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Planification décentralisée des activités de production et de transport: coordination par négociation

Directeur de recherche : Rémy Dupas
Jean-Christophe Deschamps

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Devant la commission d'examen formée de :

M. DUPAS Rémy	Professeur, Université Bordeaux 1	Directeur
M. DESCHAMPS Jean-Christophe	Maître de conférences, Université Bordeaux 1	Co-directeur
Mme. THIERRY Caroline	Professeur, Université Toulouse 2	Rapporteur
M. GONCALVES Gilles	Professeur, Université d'artois	Rapporteur
M. VALLESPIR Bruno	Professeur, Université Bordeaux 1	Président
M. ZHAN Dechen	Professeur, Institut de technologie d'Harbin	Examinateur

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Résumé étendu

de la thèse de doctorat de Mademoiselle Zhenzhen JIA

Planification décentralisée des activités de production et de transport: coordination par négociation

1) Contexte et Objectifs

Le pilotage des chaînes logistiques (*Supply Chain Management*) est une problématique d'importance stratégique pour les entreprises; c'est un domaine en constante évolution depuis la création de ce concept dans les années 1980. Les entreprises en compétition dans un marché globalisé cherchent à accroître l'efficacité de leur chaîne logistique qui est constituée d'un nombre croissant de partenaires. La performance de cette chaîne dépend fortement de la coordination des flux de matières, des flux d'informations et des flux financiers qui circulent entre les différentes entreprises indépendantes qui la composent.

Ces dernières années, les entreprises concentrent leurs activités sur leur "cœur" de métiers ainsi que sur leurs compétences premières tout en externalisant les autres activités à d'autres partenaires industriels ou commerciaux lorsque cela est possible. Les entreprises de transports de type 3PL (*Third-party Logistic Provider*) ont précisément émergés pour réaliser tout ou partie des activités de transport dans le domaine de la distribution des produits au sein de la chaîne logistique. Dans ce contexte 3PL, les activités de production et de transport sont effectuées par des entités différentes. C'est pourquoi la coordination entre le producteur et l'opérateur de transport est essentielle pour assurer de bonnes performances de l'ensemble de la chaîne.

Les principales limitations des méthodes, des pratiques et des recherches actuelles sur la coordination entre activités de production et de transport sont les suivantes:

- Les activités de transport sont différentes des activités de production car elles concernent par nature une transaction entre 2 ou plusieurs sites alors que ce n'est pas le cas de la production qui est généralement située dans un seul lieu. Cette spécificité nécessite de porter une attention particulière aux activités de planification du transport mettant en jeu plusieurs sites. Par ailleurs, les approches conventionnelles portant sur le couplage des activités de transport et de production ne considèrent généralement pas explicitement des transporteurs totalement indépendants du producteur. Dans le contexte de transport évoqué ci-dessus, le problème de la coordination des activités recèle une dimension de complexité supplémentaire due à l'autonomie de l'opérateur de transport.

- Les approches collaboratives existantes telles que ECR (*Efficient Customer Response*), VMI (*Vendor Management Inventory),* CPFR *(Collaborative Planning, Forecast and Replenishment)* requièrent un climat de confiance mutuelle entre les partenaires pour implémenter un partage d'informations. Ces approches sont limitées à des partenaires impliquées dans une relation de long terme; par ailleurs ces approches ne prennent pas en compte explicitement les spécificités du transport.

- Les outils tels que l'APS *(Advanced Planning System)* ou le DRP *(Distribution Requirement Planning)* sont des solutions logicielles intégrées qui requièrent de rassembler l'ensemble des informations des partenaires de la chaîne logistique. Les solutions réellement décentralisées pour la résolution du problème de planification collaborative entre production et transport exécutées par des partenaires indépendants sont très peu nombreuses.

- Les travaux de recherche dans ce domaine visent à intégrer toute l'information des différents partenaires en vue de planifier les activités. La plupart des études dans le domaine de l'optimisation de modèles de planification se focalisent sur la formulation de modèles intégrés de production et de transport. L'objectif de ces modèles consistent à maximiser le profit total ou à minimiser les coûts dans la chaîne en supposant qu'il existe une entité centralisée et indépendant capable de prendre les décisions pour l'ensemble des partenaires. Ces modèles ne sont pas adaptés dans le contexte d'une prise de décision décentralisées.

Ces limitations nous conduisent à étudier le développement d'une approche de coordination selon un mode décentralisé, entre les activités de planification de la production et celles du transport dans un contexte d'opérateur de transport 3PL. Il convient de remarquer que le producteur et l'opérateur de transport peuvent avoir dans ce cadre des objectifs antagonistes et conflictuels. Ils tendent d'une part à conserver la confidentialité de leur information et mettent en œuvre leur propre processus de décisions pour la planification qui visent à améliorer leur profit ainsi que la compétitivité de leurs activités. Ils communiquent d'autre part par l'échange des informations nécessaires pour assurer une coordination effective en vue d'améliorer leurs performances. Notre approche de la collaboration est fondée sur le principe de la négociation entre les deux partenaires afin d'arriver à un compromis profitable par chacun d'eux.

Les objectifs de cette thèse consistent donc à répondre aux trois questions suivantes:

- *Comment effectuer la prise de décision locale?* Les décisions de planification sont simulées à l'aide de modèles mathématiques. Etant donné la complexité du problème et sa dimension inter-entreprise, il n'est pas envisageable de développer un modèle de décision de planification intégré basé sur l'ensemble des informations du producteur et du transporteur. Le premier objectif consiste donc à élaborer des modèles de décision séparés permettant de planifier les activités de production et celles de transport.

- *Quel est l'objet de la négociation?* Celle-ci repose sur des informations et des concepts partagés entre le producteur et l'opérateur de transport afin d'aligner et de faire coopérer au mieux ces deux activités dans un objectif d'amélioration des performances de la chaîne. Le second objectif vise à identifier ces informations partagées et à formaliser les concepts qui sont à la base d'une négociation entre partenaires.

- *Comment négocier?* Lorsque les plans de livraison demandés par le producteur et les plans de ramassage proposés en réponse par le transporteur ne sont pas cohérents, il convient de proposer un mécanisme qui permette d'arriver à un compromis acceptable pour les deux parties tout en visant l'amélioration des performances globales et locales de la chaîne. Le troisième objectif consiste donc à définir un protocole opérationnel de négociation mettant en œuvre de façon cohérente les différents les objets de négociation pour assurer la convergence du processus.

2) Méthodologie et contribution

La méthodologie retenue fait appel à une démarche d’analyse décomposée en deux étapes :

- La première phase se focalise sur le cas d'une relation dyadique au sein d'une chaîne logistique, incluant un producteur et un opérateur de transport (3PL). L'objet de l'étude est le développement des modèles décisionnels en programmation linéaire et leur intégration dans l'élaboration d'un protocole de négociation permettant la coordination de décisions de planification, par nature distribuée entre deux acteurs (négociation « point à point »), dans une recherche de solution « gagnant-gagnant ». Différents modèles sont développés dans l'optique de modéliser plusieurs comportements:
    - o Le principal modèle d'optimisation concernant le producteur est classique et cherche à maximiser son profit. Deux extensions de ce modèle permettent d'une part d'évaluer la faisabilité et la performance d'un plan de ramassage (pick-up) proposé par le transporteur, d'autre part de trouver une solution révisée intégrant les contraintes du fournisseur de transport.
    - o De la même manière, le modèle principal de planification du prestataire de transport tend à maximiser son profit. Deux variantes de ce modèle permettent l élaboration de plans de ramassage maximisant le service au client (i.e. producteur) ou minimisant l'écart par rapport au plan maximisant le service client mais en intégrant une contrainte additionnelle de profit minimum.

Les éléments de base de la négociation sont posés comme suit:

- o La notion d'espace de négociation, pouvant se caractériser comme l'intervalle de valeurs admissibles pour le critère d'optimisation choisi, i.e. la maximisation du profit de chaque partenaire.
- o La définition d'un critère d'acceptation directe d'un plan proposé par l'un des partenaires qui permet de ne rentrer dans un processus de négociation entre producteur et opérateur de transport, que lorsque l'espace de négociation est suffisamment « large » pour atteindre une issue favorable à cette négociation, i.e. une amélioration de la performance globale.
- o Le concept d'intervalle de relaxation appliqué au critère (profit), permettant à chaque itération du processus de négociation de mettre à jour les bornes définissant l'espace de négociation ; il autorise ainsi l'atteinte d'une solution de planification à profit individuel moindre qui tend à maximiser la performance globale.
- o Le principe de compensation, qui s'interprète comme une incitation financière de l'un des partenaires vis-à-vis de l'autre à accepter une légère dégradation de sa performance, moyennant l'acceptation de ce dédommagement.

Les modèles décisionnels et le protocole sont implémentés à l'aide d'un couplage des outils XPRESS-MP et EXCEL au sein d'une plate-forme de simulation, à partir de laquelle des expérimentations sont mises en œuvre pour évaluer l'impact des différents facteurs pouvant impacter la performance de la relation entre partenaires. Ces expérimentations s'appuient sur la méthode des plans d'expérience, reposant, entre autres étapes, sur la définition des réponses du système étudié, l'identification des facteurs influant ces réponses, et l'énumération (complète ou partielle) des différentes expérimentations à mener pour analyser l'effet de la variation des valeurs des facteurs sur les réponses du système observé.

- La deuxième phase se veut généraliser le problème étudié à la considération d'une relation contractuelle liant un producteur à plusieurs prestataires de transport. La multiplicité de ces derniers conduit à la prise en compte de la répartition des charges à transporter sur un ensemble d'opérateurs ; les modèles issus de la première phase d'analyse sont modifiés afin d'intégrer la stratégie de partage de charges en fonction des capacités affichées par chaque transporteur, à la recherche du meilleur profit pour chaque partenaire. Ainsi, le protocole de négociation se décompose en deux parties :

    - Une première étape amène le producteur à estimer la capacité propre de chaque prestataire de transport et à affecter les charges à transporter en fonction de préférences financières.
    - Une deuxième étape s'appuie sur le postulat qu'une fois la répartition des charges de transport terminée, la négociation s'effectue de manière indépendante pour chaque relation individuelle entre un opérateur de transporteur et le producteur, reprenant ainsi les fondements d'une négociation « point à point ».

Les nouveaux comportements ainsi intégrés dans le développement des modèles et processus de négociation sont testés et validés sur la base d'un ensemble de jeux de tests.

3) Résultats

Les expérimentations réalisées dans le cadre de la thèse s'appuient sur des jeux de données théoriques, dont l'objectif est de permettre de conclure sur l'importance de certains facteurs sur l'amélioration de la performance des partenaires. Ainsi,

- Les différents tests définis dans le cadre du plan d'expérience appliqué à l'étude de la relation dyadique associant un producteur et un prestataire transport met en exergue un profit global (au périmètre des deux acteurs) faiblement augmenté dans la plupart des tests menés. Le protocole joue son rôle attendu dans l'amélioration du profit du prestataire transport sans dégrader pour autant celui du producteur. Dans la plupart des cas étudiés, les deux partenaires sont gagnants à l'issue de la négociation. Une analyse plus fine permet de démontrer la dominance de l'impact de certains facteurs sur la performance des partenaires. Un plan d'expérience plus spécifiquement centré sur l'analyse des facteurs propres au processus de négociation (hors paramétrage propres aux modèles décisionnels implémentés) démontre que la performance est essentiellement impactée que par le principe de compensation.

- Les jeux de tests définis dans le cadre de N opérateurs de transport permettent de vérifier que le protocole et les modèles associés se comportent de manière conforme aux attendus; ils mettent en évidence la recherche du compromis entre une planification fondée sur l'utilisation d'un nombre réduit d'opérateurs de transport entrainant le non respect des contraintes de temps sur certains ramassages, et une planification ayant recourt à un nombre plus important d'opérateurs au prix d'une augmentation des coûts. Ils révèlent cependant un gain de performance parfois très faible après négociation

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Abbreviation list

AC	Acceptance Criterion
AMR	Advanced Manufacturing Research
AOM	Advanced Order Management
APS	Advanced Planning System/Advance Planning and Scheduling
ATO	Assembly to Order
BTO	Buy to order
BPP	Best Profit Production
BPT	Best Profit Transportation
BST	Best Service Transportation
CEP	Courier, Express, Parcel
CPFR	Collaborative Planning, Forecasting, and Replenishment
CRM	Customer Relationship Management
CRP	Continuous Replenish Program
CSCMP	Council of Supply Chain Management Professionals
DC	Distribution Center
DMU	Decision Making Unit
DRP	Distribution Resource Planning
ECR	Efficient Consumer Response
EDI	Electronic Data Interchange
ER	Evaluation Production
ERP	Enterprise Resource Planning
FTL	Full Truckload
LTL	Less than Truckload
IS	Information System
IT	Information Technology
KPI	Key Performance Indicators
MES	Manufacturing Execution System
MRP	Material Requirement Planning
MTO	Make to Order
MTS	Make to Stock

PSI	Purchase, Sales and Inventory
QR	Quick Response
RD	Release Degree
RP	Released Production
RT	Released Transportation
SC	Supply Chain
SCC	Supply Chain Council
SCE	Supply Chain Execution
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SRM	Supplier Relationship Management
STS	Ship to Stock
TMS	Transportation Management Systems
VICS	Voluntary Inter-industry Commerce Standards
VMI	Vender Managed Inventory
WMS	Warehouse Management Systems
xPL	x=1 to 4, X Party Logistic

General introduction

General introduction

The field of Supply Chain Management (SCM) has tremendously evolved since the concept of SCM was born in the 1980s. Enterprises are increasingly seeking to rely on effective supply chains, or networks, to compete in the global market and networked economy. With the increase of globalization and competition, more and more partners are involved in the supply chain. Consequently, supply chain performance largely depends on the coordination of materials, information and financial flows of several separated firms.

Nowadays, companies attempt to concentrate on their core competencies while they outsource all other activities to external firms, when possible. Particularly, an independent company, so called a third party logistics provider (3PL), has emerged and performs all or part of a producer's product distribution function. This 3PL is also called transport operator in the thesis. In the 3PL context, the activities of production and transportation are executed by different organizations. Therefore, coordination between the producer and the transport operator is essential in order to achieve better supply chain performance.

The main limitations of current research on coordinating production and transportation problems result from several aspects:

- Transportation refers evidently to the transaction which links as least two locations (i.e. initial location and destination). This is different from the production or sale which generally takes place in one location. Hence, transportation planning decisions should be paying more attention in order to efficiently manage the decisions at both locations and thus limit the increase of uncertainty. The conventional production-transportation problem has not explicitly considered independent transport operators. Nowadays, in the context of 3PL transport operators, supply chain (SC) structure and SC business processes become more complex. The production - transportation problem becomes different from the conventional one due to the difficulty of coordinating the two members.

- Current collaborative approaches such as Efficient Consumer Response, Vender Managed Inventory and Collaborative Planning, Forecasting, and Replenishment require a confidence climate to implement information sharing. These approaches are limited to the SC members who are involved in long term relationships and have mutual benefit relations. Moreover, transportation is not considered explicitly in these approaches.

- Some SCM studies integrate the information of all partners for planning. Most of prior studies in the field of mathematical optimization models focus on formulating an integrated production and transportation planning model. The objectives of these models are to maximize the total profit or minimize the total cost of the supply chain by supposing that there is an independent planning department or supervisor which makes decisions for all supply chain participants. These models are not suitable for decentralized decision making context.

- The current SCM applications in industrial practice such as Advanced Planning System, Distribution Resource Planning are integrated solutions which require gathering all necessary information from involved SC members. There are few existing decentralized SCM solutions to solve the problem of collaborative planning between production and transportation which are executed by interdependent SC members.

For these reasons, the main objective of this thesis consists in developing an approach to coordinate transportation planning with production planning decisions in the 3PL environment under a decentralized coordination mode.

In the 3PL context, the producer and the transport operator may pursue some conflicting objectives and cannot completely share the information. On the one hand, they try to keep their private information and implement the autonomy through their own decision making processes with an objective to increase their profit and business competitiveness. On the other hand, they have to communicate by exchanging necessary information in order to ensure an efficient coordination and to achieve better supply chain performance. Therefore, three research challenges are investigated in this thesis:

- *How to make local decisions?* The planning decisions can be simulated by mathematical models. Since it is an inter-enterprise planning problem, it is unrealistic to develop an integrated decision model which collects all information from producer and transport operator. It is necessary to build separated decision models, corresponding to partners' decision making processes which locally plan production and transportation activities.

- *What to negotiate?* It is also important to identify the necessary information which should be shared between producer and transport operators in order to align and better coordinate their activities so as to improve the performance of the SC. For instance, the SC will get a better performance when the producer's delivery requirement is consistent with the transport operators' pickup plan.

– *How to negotiate?* In the case of a producer's delivery requirement which is not consistent with the transport operators' pickup plan, it is important to propose a mechanism which can coordinate the production and transportation decisions and improve the global performance of the SC as well as the individual performance of each partner.

This thesis is organized into the following structure shown in Figure 1.

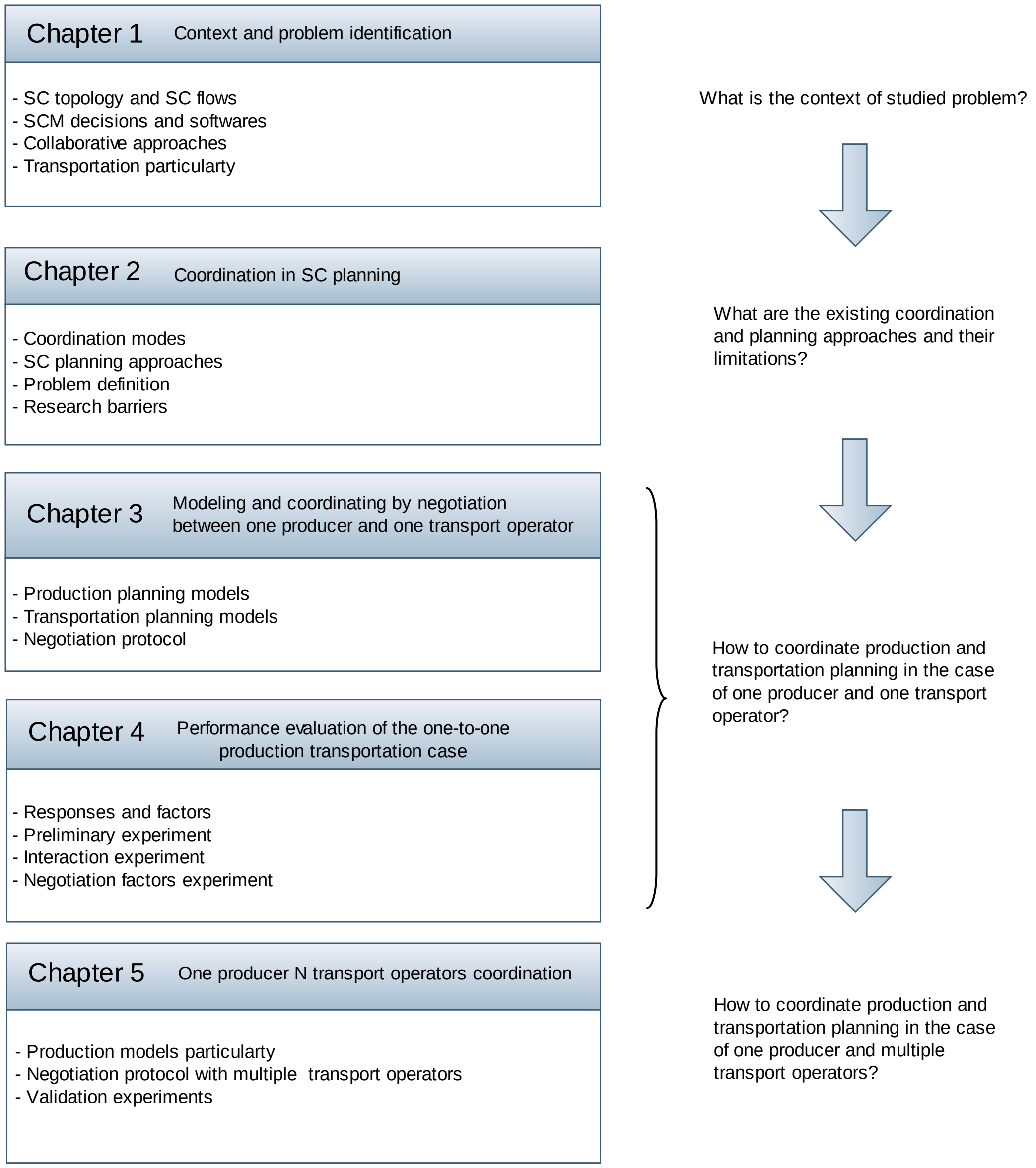


Figure 1 Outlines of the thesis

The first part, including the first two chapters, aims to give a more precise description of the study background, in order to clearly understand the scientific key issues of this work.

Chapter 1 focuses on introducing supply chain related concepts, and performance measurement concepts. This part intends to define the scope of our research problem by answering the following questions. Which supply chain structure we analyze? Which SCM functions are we interested to take into account? Which decision level is considered for the study? Which kind of relation is considered for the partners involved in the study: coordination or cooperation or collaboration? What problems are we going to solve? What are the limitations of the existing SCM solutions? What are the main indicators to evaluate the SC performance?

Chapter 2 focuses on coordination problems in SC planning and more precisely between production planning and transportation planning. Coordination mode and SC planning approaches will be discussed. The research problem and barriers are presented in the specific context of the decentralized production–transportation coordination.

The second part studies the simplest coordination context, involving on producer and one transport operator, in order to assess key parameters that can impact SC performance during negotiation.

In chapter 3, we propose analytical models to describe decision making processes supporting separately the production and transportation planning. A negotiation protocol is also described to define how to coordinate one producer and one transport operator in a distributed planning approach.

Chapter 4 is concerned by the evaluation case of an elementary SC restricted to one producer and one transport operator. The experimental study carried out in this chapter is based on the Taguchi method of design of experiments. The objective of this chapter is to investigate the process as a whole and identify a list of main parameters which can affect the SC performance by their importance.

The last part intends to extend planning problems previously studied in a more complex coordination context. Thus, the chapter 5 extends the negotiation to multiple transport operators. As the relations between producer and transport operators change, the negotiation protocol changes as well. In the multiple transport operators context, producer has to solve the allocation problem of a given delivery demand among a non limited number of available transport operators before going on with individual negotiations concerning each transport operators.

At the end of this thesis, a general conclusion states the main contributions, synthetizes key experimental results that have been obtained by simulation and proposes a discussion on perspectives of this work.

Chapter 1

Context and problem identification

Chapter 1 Context and problem identification

1.1 Introduction

In order to define the thesis objectives, it is necessary to introduce some general concepts related to supply chain (SC) and supply chain management (SCM) based on a literature review of academic research and industrial practices. Consequently, section 1.2 of this chapter introduces some essential information about supply chain such as topology and flows. Section 1.3 presents the concept of supply chain management which has been developed and studied for more than three decades to solve various SC problems. This section also presents elementary characteristics of decisions in the context of SCM which are the decisions nature and the decisions hierarchical levels. These elementary characteristics are then used to introduce two classifications of main SCM decisions: the SCM functions and the SCM business processes. Concerning the industrial practice, the evolution and the classification of SCM software are also presented in this section. Since the different members in SC may pursue their own objectives, the decisions taken by different SC members may conflict to the SC global objective. Thus collaboration becomes more and more important in SCM in order to achieve global high level performance. Therefore section 1.4 of this chapter presents some concepts of collaboration such as collaboration levels and collaboration approaches. Section 1.5 of this chapter focuses on transportation in SC and indentifies the collaboration limitations between transportation and production which lead to the targets of our research. Finally, a summary of the thesis objectives is presented at the end of this chapter.

