, 2, 4	2, 3	
Principle of intercompany trust		5	Referent power
Principle of transparency of stock level/production schedules		2, 5	
Principle of sharing profit and risk		2, 6	
Principle of referent		2, 5, 6	Referent power
Principle of expert	3	4	Expert power Referent power
Principle of relationship duration	3	1, 4, 5	Partnership between companies

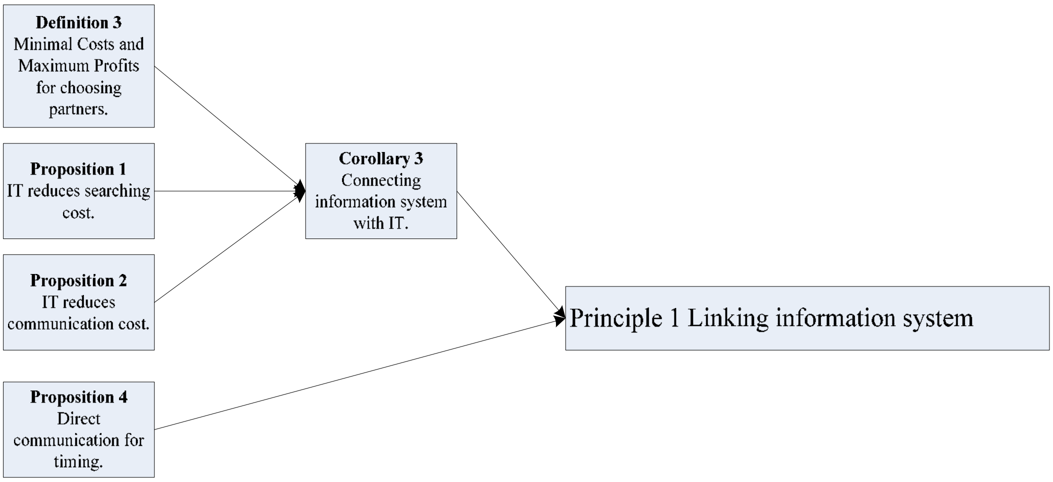

Figure 3.1 The deductive map of Principle 1

2. Principle of information sharing/exchange

Collaborators follow from Definition 3 trying to maximize profit and minimize cost. The elimination of uncertainty between collaborators can result in substantial cost saving for the entire collaborative organization according to Corollary 2. Figure 3.2 shows the deductive map of Principle 2.

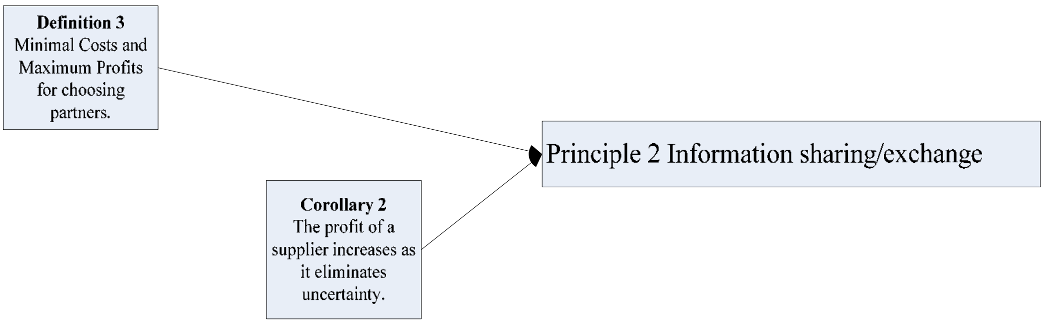

Figure 3.2 The deductive map of Principle 2

3. Principle of integrating information system

Collaborative members have to create horizontal bridge links that permit collaborators at the same level to communicate directly, following from Proposition 4. Corollary 3 suggests that communication technology enables electronic communication. Information technologies, such as ERP and agent-base technologies, are critical tools to accomplish agility, distribution, and mass customization (Huang and Nof 2000). However, compatible information between two enterprises is required according to Corollary 2. Different information systems in enterprises must be integrated. Modern protocol technology that enables effective collaboration tasks is a typical example (Nof 2003). Figure 3.3 shows the deductive map of Principle 3.

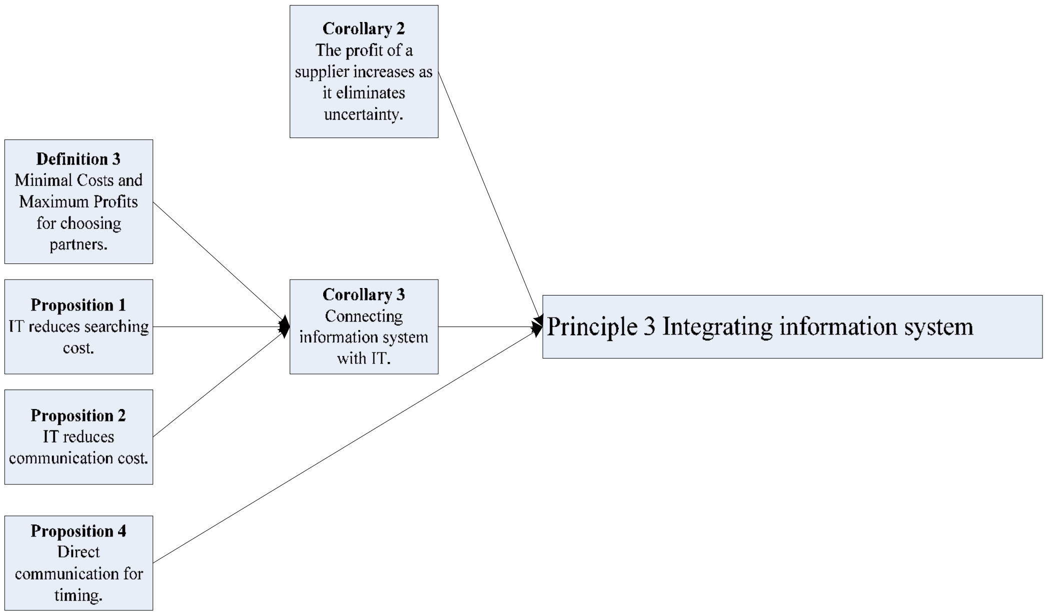

Figure 3.3 The deductive map of Principle 3

4. Principle of intercompany trust

Trust is related to information security, confidentiality, and the reputation of the business. Trust is foundation of willing to communication between companies. The trust of a collaborative organization administration for a member enhances the member to remain loyal to the collaborative organization. It will increase their willingness for active involvement in the collaborative organization. It will encourage collaborative organization members to invite and bring other valuable members into the collaborative organization (referent power). Figure 3.4 shows the deductive map of Principle 4.

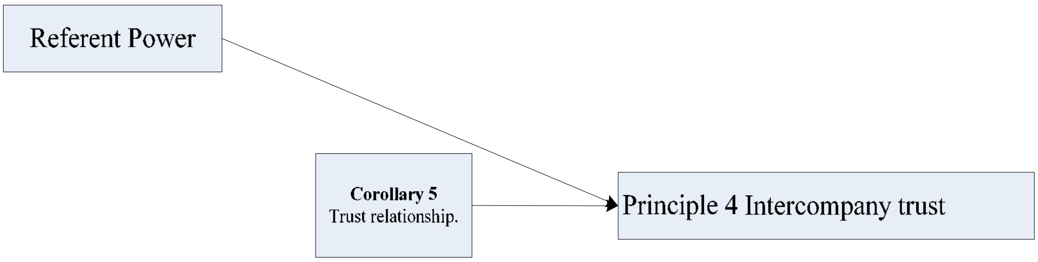

Figure 3.4 The deductive map of Principle 4

5. Principle of transparency of stock levels/production schedules

The clairvoyance of uncertainty can improve inventory cost based on Corollary 2. If a company is transparent in its stock levels or production schedules to its customers and suppliers, the customers and suppliers have no uncertainty in receiving demand orders and in shipping demand orders, respectively. The degree of transparency of stock level/production schedules depends upon the trust relationship based on Corollary 5. The access to stock level/production schedules may be direct (the partner has access to the main database) or indirect (by way of a set of translated files that contain only the filtered information) (Jagdev and Thoben 2001). Researchers have found that inventories based on the planned downstream order schedules result in the lowest average inventory level for the entire supply chain, especially in the highly variability of end-user demand (Viswanathan *et al.* 2007). Figure 3.5 shows the deductive map of Principle 5.

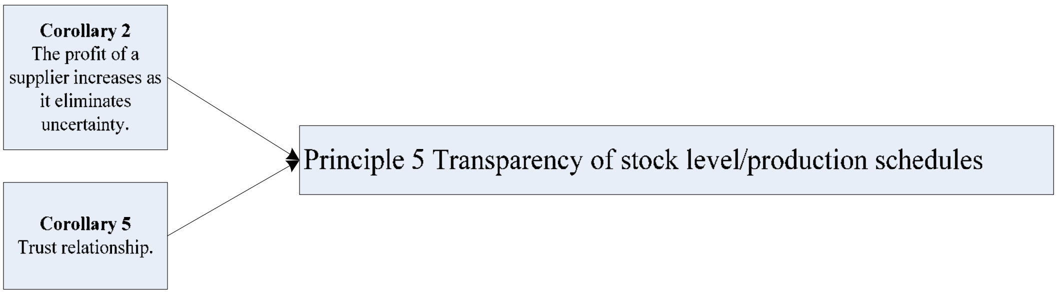

Figure 3.5 The deductive map of Principle 5

6. Principle of profit and risk sharing

Retailers share either the projected net requirement or future planned order information with suppliers for collaborative production. The suppliers can achieve dramatic cost down in inventory based on Corollary 2. However, the retailers usually do not receive any saving. Communication between collaborators requires specific-investment in integrating information. This investment could result in opportunism risk and risk of return on investment, because the retailers may be reluctant to share information due to potential financial loss. Value sharing can increase the motivation to share information between collaborative members. By Corollary 6, successful inter-company coordination requires the members to share profits and risks, in addition to information sharing. Figure 3.6 shows the deductive map of Principle 6.

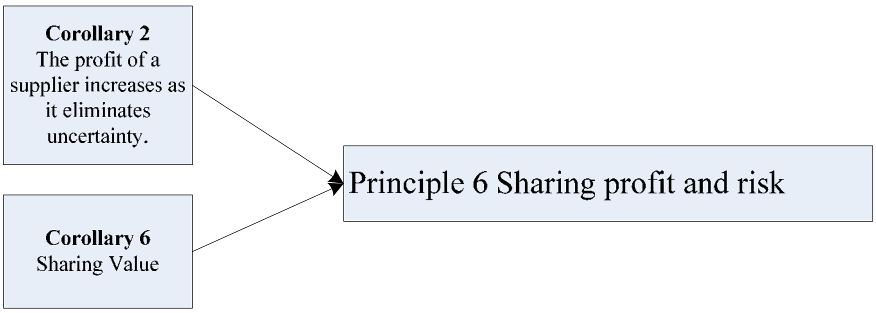

Figure 3.6 The deductive map of Principle 6

7. Principle of referent

A company collaborating with other companies increases its ability to make profit and increase survivability, Corollary 6. Google combines HTC, a hardware producer, and Android, a software company, introducing the Nexus One phone during 2010. A company finds other partner companies, which create profits without increasing the operation and opportunism risks, Definition 3. Figure 3.7 shows the deductive map of Principle 7.

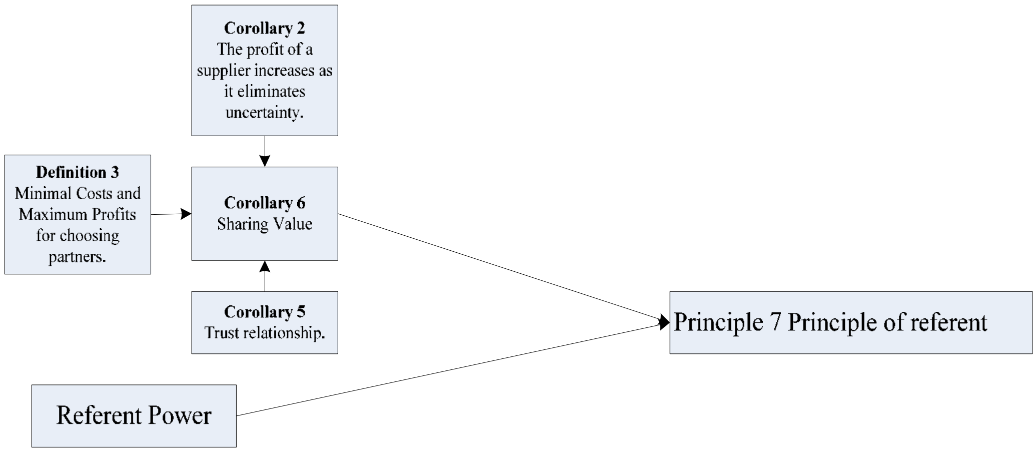

Figure 3.7 The deductive map of Principle 7

8. Principle of expert

A company that has core technology is an expert in the industry. The company possesses some special knowledge or ability (expert power) to solve a problem, perform a task, or explore a new market. This ability becomes a brand and goodwill referent power in the market. A company who selects a goodwill partner could reduce its supplier selection cost because of the reduced evaluation cost. An expert company with core technologies is attractive for collaborative production. Figure 3.8 shows the deductive map of Principle 8.

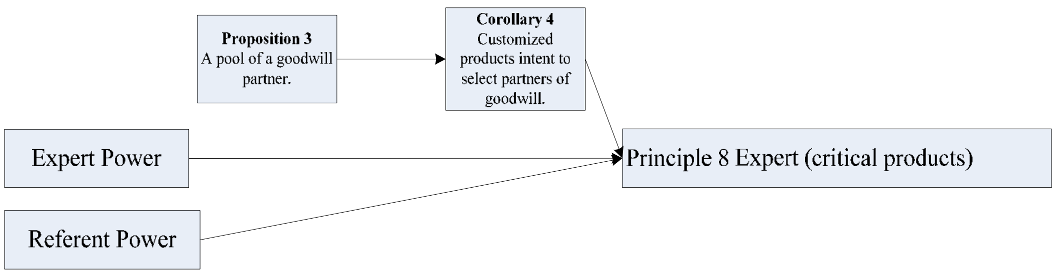

Figure 3.8 The deductive map of Principle 8

9. Principle of relationship duration

A long-term relationship can reduce transaction cost between two companies. It is especially attractive for companies to sign a long-term contract in a stable environment (Jagdev and Thoben 2001, Huang and Wu 2003). A virtual organization will be formed to meet the demand if the market is unstable. Companies can maintain their flexibility in prices and capacity planning in a virtual organization. However, searching for new partners will increase cost based on Corollary 1. A company could establish a pool of good reputation partners for further collaboration so that the selection cost can be reduced, Proposition 3. A company may select partners with good reputation in this pool based on Corollary 4. A company can put the partners with a good reputation in the pool and establish informal trust relationships in an unstable market, Corollary 5. The informal duration trust can play a role similar to the long-term contact in a stable market without sacrificing excessive cost. Figure 3.9 shows the deductive map of Principle 9.