1.2 SC concepts

There is no standardized definition of the concept of a supply chain; it is relatively broad and encompasses different meanings. Consequently, this section firstly presents some definitions of this concept coming from literature, then describes the different flows inside the SC and gives finally a typology of SC.

1.2.1 SC definition

The literature offers a variety of definitions of supply chain. Many researchers propose supply chain definitions according to the orientation of their supply chain research.

According to Stevens (Stevens, 1989), a supply chain is defined as "*a connected series of activities concerned with planning, coordinating and controlling materials, parts, and finished goods from suppliers to customers. It is concerned with two distinct flows (material and information) through the organization.*" This definition points out material flow and information flow in SC.

Lee and Billington (Lee and Billington, 1995) define a supply chain to be "*a network of facilities that procure raw materials, transform them into intermediate goods and then final* *products, and deliver the products to customers through a distribution system*". This definition emphasizes the transformation process of material flow and points out the network structure of SC.

Ganeshan et al. (Ganeshan et al., 2003) define a supply chain as "*a system of suppliers, manufacturers, distributors, retailers, and customers in which materials flow downstream from suppliers to customers and whereas information flows in both directions*". Their definition extends SC definitions by the directions of material and information flows.

Mentzer et al. (Mentzer et al., 2001) define a supply chain "*to be a set of organizations directly linked by one or more of the upstream and downstream flows of products, services, finances, and information from a source to a customer*". This definition adds a financial flow to SC flows.

Christopher (Christopher, 2005) defines a supply chain as "*a network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer*". This definition points out the output of a SC is not limited to products but also services.

Figure 1.1 shows an example of supply chain. The dash arrow presents information flow towards upstream while the solid arrow presents material flow towards downstream. The components provided by suppliers are transformed by manufacturing enterprise into semi-finished products and furthermore to final products and distributed to customers through distribution centers. There are many organizations involved in a supply chain.

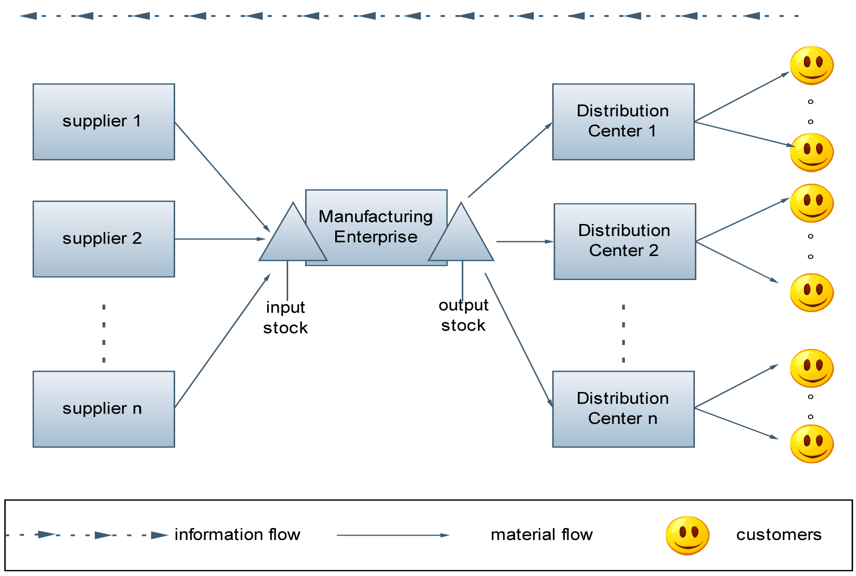


Figure 1.1 A supply chain example

All the definitions presented above have some common elements about supply chain:

- **Set of organizations:** All the definitions characterize supply chain as a network of organizations through which materials/goods are transferred.
- **Flows:** Material flow starts from supplier to end customer with a transformation process from raw materials until end products. Information flow goes upstream or in both directions. Financial flow is not mentioned by all the definitions above but as a common and accepted concept in supply chain management. It can be viewed as a complementary part of SC definition.
- **Customer:** All the definitions mention the delivery of the final products to end customer.

Based on the observations above, we propose our own supply chain definition:

> A supply chain is a network of interdependent organizations which provide products or service to satisfy the consumption of end customers. These supply chain organizations are involved in different processes and activities through which materials are transformed to products and flow downstream while finances flow upstream and information flow in both directions.

1.2.2 SC flows

The most common flows found in the SC definitions in previous section and in the literature of supply chain management can be divided into three main flows, material flow, information flow and financial flow.

- **Material flow**: The material flow includes the movements of components/goods from supplier to customer including the movements inside organizations. Transportation is an important activity in managing these material flows.
- **Information flow**: The information flow involves transmitting orders and updating the status of delivery. In global view the information flows upstream in supply chain. However in detailed view, there are information loops between organizations when collaboration is involved.
- **Financial flow**: The financial flow consists of credit terms, payment schedules, and consignment and title ownership arrangements.

We are intending to dealing with the synchronization of the material flow and information flow, especially the synchronization of material flow during the production and transportation processes. The financial flow is not the focus of this thesis. Nevertheless, financial exchanges are discussed in the context of negotiation between SC members.

1.2.3 SC topology

It is important to have a clear understanding of supply chain topology in order to perceive the complexity of the managed supply chain. The simplest supply chain is a dyadic supply chain which involves only one supplier-customer relationship shown in Figure 1.2. Supplier provides products or services to satisfy the demands required by the customer. In conventional production strategy, customer's procurement department transmits purchase orders to supplier with the objective to maintain a desired inventory level and to satisfy consumption needs. Because of the production and delivery lead time, supplier makes its production planning based on forecast demand planning. Due to the uncertainty of customer's demand or the forecast accuracy problem, it is vital for supplier to make efficient production planning and transportation planning to ensure that products are delivered at right time at right quantities. This dyadic supply chain is the simplest element in supply chain structure. There are other more complex supply chain structures.

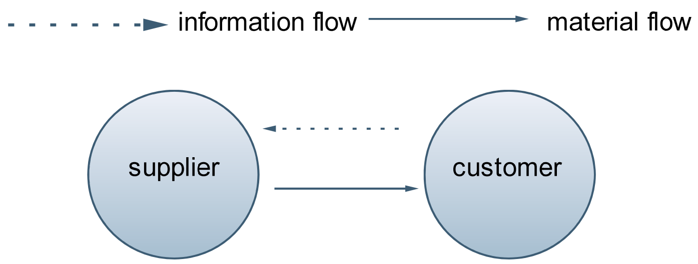


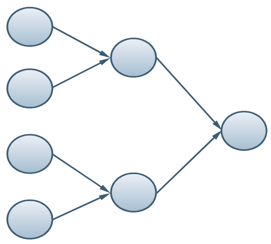
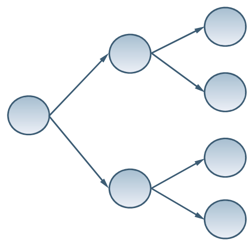
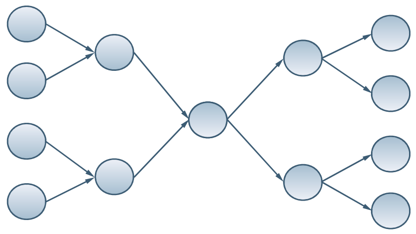
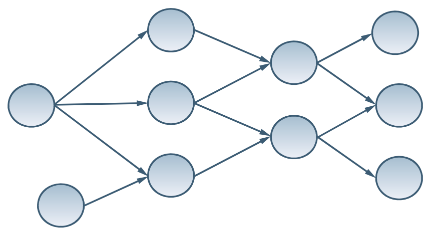
Figure 1.2 A dyadic supply chain

Beamon and Chen (Beamon and Chen, 2001) classified the supply chain structure into four main types which are illustrated in Table 1-1.

- **Convergent**: each node in the chain has at most one successor, but may have many predecessors. Examples of a convergent structure supply chain are shipbuilding, airplane manufacturing and building construction.
- **Divergent**: opposite to convergent supply chain, in the divergent supply chain, each node has at most one predecessor, but many successors. For example most types of mineral processing organizations are divergent.

- **Conjoined**: a combination of convergent and divergent structure. A convergent and a divergent sub-chain are connected in sequence to form a single chain. Examples are farming, merchandise catalog and web-based companies.
- **Network**: this cannot be classified as convergent, divergent or conjoined and is more complex than the three previous types. Examples are automobile manufacturing and electronics manufacturing.

Table 1-1 Topology of supply chain

Convergent	Divergent
	
Conjoined	Network
	

Most of supply chains have network topology as shown in Table 1-1 but with more supply chain members and links. These networks become more and more complex with the increasing size of real world supply chains. Processes and activities become complex to control and to synchronize at the meanwhile. It requires an efficient approach to manage these complexities in the chain. Therefore the concept of supply chain management emerges.

1.3 SCM concepts

A supply chain is composed by a set of organizations. Each of them can be modeled from a cybernetic point of view as being made up of three interacting systems: control system, information system and physical system as shown in Figure 1.3.

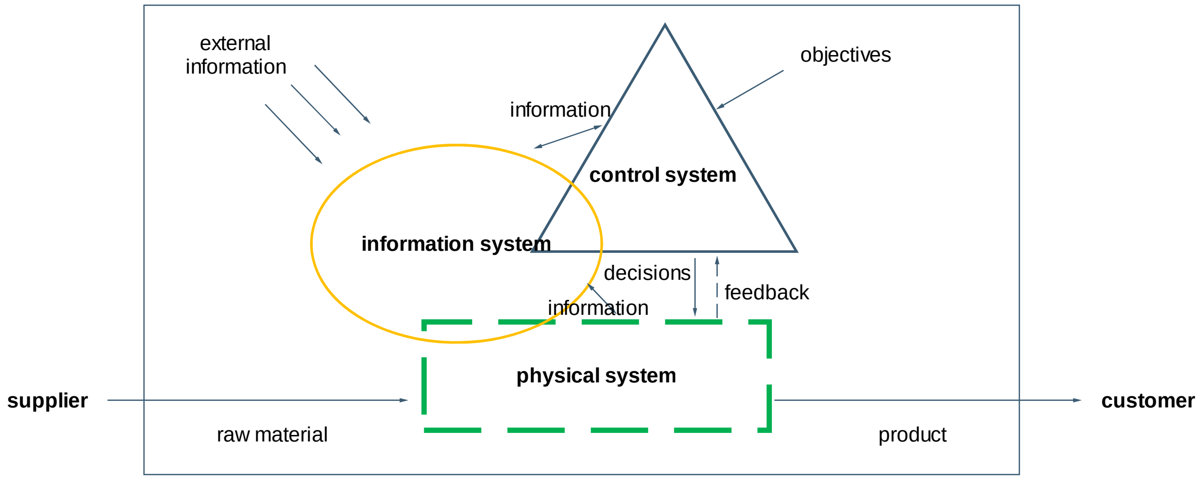


Figure 1.3 Enterprise system model

Information system, presented by ellipse, manages and stores information in an organized structure. It could be composed of databases, decision support software or other information technology. Both control system and physical system can retrieve and store information through information system.

Control system (decision making system), presented by triangle, makes decisions for physical system with a purpose of achieving specific objectives with the help of information system. Control system is also called decision making system. It retrieves parameters of physical system from information system. Based on the objective and feedback from physical system, control system can makes instructions to guide the activities of physical system. It serves as a brain of an enterprise and represents a group of intelligent resources such as human or decision support tool.

Physical system, presented by rectangle**,** is composed of machines that transform supplier raw materials to final products to fulfill customer demands. The physical system follows the instructions of control system and sends the feedback of real time execution information so that the control system can adjust decisions based on the feedback.

In brief, an organization (or enterprise) functions with information system, control system and physical system together. Control system is the most critical part among these three systems. It controls the execution of physical system and determines the enterprise performance.

In the supply chain, different members, activities, flows and structures are involved. It is not easy to make them cooperate; therefore the concept of supply chain management was developed to improve supply chain performance. SCM decisions are implemented inside the control system of each organization involved in SC. In this section, we give the definition of SCM adopted in this research after a brief review of existing definitions. Then we classify

SCM decisions from different points of view. After a synthesis of supply chain software, we finally classify all the functions and supply chain software into a SCM framework.

1.3.1 SCM definition

The concept of supply chain management (SCM) has emerged for several decades, and even the term itself dates back to the early 1980s. Some authors define SCM in operational terms involving the flow of materials and products, some of them view it as a management philosophy, and others define it in terms of management process (Tyndall et al. 1998). Therefore this notion must be clearly defined.

- Stevens (Stevens, 1989) defines the objective of SCM as the synchronization of customers' requirements with suppliers' materials flow in order to affect the balance of conflicting goals of high customer service, low inventory management and low unit cost.
- Chase (Chase, 1998) defines SCM as a total system approach to manage the entire flow of information, materials, and services in fulfilling a customer demand.
- Quite similar to Chase, Johnson and Pyke (Johnson and Pyke, 2000) mention that supply chain management is used to describe the management of the flow of materials, information, and funds across the entire supply chain, from suppliers to component producers to final assemblers to distribution (warehouses and retailers), and ultimately to the consumer.

These definitions emphasize the management of flows involved in SC. Others emphasize the management of business processes and the objectives of SCM.

- Mentzer et al. (Mentzer et al., 2001) consider that SCM is the systemic, strategic coordination of the usual business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole.
- Lambert (Lambert, 2008) defines SCM as the integration of key business processes across the supply chain for the purpose of creating value for customers and stakeholders
- Stadtler and Kilger (Stadtler and Kilger, 2008) define SCM as the task of integrating organizational units along a supply chain and coordinating material, information and financial flows in order to fulfill (ultimate) customer demands with the aim of improving the competitiveness of a supply chain as a whole.

- Jespersen and Skjott-Larsen (Jespersen and Skjott-Larsen, 2005) mentioned the definition of SCM defined by the Council of Supply Chain Management Professionals (CSCMP) as a function which encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.

From these different definitions, some common elements of SCM can be indentified:

- **Integration and coordination** of business processes across the supply chain as a whole.
- Involvement with many **partners**, such as suppliers, customers, etc.
- **Objective** of improving SC performance of both individual members and the whole SC.
- Focusing on **long-term** relationship.

The literature review illustrates that supply chain management involves multiple firms, multiple business activities, whose coordination is achieved across business activities and across firms in the supply chain. From these definitions, it can be seen that the definitions of SCM are still evolving and therefore, there is no universally agreed definition at this time.

For the purpose of this thesis, we define supply chain management as an approach aiming to coordinate all the activities along the supply chain in order to fulfill customer demand with the purposes of improving the long-term performance of the individual members and the whole SC.

1.3.2 SCM decisions classification

SCM involves many decisions which help to manage the activities in SC. The classification of SCM decisions is helpful to understand how decisions are structured and linked with others in SCM. Thus at first we present two elementary characteristics of decisions in the context of SCM. Then, based on these elementary characteristics, two SCM decisions classifications are introduced: SCM functions and SCM business processes.

1.3.2.1 *Decision characteristics*

The decisions in supply chain management can be classified by different characteristics. We identify firstly the main characteristics which are related to the nature of SCM decisions and then we present the decisions hierarchical levels of these decisions.

1.3.2.1.1 *Decisions nature*

According to the nature of decisions, SCM encompasses procurement management, production management, transportation management and sales management. In the following part, we present the regular decisions of each process.

- Procurement

Procurement is responsible for supplier identification, supplier selection problem, negotiating supply contracts, managing suppliers, formulating purchasing process, and processing orders. The procurement department receives a list of raw materials required by production department. To satisfy production department’s needs, the procurement department sends purchasing orders to selected suppliers for ordering necessary raw materials which will be delivered at right time at right quantities. Besides raw material, service could also be purchased; 3PL is an example of service procurement. Procurement department orders transport service from selected 3PL provider to deliver finished goods from factory warehouse to distribution centers or customers. Moreover, purchasing managers develop metrics for managing procurement costs, service levels, and quality.

- Production

Production is responsible for transforming raw materials, parts or components by using various resource of the organization into value-added product/service having the requisite quality level. The decisions define products to manufacture, allocation of production load to plants, allocation of supply to demand, capacity management, production scheduling which includes construction of the master production schedules, scheduling production on machines, coordinating production schedules. It also includes forecasting labor requirements, determining material requirements and equipment maintenance, workload balancing, quality control measures. These decisions have a big impact on the revenues, costs and customer service levels of the firm.

- Transportation

Transportation is responsible for moving the material flow from an initial location to a destination. Since transportation composes more than 30 percent of the logistics costs (Tseng et al., 2005), it is worthy of the management effort to increase the efficiency of transportation economically. The key decisions of transport management are shipment sizes which involve using full truck load or less than truck load, routing and scheduling. Supply chain adopts a combination of various modes like air transport, road transport, rail transport, water transport, pipelines and intermodal transport for the transportation purpose. Road transport by truck is often the initial and final stage of freight transport. Trucks are able to access many more locations than planes or railroads. Transportation managers will often manage carriers, transportation costs within specified metrics, third-party transportation providers; they also negotiate contracts and ensure that freight moves smoothly among different locations.

- Sales

Sales take place in market segments and make transactions with customers. Thus a sales department manager is responsible for demand planning process to forecast future market demand based on historic data of sales records. A sales department manager is also responsible for customer order management and fulfillment, ensuring customer service level and after sale services.

1.3.2.1.2 *Decisions hierarchy*

According to decision levels, SCM decisions may be structured in relation to the three hierarchical levels commonly defined in operations management: strategic level, tactic level and operational level (Anthony 1965, Stadtler and Kilger, 2008). These three levels are differentiated by their planning horizon: strategic level is in years, tactical level is in months, and operational level is in weeks or days. Figure 1.4 shows the decisions hierarchy of SCM in a pyramid shape. The higher level sets conditions for the lower level.

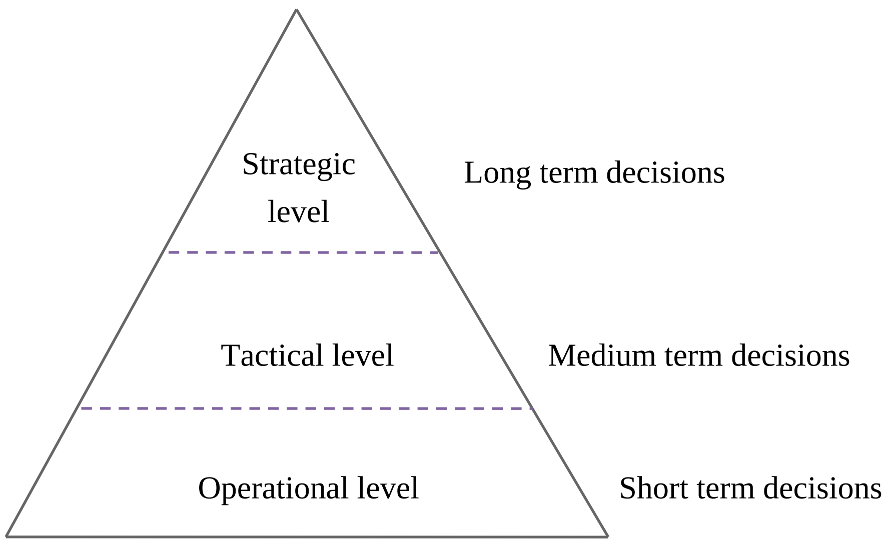


Figure 1.4 Decisions hierarchy in a supply chain

- Strategic level

For the most part, the strategic decisions are global and try to integrate various aspects of the supply chain. They typically concern the design and the structure of a supply chain and have long-term effects, noticeable over several years (Stadtler and Kilger, 2008). The decisions at this level include product design, production strategy which could be made internally or outsourcing, supplier selection, logistic network design and the path of material through the logistics network.

- Tactical level

The planning horizon of tactical level classically ranges from 6 to 24 months with the respect of strategic decisions. Tactical decisions determine regular operations, in particular rough quantities and times for the flows and resources in the given supply chain with seasonal consideration, e.g. seasonal demand (Stadtler and Kilger, 2008). They are aggregated decisions for a period of time for example a week, two weeks. The decisions at tactical level are input of constraints for those of operational levels. The rough quantities and times will be further specified at operational level.

- Operational level

Operational decisions are responsible for real time execution and control, which should specify all the elementary activities in detail. Therefore, the input of short-term planning should be in detail and accurate. The planning horizon ranges from a few days to three months. Short-term planning should consider actual performance of the supply chain, e. g. concerning lead-times, customer service level and also other strategic issues from upper levels (Stadtler and Kilger, 2008). Operational decisions involve making schedule changes to production, purchasing agreements with suppliers, taking orders from customers and moving products in the warehouse.

The Figure 1.5 (AMR, 1998) shows the relationship between operational, tactical, and strategic planning. We can see the planning detail increases from strategic planning to operational planning while the planning time horizon decreases. The planning time horizon of transportation planning is from minutes to weeks or months, and manufacturing planning (production planning) is from minutes to quarters. There is an overlap and thus manufacturing planning and transportation planning can adopt the same planning time horizon.

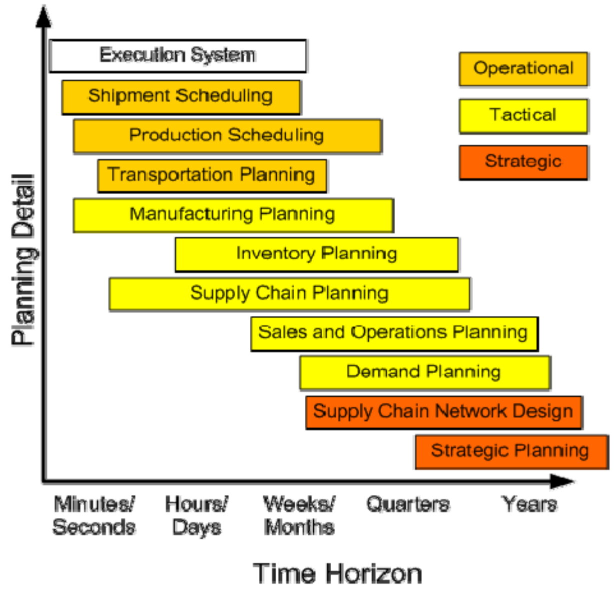


Figure 1.5 Operational tactical strategic planning (AMR, 1998)

SCM decisions studied in this thesis concern tactical and operational level decisions. We assume supply chain structure already exists thus we do not study strategic network design problem; we define the planning horizon as a month and make decisions for each day. Lead-times such as production lead time and transportation lead time are also concerned.

1.3.2.2 *SCM functions*

According to decision nature and hierarchy, SCM decisions can be grouped into many functions which include strategic network planning, master planning, purchasing & MRP, production planning and scheduling, distribution planning and transport planning and so on. Figure 1.6 shows a planning matrix (Meyr et al., 2002) which integrates the main SCM functions according to the two dimensional axis previously mentioned: decisions nature and decisions hierarchy levels:

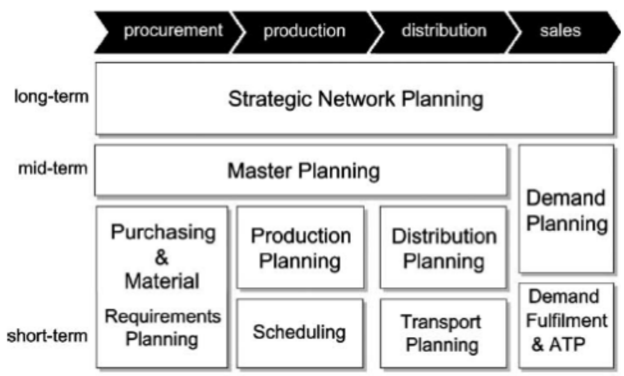


Figure 1.6 A supply chain planning matrix (Meyr et al., 2002)

- Strategic network planning

Strategic network planning covers the decisions of procurement, production, distribution and sales at long term level, especially plant location decisions and distribution structure design. Strategic sales planning can also be considered to define which products allocate to which markets. This function determines the design of supply chain and the paths through which materials flow between suppliers and customers.

- Master planning

Master planning coordinates decisions of procurement, production and distribution on a mid-term planning level with the utilization of production, transport, supply capacities, stock as well as on the balancing of supply and demand. The decisions on production and transport quantities are obtained simultaneously while minimizing total costs for inventory, overtime, production and transportation. The planning horizon should be long enough to cover all demand peaks.

- Purchasing & MRP

This function deals with the decisions on short-term level and generates the replenishment orders, production orders for components and parts in a multi-stage production environment. Material Requirements Planning (MRP) calculates time-phased plans of secondary demands for components and parts based on a time series of primary demands which are usually finished products. Once the demand of components and parts are determined, purchasing orders are transmitted to corresponding suppliers.

- Production planning and scheduling

This function includes three tasks, lot-sizing, machine scheduling and shop floor control with the aims of generating detailed production schedules for the shop floor over a relatively short interval of time. The decisions cover both mid-term and short-term levels. The planning interval for production planning and scheduling varies from one day to a few weeks depending on the industry sector. The decisions at this detailed, short term level strongly depend on the production system. Therefore this function is specialized for different companies. If multi-stage production processes and product structures exist, they have to be coordinated in an integrative manner.

- Demand planning

The task of demand planning is to predict the future customer demand for a set of items. Demand planning usually covers many time periods, typically 12 - 24 months and makes decisions on a mid-term level. An important aspect of demand planning is to define aggregation or disaggregation of data for products, customers and time. The input is forecast data from former planning runs, historic customer orders, shipments, etc.

- Demand fulfillment & ATP (Available To Promise)

This function determines how the current customer demand is fulfilled on short-term level. It also determines the present and future availability of supply and capacity that can be used to accept new customer orders. The main target of the demand fulfillment process is to generate fast and reliable order promises to the customer which improves conventional approach – quoting orders against inventory and supply lead-time – that often results in unfeasible order promises and decreasing the on time delivery.

- Distribution planning and transport planning

Distribution and transport planning comprises mid-term and short-term decisions. Mid-term decisions include transport frequency, distribution path selection, aggregated transport quantities. Short term transport planning is usually carried out daily with a planning horizon of one day or a few days including decisions of quantities to be shipped on current day, adjustment of quantities of various items on the same transport link to a full vehicle load or a multiple vehicles load.

1.3.2.3 *SCM business processes*

The decisions in the scope of SCM can also be classified according to the main enterprise business processes. SCOR model is most common process reference model for SCM. Many large corporations, such as Siemens, IBM, and Intel, utilize SCOR to analyze and measure their supply chain performance.

The Supply Chain Operations Reference (SCOR) model, developed by the Supply Chain Council (SCC) in 1996, "*provides a unique framework that links business processes, metrics, best practices and technology features into a unified structure to support communication among supply chain partners and to improve the effectiveness of supply chain management and related supply chain improvement activities*" (Naslund and Williamson, 2010). SCOR-model helps to standardize terminology for supply chain and thus facilitates communication across partners and extends supply chain from the suppliers' suppliers to the customers' customers. By using SCOR-model, no matter how complex the partners' relationships can be, it is described by a common set of definitions. Five primary management processes – plan, source, make, deliver and return – which will be presented in the following part provide basic organizational structure of SCOR-model as shown in Figure 1.7. Each of these processes can be divided into the following four hierarchical levels: process types, process categories, process elements and implementation. SCOR-model only covers the first three levels while the lowest level is not included in the model scope because it is too specific to each company. The first level defines the scope and content of the model and specifies performance targets. The second level is used by companies to implement their operations strategy through the configuration they choose for their supply chain. The third level defines a company's ability to compete successfully in its chosen markets. The SCOR-model describes processes which focus on the activities involved but not the persons or organizations that perform the activity.

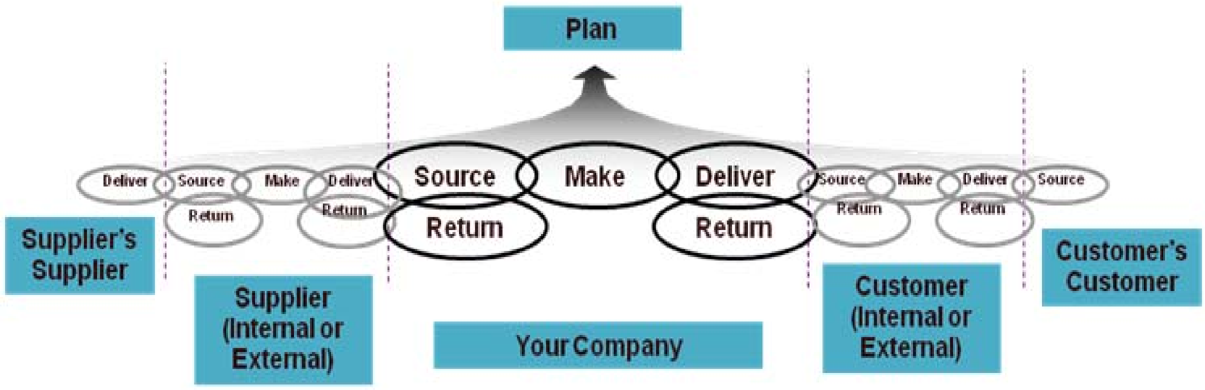


Figure 1.7 Five major management processes in SCOR-model (Supply Chain Council, 1996)

- **Plan** covers processes to balance resource capacities with demand requirement and communicate plans across the supply chain; measure supply chain performance; manage inventories, capital assets, transportation and compliance.
- **Source** covers supplier identification, supplier selection, the measurement of supplier performance as well as scheduling of their deliveries and the receiving of products and processes to authorize payments.
- **Make** covers processes that transform material, semi-product into final product including the processes to produce, test and packaging until finished products are ready to be delivered. Furthermore, "Make" covers the management of in-process products, equipment and facilities.
- **Deliver** covers processes of import/export order management, warehouse management, inventory management, service levels management and delivery of products at a customer's location.
- **Return** covers processes for returning defective or excess supply chain products. The return process extends the scope of the SCOR-model into the area of post-delivery

customer service. It covers the authorization of returns, scheduling of returns, receiving and disposition of returned products as well as replacements or credits for returned products. In addition it manages return inventories as well as the compliance to return policies.

The SCOR model is consistent with supply chain planning matrix shown in Figure 1.6. The procurement, production and distribution processes in supply chain planning matrix correspond respectively to “Source”, “Make” and “Deliver” process in SCOR-model. All the planning functions within the matrix including all the decisions at long term, mid-term and short-term levels correspond to the “plan” process in SCOR-model.

Guided by the concepts of SCM theory presented above, many SCM solutions in the form of information systems are developed in market and are adopted in industrial practice. In next section, we introduce the evolution and classification of SCM software and we also present the limitations of them in industrial practices.

1.3.3 SCM software

Today, no organization can envisage operations without the development of information technology tools. Information technology has become critical to monitor the flow of goods through the supply chain and to provide quick and reliable information. This section presents the evolution of SCM software and the classification of currently well known SCM software.

1.3.3.1 *Evolution of SCM software*

The evolution of information systems (IS) for supply chain management shown in Figure 1.8 starts from material requirement planning (MRP). MRP was introduced in the 1970’s as a computerized inventory control system that would calculate the demand for component items, keep track of when they are needed, and generate work orders and purchase orders that take into account the lead time required to make the items in-house or buy them from a supplier. MRP II is much broader in scope than the MRP. It incorporates marketing and financial functions and capacity planning as well. Enterprise resource planning (ERP) updates MRPII with relational database management, graphical user interface, and client/server architecture (Russell and Taylor, 1998). ERP has extended the scope of planning system to entire enterprise, from marketing to product development, aiming to achieve total organizational excellence through integration. ERP systems as configurable information systems packages that integrate information and information-based processes allow data to be shared across many boundaries and divisions within the company. The transaction data managed by EPR system go through the entire company which is utilized by different departments further. The next step of this evolution came in the mid 1990's with the introduction of the information systems applied to SCM. The SCM software maintain timely information across the overall supply chain and facilitate the synchronization of the entire supply chain. More developed than EPR systems, the SCM software not only integrate and optimize internal business processes of a single organization but also the interaction of the organization with its business partners across the entire supply chain. The functions of ERP systems include manufacturing management, financial management, and human resource management while those of SCM software comprise manufacturing management, inventory management, logistics management, and supply-chain planning. ERP systems serve as a database and provide a fast, reliable basis for SCM applications. Thus SCM application can pull up-to-date information from ERP. The SCM software can also be implemented in the company which has no ERP solution before. It just cost more time and energy to implement. The detailed description of main SCM software in market is presented in section 1.3.3.2.

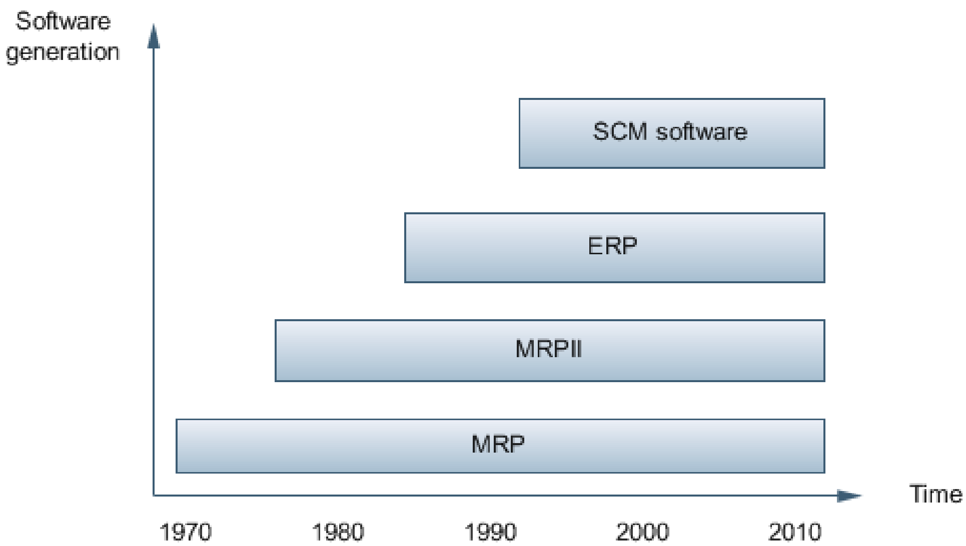


Figure 1.8 Evolution of the information systems: from MRP to SCM software (Scavarda et all, 2006)

1.3.3.2 *Classification of SCM software*

Currently there are many SCM products available in the market which provide technology solutions to the management of a supply chain such as SAP. SCM software can be classified into four main families ERP, APS, SCE and MES. Figure 1.9 shows a classification of SCM software.

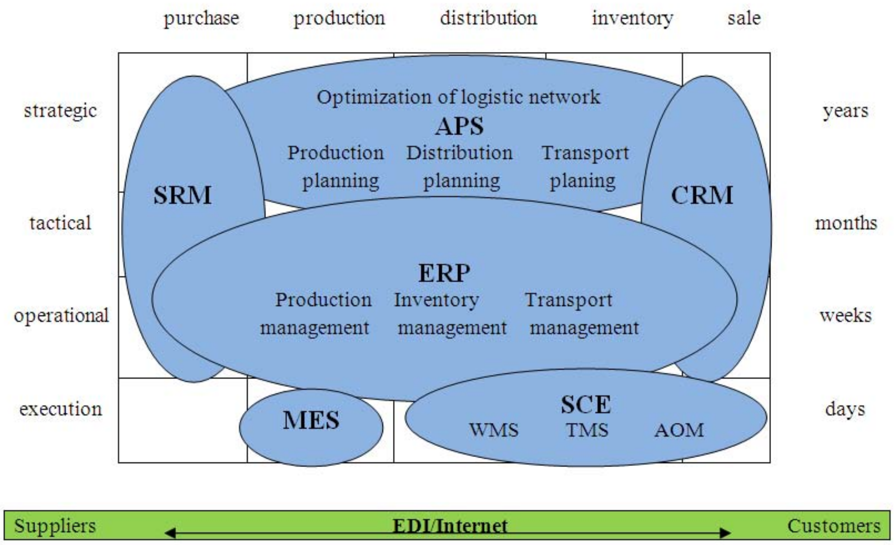


Figure 1.9 SCM software classification (Luiz, 2006)

- ERP

The main function of ERP (Enterprise Resource Planning) is to manage the internal transactional functions of the enterprise such as customer invoicing, accounting, inventory control, customer profiles and contract information tracking. MRP and distribution requirement planning (DRP) are two planning functions which can be included in EPR software.

- DRP is a computerized system that integrates distribution with manufacturing by identifying requirements for finished goods and producing schedules for inventory and its movement within the distribution process. DRP systems receive data on sales forecasts, customer orders and delivery requirements, available inventory, logistics, manufacturing and purchasing lead times from different departments. This data is analyzed to produce a time-phased schedule of resource requirements that is matched against existing purchase and production schedules to identify the actions that must be taken to synchronize supply and demand. DRP is comprised of five interconnected parts: sales analysis, forecasting, purchase planning, pricing simulation and PSI (Purchase, Sales and Inventory). These parts provide all the detailed information you need to analyze sales and other data to plan your purchasing and distribution requirements (Martin, 1995, Ross, 2003). Although DRP deals with distribution problem, it is a function within ERP which is internal transaction management software.

ERP keeps enlarging their scope of functions by integration an increasing number of modules such as CRM (Customer Relationship Management), SRM (Supplier Relationship management), business intelligence. Those extended versions of the ERP, called the X'ERP. Table 1-2 (Scavarda et all, 2006) gives the descriptions of SRM and CRM to show what they serve in SCM.

Table 1-2 Descriptions of SRM and CRM

Information systems	Description
Supplier Relationship Management (SRM)	It is a complete integrated suite that addresses the entire interactions between a buyer and a supplier that drive price and value. It evaluates the spending which leads to a robust sourcing strategy, a right-sizing of the supplier base and a reduction of the overall material costs (Scavarda et all, 2006).
Customer Relationship Management (CRM)	It tracks and analyses explicit information about current customers and sales prospects. It matches customers' needs with product plans, developing and implementing business strategies and supporting technologies that close the gaps between an organization's current and potential performance in customer acquisition, growth, and retention. Examples of its functionality are sales force automation, data warehousing, data mining, decision support, and reporting tools. CRM is the logical counterpart of SRM (Taylor, 2004, Hendrick et al., 2006, Scavarda et all, 2006)

- APS

The main function of APS (Advanced Planning System/Advance Planning and Scheduling) is the planning of the logistics chain. Advanced planning and scheduling is a component of specialized applications that is usually integrated within the context of SCM or supplied independently for the purpose of planning the production process. These systems decidedly do not replace conventional ERP systems; they are either add-ons or directly integral components which create the support mechanism for planning and decision-making at all levels (Klčová et. all, 2009). Current APS which is widely used by practitioners only provide interfaces for data exchange between parties, but do not support inter-organizational collaborative planning. In APS, an integrated planning requires a central entity equipped with all relevant data and the decision authority to implement the system wide optimal plan. However, this approach comes with a number of downsides: The need for disclosing potentially confidential information by the decentralized parties, the conflict of central targets with the incentive structure in decentralized organizations, and the missing guarantee for truthful information disclosure (Stadtler and Kilger, 2008).

- SCE

The SCE (Supply Chain Execution) aims at providing a quick answer to the complex requirements of large customers such as large volumes, short lead times, high demand variability and complex trading conditions. SCE's planning capabilities are limited to stock levels. They do not access upstream information parameters unless linked to Advanced Order Management or Advanced Planning System. SCE integrates three major functions: AOM – Advanced Order Management, WMS – Warehouse Management System and TMS – Transport Management System.

➢ *TMS*

TMS (Transportation Management Systems) facilitates the procurement of transportation services, the short-term planning and optimization of transportation activities, and the execution of transportation plans (ARC, 2003). It can include everything from network-design tools for routing deliveries to operational applications for tracking shipments, scheduling drivers, and calculating how much it will cost to run a shipment between any two points (Taylor, 2004). TMS planning module offers the user various suggested routing solutions. In the case of outsourcing, "transportation provider analysis" module can select a best transportation provider with best transportation mode and the lowest cost. Consequently the TMS system makes a transport routing plan on the shipper's side without considering transportation capacities but chooses asset-based carriers to execute the solutions. The selected carriers do not make transport planning at their sides.

➢ *WMS*

WMS (Warehouse Management Systems) manages inventory control, product placement, and picking in a warehouse (Kahl, 1999). Just like ERP and APS, it is highly modularized, with different sets of modules for managing supply, demand, and internal operations. The modules on the supply side automate the process of receiving incoming goods and assigning them to the appropriate storage locations. The ones on the demand side assist in assembling outbound orders and preparing them for shipment. There is usually an inventory management or materials-handling module to bridge the gap between the supply and demand modules (Taylor, 2004).

➢ *AOM*

AOM (Advanced Order Management) is a computer application and component of SCE packages which supports the management of administrative processing of orders and promotions and can enhance order tracking and increase order fill rates.

- MES

Main function of MES (Manufacturing Execution System) is to provide real time information on the execution of manufacturing orders. They deal with the management of raw materials, equipment, personnel and documentation hence have some overlapping functions with ERP. With the increasing function of ERP, MES space for growth is limited.

To conclude, each information system has its own functionality and focuses on different SCM problems. APS as a complement to ERP focuses on strategic and tactical level decisions on planning of the logistic chain while ERP focuses on tactical and operational decisions on internal transactional functions of the enterprise. They both cover all the sections of SCM processes from procurement to sales. SRM and CRM extend ERP functions and have a specific focus on managing suppliers and customers respectively. MES and SCE manage real time execution decisions. The software presented above can be implemented in enterprises by integrating with each other or as an independent suit. Thanks to EDI (Electronic data interchange) and internet, it becomes time-saving even if a large volume of information is transferred between software and between suppliers and customers. Although SCM software largely increases the efficiency of decision making, the implantation and configuration of these solutions in enterprises are time and resource consuming, and the solutions proposed by software are not always the good return of investment.

Although APS, TMS and DRP concerned about distribution or transportation problems, they are integrative solutions which do not support inter-organizational collaborative planning. Thus there is a gap in research on production planning and transportation planning across enterprise boundaries.

Consequently, this thesis is intended to study, analyze and propose an approach for planning as well as synchronizing inter-organizational production and transportation activities.

1.4 Collaborative supply chain

For the decentralized control in supply chain, collaboration is essential to attain the best solution in terms of efficiency for all the SC partners. The globalization of supply chain management has forced companies to look for more effective ways to coordinate the flows of materials. The essence of recent supply chain development is collaboration across the supply chain. Lack of collaboration in supply chain leads to inefficient production, redundant inventory stock, and inflated costs (Li, 2007). In the past supply chain management has been well developed based on integrated approaches. However, in the area of supply chain collaboration, it is still a challenge to deal with inter-organizational relationship. One reason results from the heterogeneity of partners. Supply chain members vary on business goals, business process, information structure, etc. They are autonomous entities which pursue local profits and need an incentive to collaborate with other members of the supply chain. It is therefore difficult to integrate all activities and business processes of involved members in supply chain because it requires a trusting environment which is not easy to achieve in today's competitive market environment. The key performance criteria of supply chain management are reactivity, reliability and inter-partners relation management. The reliability of a member's activities is linked with supply chain functions. The reliability can be achieved when a member coordinates effectively with his suppliers and customers. This coordination is usually based on information exchange or information sharing. The shared information varies according to the collaboration degree.

Because of the autonomy of supply chain members, they may focus on local objective which may conflict with those pursued by the global supply chain. That is why collaboration plays an import role to make supply chain members work well together for achieving excellent supply chain performance. In the following part of this section, we will clarify some synonyms for collaboration which represent different collaboration levels. Some common collaborative approaches will also be presented.

1.4.1 Collaboration levels

Supply chain collaboration deals with an inter-organizational relationship in a supply chain where the involved members agree to invest resources, mutually achieve goals, share information, resources, rewards and responsibilities as well as jointly make decisions and solve problems (Soosay et al., 2008). Kampstra introduced the ladder of collaboration that shows five levels of collaboration; arm's length, communication, coordination, intensive collaboration, and partnership (Kampstra et al., 2006).

1. The first level of collaboration is arm's length relationships. The collaboration at this level involves basic purely transactional information such as invoice, order without any collaboration and do not correspond to a true collaboration level.
2. The second level of collaboration is "Communication" which focuses on dealing with physical supply chain constraint with the goal to improve productivity. Communication allows the collaboration members to enhance decision-making by information sharing or forecasts through simple IT systems and may result in improved delivery rates, fewer inventories, etc.

3. The third level of collaboration is "Coordination" which focuses on dealing with both physical and policy constraints with the purpose to synchronize intra and inter-organizational processes. "Coordination" requires the necessary additional investments in IT infrastructure and planning modules.
4. The fourth level of collaboration is "Intensive collaboration" which focuses on further dealing with policy constraints with the goal to improve the strategic management decision-making and enhance innovation in the chain. The collaboration members increase involvement at this level. Collaboration tends to spread to other areas of the enterprise besides logistics flows.
5. The fifth level of collaboration is "Partnerships" which extends to financial linkages, such as sharing of investments and profits. The aim of this level is to drastically improve knowledge sharing between members and reduce research and development time, to invest new capabilities for new market needs. Partnerships are a special case of collaboration where integrated supply chain actors no longer collaborate but act as one.

In this thesis, the purpose is to synchronize inter-organizational production transportation activities without affecting strategic decision making. Production planning and transportation planning modules are jointly studied in order to model inter-organizational relation. Therefore, our orientation is a coordination problem of production and transportation planning.

1.4.2 Collaborative approaches

Supply chain management has moved to a new level with the introduction of collaborative approaches that involve multiple partners. Common and widely used collaborative approaches include ECR (Efficient Consumer Response), VMI (Vendor Managed Inventory) and CPFR (Collaborative Planning, Forecasting, and Replenishment).

1.4.2.1 *ECR*

"ECR (Efficient Consumer Response)" is a strategy adopted by retailers, wholesalers, and manufacturers that they work together in order to increase the service level to satisfy the needs of consumers. "Win-Win" relationship can be achieved by improving the efficiency of the supply chain as a whole, beyond the boundaries of retailers, wholesalers, and manufacturers whose profits are larger than if pursuing their own business goals. ECR has two components in his definition, consumer and effective response. The former emphasizes the needs of consumer and the latter orients to a supply chain optimization process (Seifert, 2003). ECR implies a complete integration of information and supply chain with the implementation of business processes reengineering. A company carried out ECR obviously decided the fate of the company, either growth and success or decline or out of market.