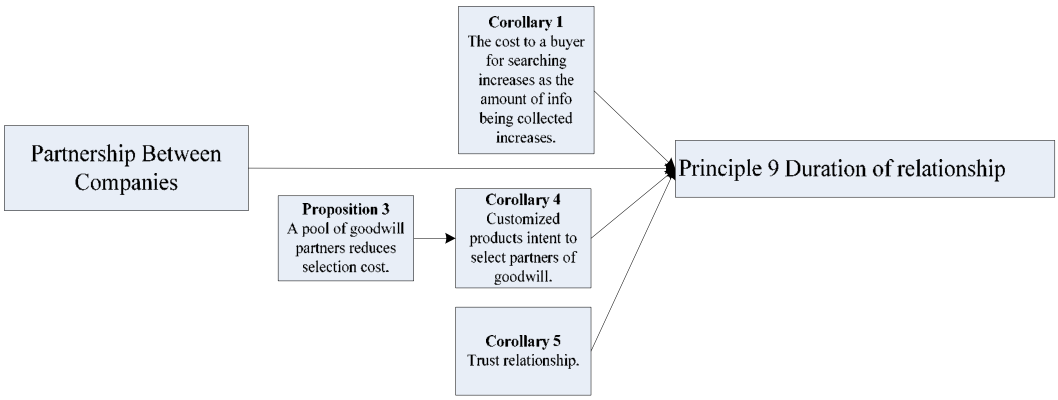

Figure 3.9 The deductive map of Principle 9

Chapter 4 Introduction of communication principles in collaborative production

The best-practice companies are contributing on the value-adding process performing collaborative production activities with other companies to minimize the total costs of products over a value chain and achieve the most suitable product quality (Huang and Wu 2003). Companies in a supply chain are pursuing the goal of reducing the uncertainty demands from the final customers. A temporarily collaborative team within which partner companies completes the orders from customers loosely harnessed. The companies in this team experienced numbers of problems when developing a distributed communication system for collaborative production. Issues of these problems have three aspects, forming collaborative organization, willingness of communication between collaborative members and information transfer between collaborators.

The first stage of problem solving is problem finding for the distributed collaborative production. The first question is an opportunity of market requires searching and inviting feasible companies to the collaborative team. It is a hard work in global sourcing because of large number of sources can be selected. The second problem relates to elimination of uncertainty between collaborative partners. A downstream company have a problem to determine an order due date since the capacity information of upstream collaborative partner is not available on-line in this newly collaborative organization. The third aspect deals with information transfer for various information systems and managerial hierarchies between distributed collaborators. Required information does not transmit smoothly between collaborative companies at the first time of collaborative organization newly formed. The objective with those background and problems is to develop a distributed computing platform for distributed manufacturing systems to accurately and timely request and deliver information among partners in a value chain so that downstream companies that are facing customers may receives benefits from their upstream partners.

The second stage of problem solving is problem shaping for the distributed communication system. The problem shaping introduces communication principles for collaborative production to revise communication problems so that the solution process can be continue. Search of collaborative partners for the opportunity of market can select referent and expert companies with good reputation according to Principle 7 and 8 to solve the first question in stage I. Flowchart of algorithm with communication principles for collaborative production analyses the second and third problems, information transfer for various information systems between distributed collaborators and disclosure of capacity information of upstream collaborative partner.

Figure 4.1 shows a case of problem shaping with communication principles for integration of production plan in collaborative production. The analysis starts at the beginning with objectives of collaborative production between collaborative companies. Actions deduce from these shapes of the communication requirements according to communication principles for collaborative production. The process of problem shaping is as follow.

Firstly, company needs to share information in production plan and schedule between collaborators, Principle 2. If information sharing is not available environment of collaborative production is not ready. Companies have to breeding environment for collaborative production.

Then, company must link into the information system of collaborative partners before sending information, Principle 1. Companies in a collaborative network have to seek a channel to relieve the burden of communication.

Next, compatible information system between companies is required, Principle 3. Different information systems between companies must be integrated. Integrated information system, such as modern protocol technology, enables effective collaborative production by communication and sharing production information effectively.

Finally, clairvoyance of stock level/production schedules means no uncertainty between collaborative partners, Principle 5. Degrease of transparency of stock levels/production schedules depends upon trust relationship. If collaborative companies are not willing to share information of stock level/production schedules Principle 4, 6, and 9 have to be launched to enhance trust relationship between collaborative companies.

The results of analysis from the flowchart indicate that the first action to do is to breeding consciousness of collaboration between productive companies. Information system linking between collaborative companies makes information sharing timely and cost effective between collaborative partners. Difference of information system between collaborative companies may lead to incompatibility in transmitting information. Therefore, the subsequent step is to integrate information system between collaborative partners. However, disclosure of capacity information of upstream and downstream collaborative companies, clairvoyance of uncertainty completely, is critical for collaborative schedule. Therefore, collaborative organization must develop intercompany trust by shared profit and risk between companies and established relationship of duration according to Principle 4, 6, and 9 so that collaborative companies willing to disclosure significant private information.

Communication design between collaborative partners has needed systematical guidelines in complex and dynamic collaborative organizations. Searching partners for new market opportunities can benefit from the guidelines between broadly scattered and highly specialized companies. Guidelines are important because the collaborative production system has to be formed and operated instantaneously. The principles support collaborative members to develop a communication system in collaborative production. The principles highlight the importance of linking the information system between collaborative members. The collaborative members require integrating their information systems. Analysis of the relationship between partners indicates that trust and specialization need to be developed.

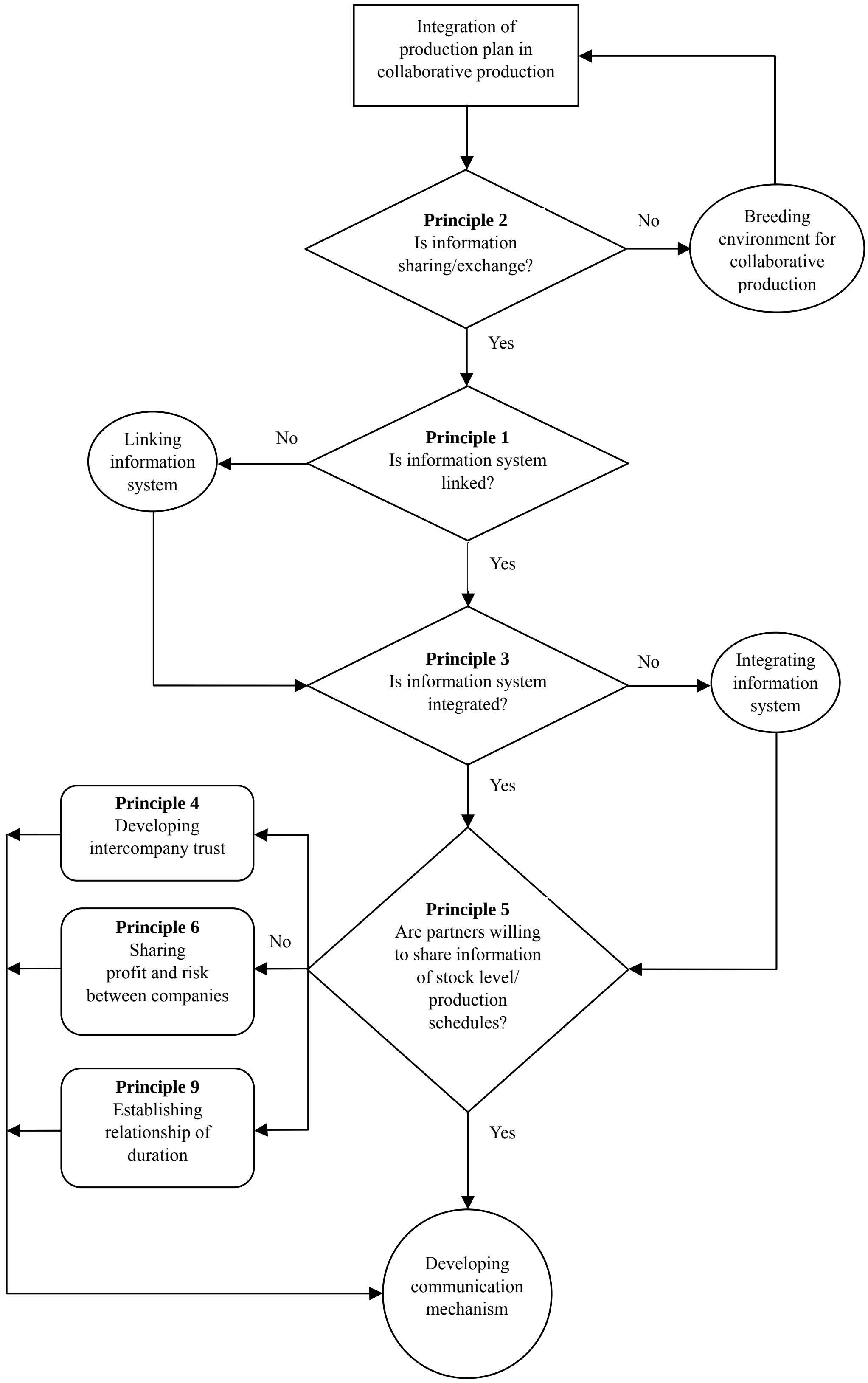

Figure 4.1 Flowchart of problem shaping for collaborative communication

4.1 Order confirmation mechanism for collaborative production networks

Dynamic structure of supply network and uncertainties within the network are two important characteristics that have to be considered in supply network production planning in a distributed production systems from the perspective of supply network. The dynamic structure of supply network usually results from product specification changes of orders or changes of suppliers. For example, a replacement of a functional subsystem may imply a replacement of a supplier. Besides, an enhancement on a product subsystem may imply recruiting a subcontractor that has better equipment. The uncertainties in a supply chain results from uncertain demand, process, and supply (Lee and Billington 1993). Any uncertainty happening in a partner company may result a disturbance on plans of other partner companies. Traditional centralized production planning approach makes a plan by collecting required information from partner companies. Prediction is made when the information is not available. Such an approach produces two problems: (1) the plan may not be feasible because of predictive errors, and (2) the plan may not be feasible because the computation is not performing timely.

Additionally, Sauer et al. (1998) pointed out that performing production planning with distributed processes has the following concerns:

1. Interdependencies between companies
2. Integration of production plans of local companies
3. Necessity to coordinate with production plans of other companies
4. Uncertainties happening in each local company

These high standards define a challenge for research of today in distributed production planning.

4.1.1 Order confirmation mechanism

Recent research of artificial agents provides a guideline for developing distributed but autonomous systems. There must be autonomous agents, communication links, and communication protocols in a collaborative agent environment (Huang and Nof 2000). The action is to developing an order confirmation mechanism following the algorithm of shaping of communication principle with communication principles for collaborative production. The mechanism consists of autonomous operations of agents and communication protocols of agents. The mechanism should be installed in the distributed computing platform to test the feasibility.

4.1.2 Agent-based production systems

Various agent-based production systems have been developed in literature. For example, Sun et al. (2001) develop a system for production design and manufacturing planning, whereas Lu and Yih (2001) develop a framework for multiple-line collaborative manufacturing. Various frameworks or architectures have been presented in those researches. Besides, simulation (centralized or decentralized) is mostly applied as a tool to validate the feasibility of the design for the whole system or for specific agents. From the viewpoint of author, an agent-based production system could be a system with two-fold. It is a ready-to-run system. On the other hand, it is a platform that allows running various what-if simulations on it.

4.2 Collaborative production networks

4.2.1 Network structure

Customer orders of today are completed by a temporary team within which partner companies are loosely harnessed by information technology (Anussornnitisarn and Nof 2003, Huang and Wu 2003). To increase the functionality and productivity of the team, partner companies have to share and contribute their information. This research defines a team structure as shown in Figure 4.2, which is developed by Huang et al. (2008). Figure 4.2 shows that

Company A is a company that faces customers. It is a downstream company in a value chain or supply network. Company A needs to utilize resources of companies B and C to accomplish a customer order. Additionally, companies D and E, and companies F and G are subcontractors of companies B and C, respectively. Company A has to receive consents of capacity utilization from all its upstream companies to confirm an order for a customer. The confirmation mechanism traditionally is done by rough estimation. A downstream company may request capacity information of upstream partners providing for the estimation through phone calls, fax, or e-mail. The process automates by applying agent technology. Each company is embedded an agent, as shown in Figure 4.2. The order confirmation focuses on capacity requirements planning only. For material requirements, mostly done by issuing purchasing orders, this research assumes that they can be done by enterprise resource planning systems.

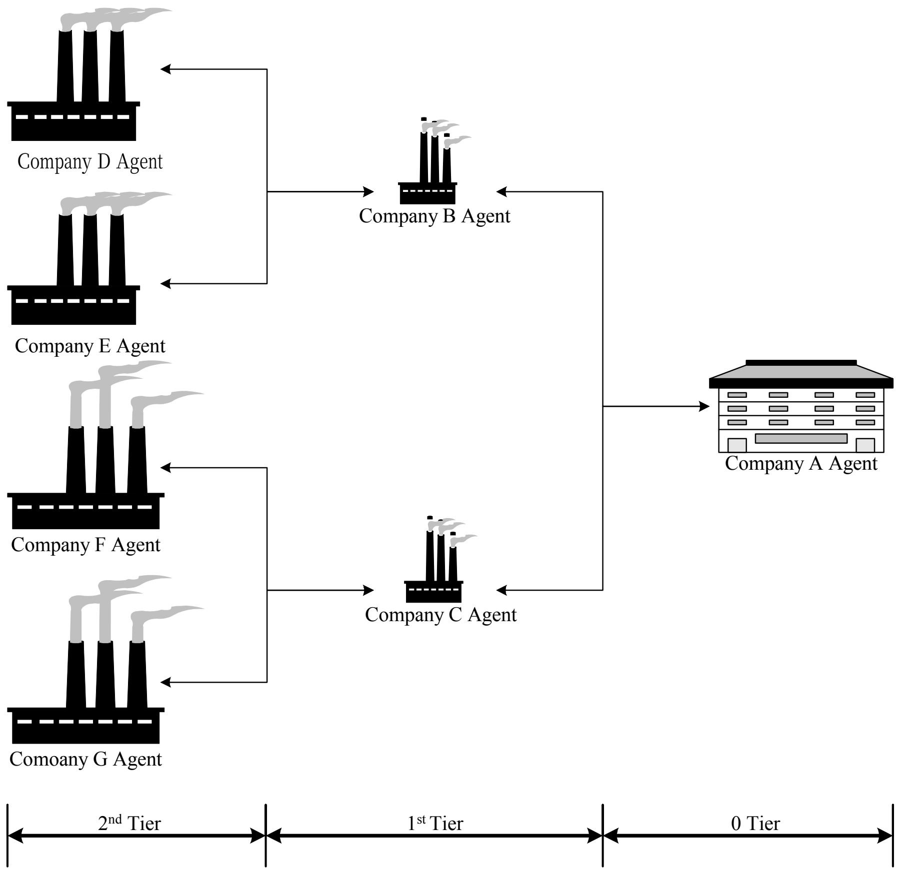

Figure 4.2 Multi Agents System Structure (Huang *et al.* 2008)

4.2.2 Three communication protocols

This research takes sequence diagrams as a model to describe protocols, because sequence diagrams can define objects (agents) execution, as well as orders of message transmission among agents (Fowler and Scott 1999).