1.4.2.2 *VMI*

It is usually the customer who monitors its inventory and plans inventory replenishment from supplier. In VMI, it is the vendor and client that work together to manage and optimize inventory for the client. Client gives up the responsibility of replenishment and transmits sales information to supplier while the supplier decides the replenishment frequency and quantities. By this way, it is possible for supplier to get all needed data such as sales record, promotion data and historical data to determine the optimal inventory level and make a replenishment plan. VMI ensures that the production and consumption are keeping the same speed, consequently bullwhip effect is effectively avoided. The implementation of VMI requires customer's confidence whose business depends on supplier's proper inventory management.

1.4.2.3 *CPFR*

Inventory strategies such as Vendor Managed Inventory (VMI), Supplier Managed Inventory (SMI) or Continuous Replenishment Program (CRP) focused on collaboration for efficient replenishment; While CPFR extends the objectives to planning and forecasting.

The Association for Operations Management defines CPFR (collaborative planning, forecasting, and replenishment) as follows (Li, 2007):

"*Collaboration process whereby supply chain trading partners can jointly plan key supply chain activities from production and delivery of raw materials to production and delivery of final products to end customers*". As a formalized process, CPFR has been worked out by the standardization committee VICS (Voluntary Inter-industry Commerce Standards) and implemented within over 300 companies (VICS, 2008). CPFR covers from suppliers to distributors with the objective to optimize supply chain by improving demand forecasts, delivering the right product at right time to the right location, reducing inventories, avoiding stock-outs, and improving customer service. CPFR emphasizes the importance of directly obtaining information of customer point of sale, inventory, and marketing plans. Broad exchange of forecasting information improves forecasting accuracy when both the buyer and seller collaborate through joint knowledge of sales, promotions, and relevant supply and demand information. It is a challenging process to integrate a disconnected forecasting and planning process in the entire supply chain.

Today's collaborative efforts are laying on the foundation of trust and joint business processes that enable future supply chain optimization. It is a trade-off between sharing information across supply chain and supply chain optimization.

This thesis is intended to propose a collaborative approach which shares minimum necessary information and results in a near optimal supply chain solution.

1.5 Transportation in a supply chain context

The large amount of research work has been done in literature on specific supply chain management problems, for example, manufacturing capacity planning, inventory control, production scheduling, transportation routing, etc. In this section we focus on a large research area in SCM which is transportation. Different transportation modes and transportation providers will be presented. Especially at the end of this section, we will identify the collaboration limitations of production transportation problem which occurs when they are executed by two independent companies.

1.5.1 Transportation modes

The transportation service can be categorized according to different shipment sizes as follows (Seiler, 2012):

- Parcel

Standardized shipment sizes start with letter and parcel consignments. They are usually covered by so-called CEP (courier, express, parcel) service providers that often evolved from postal service providers. The big providers will cover almost any distance using different transportation modes and offering different transportation speeds. They usually rely on their own network of hubs and large fleets of transportation vehicles, including standard trucks, delivery trucks and airplanes.

- LTL

LTL stands for less than truckload freight shipping. Shipment sizes that will not completely fill a truck or sea container are usually served by specialized logistic service providers. For truck transportation, these are usually referred to as LTL carriers. LTL is a service offered by many freight and trucking companies that goods are delivered by a small shipment. These service providers are specialized in consolidating shipments from different shippers with a fleet of vehicles and within their own network structure which consists of a number of hub locations. The driver picks up the shipment along a short route and brings it back to a logistic platform where it is processed in order to be transferred to another truck. The latter brings the shipment, along with other small shipments to another terminal. The LTL shipment is then moved from a truck to another truck until it reaches its final destination. The main advantage to using an LTL carrier is that a shipment may be transported for a fraction of the cost of hiring an entire truck and trailer for an exclusive shipment.

- FTL

FTL (full truckload) is used in truck transportation when shipment sizes get large enough so that a whole truck or container can efficiently be deployed to serve the complete shipment. Operations are usually performed point to point; that is the truck goes directly from the dispatching location to the receiving location and the load is not handled at intermediate locations. This usually results in shorter transportation times for FTL shipments in comparison to LTL shipments.

- Special

Load sizes that exceed truck and container capacity are referred to as special loads. It could be liquids such as oil, chemicals or big piece which cannot be split into multiple smaller loads. Carries often use specialized equipment to fulfill these transportation demands.

1.5.2 Transportation providers

There are different transport operators in logistic market among which 3PL and 4PL are recently emerged and evolving rapidly in logistic business area. Let us present the main differences of 1PL, 2PL, 3PL and 4PL. (Farahani et al., 2011, Roques et Deschamps, 2011)

– **A first-party logistics provider (1PL)** is a firm or individual that needs to transport goods or anything from one place to another. Both sender and receiver could be referred as a 1PL provider since anyone is considered as a 1PL provider as long as it has goods moved from their place of origin to their new place. A 1PL can be a manufacturer, trader, importer/exporter, wholesaler, retailer or distributor in the international commerce field. It can also be institutions such as a government department.
– **A second-party logistics provider (2PL)** is an asset-based carrier, which actually owns the means of transportation. Typical 2PLs would be shipping lines which own or rent their ships; airlines which own or rent their planes and truck companies which own or rent their trucks.

- **A third-party logistics provider (3PL)** is an outside organization which executes all or part of logistics activities that have usually been performed within an organization. For example, if a company without its own fleet of transportation decides to use external transport service, it could use a 3PL provider. 3PL is an emerging business area in many countries. A well known 3PL is DHL. In our opinion, 3PL is 2PL plus logistic service.
- **A fourth-party logistics provider (4PL)** is a consulting firm specialized in logistics, transportation and supply chain management. 4PL is defined as an independent, non-asset-based integrator that assembles the resources, capabilities and technology of its own organization and those of complementary service providers to cooperate and implement comprehensive supply chain solutions for clients. The difference between 3PL and 4PL is that a 3PL provider targets a function, while a 4PL provider targets the management of the entire process. 4PL use 2PLs and/or 3PLs to supply service to customers. Some have described a 4PL as a general contractor who manages other 3PLs, truckers, specialist firms, essentially taking responsibility of a complete process for the customer.

Figure 1.10 shows the difference between conventional logistic operations and 3PL and 4PL. Logistic operations are operated by internal logistics department or a subsidiary company which is usually under control of the manufacturing enterprise. However, later, with the emergence of 3PL and 4PL, logistics operations are outsourced to professional logistic providers, which are independent of the manufacturing enterprise. 3PL provides professional logistics services for manufacturing enterprise while 4PL could outsourced manufacturing enterprise’s logistical operations to two or more 3PL providers and coordinate the activities of 3PLs and other specialized firms such as IT consultancies, software technique companies.

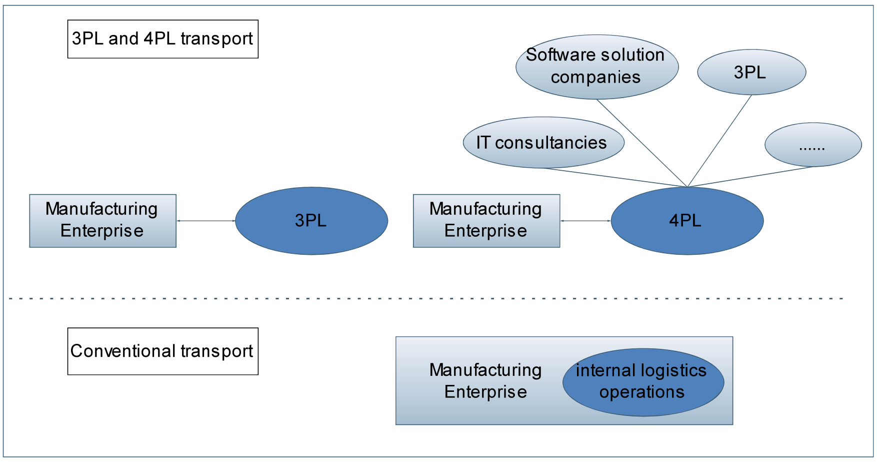


Figure 1.10 Evolution of logistic market (Farahani et al., 2011)

1.5.3 Collaboration limitations

Production and transportation are the two most important activities in SCM. Transport activities are usually executed and controlled by internal logistics. However with the emergence of 3PL and 4PL, transport activities are outsourced. The 16th Annual Third Party Logistics Study (CSCMP, 2012) has shown that nearly two-thirds (64%) of shipper respondents report an increase in their use of outsourced logistics services, and 76% of 3PL respondents agree this is what they are seeing from their customers. Regionally, 58% of North America shippers reported increased use, as well as 57% of European, 78% of Asia-Pacific and 73% of Latin American shippers. Consequently production and transportation are executed by different organizations. A coordination problem across companies' boundary arises here.

The main difficulties of collaborative production and 3PL transportation problem result from several aspects. The evolution of the role of transportation makes a new independent SC member - transport operator. To collaborate with production using current collaborative approaches, it requires a confidence climate which cannot be guaranteed all the time. Moreover, collaborative approaches do not consider transportation explicitly. And also the current SCM software is an integrated solution which is not suitable for production and 3PL transportation problem. These limitations are explained in detail as follows.

- Limitation of the role of transportation

Transportation refers to the transaction which links two locations, that is to say, transportation has two implicit objects to manage, initial location and destination. This is different from production or sale which generally takes place in one location and thus increases the management uncertainty. Usually in the conceptual model of SC, the transportation of raw materials or goods is presented by a link between locations or SC members. Moreover, the model usually includes suppliers, manufactures, customers but neglects transport operators. A reason for this is that transportation is considered as an internal department which has been integrated within the manufacturing enterprise. With this condition, integrated production transportation problem, procurement transportation problem, inventory transportation problem have been studied for decades. Nowadays with 3PL and 4PL, transportation has been separated from manufacturing enterprise and therefore SC structure and business processes become more complex with the appearance of transport operators. Production transportation problem becomes different from the conventional one and more complex with the difficulty of coordinating the two members. The conventional production transportation problem has not explicitly considered independent transport operators.

- Limitation of confidence climate

Current collaborative approaches like ECR, VMI and CPFR require a confidence climate to implement information sharing. These approaches are limited to the SC members who are involved in long term relationship and have a mutual benefit relation. However SC members have a risk to explore their confidential information and thus lose competitiveness in market. For the SC members who involve in short term relationships or the members who have no willing to expose private information, it is essential to develop other collaborative approaches which get rid of confidence limitation. Moreover transportation is not considered explicitly in these approaches. Nevertheless, it is still important to consider the development of effective incentive mechanisms to encourage SC members to share necessary information in order to fulfill customers' demands and improve SC performance.

- Limitation of models

Conventional SCM integrate all members' information for making plans. Most of prior studies in the field of mathematical optimization models focus on formulating an integrated production and transportation planning model. They propose efficient solving algorithms which integrates all the functions (e.g. replenishment, production, inventory management, distribution, etc.). These models try to maximize the total profit or minimize the total cost of the supply chain by supposing that there is an independent planning department or supervisor which makes decisions for all supply chain participants.

In this part, we focus on the research with separated production and transportation models. Barbarosoglu and Ozgur (Barbarosoglu and Ozgur, 1999) developed a mixed integer linear programming model with an objective of minimizing cost and used Lagrangian and heuristic relaxation techniques to transfer the problem to a decentralized two-stage model: one for production planning and another for transportation planning. In this research transportation lead time and backorder demand are not considered. Bredstrom and Ronnqvist (Bredstrom and Ronnqvist, 2002) proposed two independent mixed integer linear programming models with the purpose of minimizing cost, one for production planning which considers transportation costs, and the other for distribution planning in a multi-period and multi-product environment. Park (Park, 2005) suggested an integrated transport and production planning model that uses mixed integer linear programming in a multi-site, multi-retailer, multi-product and multi-period environment. The author proposed a two-phase heuristic model to solve this production and distribution planning model. The first stage establishes an initial distribution and production plan, which is improved in the second phase by modifying the transport parameters. The output of production planning sub-model acts as the input in transport planning sub-model with an overall objective of maximizing overall profits.

Backorder demand and inventory capacity are not considered. Selim et al. (Selim et al., 2008) proposes a multi-objective linear programming model with objectives of maximizing overall benefit, minimizing total cost, maximizing service level for collaborative production and distribution planning. They include uncertainty in their research by adopting a concept based on fuzzy objectives. Jung et al. (Jung et al., 2008) compared linear programming models for centralized and decentralized production and transportation planning environments using a numerical example with 4 product types, 10 manufacturing centers, 5 distribution centers, 10 markets or retailers. Song, Hsu and Cheung (Song, Hsu and Cheung, 2008) studied a problem of a third party logistics provider coordinating shipments between suppliers and customers through a consolidation center. Products are grouped at consolidation center and are transported to the same destination in a single shipment. The problem is formulated as a nonlinear optimization problem and the Lagrangian dual of this general problem can be solved optimally as a linear program. Although the above research used separated production model and transportation model, they still adopted centralized supply chain planning approach to achieving global optimization. Moreover, Mula et al. (Mula et al., 2010) presented a review of mathematical programming models for supply chain production and transportation planning and proposed a taxonomy framework based on the following elements: supply chain structure, decision level, modeling approach, purpose, shared information, limitations, novelty and application. However one of the main searching criteria to select papers is “centralized model” in this review. In brief, the research on centralized production transportation problem has been well and thoroughly studied for decades.

- Limitation of SCM software

The current SCM applications in industrial practice such as APS, DRP are integrated solutions which require gathering all necessary information from involved SC members. For the small companies which cannot afford the implementation of SCM applications, the integrated SCM is not suitable. As each supply chain member is autonomous concerning his activities and his decision making plans (production plan, delivery plan, pick up plan), it has limited information of its partners which may cause conflicts decisions. Coordination is indispensable to balance the conflicts and synchronized flows in order to improve SC performance. Nowadays 3PL and 4PL have emerged which perform all or part of a producer’s transport tasks. Due to the professional services provided by the 3PL or 4PL, it is more efficient for a producer to focus on his competence. Unfortunately the TMS is efficient in 1PL or 2PL context but not compatible with 3PL or 4PL transportation. There are few existing decentralized SCM solutions to the problem of collaboration between production and transportation which are executed by interdependent SC members. For this reason, our research considers to solve the problem with a decentralized control which has been drawing great interest in recent years.

Consequently, our research is to get rid of these limitations and to propose an effective approach to enable the producers and independent transport operators to collaborate. Because of the autonomy of SC members, conflicts may occur between producers and transport operators. Thus it is also important to propose incentive mechanisms to motivate minimum information sharing to achieve collaborative production transportation.

1.6 Conclusion and thesis objectives

In this chapter, we have presented relevant concepts of SC, SCM and collaborative SC and we have shown the limitations of collaboration between production and transportation. Ensuring a good understanding of the SC background knowledge we define our problem according to the concepts presented in this chapter by the main following hypotheses:

- Topology of SC studied is network. There are two main partners in the supply chain: producers and transport operators. Customers are external partners which are not taken into account in this supply chain. One transport operator can serve one or many producers and deliver to one or many customers. One producer can cooperate with one or many transport operators.
- Material flow and information flow are considered with little consideration of financial flow. Transport operators pick up final product from producers and deliver them at customers. Information is exchanged between producer and transport operators.
- Producer produces based on actual customer demands.
- SCM decisions studied in this thesis concern tactical and operational level decisions. We suppose the logistic facilities already exist and the possible paths which link facilities are identified. We only consider one transport mode in this thesis which is road transportation by trucks because they are most effective over short distances.
- The collaboration is defined in the context where production and transportation decisions are executed by different companies. One company takes charge of production while the other takes charge of transportation. They are independent companies which have their own objectives that could conflict. There is no centralized decision center which can gather all the information from all companies but each company has his own decision center and makes decisions based on local information and information received from partners.

The work carried out in this research concerns the study of relation between producer and transport operator. The aim is to seek for an efficient way to coordinate these two partners, to improve exchanges of information and to solve conflicts of objectives. Of course supply chain is not limited to the relation between two partners. It is generally a network of many enterprises very complex to manage. The scientific position of our work concerns the study of a particular part of supply chain management which is the collaborative production and transportation problem.

The objective of our research is to develop an efficient way to coordinate production and transportation activities in a decentralized context. The objectives are presented as follows:

1. Develop separated analytical models at a tactical decision level which model the main decisions of production and transportation. These models have to cover the planning activities of production, inventory, pickup and delivery
2. Define a coordination context between producer and transport operator and propose an efficient coordination protocol to coordinate production and transportation decisions. This protocol has to solve objectives conflicts of different partners in supply chain by information exchanges.
3. Analyze the global and local performance of the SC and identify the limitations of proposed protocol. This will be carried out through a series of simulations to evaluate the performance of each partner.

In order to face the collaboration limitations in production and transportation that were identified in this chapter, specifically we focus on the coordination concept which is considered as one of collaboration levels that fits to our research objective. Coordination approaches and especially coordination of SC planning will be presented in next chapter in detail in order to propose an efficient coordination protocol which is one of objectives of this thesis.

Chapter 2

Coordination in SC planning

Chapter 2 Coordination in SC planning

2.1 Introduction

The coordination was found to be located at the middle position of the five possible levels of collaboration presented in chapter 1 (see section 1.4.1). In this chapter we focus on coordination in SC planning and more precisely between production planning and transportation planning. Coordination mode and SC planning approaches will be discussed. The following part of this chapter is made up of four sections. Section 2.2 is about general coordination issues. In real situations, coordination between SC partners usually implies decisions at the tactical level (i.e. master planning), that is the reason why main concepts and conventional approaches in SC planning are reviewed in section 2.3. Based on these general notions, section 2.4 of the chapter discusses problems encountered in coordinating a distributed planning decision making in the specific context of the production–transportation coordination. Finally, our research problem and barriers are presented and a conclusion comes to end the chapter.

2.2 Coordination

SC coordination focuses on synchronizing intra or inter-organizations flows, resulting from decisions on logistics, inventory management, forecasting, production, transportation. Similarly, various interfaces such as supplier–manufacturer, manufacturer–retailer can be effectively managed using coordination. More precisely, coordination is the management of dependencies between activities (Malone and Crowston, 1994) and its purpose is to collectively achieve goals that individual actors cannot meet.

As managing capabilities and resources across enterprise boundaries becomes increasingly important, coordination is considered as an important issue to deal with performance improvement, and is essential to meet the following needs:

1. Different facilities making up a supply chain frequently have different and conflicting objectives. For instance, although manufactures typically want to implement long production cycle time, they need to adapt their activities to the diversity of customers' needs and changing demand. Thus, the manufactures' goals are in direct conflict with the customers' desire for diversity. Similarly, the manufacturers' objective of making large production batches typically conflict with the objectives of both warehouses and distribution centers to reduce inventory. To make matters worse, this latter objective of reducing inventory levels typically implies an increase of transportation costs (Ferry et. all, 2007). In this case, it is vital to coordinate these facilities to make a trade-off of these decisions.

2. Certain decisions should be synchronized. Particularly in the production-transportation problem, the delivery decision made by producer and pickup decisions made by

transport operator should be consistent. The inconsistency comes from either producer who cannot supply enough products or transport operator who cannot pickup required products totally. Moreover, producer delivery demands and transport operator capabilities change over time which makes the synchronization difficult to achieve. These dynamic aspects also strengthen the coordination needs in supply chain.

Being aware of the problems, we intend to characterize the coordination through the definition of various modes and mechanisms that can be used to implement an efficient distributed coordination control. Useful indicators to measure coordination performance in the SC are presented and some specific indicators dedicated to evaluate transportation activities efficiency are drawn up.

2.2.1 Coordination modes

The mode of coordination is related to the structure of decision making system. In order to well present different structures of decision making system, decision making unit (DMU) is an important concept to explain first. DMUs compose the decision making system under the form of an organized structure which determines implicitly the coordination modes.

A DMU is the unitary element to make decisions. Figure 2.1 models the DMU based on IDEF 0 modeling methodology. According to the cybernetic decomposition presented in section 1.3 of chapter 1, DMU can be assimilated to the control system of the enterprise system model; physical system is made up of execution modules; information exchanges between these structural elements contribute to define the information system. More precisely, in the supply chain context, the physical system of each enterprise can be viewed as an execution module including different technical and human resources useful to transform products.

There are two kinds of information treated by a DMU, internal information and external information. Internal information is the information inside the DMU such as the resources under control, local objectives, while external information refers to the information received from outside such as environmental information, customer demand or information received from other DMUs. A DMU makes decisions to control other DMUs or physical system based on internal and external information. More precisely, it aims to achieve certain performance based on external demand and local resource capacities. The downward arrow labeled "control" (see Figure 2.1) received from other DMU is a group of information including objectives, decisions, constraints and information, called decision frames (Doumeingts et al., 2006). In general, a decision frame contains aggregated information which should be respected by the controlled DMU. Sometimes, the objectives received from other DMU may conflict with local objective. A DMU should also be able to resolve conflicts and make trade-offs in this case.

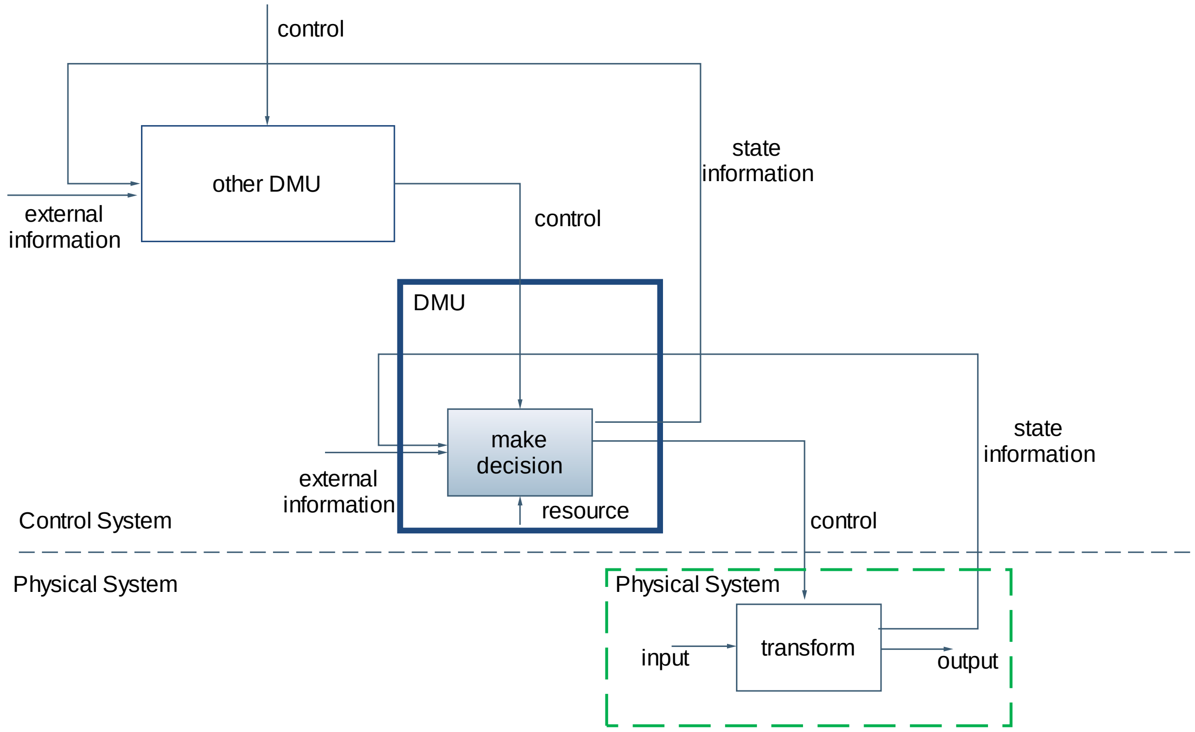


Figure 2.1 A DMU and its relations with environment

The structure of a decision making system displays how the DMUs are organized and how they interact. Four basic structures have been identified (Dilts et al., 1991, Benaskeur et Irandoust, 2009): centralized, hierarchical, hybrid, decentralized. The relations between these four structures are shown in Figure 2.2.

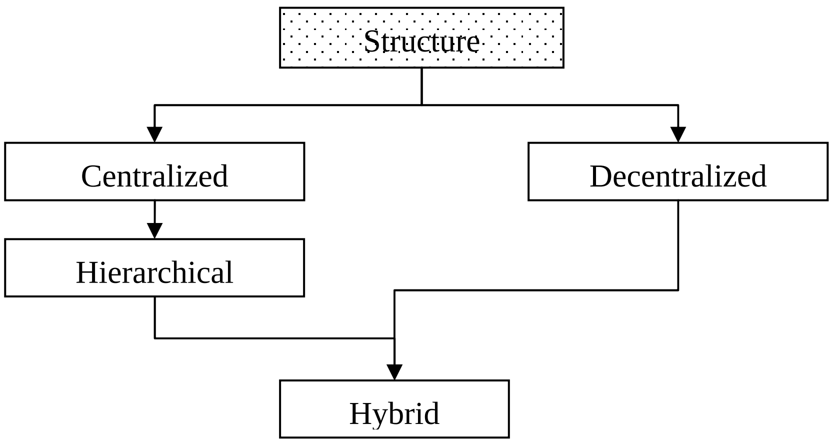


Figure 2.2 Relations between four basic structures of a decision making

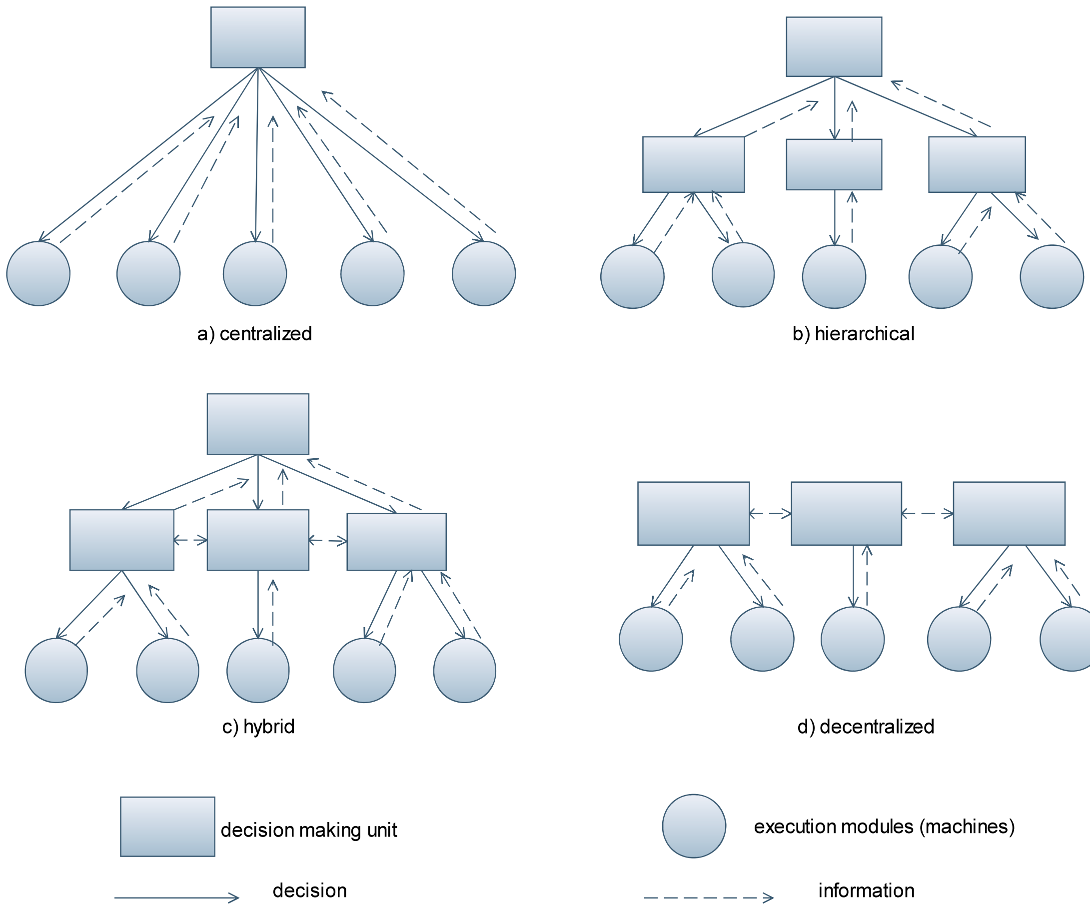


Figure 2.3 Differences of structures of decision making system

Figure 2.3 presents these four structures; rectangles represent DMUs, circles represent execution modules (physical systems) such as machines controlled by DMU; the solid connection lines show the decision frames and dash lines show the information direction. Consistent with the various structures of decision making system presented before, four coordination modes could be defined:

- **Centralized**

The simplest coordination mode is a centralized one. It corresponds to the case of an enterprise with a single centralized DMU which has a full control of execution modules composing the physical system through the management of all information and decisions of the enterprise. The central DMU such as a head office collects information from departments under control and makes decisions for these departments. The lower level departments could save their effort in decision making and just execute actions in respect with the decision frames received from central DMU so as to concentrate on their own activities and improve efficiency. The advantage is that the central DMU has a full control of the enterprise and can make optimal decisions for achieving the objective of enterprise. The disadvantage is that the central DMU has a large amount of information to analyze and to process. The enterprises using this coordination mode are also sensitive to any failure or error which can occur during the information exchange or decisions making. Thus this coordination mode is suitable for small enterprises.

- **Hierarchical**

This coordination mode is a little more complex than the centralized coordination. The DMUs could be within the same enterprise and be organized hierarchically. Each DMU distributes the decision frames to the subordinate departments. The lower level departments have their own DMUs which have authority for specific decisions and they make decisions based on local information and decision frames from upper level. The decisions made by lower level DMUs may conflict with each other so that they submit their decisions to central DMU which acts as an arbitrator and balances and redistributes the decisions to lower level DMUs. Let us remark that Pujo and Kieffer (Pujo and Kieffer, 2002) classify this structure as an extension of the centralized case. The advantage of this structure is that each DMU only treats partial information so that it reduces the processing time to make decisions. The lower level DMUs have a certain autonomy and can protect their privacy efficiently since they do not need to explore their confidential information. The disadvantage is that the decisions made by lower level DMUs are locally optimal. It needs a central DMU to balance and make decisions to search a solution closed to the global optimal one and it is not an easy problem to solve the conflicts between departments. This coordination mode is suitable for big enterprises with many departments or geographical separated branches.

- **Hybrid**

Hybrid coordination is similar to hierarchical coordination but is more complex; indeed, DMUs at the same level can exchange information and make decisions which can affect each other. Besides all the advantages and disadvantages of hierarchical coordination, the lower level DMUs make decisions based on the decision frames received from upper level and local resource information and also the external information received from other DMUs at the same level. Thus the decisions are more feasible and consistent with those taken by other DMUs. This coordination mode is more reactive and adaptive.

- **Decentralized**

Decentralized coordination is the most complex in these four coordination modes. An example for illustrating this coordination mode is explained as follows. It involves more than one enterprise but without a centralized DMU which can guarantee the optimized solution for the whole supply chain. The decisions of these involved enterprises are decentralized. Enterprise has choice to establish a partnership with an enterprise or another. Each enterprise is responsible for its own development and making its local optimal decisions. However there is not a third party organization to guarantee that the local decisions of enterprises will converge to a global optimum supply chain solution. To solve conflict problems, the two successive enterprises negotiate on their decisions by exchanging information of transaction orders and feedback decisions. If two enterprises cannot find a converged solution, the partnership may break down. The advantage is that this structure is flexible and the privacy information of each enterprise is well protected. But the disadvantage is that the decisions are locally optimal but not globally optimal. This coordination mode is suitable for the enterprises which have an unstable relationship in supply chain since it is hard to involve a third party organization to manage this variable relationship because each time the relationship changes in supply chain the third party organization needs to reconfigure.

With the development of enterprise, the dimension of system grows so rapidly that the central DMU has difficulty to process a huge volume of information because of the computational challenge. Therefore, hierarchical coordination as an effective method to decompose the complex decision making problem has been established. The autonomy of a DMU is limited by decision frames sent by its upper level DMU. Hybrid coordination improves the hierarchical coordination in terms of autonomy. It is enhanced by the interactions between same level DMUs which however at the same time increase the interaction complexity. A central DMU is involved in all centralized, hierarchical and hybrid coordination. On the contrary in decentralized coordination the DMUs are totally decentralized and with no central DMU. Therefore, the autonomy increases from centralized to decentralized coordination which may cause more conflicts between DMUs. Consequently the interaction complexity of finding a converged solution increases from centralized to decentralize as shown in Figure 2.4.

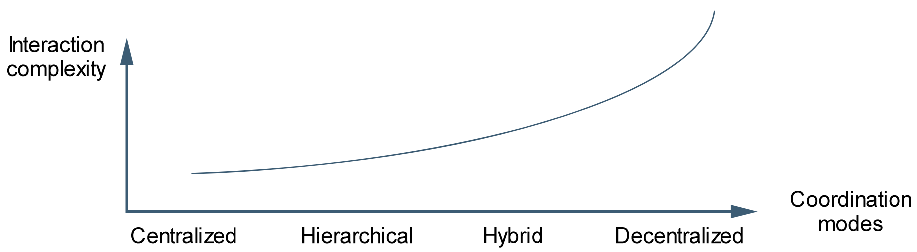


Figure 2.4 Interaction complexities of the four coordination modes

Table 2-1 summarizes the four supply chain coordination modes presented above by showing their advantage and disadvantage and for which kind of enterprises it is suitable.

Table 2-1 Summary of supply chain coordination modes

Type	Advantage	Disadvantage	Suitable for
Centralized	Fully control, optimal solution	Large amount of information	Small enterprises
Hierarchical	Reduced information amount and processing time	Local optimal lower level decisions	Big enterprises with many departments or geographical separated branches
Hybrid	All advantage of hierarchical mode Local autonomy	All disadvantages of hierarchical mode Complex control	Big enterprises with many departments or geographical separated branches
Decentralized	Flexible and privacy respected	Locally optimal	Unstable partnership

In this work, the studied problem involves a decentralized coordination mode for the supply chain, considering the hypothesis that transportation and production operations are controlled by different partners.

2.2.2 Coordination mechanisms

The way how supply chain partners are explicitly coordinated could be characterized by coordination mechanism. A mechanism is defined as a "*specification of a message space for each individual and an outcome function that maps vectors of messages into social decisions and transfers*" (Jackson, 2003). The implementation of the optimal strategies of coordination mechanism by decentralized self-interested parties may lead to a coordinated outcome and neither violates the individual rationality of the participating parties nor the budget balance of the system (Albrecht, 2010). A coordination mechanism defines a set of rules specifying the actions taken by different participants to coordinate a supply chain. Arshinder, Kanda and Deshmukh (Arshinder et al., 2009) distinguish four types of coordination mechanisms between supply chain members, described as follows:

– **Contracts**: Different kinds of contracts, such as buyback contracts, revenue-sharing contracts and quantity flexibility contracts have been proposed in order to increase total SC profit, to reduce overstock/under stock costs and to share the risks among the SC partners (Amrani-Zouggar et al., 2009, Cachon, 2003).

- **Information Technology**: IT is used to improve inter-organizational coordination (McAfee, 2002, Sanders, 2008). IT (internet, electronic data interchange), ERP (Enterprise Resource Planning), agent, E-business and other information technology, enable firms to rapidly exchange products, information and money and utilize collaborative methods to optimize SC operations.
- **Information sharing**: The SC members could be coordinated by sharing information regarding demand, orders, inventory, POS (Point Of Sale) data, etc. (François et al, 2006). Information-sharing policy may result in inventory reductions and cost savings.
- **Joint decision making**: It makes joint of partners considerations to improve SC performance involving many factors such as human, technology, strategies. The typical examples of joint decision making are VMI (Vendor Manage Inventory) and CPFR (Collaborative Planning, Forecasting and Replenishment), defined in chapter 1.

Besides these coordination mechanisms, we consider negotiation as another indispensable coordination mechanism in SC coordination. It is defined as follows:

- **Negotiation**: It defines the actions implemented by self-interested participants by respecting individual objectives. Negotiation may lead to a compromising solution for the participants which have conflicting objectives.

These five coordination mechanisms are not exclusive but compatible. They often show up at the same time in the supply chain coordination practice. For example, joint decision making cannot be achieved without information sharing. Since our interest does not focus on information technology, we just consider IT as a kind of support which can facilitate SC coordination. In this section, we will present correspondent literatures of these mechanisms.

2.2.2.1 *Coordination by contract*

The supply chain members are autonomous and primarily concerned with optimizing their own objectives. This self interest may result in poor performance. In order to align each member's objective with the supply chain's objective, contracting is a way to coordinate supply chain members such that optimal performance is achievable. Contract characterizes the information and financial flow and specifies the duties and rights of each member which coordinate contractual members by set of transfer payments. More precisely Longman dictionary defines that a contract is an official agreement between two or more competent parties stating what each will do. A contractual relationship is implemented by (1) an offer, (2) acceptance of the offer, and (3) a valid consideration which is legal and valuable. Each involved party in a contract acquires rights and duties relative to those of the other parties. A contract is composed by a set of contractual clauses which define the rules of material and information exchange. Some general SC contract clauses have been identified in literature (Anupindi et al., 2003, Tsay et al., 2003) and are presented below:

1. **Horizon Length**: It specifies the valid duration of the contract.
2. **Pricing**: This clause covers broad items in a contract in order to incorporate all financial flow. Among them, purchase price is an important item to be defined in a contract which could take many forms, such as linear or non-linear prices expressions. Moreover, it can also involve other type of payment: buy back of the unsold goods from buyers, compensation of the holding cost from a supplier to a buyer, penalty due to stock-out, etc. Pricing may also depends on other parameters of the contract.
3. **Periodicity of Ordering**: It specifies the frequency of ordering. It can be fixed if the buyer can monthly place orders on a specific day; it can also be random so that the buyer can place orders at any day in a month.
4. **Quantity Commitment**: Quantity commitments concern orders, buyer's demand, or capacity of the supplier.
   - **Order Commitments** include two generic forms:
     - *Total Minimum Commitment:* For single products, a buyer commits to cumulative purchases of at least a certain quantity; this is defined as the Total Minimum Quantity Commitment. For multiple products, this usually takes the form of commitments to purchase at least a certain minimum value of goods, referred to as Total Dollar Volume Commitment.
     - *Periodical Commitment:* A buyer purchases a certain quantity every period.
   - **Demand Commitment**: it specifies the fraction of the buyer's demand to be procured from the supplier.
   - **Capacity Commitment**: a buyer usually reserves a fraction of the supplier's capacity.
5. **Delivery Commitment**: A supplier usually makes a commitment to the material delivery process. A commitment to the lead time would specify the delay in delivery of the material. Service level agreements on the lead time for the entire orders or on fractions of the orders are common. Of course, this is usually coupled with a mutually agreed upon shipment policy. A shipment policy will specify if a buyer accepts multiple shipments for the same order.
6. **Quantity Flexibility**: Quantity of delivered products from the supplier to a buyer must be specified and can be formalized within the contract. A buyer would ask a supplier to provide some flexibility to adjust purchase quantities through time after making some commitment on the purchase quantities. The magnitude and frequency of adjustment may be specified in the contract. Furthermore, the additional flexibility may cause extra cost to the buyer.

7. **Information Sharing**: it outlines what type of information will be shared between the buyer and a supplier. For example, a retailer may pass on the demand forecasting data to its supplier.
8. **Allocation Rules**: allocation rules specify how to distribute the manufacture's available stock or capacity among multiple retailers in a shortage scenario.
9. **Buyback or Returns Policies:** A buyback clause specifies a manufacturer whether he may buy back some or all the unsold products of a retailer by only partial credit.
10. **Quality**: Quality terms should clarify product specifications, defect rates, etc.

This clauses list is used to formulate different contracts, such as buyback contract, revenue sharing contract (Cachon, 2003). The most common types of contracts are succinctly detailed below:

– **Buyback contract**: a manufacturer specifies a wholesale price and a buyback price at which the retailer can return any unsold items at the end of the season/period. The manufacture is willing to take on some of the cost of overstocking because the supply chain will end up selling more on average.
– **Quantity flexibility contract**: a manufacturer allows the retailer to change order quantity after observing demand. No returns are required. The manufacturer bears some of the risk of excess inventory. The retailer commits to order a minimum quantity.
– **Revenue-sharing contract**: manufacturer charges retailer low wholesale price and shares a fraction of revenue generated by the retailer. There are no returns allowed. Lower wholesale price decreases the cost of retailer in case of overstock. Retailer increases the level of product availability.

Some researchers have studied coordination problem by contract. Huang and Liu (Huang and Liu, 2006) for instance, analyzed the impacts of the dependence on the SC in three different models: decentralized with little coordination by only transactional contract, centralized coordination and decentralized coordination by revenue sharing contract. They concluded that the more evidently the price affected the demand, the more revenue sharing contract improved the performance of SC. Amrani-Zouggar et al. (Amrani-Zouggar et al., 2009) identified some important clauses in purchase contract and their risks and studied the impacts of different kinds of purchase contracts on the supply chain planning performance. Eskandari et al. (Eskandari et al., 2010) studied a supply chain consisting of one supplier and two retailers facing stochastic demand and coordination with revenue sharing or buyback contract. A linear demand model is proposed. Both cases of centralized SC and coordinated supply chain using contract are studied using simulation optimization decision tool. Finally let us remark that although certain clauses have been specified in a contract, there is still flexibility to adjust activities of supply chain business processes to confront uncertainties.

2.2.2.2 *Coordination by information sharing*

Information sharing and information exchange are two terms which are similar and often exchangeable in literature. Information sharing is achieved by information exchange. But we can still distinguish them by the way to access information as shown in Figure 2.5. Partners keep a copy of exchanged data in local information system in the information exchange. But they access the shared information in a common database in information sharing. However this difference is not absolute. Sometimes information is shared by information exchange but without a common database. In this thesis we do not distinguish these two terms. We consider SC partners sharing information by information exchange.

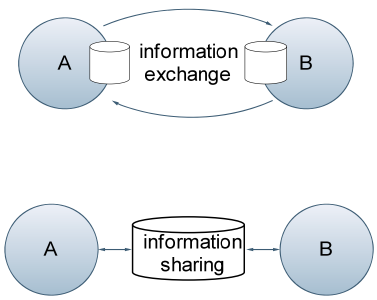


Figure 2.5 Information exchange and information sharing

Information sharing is very important in supply chain planning. Enhanced information sharing will improve the quality of decision-making and reduce demand uncertainty. Thus communication and information sharing between companies/units are critically important for overall supply chain performance. Collaborative approaches (see section 1.4.2 of chapter 1) such as vendor managed inventory (VMI), collaborative planning, forecasting and replenishment (CPFR), quick response (QR), and continuous replenishment program (CRP), increase the level of interaction between companies. All of these approaches have some common points, sharing information and decreasing the uncertainty so as to avoid bullwhip effect (Chan and Chan, 2006). Stank et al. (Stank et al., 1999) studied inter-enterprise coordination by effective communication, information exchange, partnering and performance monitoring in food industry supply chains. Zhu et al. (Zhu et al., 2002) established a collaboration planning model for supply chain coordination by information sharing. The factors such as price and inventory are considered in the model.

2.2.2.3 *Coordination by negotiation*

From a general point of view, negotiation is a form of decision-making where two or more parties jointly search a space for possible solutions with the goal of reaching a consensus. It is an efficient way to solve the problem by releasing certain constraints when there is no possible solution to satisfy all partners' constraints. A negotiation process may fail because of several reasons:

- Neglect the interest and value of other partners
- Refuse to communicate useful information regularly
- Keep confidentiality at a high level
- Force smaller industrial partners to systematically make a concession for all gained advantages

Only when the negotiation process is executed cooperatively, the negotiation result can arrive to a win-win situation (François et al., 2006). It is clear that negotiation theory covers a wide range of phenomena encompassing different approaches such as artificial intelligence, social psychology and game theory. Negotiation research can be considered to deal with three broad topics: negotiation objects, negotiation protocols and decision making models (Jennings et al., 2000).

- **Negotiation objects** are a range of issues over which there are conflicts requiring reaching an agreement. The negotiation object may contain a single issue or hundreds of issues defining what to negotiate.
- **Negotiation protocols** define the interaction process which specifies how to negotiate and when to negotiate.
- **The decision making models** interact according to negotiation protocol and are influenced by the range of decisions and negotiation objectives.

There are two important issues to define the negotiation complexity, namely negotiation domain and the interaction type. Negotiation domain defines the cardinal number of negotiation objects; it can be single-issue for example price only or multiple-issue for example price and quantity. Interaction types are characterized by the cardinal number of involved negotiation parties. It could be one-to-one, many-to-one, or many-to-many.

It is easy to understand that there is information exchange in negotiation. At least the negotiation objects should be the exchanged information. The difference between negotiation and information sharing, up to my knowledge, is that negotiation pursues agreement by exchange minimum information while information sharing focuses on information symmetry.

In complex SC, centralized planning is not practical as it would require complete information sharing between entities. This motivates the development of negotiation-base approaches for supply chain planning. Chen et al. (Chen et al., 1999) developed a framework of multi-agent system for supply chain management where functional agents can join in, stay, or leave the system. Supply chain may emerge dynamically through the negotiation process between functional agents. A pair-wise negotiation protocol and third party negotiation protocols are constructed. The decision making process inside an agent is general and simple in this work. Dudek and Stadtler (2005) develop a non-hierarchical, negotiation-based scheme which combines mathematical programming for each party's optimal planning and negotiation so that the two parties' order/supply plans can be synchronized.

2.2.2.4 *Coordination by joint decision making*

Notions of information exchange, negotiation and joint decision making are not exclusive. Negotiation includes information exchange while joint decision making includes negotiation. One of the most representative joint decision making approaches applied to SCM is collaborative planning which involves contract, information exchange, and negotiation at the same time. This notion will be presented in detail in section 2.3.2.3.

In our work, the coordination mechanisms which will be presented in chapter 3 is based on joint decision making mechanism. It refers to SC contract, information sharing and negotiation at the same time.