1. Protocol for normal condition

Figure 4.3 (Huang et al., 2008) shows a protocol for normal condition. The protocol is triggered by a new order entry in a downstream company (represented by the 0Tier Agent). As soon as 0Tier Agent received the order, it starts a plan_procedure()[1] to check the availability of its capacity. Then, an order_plan_ message() is sent to its upstream collaborators (i.e., 1st Tier Agent) to request for the associated capacity. Similar procedure is repeated toward the upstream partners until the message is sent to the most upstream company (i.e., nth Tier Agent). The *n*th Tier Agent does not only execute plan_procedure(), it also execute schedule_procedure()[2]. The function of schedule_procedure() is to schedule the operation on the new order as early as possible. After the company completes the schedule_procedure(), it sends an order_schedule_message() to its downstream partners (i.e., (n-1)th Tier Agents). Then, the (n-1)th Tier Agents applies message_evaluate() to determine the constraints in schedule. When message_evaluate() is completed, a schedule_procedure() is preceded. Afterwards, an order_schedule_message() is sent to the downstream partners (i.e., (n-2)th Tier Agents). The procedure continues until an order_schedule_message() reaches the 0Tier Agent.

When an order_schedule_message() reaches the 0Tier Agent, 0Tier Agent performs message_evaluate() and schedule_procedure() just like other agents in the upstream did. Additionally, it confirms the order by performing confirm_ procedure() and sends an order_confirm_message() upwards. The confirm_

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[1] plan_procedure() is explained in Chapter 4.3.2.
[2] schedule_procedure() is explained in Chapter 4.3.3.

procedure() and order_confirm_message() are prorogated to the upstream partners for blocking the capacities of resources.

Protocol for normal condition starts from performing a plan_procedure() in the 0Tier Agent, and ends when each of the nth Tier Agents performs a confirm_procedure() based upon receiving an order_confirm_message() from (n-1)th Tier Agents.

2. Protocol for abnormal condition

Unfortunately the plan_procedure() may not work successfully in each upstream agent. The agent must send info_request_message() to obtain the real latest start time embedded in info_send_message() form its downstream agent if any of the agents cannot make the plan, as shown in Figure 4.4 (Huang et al., 2008). Based on the real latest start times from the downstream agents, the agent may find the earliest one which may be fortunately later than the infeasible plan made previously by the plan_procedure().

Figure 4.4 only shows an interaction occurring between the 0Tier Agent and the 1st Tier Agent. Actually, there may be many interactive messages between upstream and downstream agents. The rest of the protocol for abnormal condition is the same with the protocol for normal condition except the interactive messages.

3. Cancellation Protocol

Sometimes a partner company within a supply network may not have enough capacity to complete the order at a specific time interval. Thus, the order must be rejected. Protocol for cancellation is designed to perform the scenario. As shown in Figure 4.5, after an upstream agent (1st Tier Agent) receives info_send_message() with detailed capacity information from its downstream agent (0Tier Agent), it applies plan_procesure() to plan the order in its facility. Unfortunately, it is not able to take the order due to overcapacity. A can't_accept_message() should be sent to the downstream agent afterward.

After the downstream agent receives the message, procedures of message_evaluate() and cancel_procedure() have to be performed, and order_cancel_message() has to be sent to the upstream agents.

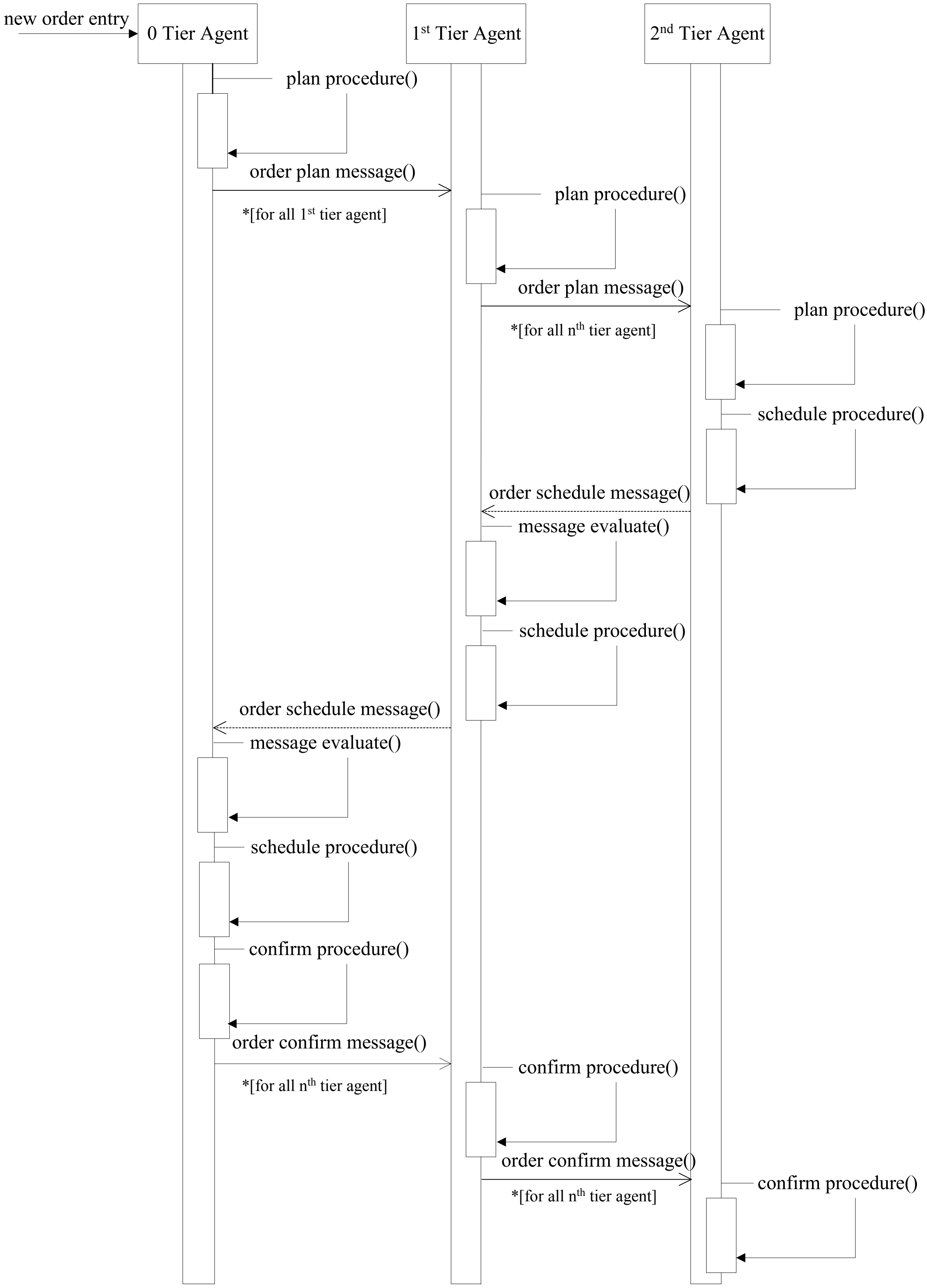

Figure 4.3 The collaborate model of order confirmation mechanism: Normal Condition Protocol (Huang *et al.* 2008)

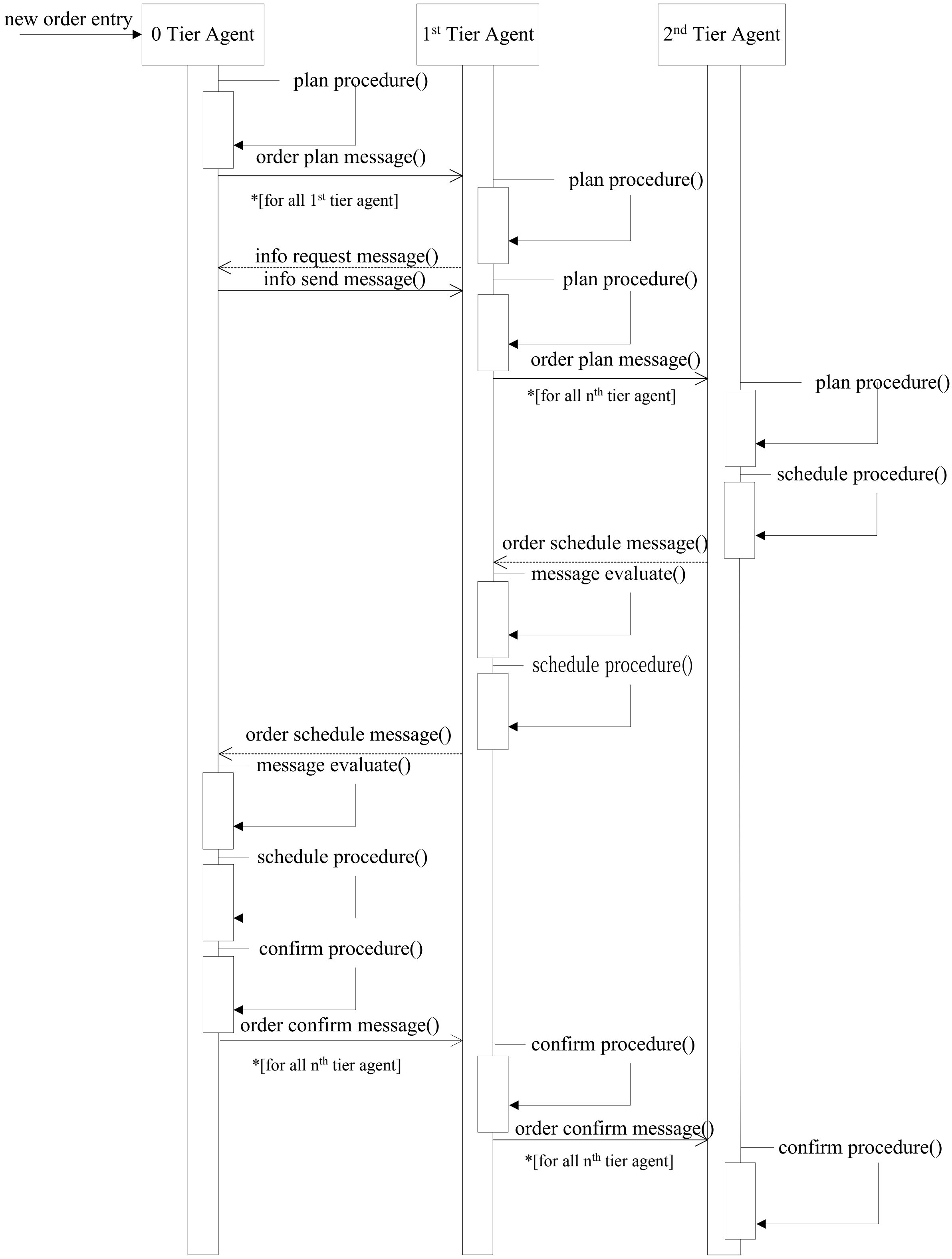

Figure 4.4 The collaborate model of order confirmation mechanism: Abnormal Condition Protocol (Huang *et al.* 2008)

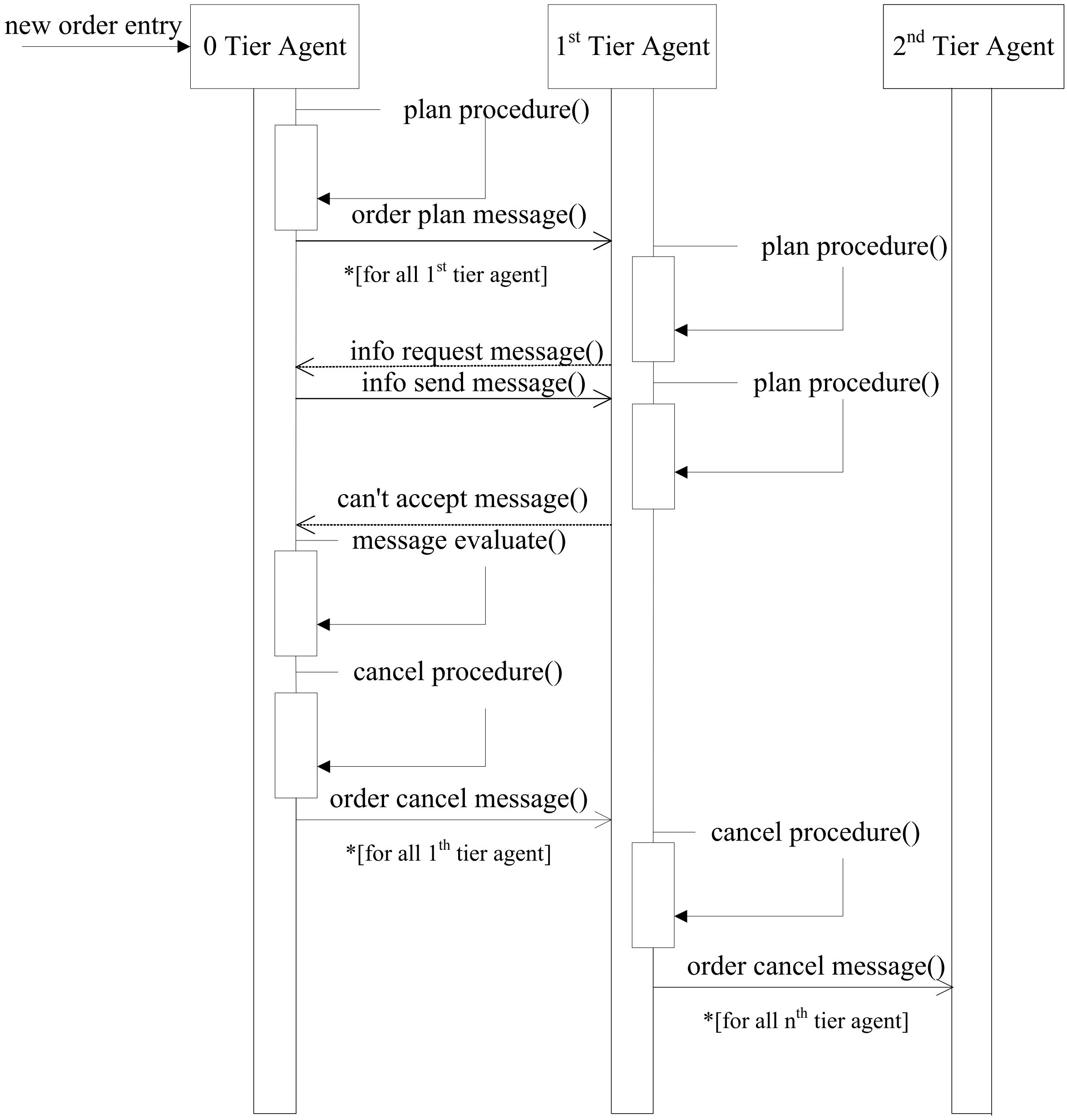

Figure 4.5 The collaborate model of order confirmation mechanism: Cancel Protocol (Huang *et al.* 2008)

4.2.3 Messages for the protocols

Messages in the above three protocols have to be specified in detail. They are summarized and defined in accordance with KQML in Figure 4.6. The seven messages in Figure 4.6 define the interactive contents between agents. Because of the limited number and format of the messages, the interactive behaviors of agents are simplified in design.

number	A01	A02	new
Type	x	z	Y
EEST	30	25	23
REST	30	26	23
OLST	36	28	
RLST	36	28	31
ELST	36	28	31
Due	38	30	34

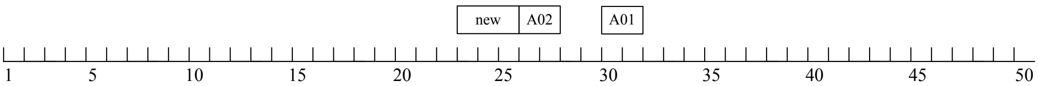

Figure 4.6 Seven message contents (Huang *et al.* 2008)

4.3 Decision processes in the protocols

Decision processes in the three protocols happen primarily in the procedures of plan_procedure(), schedule_procedure(), and confirm_ procedure(). The procedures are associated with five types of time variants described in Chapter 4.3.1. Besides, in the following paragraphs production structures of three products, shown in Figure 4.12, are applied in the illustration. Unlike bill of bacterial that specifies the relationship between component and subcomponents, Figure 4.12 specifies the flows of products over partner companies and their lead times. For example, product types *x* flows from companies D, E, F, G in the second tier, then to companies B and C in the first tier, and finally to the company A in the 0 tier.

4.3.1 Time variants of orders

Each order[3] is associated with two types of information: due date and lead-time for processing. Based on the two types of information, five time variants are defined as follows:

1. Expected Latest Start Time (ELST): ELSE = due date – lead time. ELST is a constraint that specifies the latest starting time for processing the order.

[3] An order may be a *customer order* for a 0Tier Agent or a *subcontracting order* for any company that takes orders from its downstream partners.

2. Real Latest Start Time (RLST): ELST may not be feasible because some other orders may preoccupy that time point. Hence, an RLST is required. RLST represents a delivery due date for its upstream partners. An RLST is determined by two conditions. If an RLST of the previous order exists, RLST of the current order = REST of the previous order + lead time of the previous order. If an REST of the previous order does not exist, RLST of the current order = ELST of the current order. By applying plan_procedure(), an agent can calculate a RLST for the order in the company.
3. Expected Earliest Start Time (EEST): An agent may have multiple up stream partner agents. An EEST of agent must be the latest order completion time for the upstream processes on those upstream agents. In other word, EEST is a constraint that specifies the earliest start time for processing the order based on the latest order that is completed by the upstream agents.
4. Real Earliest Start Time (REST): Though an agent decides an EEST based on the latest completion times of the upstream partners, the EEST may not be feasible because some other order has occupied the resource at EEST. An REST represents a feasible earliest start time on the order. If the previous REST of order is available, the REST of the current order = REST of the previous order + lead time of the previous order. If the previous REST of order is not available, the REST of the current order = REST of previous order + lead time of the previous order. By applying schedule_procedure(), an agent can calculate a REST. Its downstream companies' EEST is partially defined by the total of REST and lead-time.
5. Operation Latest Start Time (OLST): OLST is the latest start time for an order based on the constraints coming from the downstream process. An OLST is a result of (RLST at the downstream – lead time of the process at the current tier). For example, factory A as a downstream company has a process, and factories B and C as upstream companies have processes with operation lead times 2 and 1 units, respectively. If the RLST of the downstream process in factory A is at 6, the OLST of factory B should be (6 – 2 = 4) and the

OLST of factory C should be (6 – 1 = 5). Since RLST changes dynamically in the calculation which is introduced in the following section, OLST has to be updated accordingly. Besides, if the process is located in the 0Tier and has no downstream process, the OLST is equal to the RLST by definition. By applying confirm_procedure(), upstream companies successively.

The plan_procedure() and schedule_procedure() both are embedded with backward scheduling and forward scheduling. Backward scheduling determines an order’s starting time by subtracting a known due date from its lead time. On the other hand, forward scheduling determines an order’s starting time by adding its lead time on the very last completion time of the previous order within the same factory agent. It is noted that ‘the previous order’ is always specified as the prior order of the current order ‘within the same factory agent’ in this research.

4.3.2 Procedure plan_procedure()

The plan_procedure() (Appendixes A and B) includes two phases. In the first phase, the procedure allocates the new order in a suitable time bucket. In the second phase, the procedure fine-tunes the order sequence by swapping the orders to get a better schedule of production. To avoid complex notations and tedious explanation of the procedure, procedures in the two phases are illustrated by example in chapters 10.2.1 and 10.2.2.

Phase I: allocating a new order in a suitable time bucket

It is assumed that a factory has two orders, A01 and A02, on its schedule, as shown in Figure 4.7. The two orders split the planning time horizon from 1 to 50 into three time buckets: (1) [1…25], (2) [27…30], and (3) [32…50]. Now, a new order A03 with a due date on time 34 and a lead time of three time periods arrives. According to the calculation in Chapter 10.1, ELST is 34 – 3 = 31 for the new order A03. The objective of Phase I is to determine which time bucket is suitable.

number	A01	A02	new
Type	x	z	y
EEST	30	25	
REST	30	25	
OLST	36	28	
RLST	36	28	27
ELST	36	28	31
Due	38	30	34

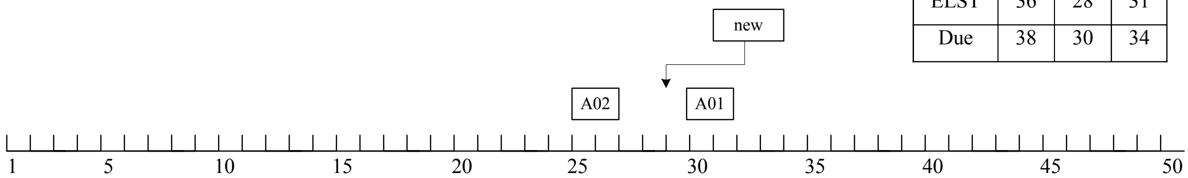

Figure 4.7 Phase I of plan procedure: finding a time bucket for new order (Huang *et al.* 2008).

The new order should not violate any of three constraints to fit into any of the three time buckets.

Constraint 1: The beginning time of the time bucket should be earlier than the due date of the new order.

Constraint 2: The size of the time bucket should be larger than the lead-time of the new order.

Constraint 3: The term (due date of the new order – the beginning time of the time bucket) should be larger than the lead time of the new order.

By checking the new order on the three constraints of the three time buckets, it is found that Time Bucket (2) [27…30] is the most suitable one for the new order. Since the earliest time of the time bucket is 27, the RLST is set 27, as shown in Figure 4.7. Now, the order sequence is A02-A03-A01.

Phase II: fine-tuning the order sequence

Based on the result of Phase I, the objective of Phase II is to find the best sequence of the orders. This research develops an evaluation equation as shown in equation (4.1) which is a total of value VP_{order}'s assigned to orders. An EV_P value will be calculated for each order sequence. The intention of Phase II is to find a minimal EV_P value by changing the order sequence. When such a minimal EV_P is found, the order is in the most suitable sequence.

$$EV_p = \sum_{i=1}^{m} PV_i \tag{4.1}$$

where the priority value is

$$PV_i = \begin{cases} \dfrac{1}{2 + OLST_i - EEST_i} \times \left(REST_i - EEST_i\right), & \text{if order is existing order.} \quad (4.2) \\ 1 \times \left|ELST_i - RLST_i\right| & \text{, otherwise (order is a new entry order).} \quad (4.3) \end{cases}$$

i is order number.

and m is total order number.

where EV_P is the evaluation value in the plan_procedure() for an agent at a specific tier with N orders. VP_{order} is the value assigned to the specific order. VP_{order} = (2 + *order*.OLST – *order*.EEST)$^{-1}$ (*order*.REST – *order*.EEST) if order is one of the existing orders, or VP_{order} = |*order*.ELST – *order*.RLST| if order is a new entry order.

Each (existing or new) order is assigned a priority value for order i based on equations 4.2 (for existing orders) and 4.3 (for new orders) to fine-tune sequence of orders (Appendix B). Note, a large priority value is undesirable and results a lower priority. The (2 + *order.OLST* – *order.EEST*)$^{-1}$, is weight of existing order, in equation 4.2 indicates that as long as the space between OLST and EEST is large, the PV_i is small. In other words, when the downstream companies schedule the order in later time with a larger OLST, the difference between OLST and EEST will be large, this results a higher flexibility of the order to change its schedule. The (*order.REST* – *order.EEST*), is weight of new entry order, indicates the difference between REST and EEST. Large difference implies that the real starting time is too much late from the expected starting time and is not desirable. The two terms trade off each other in equation 4.2 for an existing order. Equation 4.3 indicates the priority value of a new order is based on the difference between ELST and RLST. Large difference implies large flexibility for changes and results a lower priority.

For our example, the EV_p of new order is 1 × |31 – 27| = 4. The agent must tune the schedule by applying fine-tuning of plan_procedure() in Appendix B to get the RLST of new order as close as ELST because the new order EV_p not equal to 0. The result is specified in Figure 4.8.

number	A01	A02	new
Type	x	z	y
EEST	30	25	
REST	34	25	
OLST	36	28	
RLST	36	28	31
ELST	36	28	31
Due	38	30	34

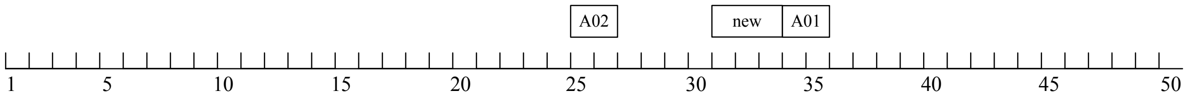

Figure 4.8 A01 has been adjusted by phase II of plan_procedure for planning new order (Huang *et al.* 2008)

4.3.3 Procedure schedule_procedure()

The schedule_procedure will be ignited to perform new order REST as close as EEST after finishing plan_procedure (Appendixes A and B) process of collaborate factory agent in supply chain. The schedule_procedure also include two phases. In the first phase, the procedure schedules the new order in the available time bucket. In the second phase, the procedure fine-tunes the order sequence by swapping the orders to get a better schedule of production. Procedures in these two phases are illustrated by example as follows.

Phase I: schedules the new order in the available time bucket

It is assumed that A03 is scheduled in factory agent A. Two upstream partners factory B and C, are taking care of the outsourcing process for A03. Additionally, the latest completion time for A03's outsourcing processes in factories B and C is 23. Therefore, the EEST of A03 in factory A is set 23. It means that the latest completion time of factory B and C are 23. However, the

REST of the previous order (i.e. A02) is 25, which means factory A cannot be free until time 25. By adding the lead time of A02 (which is 2) to 25, the REST of A03 is 27 by Phase I of schedule_procedure (Appendix C) process, as shown in Figure 4.9.

number	A01	A02	new
Type	x	z	y
EEST	30	25	23
REST	34	25	27
OLST	36	28	
RLST	36	28	31
ELST	36	28	31
Due	38	30	34

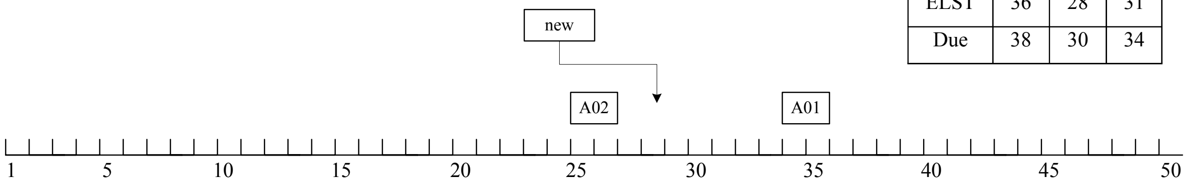

Figure 4.9 Phase I of schedule procedure: finding REST for new order (Huang *et al.* 2008).

The key process in the Phase I of schedule_procedure() is to receive information about the latest completion time from the upstream partners.

Phase II: fine-turning the order schedule

Similar to the Phase II of plan_procedure(), schedule_procedure() has a fine-tuning process to find a suitable order sequence. Detailed procedure is presented in appendix B. To fine-tune orders' schedule, each order is assigned an evaluation value based on equation 4.4.

$$EV_s = \sum_{i=1}^{m} PV_i \tag{4.4}$$

where the priority value is

$$PV_i = \begin{cases} \dfrac{1}{1+OLST_i - EEST_i} \times \left(REST_i - EEST_i\right), & \text{if order is existing order.} \quad (4.5) \\ \dfrac{1}{1+RLST_i - EEST_i} \times \left(REST_i - EEST_i\right), & \text{otherwise (order is a new entry order).} \quad (4.6) \end{cases}$$

i is order number.

and m is total order number.

where EV_S is an evaluation value in the schedule_procedure() for the system with N orders. VS_{order} is the value assigned to the specific order. VS_{order} = (1 + *order*.OLST – *order*.EEST)$^{-1}$ (*order*.REST – *order*.EEST) if order is one of the existing orders, or VS_{order} = (1 + *order*.RLST – *order*.EEST)$^{-1}$ (*order*.REST – *order*.EEST) if order is a new entry order.