2.2.3 Coordination performance measurement

This section discusses the problem of coordination performance measurement in order to identify indicators which can be used to measure coordination performance. SC performance measurement is concerned with the evaluation results of the physical system so that efficiency of business processes, global productivity and profitability may be improved based on information feedbacks. Performance measurement and indicators have an important role to play in setting objectives, evaluating performance, and determining future courses of actions. It provides the necessary information of feedback for decision makers and process manager; it plays a critical role in monitoring performance, enhancing motivation and communication, and diagnosing problems. Furthermore, performance measurement provides an approach for identifying the success and the potential of management strategies; it facilitates the understanding of the situation (Chan, 2003). Measuring performance on supply chain can be a difficult task in defining indicators in relation to physical behaviors that can be observed and evaluated. Each defined indicator can only reflect part of performance. Thus many indicators should be defined and structured in a reasonable way, to implement an effective performance measurement. These ones could be grouped from different perspectives such as quantitative or qualitative measures, financial or non-financial measures. The following groups are known to be useful to evaluate the performance of the supply chain: cost, resource utilization, quality, flexibility, trust. Table 2-2 shows the indicators identified by Chan (Chan, 2003).

Table 2-2 Performance indicators (Chan, 2003)

Groups	Indicators	Definition
Quantitative		
Cost	Distribution cost	The transportation and handling cost, safety stock cost and duty.
	Manufacturing cost	Labor, maintenance and re-work costs. Also, there are purchased materials, equipment charges and supplier's margin.
	Inventory cost	The work-in-process and finished goods inventories.
	Warehouse cost	Associated with allocation from one tier to another.
	Incentive cost and subsidies	Taxes and subsidies.
	Intangible cost	Quality costs, product adaptation or performance costs and coordination.
	Overhead cost	Total current landed costs.
	Sensitivity to long-term cost	Productivity and wage changes, exchange rate changes, product design and core competence.
Resource utilization	Labor, machine, capacity, energy	Investigate the percentage of excess or lack of that particular resource within a period
Qualitative		
Quality	Customer dissatisfaction	The number of customer complaints
	Customer response time	The amount of time between an order and its corresponding delivery.
	Lead time	The time required once the product began to be processed until the time it is completely finished
	On-time delivery	The percentage of orders delivered on or before the due date.
	Fill rate	The proportion of orders that can be filled.
	Stock out probability	-The instantaneous probability that a requested item is out of stock -The number of backorders that is the number of items backordered due to stock out.
	Accuracy	Percentage of accurate goods delivered to clients.
	Responsiveness	The number of periods on which there are backorders
Flexibility	Volume	-The extent of change and the degree of fluctuation in aggregate output level which the system can accommodate without incurring high costs or large changes in performance outcome -The demand which can be profitably sustained.
	Delivery	The percentage of slack time by which the delivery time can be reduced.
Trust	Consistency	The percentage of late or wrong delivery to the next tier which lead to an inconsistent supply: - The percentage of time delayed (late deliveries) - The percentage of returned goods (wrong deliveries)

The performance indicators defined above can generally be applied in SC. A recent investigation has been conducted with transport operators to define the performance indicators they use to measure their performance (Roques et al., 2012). Table 2-3 synthesizes the most common indicators, classified in three categories depending on the considered performance domain.

Table 2-3 Transport operators performance indicators

Groups	Indicators	Definition
Productivity	Vehicle service time	Accumulated time of the activities that a vehicle makes transportation with charge
	Vehicle effective service time	Accumulated time of the real activities that a vehicle makes transportation with charges from one place to destination without considering all kinds of stop time, e.g. technical breakdown
	Vehicle waiting time	The time when a vehicle and a driver are considered on service but not on effective service.
	Vehicle utilization rate	Ratio between the effective service time and service time
	Fleet utilization rate	Ratio between the total number of utilized vehicles and the number of vehicles owned by a fleet.
Capacity utilization	Filling rate	The filling rate of a vehicle regarding weight or volume.
Service quality	Time respecting rate	Ratio between the number of on time deliveries and total number of deliveries
	Loss rate	Ratio between the number of products which are lost during the transportation and the number of total products transported by a fleet.

All the indicators defined in this section help to identify the optimization criteria used in planning models which will be developed in the next chapter of this thesis; it also helps to specify the implemented experiments in order to evaluate the coordination performance.

2.3 SC planning

Coordination has been discussed as a general concept in previous sections. It involves rarely decisions made at the operational level between SC partners but generally concerns exchange of tactical plans in order to prepare required resources to perform the forecasted activities. Coordination usually implies that planning processes performed by each partner need to be synchronized with those of suppliers and customers. In order to focus on the coordination in SC planning, this part firstly presents SC planning basic concepts. The SC planning and coordination approach are presented secondly.

SCM is sometimes broken down into the stages of planning, execution and shipping. As a critical component of supply chain management (SCM), supply chain planning (SCP) may include supply chain modeling, production and distribution planning to balance future supply and demand. It predicts future demands so as to plan production and logistic activities and make decisions by specifying what to do, when to do it, what resources are required and how much tasks should be done. The output of SCP serves as a guide for production system.

2.3.1 SC planning concepts

Since supply chain planning plans future activities, decisions must be made on a temporal planning horizon, during which, for example, production department will decide how and when to produce and determine material requirements based on internal resource capacity. The planning horizon is a time interval on which decision making is considered to plan further production activities. The length of planning horizon is relevant to decision level. In a conventional hierarchical decisional system, the length of planning horizon at the upper level is larger than that defined in lower level; the definition of the length of planning horizon is also strongly related to the degree of uncertainty in the external environment: more the decisions concern activities far from the current instant, more the information used to make decisions is uncertain. So, higher the uncertainty is, shorter the planning horizon should be adopted. The planning horizon can be divided into more detailed temporal elements which are discrete and called planning period. A period is a time interval on which decision making results are temporarily fixed. This notion should be also defined as the time interval after which previous decision making should be verified and modified if necessary. The length of planning period determines the detail degree of decisions in the solution plan. Based on the concepts of planning horizon and period, managerial decisions are usually classified, according to the definition of strategic, tactical and operational decisional levels, as defined in chapter 1.

The decision making system efficiency is directly linked to the concepts of planning horizon and period. More particularly, the notion of period is essential to find a compromise together between opposite properties of the decision making process: stability versus precision. Stability shows the frequency of modification and precision defines the ability of finding appropriate solutions closer to current pursued performance objectives.

If the period is defined with too big value, the manufacturing situation in terms of performances could be noticeably different from the pursued objectives. Trajectory correction does not always allow orienting to initially defined target performance objectives (Figure 2.6a). When period is too short, corrected decisions are continuously made in order to precisely follow the ideal trajectory. However frequent decision making is then quite useless and costly (Figure 2.6b).

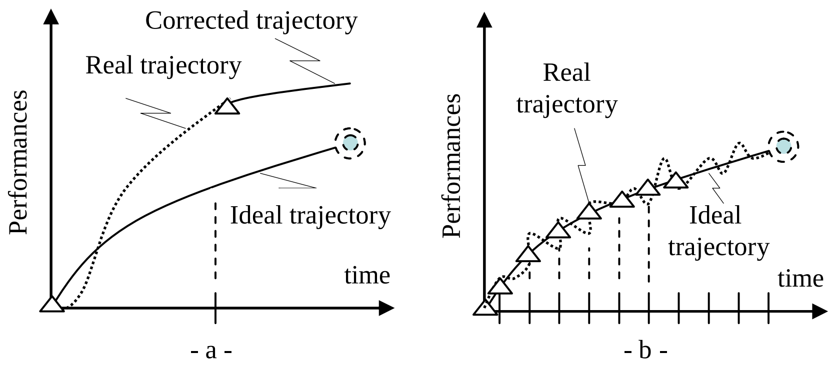


Figure 2.6 Periodic-driven decisions making

The definitions of planning horizon and period (H/P) also affect the coordination of two SC partners. Figure 2.7 shows the inconsistent planning horizon relation between supplier and customer with the same definition of periods. If the length of planning horizon of customer is longer than that of supplier, the supplier could take just a necessary part of received information from customer as presented in Figure 2.7a. If customer's planning horizon is shorter than that of supplier, the received information is inadequate to make supplier's planning as shown in Figure 2.7b. Supplier may need to wait for further information or complete the absent information by forecasting. The inconsistent definition of periods between supplier and customer also causes problems of planning. Figure 2.8 shows the relation between supplier and customer with the same definition of planning horizon but different definitions of periods. If customer's period duration is smaller than that of supplier, information aggregation may be needed for supplier to proceed with planning tasks as presented in Figure 2.8a. On the contrary, information disaggregation should be considered in Figure 2.8b. Anyway, no matter which kind of inconsistency (planning horizon or period or both) it involves, it is a complex coordination problem and not easy to be solved.

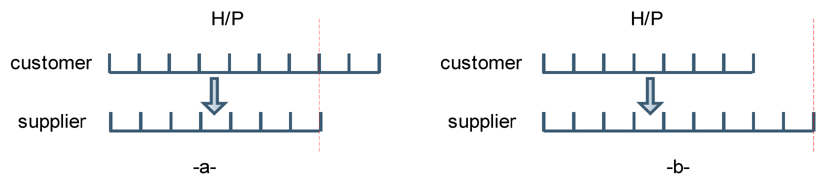


Figure 2.7 Inconsistent planning horizons between supplier and customer

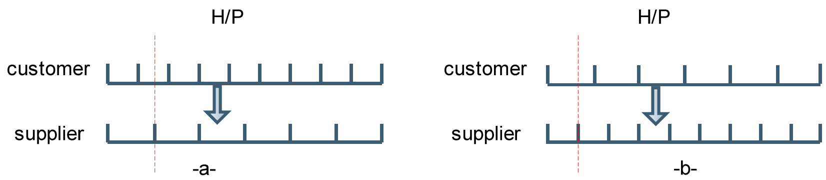


Figure 2.8 Inconsistent periods between supplier and customer

In this thesis, we focus on the coordination of decisions themselves without considering the inconsistent information representation problem. We suppose that the DMUs have the same definition of planning horizon, period and information is instantaneously transferred between DMUs.

2.3.2 SC planning approaches and coordination

There are many SC planning approaches in literature such as integrated SC planning, hierarchical planning, collaborative planning, upstream planning, etc. For the interest of coordination in this thesis, we classify SC planning approaches in terms of coordination mode which are centralized, hybrid and decentralized. The hierarchical planning is perceived as an extension of centralized planning. Related literature is reviewed in the following sections.

2.3.2.1 *Centralized planning*

There is a large volume of research in literature which deals with centralized planning problem through integrated mathematical model (see section 1.5.3 in chapter 1).

Beyond this kind of research, some researchers dedicate their work to coordinate SC planning under centralized mode. Chandra and Fisher (Chandra and Fisher, 1994) compared two approaches to managing the production and transportation planning. In one approach, the production scheduling and vehicle routing problems are solved separately. In the other approach, they are coordinated within a single model. The coordination is realized by centralized coordination mode. Thomas and Griffin (Thomas and Griffin, 1996) review the literature addressing coordinated planning between two or more of the SC main stages (i.e. procurement, production and distribution). The references are related to buyer-vendor coordination, production-distribution coordination, inventory-distribution coordination and strategic planning.

Hierarchy planning can be viewed as an extension of centralized planning because the DMU makes centralized planning for all lower level DMUs. Hierarchy planning is the most representative case and widely used centralized planning approach which is the conceptual framework underlying APS.

The basic idea of hierarchical planning is that the overall planning problem is decomposed into sub-tasks which are interrelated in a hierarchical way. The essence of hierarchical planning is to use aggregated information at different levels. Higher level decisions form instructions for decision making at subordinate levels. Anticipation aims at drawing higher level decisions which do not hamper lower level decision making. The anticipated lower level in Figure 2.9 is considered as part of higher level which abstracts the aggregated information of lower levels. This abstract relation is presented by feed forward link which is a solid arrow in Figure 2.9. Feedback is to report the consequences of top level decisions once they were incorporated into lower level problem. Feedback communication is indicated by the dashed arrow. It can result in a re-evaluation of higher level decisions even before the plan is actually put into practice (Dudek, 2004).

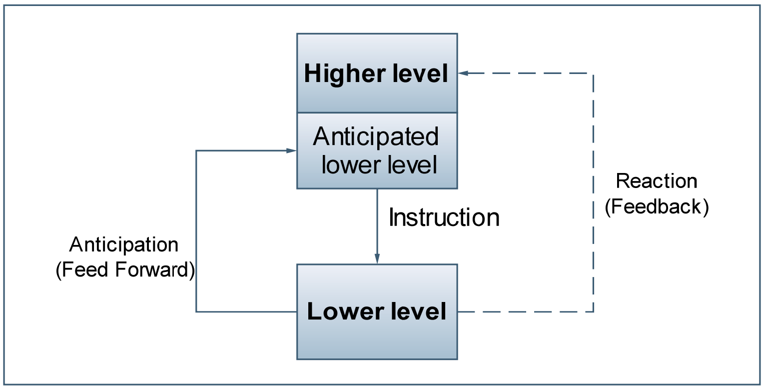


Figure 2.9 Hierarchical planning system (Schneeweiss, 1999)

We are interested in hierarchical planning because the anticipation-reaction principle shown in Figure 2.9 has similarities to the coordination between SC partners. The coordination between SC partners can be viewed as an anticipation-reaction schema without the aggregation and disaggregation in the hierarchical planning. A partner can make planning by anticipated information of other partners at beginning and react later when concrete information is received from other partners.

Hierarchical planning systems usually include more than two levels and comprise more than one separated planning task at a given level. In general hierarchical planning can be decomposed into different phases. The first phase of planning is aggregate planning. It takes a wider perspective and develops the requirement and usages of resource over a long time. The planning horizon is usually one year or more. The variables and constraints are measured by aggregated units such as product family. The next phase after aggregate planning is master production planning. The specific production quantities of each product or component are defined. The last planning phase considers segment-specific scheduling and sequencing problems, for example production in a job shop or in a flow line or just in time (JIT) production. The decisions taken at these three phases correspond to strategic, tactical and operational decisions presented in chapter 1.

For instance, Ozdamar and Yazgac (Ozdamar and Yazgac, 1999) adopted a hierarchical approach in order to use aggregated date to satisfy weekly fluctuation demand with an optimal fleet size. The overall system costs are optimized considering factory and warehouse inventory costs and transportation costs. Constraints include production capacity, inventory balance and fleet size integrity. In the first planning phase, a model which involves an aggregation of products, demand, capacity, and time periods is solved. In the next planning phase, the aggregate decisions are disaggregated into refined decisions in terms of time periods, product families, inventory and distribution quantities related to warehouses. Infeasibilities in the disaggregated solution are resolved through an iterative constraint relaxation scheme.

As a centralized planning approach, hierarchical planning is supported by a broad range of procedures elaborated in the literature during the last decades as well as modeling tools like APS which are widely used by practitioners. It works well as an integrated SC planning solution. In general, the centralized planning integrates all supply chain members to optimize the entire supply chain. However, it requires a confidential environment where the members could accept to expose all needed information to implement the integration. Thus it is not quite adaptable to the decentralized planning environment.

2.3.2.2 *Hybrid planning*

Some researchers deal with coordinated SC planning under hybrid mode. The main research areas are optimization methods based on relaxation modeling strategy or multi-agent system. Ertogral and Wu (Ertogral and Wu, 2000) adopted Lagrangian relaxation scheme to figure out the coordination of production planning in the supply chain. They developed a facility agent for local planning and a central agent for arbitrating among the facility agents. The auction-theoretic coordination mechanism is adopted to achieve a final solution between the facility agent and the central agent. Tang et al. (Tang et al., 2005) synchronized production and transportation planning under multiple time and direct shipping strategy using a non-linear mixed integer programming and Lagrange relaxation decomposition method to minimize total costs of production set-up, inventory, transportation and rent costs in vehicles over the planning horizon. Pibernik and Sucky (Pibernik and Sucky, 2007) developed a distributed coordination approach for inter-domain planning in a supply chain.

However these researches assume the presence of an extra coordinator which has a complete control of the whole supply chain to guarantee the convergence of the final solution. This notion of extra coordinator is absent in the decentralized planning approach.

2.3.2.3 *Decentralized planning*

Decentralized approaches in SC planning have actually drawn strong interest of the SC researcher’s community. Zimmer (Zimmer, 2002) considered order and delivery decisions in a just-in-time environment, with one supplier and one producer. The target of the study was to find a coordination mechanism to improve decentralized planning. This study revealed that in a decentralized planning situation without coordination, the supply chain's total costs are higher than in a centralized system. When employing a coordination mechanism with information sharing and incentives, the decentralized system performance was at the same level as that of a centralized one. This result indicates that in supply chains with decentralized planning, the correct use of coordination mechanisms enables optimal supply chain performance. Albrecht and Stadlter (Albrecht and Stadlter, 2008) present a coordination approach for decentralized planning with iterative exchange of primal information without requirement of a central decision-making entity. Decentralized parties' decisions are modeled and solved as linear or mixed-integer programs. Experiments are limited to deterministic models for supply chain consisting of one buyer and one or several suppliers. Jung et al. (Jung et al., 2008) propose a decentralized supply chain planning framework for third party logistics partnership between the manufacturer and the third party logistics provider to generate a good supply chain plan in terms of total costs. The manufacturer and the third part logistics provider share customer demands and exchange required supply quantity and possible supply quantity during the negotiation process through iteration. Distribution planning pulls the production planning. However, their research considers the distribution model in a similar way as the production model and also neglect production lead time and transportation lead time since the proposed framework and models are for a mid-term operational supply chain planning (e.g. a basic time unit is a week). Moreover, since this approach is based on sharing customer demand, it cannot work when the manufacturer keeps the information of customer demand private.

More generally, decentralized approaches could be classified in two categories: sequential planning and collaborative planning.

<u>Sequential planning</u>

Sequential planning is a typical way that most organizations have deployed for optimizing planning solutions. Supply chain members are linked by transmitting transactional orders. Each member purchases parts or components from upstream suppliers and pursues to maximize its own profit without considering the impact on other supply chain members. The plans are determined level by level. Sequential planning usually starts from the most downstream partners. Its plan defines the supply requirements for its suppliers. These requirements are passed to suppliers and the procedure continues in upstream direction. (Bhatnargar et al, 1993)

<u>Collaborative planning</u>

Collaborative planning takes into account the limitations of both sequential planning and centralized planning and provides a trade-off which can improve supply chain performance compared with sequential planning and also get rid of confidential environment limitation required by centralized planning.

Collaborative planning aligns plans of individual SC members with the aim of achieving coordination in light of information asymmetry (Stadtler 2007). Information asymmetry means that SC members do not possess the same information. One party has more or better information than the other or the presentations of information are different. A dominant party cannot accept to be under constraints issued from plans performed by others partners. A centralized planning approach may also be considered unacceptable or even infeasible when it requires him to share strategic and/or confidential information with other parties with the risks to lose his dominant position. Moreover, the differences of information representation also make it difficult to apply a centralized planning approach. The coordination approaches make use of mechanisms such as compensations, attractive buyback prices for perishable goods (Cachon and Lariviere, 2005) to lead supply chain partners to act in ways that are "best" for the chain as a whole (Kouvelis et al., 2006). In theory "best" often means "optimal", however in practice, decisions resulting from coordination do not guarantee the optimality but, the more the coordination becomes efficient, the more the decisions tend to obtain solutions closed to the optimal one.

Collaborative planning can be classified by three dimensions: leadership, topography of a supply chain, and objects of collaboration; a complete list of criteria can be found in (Stadtler 2007).

- **Leadership**: Usually, one of the SC participants is the most powerful. It initiates and drives the collaborative planning process while other participants are followers who support the planning process.
- **Topography**: The topography refers to the number of tiers: two-tier or multi-tier collaboration.
- **Collaboration object**: It is similar to the negotiation object previously described in this chapter. SC members may exchange information about the item itself in so-called "material-related collaboration"; they may also collaborate on capacity or services that are required to make and transport items in so-called "service-related collaboration". Consequently, both materials and services may form the object of collaboration. Demand, inventory and procurement collaborations are material-related collaborations, capacity and transport collaborations are service-related (Stadtler 2007).

A typical generic SC collaboration process consists of the following six phases shown in Figure 2.10 (Stadtler, 2007):

1. **Definition:** In this phase, collaborative partners define the goal of working together in a formal agreement such as a contract. Four main issues have to be considered: gives & gets, the collaboration objects, the time horizon of the collaboration and an agreed dispute resolution mechanism in case of conflicts (Anderson and Narus, 2004). “Gives” address the contribution of each partner to the collaboration, whereas “gets” is the specific gains of each partner participating in the collaboration. Different resolution mechanisms such as negotiation, arbitration by a third party might be taken into account in case of conflicts.
2. **Local Domain Planning:** A partner plans his future activities in a local domain by taking into account a certain local planning situation such as his individual objective function, current detailed internal information, process restrictions and assumptions about the environmental development.
3. **Plan Exchange**: Plan exchange is a starting point for negotiations. Partners exchange information with a purpose to increase the planning quality. It is a sensitive process since the exchanged information may explore partners’ confidence. The exchanged information is usually defined in the definition phase
4. **Negotiation and Exception Handling:** With the exchanged information SC partners gain an overview of the planning situation and identify whether the predefined goals are achieved. Once there are exceptions, SC partners need to negotiate and handle the exceptions, such as not fully satisfied demands.
5. **Execution**: An adjusted plan is generated after negotiation and exception handing phase which contains replenishment of production and purchasing orders. It is then executed to fulfill the planned goals.
6. **Performance Measurement**: The performance of partners and the whole SC are measured by key performance indicators (KPI). The planning results, both the local plans and SC collaborative plan, are compared with the real-world data by KPI.

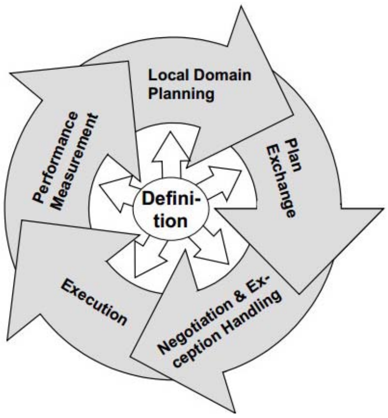


Figure 2.10 Phases of a generic SC collaboration process (Stadtler, 2007)

2.3.2.4 *Synthesis of planning approaches*

The SC planning approaches presented in this section are centralized, hybrid and decentralized which are consistent with coordination modes in section 2.2.2. Figure 2.11 shows the difference of sequential, collaborative and centralized planning by information flows. In centralized planning, confident/trustful environment is required to enable a centralized control of information. In sequential planning, the information flow is upstream and unidirectional. In collaborative planning, the information flow is bidirectional. Supply chain members exchange not only transaction orders but also other necessary relevant information which may impact the decisions of other members and respect the voluntary of members. Since collaborative planning cannot guarantee an optimized solution for the entire supply chain, the research on collaborative planning area is to search a near-optimal solution without integrating information for all supply chain members so as to respect the privacy of members.

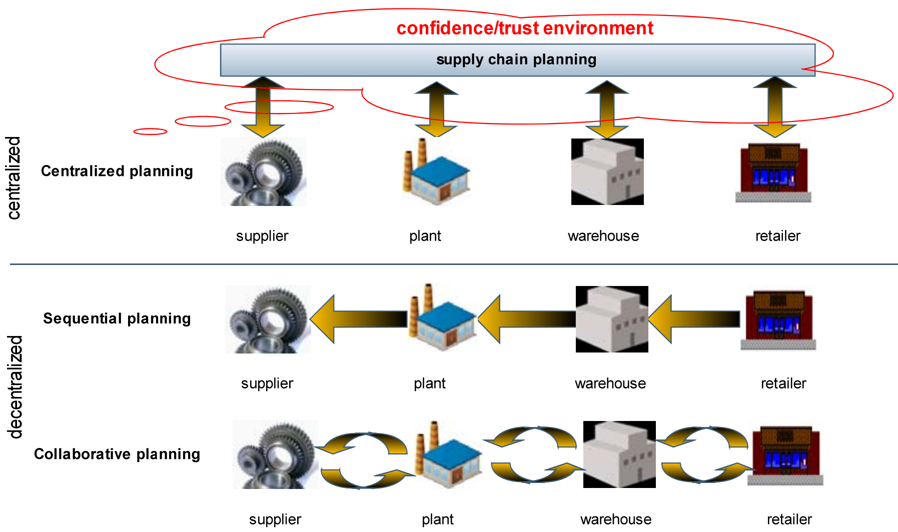


Figure 2.11 Differences between sequential planning and collaborative planning

In this thesis, collaborative planning is adopted in the decentralized coordination mode.