For this example, the priority value of a new order is 1 × |31 – 27| = 4. It is not equal to zero; therefore the agent must tune all operations in supply chain system to get RLST as close as ELST by Phase II procedure. If the EEST is 23, and REST is 23 after schedule_procedure schedule, the priority value is $\frac{1}{1+31-23} \times (23-23) = 0$. Then the agent scheduling stops. The REST of A02 is changed from 25 to 26 (Figure 4.10). REST of A01 is changed back to the same time as in Figure 4.7.

number	A01	A02	new
Type	x	z	y
EEST	30	25	23
REST	30	26	23
OLST	36	28	
RLST	36	28	31
ELST	36	28	31
Due	38	30	34

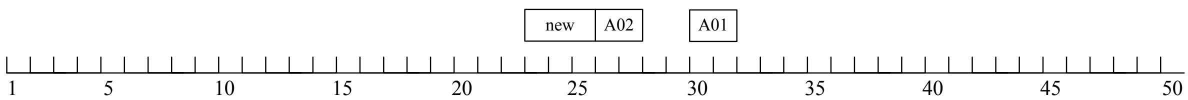

Figure 4.10 A01 and A03 have been adjusted by phase II of schedule_procedure for planning new order (Huang *et al.* 2008)

4.4 Development of Distributed Factory Agent System

Each business is an independent entity by introducing factory agents as the basic units in a distributed production network. Each factory planned by itself when received a new order and the loading affordability was confirmed by coordinating within the agents of factory in each entity. The order would be scheduled only if plan_procedule() accepted it. Then the customers could check the production information anytime. The system would communicate and coordinate with customers to find out alternative solutions when the order was rejected.

4.4.1 System design

Java language was used as the application program for factory's agents in distributed production network. The class diagram for this application program was showed in Figure 4.11.

The class deployment for the system is detailed in figure 9. Functions of some important classes are summarized as follows:

1. ProcessModel: protocol specifications
2. CapacityModel: order sequences and status
3. TcpClient: to connect to upstream factory agents through Socket class of java.net package. Each upstream factory agent is deployed by TcpServer class.
4. TcpServer: to create a server program as an upstream factory agent through Socket class of java.net package.

The TcpClient and TcpServer classes indicate that each factory has a capability to play a role of customer by using TcpServer to communicate with its suppliers and has a capability to play a role of supplier by using TcpClient to communicate with its customer.

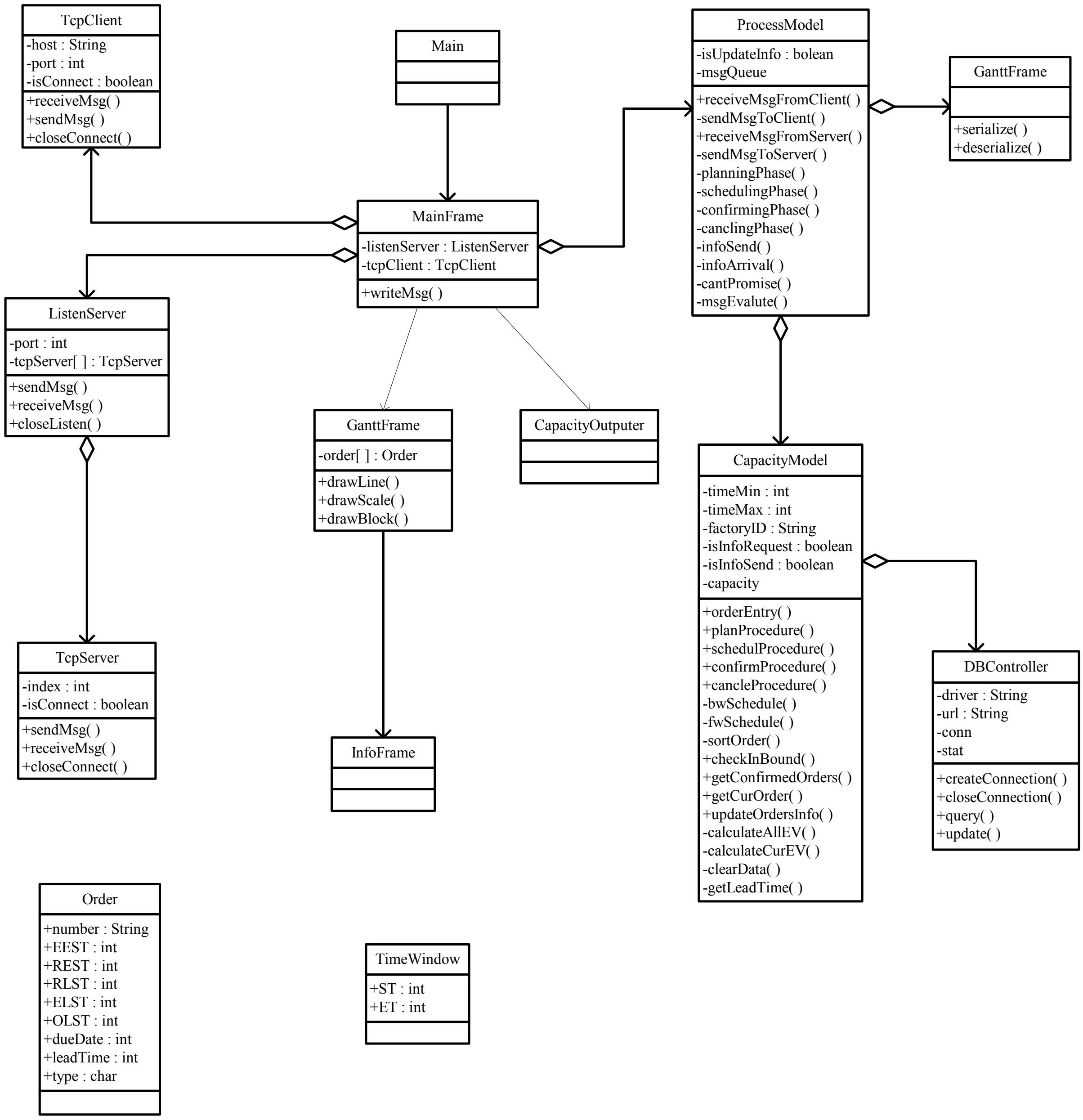

Figure 4.11 Class diagram of Java language structure (Huang *et al.* 2008)

4.4.2 Product Specification

In this illustration, three types of products are produced by Factory A. The product production structures are described in Figure 4.12.

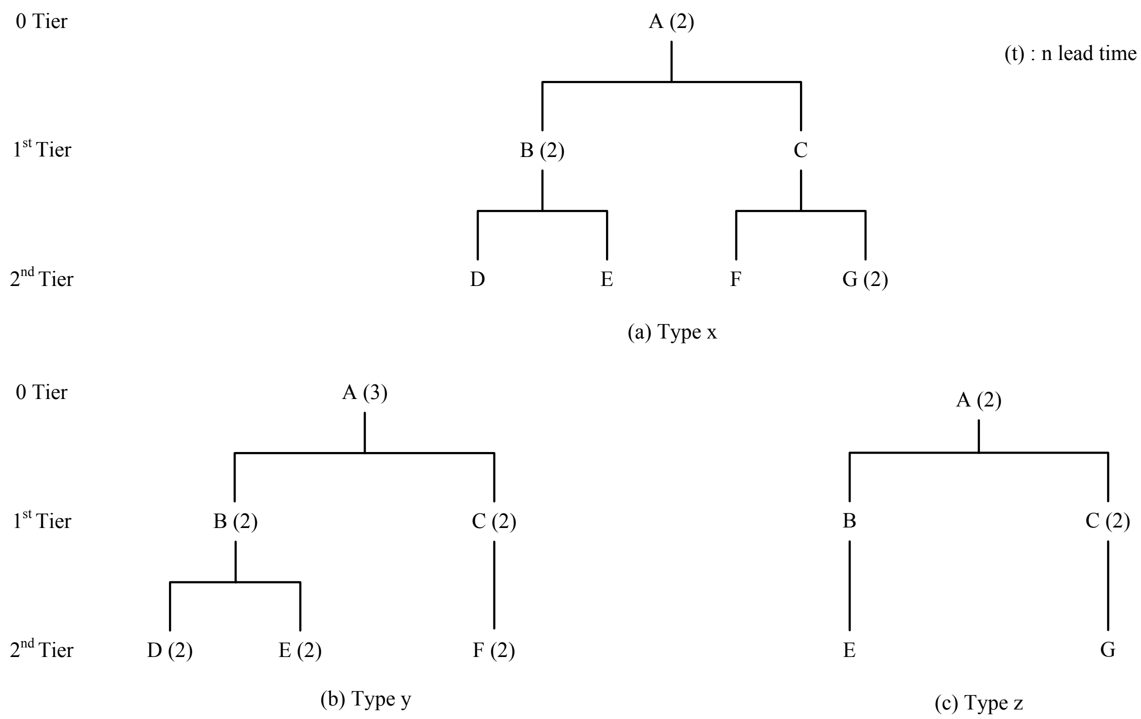

Figure 4.12 Product production structures (Huang *et al.* 2008)

To realize the above protocols and the concepts of product production structure and multi-agent system structure, this research develops a distributed computing system over multiple computers. Each computer represents a factory (agent). The computers are connected over the Internet. Because of that, the agents are not limited by the upstream or downstream relationship, though the conceptual relations in the following illustration are connected in a rigid structure of Figure 4.13, which has the same topology as Figure 4.3. In other words, the system developed in this research allows a company to appear in upstream and downstream positions simultaneously, as long as there are two computers to represent its processes. The distributed production network structure based on previous supply chain environment and the confirmation mechanism of collaborative protocols and operation evaluation rules are evaluated.

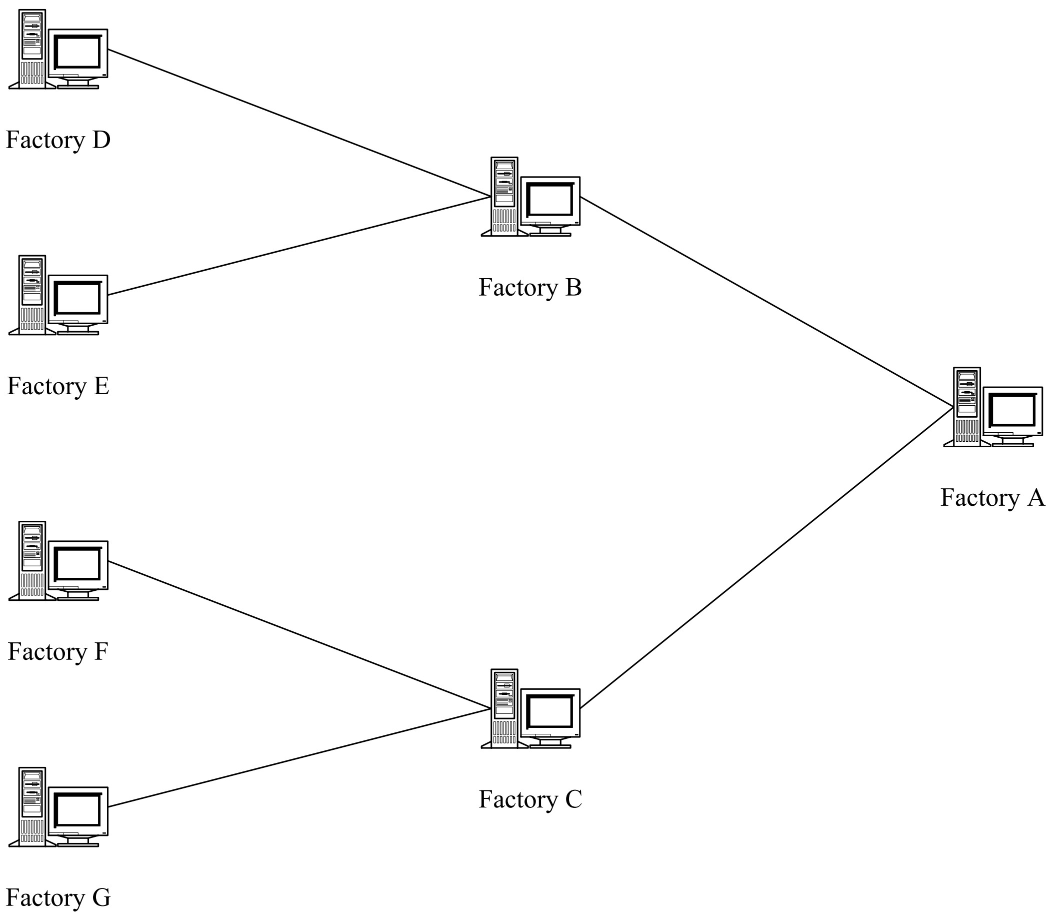

Figure 4.13 System network structure and software allocation (Huang *et al.* 2008)

4.4.3 System input

Sixteen orders, listed in Table 4.1, are the order information for input system one after the other according to the order number. There are 16 orders for different interactions and protocol mechanisms application in a planning period between 1 and 50 time unit in each factory. The order will input the system in different specific time. The order receiving sequence was show as column 1. The order entered system according to sequence one by one.

Table 4.1 Product orders for evaluation (Huang *et al.* 2008)

Order Number	Product	Due Date	Order Number	Product	Due Date
1	x	26	9	x	35
2	z	10	10	x	42
3	x	10	11	y	44
4	y	40	12	z	16
5	x	22	13	x	34
6	y	21	14	z	29
7	x	15	15	z	13
8	z	12	16	x	19

4.4.4 Experiment

When Order 1 is entered into the system, the factory agent began planning and scheduling collaboratively according to the defined messages, protocols, and procedures. Then Orders 2 to 6 were put into system for scheduling. Since the capacity of each factory was rarely load in the beginning. The interactions between agents of factory follow protocol for normal condition and perform order confirmation. After confirmation of Order 6, schedules of factories are shown in Figure 4.14.

When planning Order 7 the load was a little overcrowding in factory A as the due date was 15. When factory A applies the protocol for normal condition for planning Order 7 in its plan, the phase II of plan_procedure eventually obtain the result are shown in Figure 4.15. Finally, according to the protocol for normal condition, factory A receives EEST of Order 7 which is 12 from its upstream factories B and C. Then, schedule_procedure is activated in factory A and the final schedule in factory, as shown in Figure 4.15.