2.4 Coordination problems of production - transportation planning

In this thesis, we focus on production - transportation problem that concerns how to coordinate production and transportation planning when they are executed by independent companies. The relationship between producer and transport operators determines the appropriate coordination solutions which strongly affect the supply chain performance.

2.4.1 Relationship between producer and transport operator

Transport operations may be executed by an internal department or an independent transportation companies such as 2PL, 3PL and 4PL (see section 1.5.2 of chapter 1). Different roles of transport operators can be mapped to different coordination mode. Table 2-4 shows the summary of relationship between roles of transport operator and coordination mode.

Table 2-4 Relationship between roles of transport operators and coordination modes

Roles of transport operators	Coordination mode
Producer's internal department	Centralized
Independent company	Decentralized

If a producer owns a fleet of trucks, he has to control production and transportation activities and get all useful information to coordinate them with the help of his internal departments. It optimally manages the different operations by using a centralized coordination mode. Transport as an internal department provides necessary information to producer and follows producer's transport order. However real world supply chains are so complex that transportation and production activities are performed by different partners, regarding their own competencies. Facing this situation, the coordination mode of production and transportation planning tends to be decentralized rather than centralized.

2.4.2 Problem definition

The main objective of this work consists in developing an approach to coordinate transportation planning with production planning models. More precisely, this research aims at studying the problem of production and transportation in the 3PL environment under a decentralized coordination mode (Jia, Deschamps, Dupas, 2010,). Two kinds of independent partners, producers and transport providers try to maximize their own profit and at the same time they target a common goal to satisfy customer demands. The supply chain structure as shown in Figure 2.12 consists of producers, transport providers and many customers or customer zones. The producer manufactures different products to satisfy the demands of different customers with limited production capacity and limited finished product storage capacity. 3PL (i.e. transport operator) manages a fleet of trucks to pick up products at producer, to deliver at assigned customers and return to the corresponding 3PL location. Each of them (producers and 3PL) is in charge to plan its own activities, but should integrate the limitations, prescribed by the other, such as capacities.

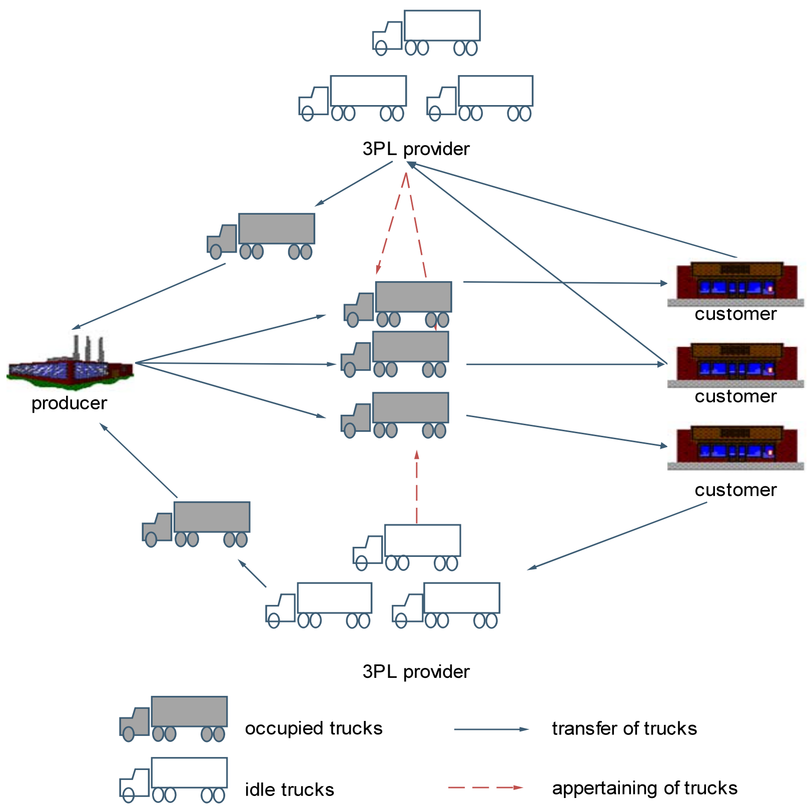


Figure 2.12 Supply chain structure

2.4.3 Research barriers

To solve this planning problem of production and transportation we have two key points to figure out: what is the coordination mode of the problem and what is the relevant coordination mechanism to solve the problem? Coordination mode affects directions of information flows. Coordination mechanisms determine what information is required for decisions, how information is processed and what information will be sent to other partners. As mentioned before, the studied problem requires using a decentralized coordination mode. As a consequence, we adopt the principles of collaborative planning as coordination mechanisms since it is adapted to decentralized coordination mode.

As defined in chapter 1, we would like to study the potential contribution of the negotiation principle applied to the collaboration of production and transportation planning, taking into account the disagreements that strongly affect the coordination performance. Thus, according to section 2.2.2.3, we aim to specify three topics of negotiation: negotiation objects, negotiation protocol and decision making models.

- Negotiation objects

Negotiation objects are pickup quantities which are the decisions that connect producer and transport operator. Since transport operator has a possibility that it cannot fulfill delivery demand, it has an option to hire extra transportation resource in order to guarantee service performance. The more extra resources are used, the more transport operator's cost increases. For this reason transport operator negotiates with producer on pick up quantities so as to reduce extra resource and then gain more profit. Of course any change in the producer's delivery plan would cause a loss for the producer. In order to improve the profit of transport operator and at the same time to reduce the loss of producer's benefit, we suppose that, through negotiation, transport operator offers compensation to producer so that the producer has an incentive to collaborate. Although producer's service level may decrease, if the decrease is controlled within an accepted range and the compensation paid by transport operator is interesting enough for producer, both producer and transport operator would benefit from negotiation. Compensation as a negotiation object is a hypothesis whose effect on the negotiation performance is waiting to be verified by our future experimentation.

- Negotiation protocol

In order to achieve a win-win negotiation objective, negotiation protocol ensures the orientation to the objective. Negotiation protocol varies with interaction type, one-to-one, one-to-many or many-to-many. In this research, only protocols involving one producer and one (or many) transport operator(s) are studied. Nevertheless each transport operator can work with more than one producer which is not explicitly considered. Transport operator could gain more money through negotiation on pickup quantities which is corresponds to the delivery plan of producer. But any change in the producer's delivery plan will decrease producer's service level and its profit. The ideal case is the negotiation protocol can lead to a win-win situation. That is the most difficult part of negotiation protocol to be solved in this thesis.

- Decision making models

Since it is an inter-enterprise planning problem, it is unrealistic to develop an integrated decision model which collects all information from producer and transport operator. It is necessary to build two separated decision models, production model and transportation model which models corresponding partner's DMU and makes planning of production and transportation activities. Production model serves to make decisions on product quantities produced in each time period, inventory levels and delivery quantities allocated to each transport operator if there are more than one. The general objective is to maximize the gain and to supply right products with right quantities on time by respecting production capacity and inventory capacity. The delivery quantities planned by the producer serve to express the orders sent to transport operator. Transport operator tries to pick up the right products with right quantities at right time according to these orders. Thus the decisions of transportation model are pickup quantities of each product in each time period and also the management of its transportation capacity and additional capacity. The objective of transportation model is also to maximize the gain and as well minimize the deviation of pickup quantities from delivery demand by respecting transportation capacity. The main difficulties of building decision models lie on the identifications of the sufficient parameters and criteria regarding coordination which can keep the generality of decisions and as well avoid unnecessary details.

By specifying these three topics, we will propose a negotiation-based approach to coordinate production and transportation planning.

2.5 Conclusion

This chapter focuses on planning and coordination issues in supply chain management. We consider the problem of production and transportation in an environment where transportation activities are executed by the 3PL.

In terms of coordination, four coordination modes are classified. The comparison and synthesis of four kinds of coordination modes centralized, hierarchical, hybrid and decentralized shows that decentralized coordination mode is more adapted to decentralized planning problem. Secondly five types of coordination mechanisms have been identified and four of them are presented in detail. They focus on different coordination concerned aspects and vary on advantages and limitations. However they are not exclusive but compatible with each other. Especially, joint decision making involves all the other three mechanisms; moreover it is more comprehensive. That is why this coordination mechanism was chosen.

In terms of planning, important concepts, such as planning horizon and period, are explained which are essential to establish planning models. The comparison of centralized planning and decentralized planning approach based on the direction of information flows can explain that decentralized planning approach should be used to deal with the coordinated planning problem of production and transportation.

We also fix following hypotheses:

- The definitions of planning horizon/period are the same for both producer and transport operator.
- The information is exchanged between producer and transport operator instantaneously.
- Transport operator provides compensation to producer to motivate the negotiation furthermore to achieve win-win situation which will be detailed in chapter 3.

Referring to section 2.3.2.3, a typical generic SC collaboration process consists of the following six phases: definition, local domain planning, plan exchange, negotiation and exception handling, execution and performance measurement. In the next chapter of this thesis, the first four phases will be considered. We will specify the chosen coordination mechanism in detail by specifying how to model production and transportation local domain planning, how to exchange plans, how to negotiate. In chapter 4 the last two phases will be considered to evaluate the performance of the proposed coordination approach by simulation.

Chapter 3

Modeling and coordinating by negotiation between one producer and one transport operator

Chapter 3 Modeling and coordinating by negotiation between one producer and one transport operator

3.1 Introduction

The management of supply chain planning can be considered as the management of a set of partners which are interrelated and responsible for making decisions to specify all kinds of activities in order to achieve one or several objectives. In the context of supply chain planning, a large number of studies focused on the relation between producers and suppliers. In this work, we consider transport operator as a special supplier which supplies transport services to its customers but without transformation activities and storages. Producer can utilize its capacity more efficiently by production leveling and products stocking without affecting customers' decisions; transport service only consists in moving goods from producers to recipients. Similar to producers, performance's objectives pursued by transport operators consist in strongly reducing their global operation costs. However these costs include specific aspects such as:

- The continuous increasing of fuel oil costs which tends to reduce the number of used vehicles and the covered distance;
- The need to limit the truck operation costs which leads to optimize each vehicle load;
- The requirement to limit the late deliveries penalties, often considered as the most important objective to satisfy.

Unlike producer whose performances vary mainly depending on internal disturbances such as machine breakdown or absence of workers, transport operations perturbations are mainly due to the dynamic transportation environment, where unexpected events occur such as traffic jam and bad weather conditions; in this situation, transport service rate is hard to guarantee. Enterprises are often obliged to be protected from demand uncertainty by defining safety stocks. Storage is usually performed by producers and not by transport operators, so that manufacturing plants support the entire cost of safety stocks. Facing this problem, producers then negotiate penalty costs to constraint transport operators to deliver goods at the requested time, and by this way intend to reduce the storage costs. These penalties strongly affect the way to optimize transportation activities.

The simplest coordination context is one producer and one transport operator relation. In this chapter we focus on coordinate production and transportation planning between one producer and one transport operator.

3.1.1 Decomposition of DMU

Each partner involved in SC can be controlled by many DMUs. As mentioned in chapter 2, a DMU groups a certain number of decision processes and can be used to model them at different levels of abstraction. Considering the supply chain as a whole, we believe that modeling each SC partner in details as a set of DMUs is not necessary to study main principles of production-transportation coordination. So, each partner, producer or transport operator is assimilated to a DMU, considering the company as an aggregated entity which is characterized by a unique planning model that represents the whole planning decision making process. This process represents decisions to make when customers' demands are received, including production of goods or services, procurement and delivery planning.

Assuming that no centralization of information is possible, regarding the producer and transport operator DMUs, the coordination of decision processes is mainly based on negotiation principles and requires synchronization of the two DMUs.

In order to study the problem, first of all, we consider identifying general characteristics of decisions making within DMUs and then identify the information required from other DMUs. Hereafter we consider constructing a way to negotiate between DMUs including what to negotiate and how to negotiate, which aims to coordinate production and transportation activities furthermore to improve supply chain performance.

So in our work, a DMU is defined by two components: "**Models**" and "**Control**" as shown in Figure 3.1.

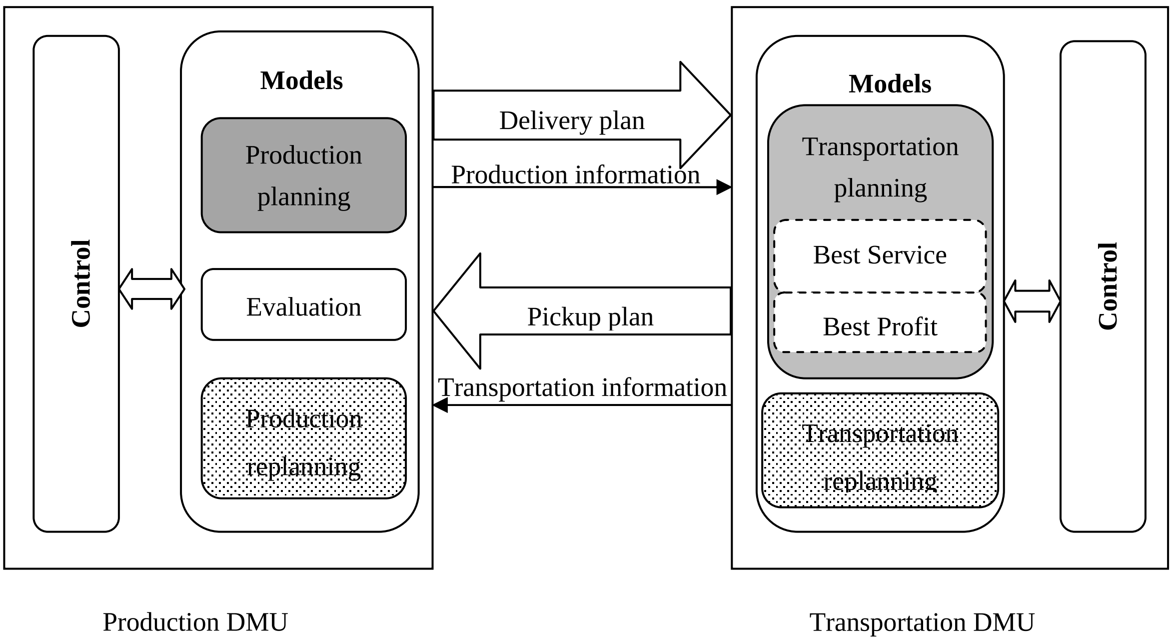


Figure 3.1 General framework of coordination between one production DMU and one transportation DMU

Models

The "Models" component is made up of several models which characterize the planning decision making. A plan is a temporal set of intended actions for the future which indicates the allocations of resource to time periods. The production plan indicates the production quantities, the time to produce, the requirement of components and production resources, and also the inventory quantities; while the transportation plan indicates the transportation quantities, the time to transport and the requirement of transportation resources.

In our approach, two main types of planning models are identified in each DMU.

- Planning model achieves an initial plan which responds to external demand and intends to satisfy constraints under given objectives. Nonetheless, in the context of collaboration between two partners, this initial plan should be later reconfigured and adapted to the constraints of other partner or the change of environment.
- Replanning model aims at finding a plan which is take into account both local and other partners' constraints which are unknown at the time when the initial planning is launched.

More precisely, the planning model is executed one time at the initialization phase while the replanning is executed many times during the decision making process.

In Figure 3.1, the production "Models" component is made up of three models: production planning, evaluation and production replanning while that of transportation is composed by two models: transportation planning and transportation replanning. The transportation planning contains two sub models: "Best Service Transportation" model and "Best Profit Transportation" model. The reason for the difference is that producer and transport operator play different roles in a customer-supplier relation. Producer sends demand to transport operator who just responds to the demand based on local constraints. The responses received by producer contain inexplicitly constraints from transport operator. Producer evaluates whether the received responses which satisfied transport operator's constraints can satisfy producer's constraints as well. That is why evaluation model is added in production "Models" component.

Control

The **"Control"** component is in charge of analyzing, comparing the output of models or received information described below; furthermore directing the decision making process through the models.

- On the producer side, based on the output of evaluation model and the received pickup plan and information, "Control" component can decide whether a replanning is necessary and how to modify model's parameters in such a way that the solution given by model could be more adapted to its environment.

– On the transport operator side, based on the received delivery plan and information, "Control" component can decide whether a replanning should be executed and how to reconfigure the model before replanning. It is also responsible for deciding how to respond to producer's demand based on the output of transportation planning.

<u>Information</u>

There are two kinds of information exchanged between two partners: information and plan.

– Information represents some necessary support data that is used to valuate parameters in decision making models. Referring to Figure 3.1, production information is for instance unitary weight of products; transportation information is for instance transportation price and delivery lead time.
– A plan is a set of organized information that corresponds to operational decisions to be followed. A delivery plan indicates the delivery quantities, the time to pickup and the destination. A pickup plan indicates the proposed delivery quantities, the time to pickup and the destination. A delivery plan and a pickup plan should be consistent after negotiation.

3.1.2 Objective and structure of chapter

Figure 3.1 shows the general framework of coordination between DMUs of producer and transport operator without any explicit details. There are still some questions waiting for answers. How the optimization models function in the "Models" component? How the "Control" component of one partner treats the output of models received from the other partner? How the "Control" components direct the decision making process to pass from one model to another?

Therefore, we have mainly two objectives in this chapter.

– The first objective is to build general analytic models which compose the "Models" components of the DMUs of producer and transport operator which will be explained in detail in section 3.2 and section 3.3.
– The second objective is to develop a negotiation protocol of one producer and one transport operator which defines how DMUs interact with each other through "Control" components. This will be explained in section 3.4.

The models and negotiation protocol in this chapter will serve as a base to simulate SC and to analyze important factors which affect production-transportation coordination and SC performance.

We use mathematical models and more precisely linear programming, to formalize the "Models" component within a DMU since it translates problems from an application area into tractable mathematical information (Penlope, 2007). The mathematical models are presented by a set of equations. Usually the goals of enterprise are abstracted as an objective function and expressed by mathematical expression. And the limitations such as capacity, priority are modeled as constraints and expressed by mathematical equations in the model.

This following part of this chapter is made up of four main parts: the first two present successively a set of production models and a set of transportation models embedded in the corresponding DMU; the third part describes the principles of coordination by negotiation of two DMU; the last part is the conclusion of this chapter.

3.2 Production models

We use production model to model the planning decision making performed by a production DMU. François (2006) has developed a general analytic production planning model in a multi-stage SC structure for enterprises involved in different supply chains whose common resource should be shared between different order makers. Our production models are based on this work. However, we suppose that:

- The inventory of raw materials required by the producer is infinite as we only focus on the interaction between producer and transport operator. Replenishment decisions of materials are not taken into account for the producer.
- The producer manufactures different products to satisfy the demands of different customers or customer zones with limited production and finished products storage capacities.
- Demands of products from all customers are known over a given non sliding planning horizon.
- Customers accept that the quantity of delivered products have small deviations from the initial ordered quantity. The deviation triggers a certain penalty cost so that early delivery and late delivery should be considered in the planning model.
- Producer knows the information of transportation prices and the delivery lead time to different customers.

The production models are modeled as linear integer programming. Different integer sets and indices are commonly used by all the models presented in this section. These sets and indices are labeled as follows:

<u>Sets and indices</u>

Sets

T		Set of periods composing the planning horizon
P		Set of products
J		Set of customers

Indices

t	$t \in T$	Index of planning period
p	$p \in P$	Index of products
j	$j \in J$	Index of customers

Generally, the planning horizon is composed by a set of time units and the plan can be updated after certain time units which are called period; for instance a period equals to two time units. Here since we make planning over a non-sliding time horizon, we do not distinguish "time unit" and "period". We use "period" to denote the "time unit" over the planning horizon as well. The "period" represents a time interval which specifies the precision of the planning. These models can be applied to make decisions for any time unit of the planning horizon e.g. each day or each month. In this thesis, we use day as time unit.

In this thesis, we identify three different purposes that a production model can serve as represented in Figure 3.1. Therefore in this section we will present a basis production model and two variations. The first one is a general production planning model referred to as "Best Profit Production" model with an aim of achieving a production plan to maximize the producer profit. It corresponds to the "Production planning" in producer DMU. The second and the third production models inherit of the main characteristics of the first one with a slight variation which corresponds to "Evaluation" and "Production replanning": the second one, referred to as "Evaluation Production" model, aims at evaluating whether a received pickup plan is feasible and what is the attained performance; the third one, referred to as "Released Production" model, releases the constraints of the first model after reconfiguration by partially releasing the profit obtained from the first model.

3.2.1 Best Profit Production model (BPP model)

Some basic elements of "Best Profit Production" model have been identified as shown in Figure 3.2.

- The customer demands are the external input;
- Production, inventory and delivery plans are the main output of the production planning;
- Local resource represents characteristics of production system.
- Objectives define the orientation of the expected output plans.

We should first define the hypothesis, objective, local resource and external environment before the modeling.

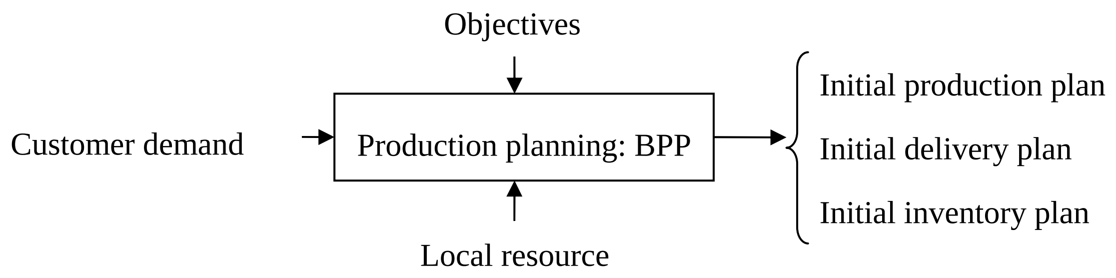


Figure 3.2 General view of production planning (BPP model)

The principle of a "Best Profit Production" model, labeled BPP model, is to make production, inventory, and delivery decisions with an objective of maximizing the company's profit.

- Producer's profit is the difference between revenue and its total costs that include production, inventory, transportation and penalty costs to customer which occur when the supplied quantity of the products have small deviations from the initial ordered quantity.
- Let us notice that in this production model, the early and late supplies are evaluated compared with the customers' demands. Both early supply and late supply trigger a penalty cost.
- The producer assigns to the customers different priorities to be served when the production capacity is not enough to fulfill total customers' demands. We express this kind of priority by employing different customer penalty costs. The higher penalty cost is, the higher priority to be served.