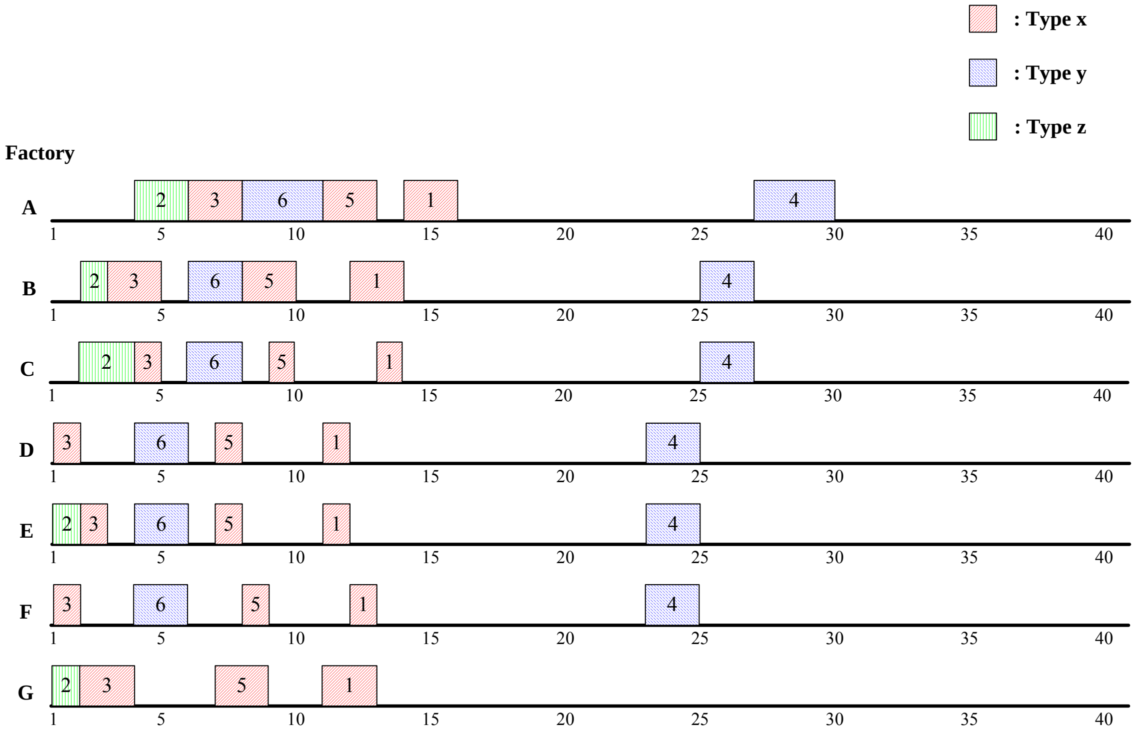

Figure 4.14 Capacity status of factories after confirmed Order 6 (Huang *et al.* 2008)

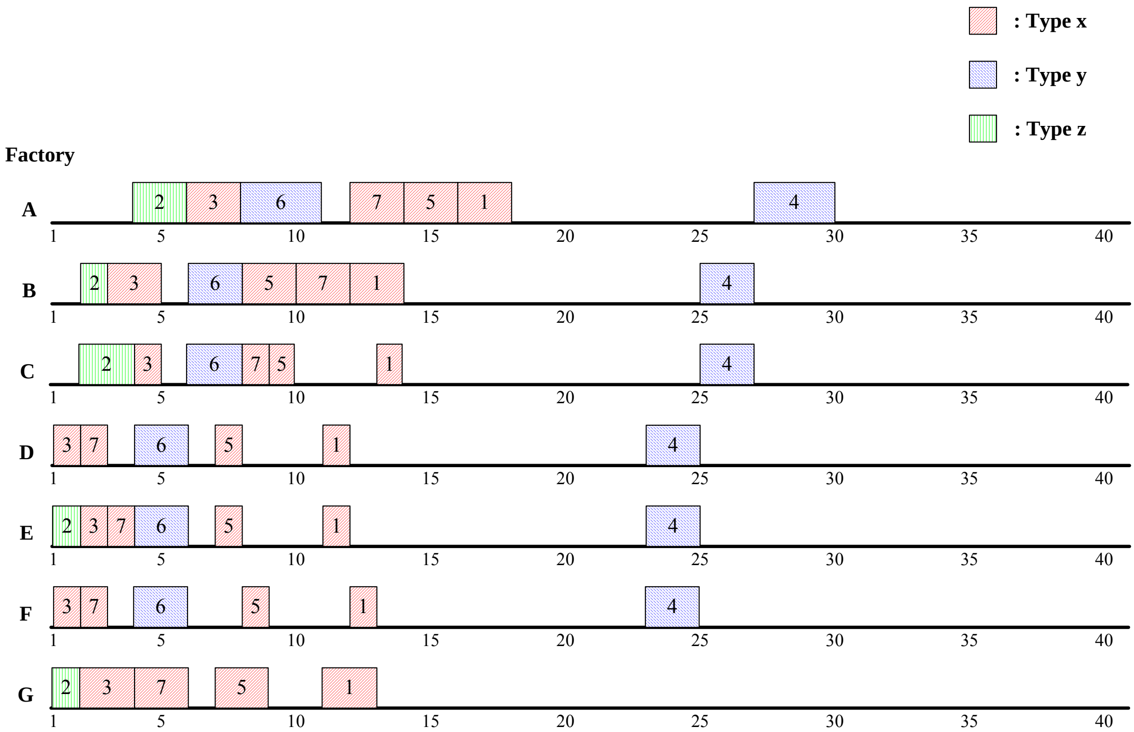

Figure 4.15 Capacity status of factories after confirmed Order 7 (Huang *et al.* 2008)

When Order 8 is enter into factory A, Protocol for normal condition is first applied. However, when the protocol comes to plan_procedure() in factory B and C, both are upstream partners of factory A, they find a necessity to receive further detailed plan of their downstream partner factory A, because the REST was greater than OLST. Hence, it performed the protocol for abnormal condition that executing synchronization to coordinate allowance getting more space for scheduling. An info_request_message() is sent to factory A. Then, factory A replies with info_send_message(). The info_request_message() is a simple string message, whereas the info_send_message() includes RLST of the order in factory A. The RLST provides a more precise plan of factory A for upstream factories B and C. After confirmation of Order 8, system capacity status of each factory is shown in Figure 4.16.

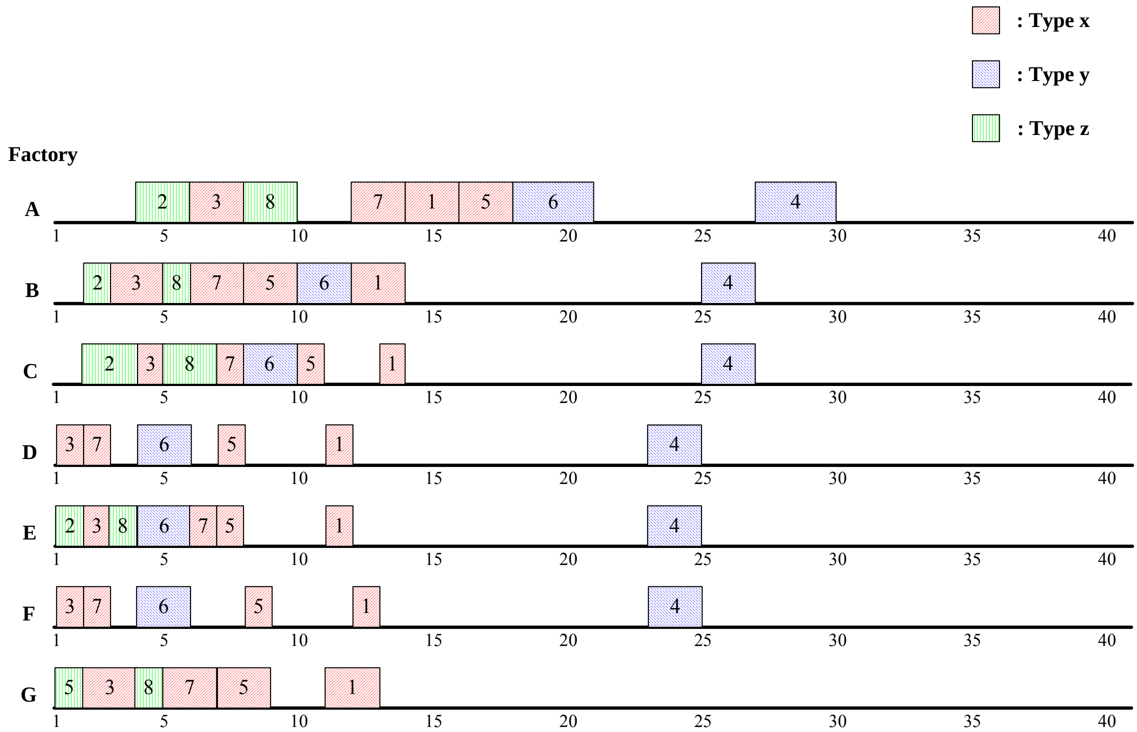

Figure 4.16 Capacity status of factories after confirmed Order 8 (Huang *et al.* 2008)

The continuing Orders 9 to 11 only need protocol for normal condition for scheduling. After confirmation of Order 11, system capacities status of each factory is shown in Figure 4.17.

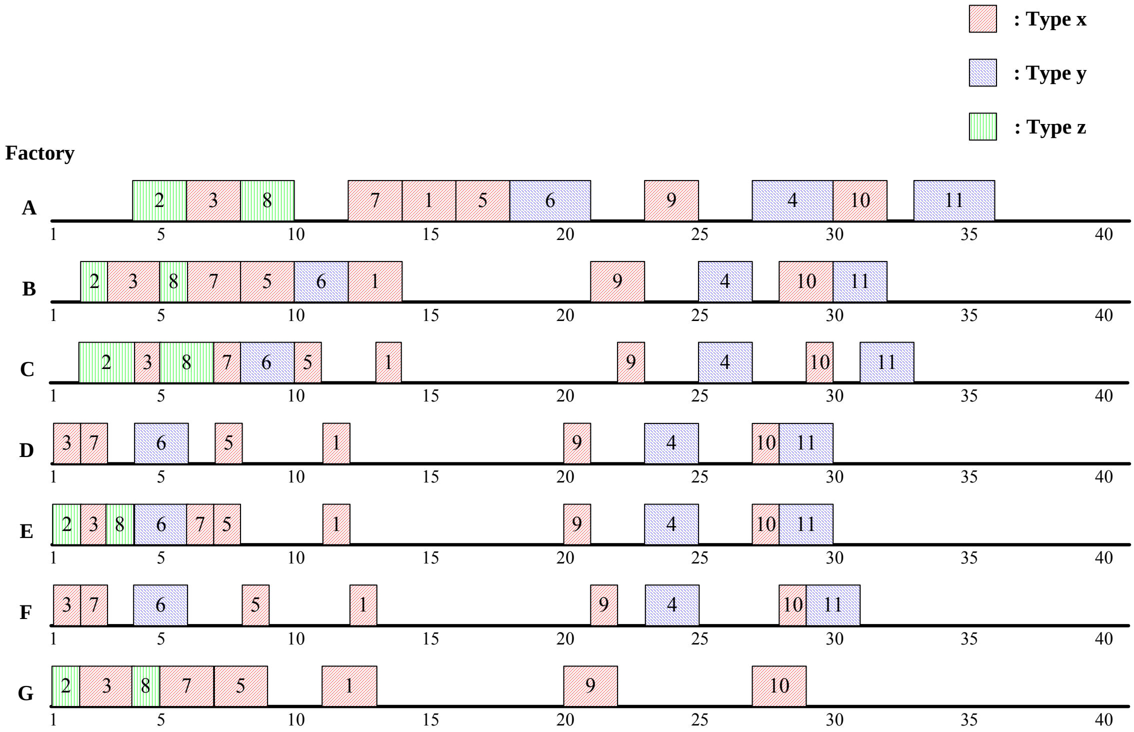

Figure 4.17 Capacity status of factories after confirmed Order 11 (Huang *et al.* 2008)

At this moment, factories are quite full of orders. When Orders 12 to 15 are fed into, protocol for abnormal condition has to be applied. System capacities status of each factory is shown in Figure 4.18 after confirmation of Order 15.

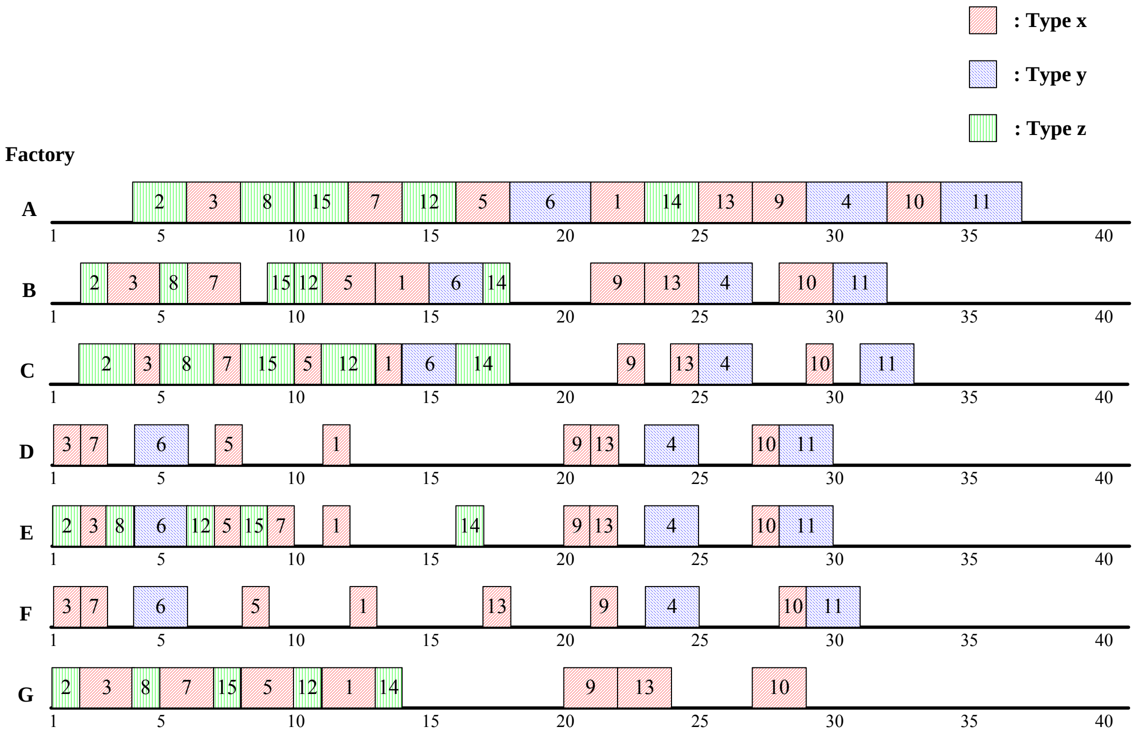

Figure 4.18 Capacity status of factories after confirmed Order 15 (Liu 2003, Huang *et al.* 2008)

Finally, Order 16, with a due date of 19, put into system. The schedule for factory A is now almost full in Figure 4.18. By examining through plan_procedure() and schedule_procedure(), it is found that Order 16 cannot be added to factory A due to overloading. Hence, protocol for cancellation has to be applied to inform associated agents to roll back to the earlier status on figure 16. The schedule of factory agent A would be back to the former status after the cancelation process and the schedules of all other factory agents have no change as shown in Figure 4.18. A summary result in association with the protocols been applied and the schedule status of the order is listed in Table 4.2. Table 4.2 addresses the applicability of the approach developed in this research.

Table 4.2 Order Experiment Results (Huang *et al.* 2008)

Order Number	Final Status	Protocol Applied
1	Accepted	Normal Condition Protocol
2	Accepted	Normal Condition Protocol
3	Accepted	Normal Condition Protocol
4	Accepted	Normal Condition Protocol
5	Accepted	Normal Condition Protocol
6	Accepted	Normal Condition Protocol
7	Accepted	Normal Condition Protocol
8	Accepted	Normal Condition Protocol Abnormal Condition Protocol
9	Accepted	Normal Condition Protocol
10	Accepted	Normal Condition Protocol
11	Accepted	Normal Condition Protocol
12	Accepted	Normal Condition Protocol Abnormal Condition Protocol
13	Accepted	Normal Condition Protocol Abnormal Condition Protocol
14	Accepted	Normal Condition Protocol Abnormal Condition Protocol
15	Accepted	Normal Condition Protocol Abnormal Condition Protocol
16	Rejected	Normal Condition Protocol Abnormal Condition Protocol Cancellation Protocol

4.4.5 Summary

The experiment in the above paragraphs shows the feasibility of the protocols, messages, and procedures that are designed in this research. Besides, due to the distributed computation, the load of computation complexity in the swapping procedures is reduced. Because the system is so easy to install and connect, issues of complexity of supply chain structure and uncertainties within the manufacturing networks may be relieved. However, current system version can only accommodate a fixed scheduling window between 1 and 50. A rolling-forward mechanism for scheduling window has to be added on the system. Besides, a salesman may need to perform what-if analysis when facing various customers' requests on orders. Hence, an undone function should be designed to allow confirmed orders over various tiers of partners to be released from the Gantt charts. Those functions have to be enhanced in the future.

The mechanism is developed based on a factory agent system and a design of three protocols: (1) protocol for normal condition, (2) protocol for abnormal condition, and (3) protocol for cancellation. Based on the protocols, messages and procedures are designed. The design is also implemented on a distributed computing environment to test the feasibility.

This order confirmation mechanism for distributed production systems was evaluated and proved by the model of factory agents. The model plan, design and use module of object-oriented technology to develop factory agent application over a distributed computing network. Orders with different due dates are entered into system for planning in sequence. Factory agent plans and schedules the responsible operation by evaluation rule and has interactive collaboration with inter-factory in supply chain according to its requirement. The experiment processes and results were proved that the order confirmation mechanism for distributed production systems is feasible.

Chapter 5 Conclusions and contributions

Communication is a key process in collaborative production. Communication between collaborators requires enough flexibility to efficiently and effectively meet the needs of their customers. Communication that is clearly defined creates values for the members to support decision making and problem solving in a collaborative production organization. However, design of communication system requires justification criteria to build a suitable communication for each individual collaborative production.

5.1 Conclusions

The communication principles deduced in this research have wide application. Partners in collaborative production could organize different types of organization to offer channels of communication. Organization could plan various communication systems with advanced communication tools to improve communication efficiency. However, communication problems of inadequacy of information, incomplete information, and timeliness of information cannot make a complete recovery.

This research discovers basic behavior (propositions) and fundamental routine (corollaries) of communication to develop underlying communication principles by introduced reciprocal effect analysis among production requirement, collaborative organization, and organizational communication, instead of individual effect. Therefore, the principles can support to establish effective communication environment to designate communication system of collaborative organization.

Research process of this research require numerous of literatures to support inductive inference of communication principles. However, it is difficult to collect literatures completely. There are more principles may be found if literatures are more complete collection. Interdisciplinary study of communication can improve clairvoyance of communication behavior. Conflict between companies will lower trust relationship.

5.2 Contributions

Most of studies of communication are focus on communication technologies, information system, and communication protocols. While communication technologies offer tools to quick transfer data and messages, communication protocols provide rules for effective transfer of data and messages. Information system equips a system to increase capability of processing and managing large amount of data and messages to support decision making. However, all of these technologies do not provide solution for basic communication problems. One of communication goals between collaborative companies is to increase willingness of information sharing. The research structure of communication triangle combines three important features of collaborative production: production requirement, collaborative organization, and organizational communication. This research analyzes six basic elements of communication inferred from these features. These analyses obtain communication principles that companies have to do in collaborative communication.

A communication triangle that introduces different features makes it possible to analyze the communication of complex and dynamic collaborative network. Cross analysis among different aspects leads to fundamental guidelines; propositions, corollaries, and principles, for supporting design of communication. Researchers have found that developing a communication method for collaborative production requires studying inter-company relationships. Transaction cost economics is the motive behind these relationships.

The principles are able to offer advice to implement communication in collaborative production. For example, Ford and ABB found out that they need deeper intercompany trust, according to Principle 4, after surveying the ineffective communication between partners (Frey and Schlosser 1993).

The principles could also provide action list for communication design in an emerging collaborative organization. For example, the competitive strategy of Wal-Mat is to reduce costs of procurement and distribution to ensure competitive advantage of low price. It could survey the principles what they should act to communicate with suppliers. Wat-Mart could take the points of Principle 1, 2, 3, and 5, linking supplier with powerful IT system, sharing information with POS system, integrating information system with EDI, and establishing RetailLink for transparency of stock level. Wal-Mart established powerful capability of information process which is the information power in the market. As Principle 8, Wal-Mart becomes an expert of sale because of powerful information. This expert power becomes a successful brand of retailer, Principle 7. Wal-Mart also could take the points of Principle 4, 6, and 9, jointing bacon cook maker, A de F Ltd. Makin' Bacon, and major bacon producer, Armour-Eckrich Meat, for a long-term relationship and profit and risk sharing to enhance intercompany trust.

Communication principles for collaborative production provide guidelines for designated communication. However, it is not a handbook to tell company how to do but what to do in communication. Company can take different actions to various situations. A further research may focus on how to establish intercompany trust and relationship duration.

Appendix A. plan_procedure() Phase I

The purpose of this phase is to find a suitable time bucket for a new order in a factory with many other orders by a scheduling process and to get an initial plan. The detail logical process is described as follows.

Notations:

order: new order entry factory.

TW[]: object array for putting time bucket.

TT: object variable for putting a time bucket.

i: total operation number of confirmed order in planning time bucket of a factory.

j: index of TW[] array, $j = 0, 1, \ldots, i+1$.

k: sequence variable.

position: position variable of new order in a factory scheduling.

Planning procedure:

Step 1: set process variable

Let process variable value $k = i+1$.

Step 2: establish time bucket array

2.1 Establish $i+2$ time bucket object array TW[] according to the total confirmed operation of order i in factory capacity operation.

2.2 The index value of time bucket object j from 1 to $i+1$. Setting starting time (ST) and ending time (ET) of TW[j] by the status of confirmed operation of order in factory capacity operation.

Step 3: select time bucket

According to current process variable *k*, selecting index *j* equal to time bucket object of *k* put into TT variable, that is TT←TW[*k*], go to step 4.

Step 4: constraint judgment

4.1 If the ST of TT is less than the due date (DD) of new order, go to step 5.

4.2 Otherwise, decrease process value k, that is *k*←*k*-1, then go to step 7.

Step 5: Check the time bucket of TT

5.1 If the difference between ET and ST of TT is greater than or equal to lead time (LT) of product type of operation of order, go to step 6.

5.2 Otherwise, decrease process value *k*, that is *k*←*k*-1, then go to step 7.

Step 6:

6.1 If the difference between DD and ST of order is greater than or equal to manufacturing LT of product type of operation of order, set the entry position variable equal to current process variable *k*, then go to step 8.

6.2 Otherwise, decrease process value *k*, that is *k*←*k*-1, then go to step 7.

Step 7:

7.1 If the entire time bucket TW[] has been selected, set the entry position variable equal to 1, go to step 8.

7.2 Otherwise, go back to step 3.

Step 8: Calculate estimate value

8.1 Put the order into the position list of factory capacity operation according to position value of order entry variable.

8.2 Decide RLST of new order by backward schedule.

8.3 Calculate priority value of new order.

8.4 End the process.

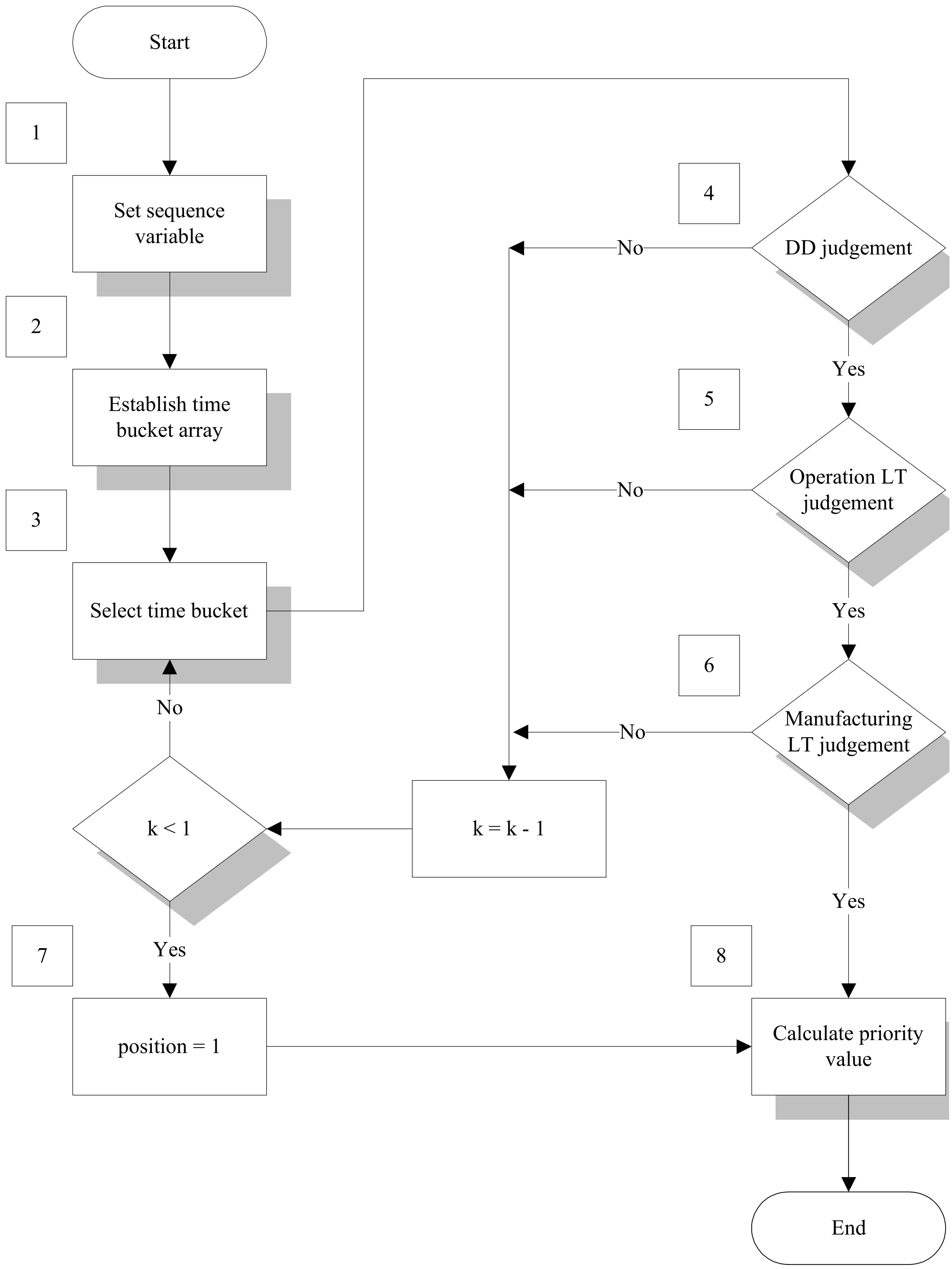

Figure A.A1 plan_procedure() Phase I (Huang *et al.* 2008)

Appendix B. plan_procedure() Phase II

Step 1: Calculate overall evaluation value

1.1 Calculating overall evaluation value of overall operation in the factory operation list.

1.2 Go to step 2.

Step 2: Setting variable

2.1 Set the sequence variable $k = 1$, operation time lag variable lag = $i - 1$.

2.1 Go to step 3.

Step 3: Executing fine-tuning process

3.1 Exchanging sequence on [k] position and [k + lag] position in the order list according to the current values of k and lag.

3.2 determining the REST of confirmed order and RLST of new order by forward scheduling.

3.3 Calculating the sun of overall evaluation value of operation after exchange, then go to step 4.

Step 4: EV judgment

4.1 If new evaluated value less than current evaluated value, then exchange sequence. Go back to step 2.

4.2 If new evaluated value equal to current evaluated value, it must further judgment. If the REST value on [k] position less than REST on [k + lag], then exchange sequence. Go back to step 2. Otherwise, operation sequence must reverse back to the status before exchange. Then increase k one unit, $k \leftarrow k + 1$. Go to step 5.

4.3 If new evaluated value larger than current evaluated value, do not exchange sequence. The Statue must reverse to before exchange. Then increase k one unit, $k \leftarrow k + 1$. Go to step 5.

Step 5: Check the operation list

5.1 Check whether the exchange process is the last operation on the factory capacity list.

5.2 If yes, end the fine-tuning process. The operation sequence in the current factory capacity operation list is the final status.

5.3 Otherwise, go to step 6.

Step 6: Check [k + lag]

6.1 Checking whether the position [k + lag] of exchanging operation is greater than i. It means greater than the last operation on the operation list.

6.2 If yes, go to step 7.

6.3 Otherwise, go back to step 3.

Step 7: Set variable

7.1 Set sequence variable $k = 1$. The operation time lag variable lag = lag – 1.

7.2 Go back to step 3.

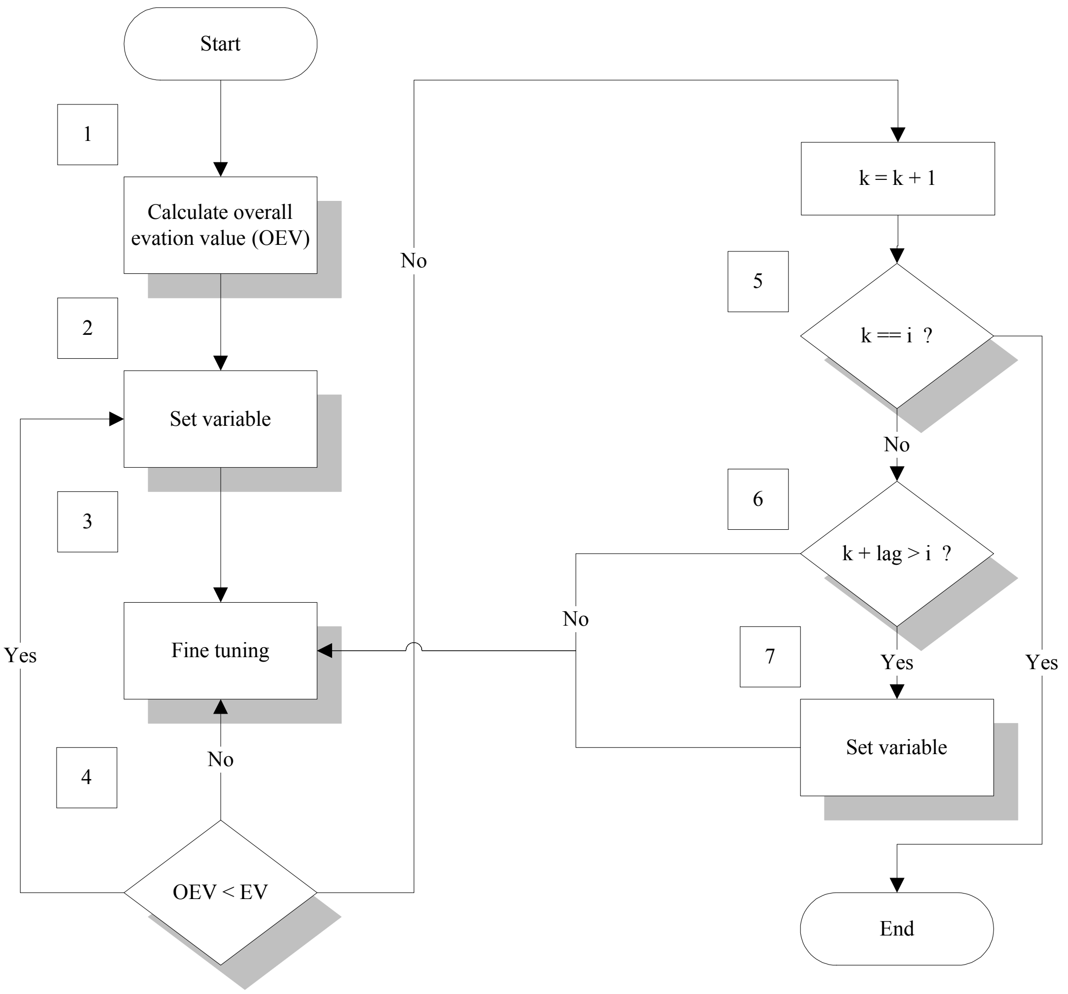

Figure A.B1 plan_procedure() Phase II (Huang *et al.* 2008)

Appendix C. schedule_procedure() Phase I

Notations:

order : new order entry factory.

TW[] : object array for putting time bucket.

TT: object variable for putting a time bucket.

i: total operation number of confirmed order in planning time bucket of a factory.

j: index of TW[] array, $j = 0, 1, \ldots, i+1$.

k: sequence variable.

position: position variable of new order in a factory scheduling.

Step 1: Status judgment

1.1 Whether has been received the request information from predecessor factory agent?

1.2 If yes, go to step 2.

1.3 Otherwise, go to step 3.

Step 2: Synchronize

2.1 Synchronizing time unit value of operation in the factory capacity list. Then go to step 3.

Step 3: Set sequence value

3.1 Let the sequence value $k = 1$. Go to step 4.

Step 4: Establish time bucket array

4.1 Establishing an $i + 2$ time bucket object array TW[] according to total operation number i of confirmed order in factory capacity list.

4.2 Time bucket index j = 1, 2, … i+1, setting the ST and ET by TW[j] of confirmed order. Then go to step 5.

Step 5: Select time bucket

5.1 Select time bucket object value $j = k$ save in TT, that is, TT ← TW[k].

Go to step 6.

Step 6: ET judgment

6.1 Checking whether ET of TT greater than setting EEST of new order.

6.2 If yes, go to step 7.

6.3 Otherwise, increase k one unit, $k \leftarrow k + 1$. Go to step 7.

Step 7: Checking time bucket

7.1 Checking whether time bucket length of TT, which is the difference between ET and ST of TT, greater or equal to operation LT of order.

7.2 If yes, go to step 8.

7.3 Otherwise, increase k one unit, $k \leftarrow k + 1$. Go to step 9.

Step 8:

8.1 Checking whether the difference between EEST of order and ET of TT is greater than operation LT of order.

8.2 If yes, set the entry position equal to current k. Go to step 10.

8.3 Otherwise, increase k one unit, $k \leftarrow k + 1$. Go to step 9.

Step 9: Check ending condition

9.1 Checking whether the entire time bucket TW[] have been took.

9.2 I yes, set entry position equal to i+1. Go to step 10.

9.3 Otherwise, go back to step 5.

Step 10: Calculate EV

10.1 Putting the order into factory capacity list in position order.

10.2 Deciding REST of each order by forward schedule.

10.3 Calculating EV of new order.

10.4 End the process.

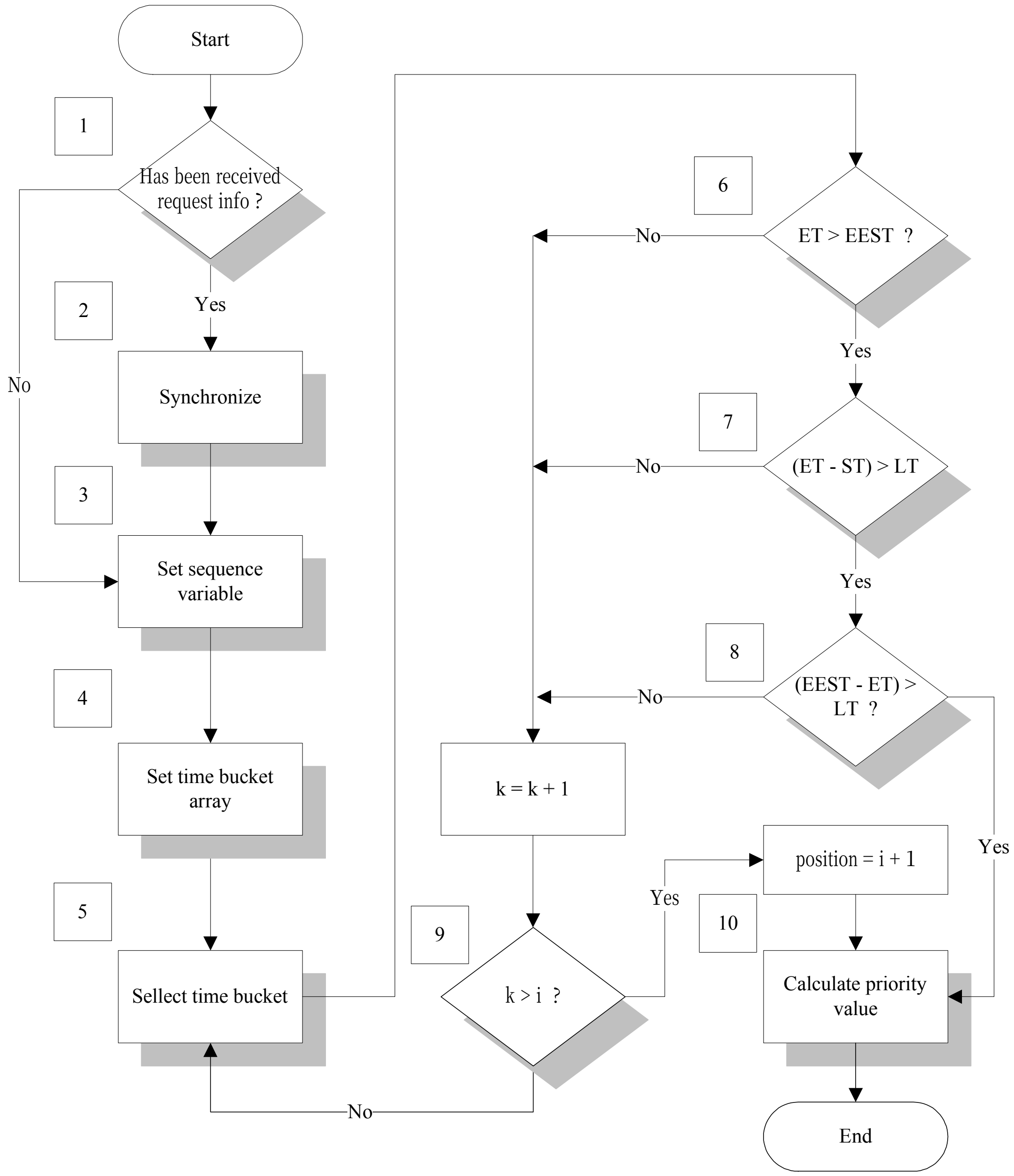

Figure A.C1 schedule_procedure() Phase I (Huang *et al.* 2008)

Appendix D. schedule_procedure() Phase II

Step 1: Calculate overall EV

1.1 Calculating all operation current EV in the factory capacity list.

1.2 Go to step 2.

Step 2: Set variable

2.1 Setting sequence variable k = 1,and time lag between operations lag = i – 1.

2.2 Go to step 3.

Step 3: Executing fine-tuning

3.1 Exchanging sequence on [k] position and [k + lag] position in the order list according to the current values of k and lag.

3.2 Deciding each REST in the order list by forward schedule.

3.3 Calculating the sum of all EV after exchanged, then go to STEP 4.

Step 4: EV judgment

4.1 If new EV less than current EV, exchange sequence. Go back to step 2.

4.2 If new EV equal to current EV, it must further judgment. If the EEST value on [k] position less than EEST on [k + lag], then exchange sequence. Go back to step 2. Otherwise, operation sequence must reverse back to the status before exchange. Then increase k one unit, $k \leftarrow k + 1$. Go to step 5.

4.3 If new EV larger than current EV, do not exchange sequence. The statue must reverse to before exchange. Then increase k one unit, $k \leftarrow k + 1$. Go to step 5.

Step 5: Check the operation list

5.1 Check whether the exchange process is the last operation on the factory capacity list.

5.2 If yes, end the fine-tuning process. The operation sequence in the current factory capacity operation list is the final status.

5.3 Otherwise, go to step 6.

Step 6: Check [k + lag]

6.1 Checking whether the position [k + lag] of exchanging operation is greater than i. It means greater than the last operation on the operation list.

6.2 If yes, go to step 7.

6.3 Otherwise, go back to step 3.

Step 7: Set variable

7.1 Set sequence variable $k = i$. The operation time lag variable lag = lag – 1.

7.2 Go back to step 3.

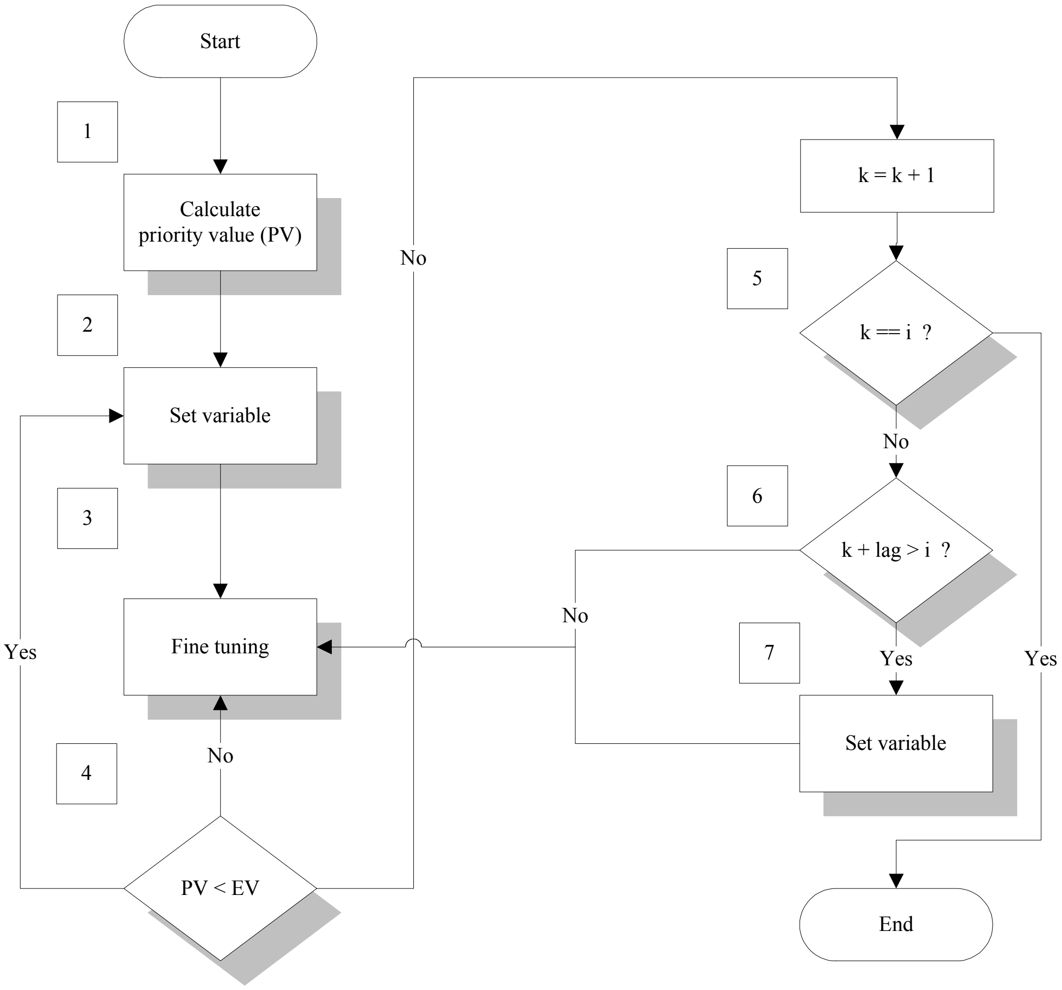

Figure A.D1 schedule_procedure() Phase II (Huang *et al.* 2008)

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