3.2.1.1 *Parameters and decision variables*

Some necessary parameters are identified for the execution of the production model which include external information and internal information. External information consists of shared information between the two operators, and external demands received from customers. Internal information consists of production lead time, capacity limitation and economic related information such as selling prices of products, production costs. All the parameters used in the production model are listed below:

<u>External information</u>

- Shared parameters

DT_j Transportation lead time to customer j

TP_j Transportation price per ton to customer j

v_p Unitary scalar of product p; this scalar represents weight or volume after packaging

- Demand parameters

$d_{p,j,t}$ Demand of product p from customer j at time period t

$Emax_{p,j}$ Maximum allowed early supplied quantity of product p to customer j per period

<u>Internal information</u>

- Production system parameters

DP_p Production lead time for producing product p

- Economic parameters

$SP_{p,j}$ Selling price of one unit product p to customer j

CS_p Unitary inventory cost of product p per period

CP_p Unitary production cost of product p

$CR_{p,j}$ Unitary late supplied cost of product per period

$CE_{p,j}$ Unitary early supplied cost of product p per period

- Capacity parameters

u_p Quantity of required resource for producing one unit of product p

$Pcap_t$ Production capacity at period t

$Icap_t$ Inventory capacity at period t

We have indentified the input and local parameters of production model and can consider decision variables as the model output which represents the planning decisions of production activities. As shown in Figure 3.2 we have identified three main output plans.

- **Production plan**. As regards the production system, it is important to specify how many products need to be produced at each time period. As there is production lead time, the production plan indicates the starting period of production activities. When the production activities finish, the finished products can either be transported to customers or rest in stock.

- **Delivery plan**. The delivery plan indicates how many products should be transported to each customer and the period on which the pickup should begin at producer.
- **Inventory plan**. Inventory plan represents the rest quantities of finished products in stock at the end of each period.

Besides these main decisions (i.e. production, delivery and inventory output plans) we identify two other considerations “late supplied quantity” and “early supplied quantity” in order to facilitate the presentation of production model, which represent the difference between the delivery quantity and customer demand at each time period,. The list of decision variables is as follows:

Decisions variables

$i_{p,t}$	Inventory level of product p at the end of period t
$b_{p,j,t}$	Late supplied quantity of product p for customer j at period t
$e_{p,j,t}$	Early supplied quantity of product p for customer j at period t
$f_{p,t}$	Production quantity of product p launched in production at period t
$l_{p,j,t}$	Delivery quantity of product p to be launched in transportation to customer j at period t

Since the decisions are the quantities of products, to present the practical meaning, these decision variables are defined as integers in the model.

3.2.1.2 *Constraints and objectives*

The decisions taken by production model are subject to the constraints of the production system, such as the availability of stock and production capacity. These constraints are expressed by some equations or inequalities. The constraints of a production model that we have identified for a production system are listed below.

Stock balance

$$i_{p,t} = i_{p,t-1} + f_{p,t-DP_p} - \sum_j l_{p,j,t} \qquad \forall p \in P, \forall t \in T . \qquad \text{(BPP.1)}$$

This constraint expresses the stock level of finished products. It describes the movement of the finished products which enter and leave the stock at each time period. The calculation of stock level of each product is based on the products rest in the stock, the entrance of the finished product and the departure of the delivery products at each time period. The quantities of finished products correspond to the production quantities which are launched in production before the production lead time. In this calculation, we suppose there is no loss of quantities during the transformation from material to qualified final products.

Deviation from customer demand

$$l_{p,j,t} + b_{p,j,t} - e_{p,j,t} = d_{p,j,t+DT_j} + b_{p,j,t-1} - e_{p,j,t-1} \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(BPP.2)}$$

This constraint expresses the difference between the required and the supplied quantities. Because of transportation lead time, the delivery quantity $l_{p,j,t}$ which is launched in transportation at time period t serves the demand at time period $t + DT_j$ if the pickup is on time. The supplied quantities can be less or a little more than the demand quantities. Therefore the difference can be sometimes positive or negative. In order to model this potential difference and to make all variables positive, two separated decision variables are used "early supplied quantities" and "late supplied quantities", which cannot be positive at the same time. These two variables represent an accumulated deviation from demand by taking into account the deviations of previous period. For example, if the late supplied quantities are 3 of previous period and the demand quantities are 10 in this period that means the delivery requirement of this period is 13; if the delivery quantities are only 11 in this period that means there are 2 late supplied units of product at this period.

Production resource capacity

$$\sum_p (u_p \cdot \sum_{\tau=1}^{DP_p} f_{p,t-\tau+1}) \leq Pcap_t \qquad \forall t \in T. \qquad \text{(BPP.3)}$$

This constraint guarantees the production loads respect production resource capacity. The calculation of production load has to take into account all the work-in-progress production tasks. As we mentioned above, $f_{p,t}$ represents the launch of production at time period t. Thus the production load at time period t equals the sum of $f_{p,t}$ over τ periods $1 \leq \tau \leq DP_p$, calculated by formula $\sum_{\tau=1}^{DP_p} f_{p,t-\tau+1}$.

Inventory capacity

$$\sum_p (v_p \cdot i_{p,t}) \leq Icap_t \qquad \forall t \in T. \qquad \text{(BPP.4)}$$

This constraint considers respecting inventory capacity, that is the space occupied by products in stock, must not exceed the total space of stock for each time period in the planning horizon. Here we apply this constraint in a general situation to all the products. It is also possible to apply this constraint to other more detailed limitations for example to limit the stocks of certain very expensive products. Products are supposed to have regular dimensions so that there is no space waste between products.

Early supply limitation

$$e_{p,j,t} \leq Emax_{p,j} \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(BPP.5)}$$

This constraint limits the early supplied quantities to customers who provide producer certain flexibility to supply products. Customers accept some quantities of early supplied products but with limitations and penalties. At each time period for each product the early supplied quantities of the product to a customer must not exceed the limitations defined by this customer.

Demand limitation

$$\sum_t l_{p,j,t} \leq \sum_t d_{p,j,t+DT_j} \qquad \forall p \in P, \forall j \in J. \qquad \text{(BPP.6)}$$

The constraint BPP.2 expresses that at each time period the supplied quantities can have small deviation from customer demand quantities; while this constraint ensures that the accumulated supplied quantities over the planning horizon of each product for each customer should not exceed the corresponding accumulated demand quantities of this customer.

Non-negative variables

$$i_{p,t}, b_{p,j,t,} e_{p,j,t,} f_{p,t}, l_{p,j,t} \geq 0 \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(BPP.7)}$$

Constraint BPP.7 ensures that all the variables in the model are positive. It guarantees the decisions taken by model should be realistic.

Objective

We have defined the parameters, decisions variables (output), constraints (local resource limitations); finally the objective of the production model is defined. To solve a planning problem, the resolution strategy can be modeled by one or several objectives. In our case, it is a mono objective function which is defined as an economic calculation taking into account the revenue, the production cost, the inventory cost, the transportation cost and the penalty cost. The objective is to maximize production profit, labeled "*P_profit*". The objective function of "Best Profit Production" model is presented as follows:

Max P_profit =Max(Revenue - Production cost - Inventory cost - Penalty cost (paid to customers) - Transportation fee (paid to transport operator)) (BPP.8)

Revenue = $\sum_t \sum_p \sum_j (SP_{p,j} \cdot l_{p,j,t})$ (BPP.9)

Production cost = $\sum_t \sum_p \left(CP_p \cdot f_{p,t}\right)$ (BPP.10)

Inventory cost =$\sum_t \sum_p \left(CS_p \cdot i_{p,t}\right)$ (BPP.11)

Penalty cost = $\sum_t \sum_p \sum_j (CR_{p,j} \cdot b_{p,j,t} + CE_{p,j} \cdot e_{p,j,t})$ (BPP.12)

Transportation fees =$\sum_t \sum_p \sum_j (TP_j \cdot v_p \cdot l_{p,j,t})$ (BPP.13)

The maximization of this objective function ensures the best production profit which takes into account the revenue by selling products (*SP*), the corresponding cost of production (*CP*), inventory cost(*CS*) and the penalty cost of not on time supplied quantities (*CR* and *CE*). The optimization model tries to avoid not on time supply in order to well satisfy customers' demand and consequently minimize the penalty costs, and also tries to decrease the inventory cost by minimizing inventory level. Of course we could also add new parameters such as security stocks to increase the elasticity of material flow to face the change of market. However, here we suppose the customers' demands are known over a given planning horizon which avoids the uncertainty. Thus security stock is not considered.

The ideal solution is as follows:

$e_{p,j,t} = 0 \qquad \forall p \in P, \forall t \in T, \forall j \in J.$

$b_{p,j,t} = 0 \qquad \forall p \in P, \forall t \in T, \forall j \in J.$

$l_{p,j,t} = d_{p,j,t+DT_j} \qquad \forall p \in P, \forall t \in T, \forall j \in J.$

$i_{p,t} = 0 \qquad \forall p \in P, \forall t \in T.$

This solution corresponds to a zero penalty cost solution.

3.2.1.3 *Numerical example*

Numerical example provides an impression of decisions format made by production model. In this example, two products are manufactured by one producer and delivered to two customers. Unitary early supplied cost is less than late supplied cost which means that customers prefer accepting early delivery products to late delivery products. The selling price to customer 2 is about 4 times of production cost and 1/5 of the selling price to customer 1. Production lead times for both products are 1 day. Total demand load can be calculated by formula $\sum_t \sum_j \sum_p v_p \cdot d_{p,j,t}$ over the planning horizon which is about 96 percent of total production capacity. Inventory capacity is sufficient. Both production capacity and inventory capacity are constant in each time period over the planning horizon. Transportation lead times to both customers are 1 day. The unitary scalar of product p could be weight or volume; in this example, we use weight. The various parameters of BPP model are presented in Table 3-1 to Table 3-3.The demands profile is given in Table 3-4 over a planning horizon of 7 days.

Table 3-1 Parameters of BPP model (Part 1)

	Unitary Late Supplied Cost (euro)		**Unitary Early Supplied Cost (euro)**		**Unitary Mean Production Cost (euro)**	**Unitary Mean Inventory Cost (euro)**	**Production Lead Time (day)**
	$CR_{p,j}$		**$CE_{p,j}$**		**CP_p**	**CS_p**	**DP_p**
	Customer 1	Customer 2	Customer 1	Customer 2			
Product 1	40	45	10	12.5	70	11.25	1
Product 2	50	55	15	17.5	90	16.25	1

Table 3-2 Parameters of BPP model (Part 2)

	Selling Price (euro)		**Maximum Quantity of Early Supplied Quantity (unit)**		**Quantity of Required Resource for producing one product unit (unit)**	**Unitary scalar of product p (weight)**
	$SP_{p,j}$		**$Emax_{p,j}$**		**u_p**	**v_p**
	Customer 1	Customer 2	Customer 1	Customer 2		
Product 1	1 350	270	4	4	1	5
Product 2	1 800	360	4	4	2	8

Table 3-3 Parameters of BPP model (Part 3)

Production Capacity (unit)	**Inventory Capacity (weight)**	**Transportation lead time (day)**	
$Pcap_t$	**$Icap_t$**	**DT_j**	
		Customer 1	Customer 2
920 ($\forall t$)	4 000 ($\forall t$)	1	1

Experiment results are shown in Table 3-4. The bold rows show the output of BPP model which correspond to production plan, delivery plan and inventory plan. Symbol "-" in the table represents the not available information which requires the information out of planning horizon in the future. The blue cells highlight the deviation of output decisions from delivery requirements.

Table 3-4 Results of BPP model

Product 1							
Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Demand of customer 1	0	0	130	150	170	150	120
Demand of customer 2	0	0	150	130	170	120	170
Total customer demand	0	0	280	280	340	270	290
Delivery requirement	0	280	280	340	270	290	-
Production quantities($f_{1,t}$)	**280**	**280**	**340**	**270**	**290**	**-**	**-**
Delivery quantities to customer 1($l_{1,1,t}$)	**0**	**130**	**150**	**170**	**150**	**120**	**-**
Late supplied quantities($b_{1,1,t}$)	**0**	**0**	**0**	**0**	**0**	**0**	**-**
Early supplied quantities ($e_{1,1,t}$)	**0**	**0**	**0**	**0**	**0**	**0**	**-**
Delivery quantities to customer 2($l_{1,2,t}$)	**0**	**150**	**130**	**170**	**120**	**170**	**-**
Late supplied quantities($b_{1,2,t}$)	**0**	**0**	**0**	**0**	**0**	**0**	**-**
Early supplied quantities($e_{1,2,t}$)	**0**	**0**	**0**	**0**	**0**	**0**	**-**
Total delivery quantities (customer1 and customer2)	0	280	280	340	270	290	-
Inventory quantities($i_{1,t}$)	**0**	**0**	**0**	**0**	**0**	**0**	**-**
Product 2							
Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Demand of customer 1	0	0	110	120	150	130	130
Demand of customer 2	0	0	200	210	170	200	150
Total customer demand	0	0	310	330	320	330	280
Delivery requirement	0	310	330	320	330	280	-
Production quantities($f_{2,t}$)	**320**	**320**	**290**	**325**	**315**	**-**	**-**
Delivery quantity to customer 1($l_{2,1,t}$)	**0**	**110**	**120**	**120**	**125**	**165**	**-**
Late supplied quantities($b_{2,1,t}$)	**0**	**0**	**0**	**30**	**35**	**0**	**-**
Early supplied quantities($e_{2,1,t}$)	**0**	**0**	**0**	**0**	**0**	**0**	**-**
Delivery quantities to customer 2($l_{2,2,t}$)	**0**	**200**	**210**	**170**	**200**	**150**	**-**
Late supplied quantities($b_{2,2,t}$)	**0**	**0**	**0**	**0**	**0**	**0**	**-**
Early supplied quantities($e_{2,2,t}$)	**0**	**0**	**0**	**0**	**0**	**0**	**-**
Total delivery quantities(customer1 and customer2)	0	310	330	290	325	315	-
inventory quantities($i_{2,t}$)	**0**	**10**	**0**	**0**	**0**	**0**	**-**

Both production and transportation activities have one time period duration. Therefore the figures in rectangles with bold lines (red rectangle) show that customer demand at time t should be transported at time t-1. In this example the customer demands of product 1 are well satisfied: the delivery quantities to customer 1 and customer 2 at each time period correspond exactly to the demand of customer 1 and customer 2 respectively. The delivery quantities to customer 1 and customer 2 of product 2 have deviations from demand of customer 1 and customer 2. In period 4, the delivery quantity to customer 1 of product 2 is 120 which will arrive at customer at period 5; there are 30 unsatisfied products compared to demand of customer 1 at period 5. In period 1, the production quantities of product 2 is 320; these products will be ready at period 2 because of production lead time and there are 310 products picked up and delivered to customers; consequently 10 products are left in storage.

3.2.2 Evaluation Production model (EP model)

“Best Profit Production” model (BPP model) makes a delivery plan by taking into account transportation constraints in the form of transportation lead time. In the context of collaboration, it is necessary for producer to be able to evaluate the feasibility of a pickup plan received from transport operator according to the constraints of production system. This is the purpose of “Evaluation Production” model (EP model). A general view of EP model is presented in Figure 3.3 where the difference with that of BPP model is the addition of pickup plan as input. If it is feasible, the output of EP model will show that the delivery plan (output) equals to this pickup plan (input).

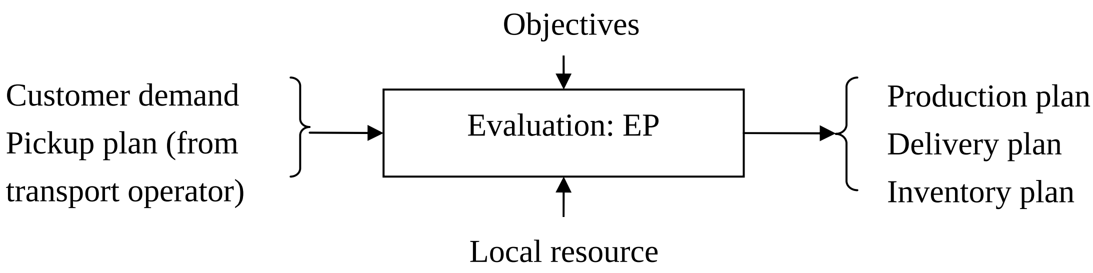


Figure 3.3 General view of evaluation (EP model)

Hypothesis

“Evaluation Production” model (EP model) is a variation of the “Best Profit Production” model. The parameters and decision variables of EP model are the same as those of BPP model. The only difference is that a new parameter $qq_{p,j,t}$, which represents a pickup plan, is added and one of the decision variables in BPP model. Delivery quantity $l_{p,j,t}$, should equal to this pickup plan. Constraints EP.1 to EP.7 are identical to constraints BBP.1 to BPP.7. The following new constraint is added:

$$l_{p,j,t} = qq_{p,j,t} \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(EP.8)}$$

This strong constraint compels the production model to strictly satisfy a pickup plan defined by the set of values $qq_{p,j,t}$.

In constraint EP.1 (corresponding to constraint BPP.1), EP model determines a production plan in order to minimize inventory level and constraint EP.3 verifies the production capacity. These two constraints are the main limitations to determine whether a pickup plan is feasible. In some cases, there is no feasible solution found with this additional constraint EP.8. It means that the pickup plan is impossible to be executed by producer under production capacity constraints; e.g. production model cannot find a production plan which can replenish inventory to satisfy the delivery quantity. A pickup plan is feasible for producer only when EP model can find a solution.

3.2.3 Released Production model (RP model)

The BPP model achieves a production plan which can be considered as the best solution for the producer when it is not involved in the logic of coordination and negotiation with its transportation environment. It could be the case of a monopolistic relation between producer and transport operator. However in the sense of the objectives of our research, a more flexible production planning is needed to complement the production DMU. In this case, producer may need to release certain constraints in order to find a less constrained solution to be adapted to transport operator. That is what “Released Production” model (RP) serves. The parameter labeled $dd_{p,j,t}$ is a pickup plan received from transport operator, which is taken into account in RP model as a target plan in order to release the output delivery plan. This model, which is presented in Figure 3.4, searches a solution which minimizes the deviation between the pickup plan and the released delivery plan with an expected profit which is decreased up to a certain acceptable level labeled “release lower profit bound of producer”.

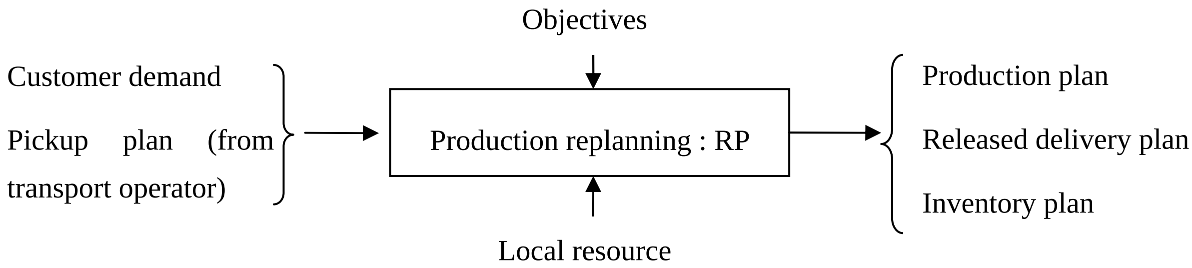


Figure 3.4 General view of production replanning (RP model)

Complementary to the parameters of BPP model, this model adds some other input parameters.

$dd_{p,j,t}$ Pickup plan received from transport operator, pickup quantity of product p in time period t to customer j

M Very big integer number

$minP$ Release lower profit bound of producer

The following additional decision variables are used:

$b_{p,j,t}^{\Delta P}$ Difference between quantity $l_{p,j,t}$ and $dd_{p,j,t}$; max(0, $dd_{p,j,t} - l_{p,j,t}$)

$e_{p,j,t}^{\Delta P}$ Difference between quantity $l_{p,j,t}$ and $dd_{p,j,t}$; max(0, $l_{p,j,t} - dd_{p,j,t}$)

$b\_control_{p,j,t}^{P}$ Binary variable, equals to 1 if $b_{p,j,t}^{\Delta P}$>0; otherwise equals to 0

$e\_control_{p,j,t}^{P}$ Binary variable, equals to 1 if $e_{p,j,t}^{\Delta P}$>0; otherwise equals to 0

$b_{p,j,t}^{\Delta P}$ and $e_{p,j,t}^{\Delta P}$ are integer variables which represent product quantities. Figure 3.5 shows the relation between the pickup plan ($dd_{p,j,t}$) and the released delivery plan ($l_{p,j,t}$). Parameter "$dd_{p,j,t}$" in this example is supposed to be constant in order to facilitate the visibility of the deviation of $l_{p,j,t}$ from $dd_{p,j,t}$.

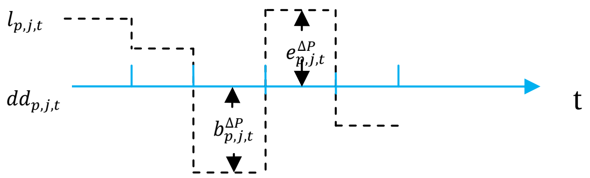


Figure 3.5 Relation between variables in "Released Production" model

Constraints RP.1 to RP.7 are identical to constraints BBP.1 to BPP.7. The following new constraints are added:

Deviation of released delivery plan from received pickup plan

$$l_{p,j,t} = dd_{p,j,t} - b_{p,j,t}^{\Delta P} + e_{p,j,t}^{\Delta P} \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(RP.8)}$$

$b_{p,j,t}^{\Delta P}$and $e_{p,j,t}^{\Delta P}$ represent the deviations of released delivery plan from the pickup plan. We use this two separated variables to ensure that all decision variables are positive.

Deviation control

$$b_{p,j,t}^{\Delta P} \leq M * b\_control_{p,j,t}^{P} \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(RP.9)}$$

$$e_{p,j,t}^{\Delta P} \leq M * e\_control_{p,j,t}^{P} \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(RP.10)}$$

$$b\_control_{p,j,t}^{P} + e\_control_{p,j,t}^{P} \leq 1 \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(RP.11)}$$

Constraints RP.9 and RP.10 express that if the deviation variable is positive, the corresponding control variable must be 1. Constraint RP.11 ensures that at the same time only one deviation variable can be positive.

Release constraint

$$P\_profit \geq minP \qquad \text{(RP.12)}$$

This constraint releases the profit of initial output plans of BPP model in which *P_profit* is identical to the one used in objective function BPP.8 of BPP model. However the expected profit has to be greater than a release lower profit bound labeled "*minP*" which ensures that a minimum profit could be obtained by producer.

Non-negative constraint

$$b_{p,j,t}^{\Delta P}, e_{p,j,t}^{\Delta P} \geq 0 \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(RP.13)}$$

Besides the non-negative variables limited in non-negative constraint RP.7, the new added variables are also non-negative variables.

Objective

The objective function of this model is formalized as follows:

$$Min\ (\sum_p \sum_j \sum_t (b_{p,j,t}^{\Delta P} + e_{p,j,t}^{\Delta P}) + \sum_p \sum_t i_{p,t}) \qquad \text{(RP.14)}$$

As we mentioned above the RP model tries to search a released delivery plan which minimizes the deviation from the received pickup plan of BPP model and also tries to minimize the inventory level. In the objective function BPP.8 of BPP model, the objective function limits inventory level implicitly. However we need to express it explicitly in objective function of the "Released Production" model. By minimizing the inventory level, the production quantities which replenish inventory are minimized at the same time by constraint RP.1 which is identical to BPP.1.

In the "Best Profit Production" model the objective function BPP.8 minimizes the not on time penalty costs, which limits implicitly that $b_{p,j,t}^{\Delta P}$ and $e_{p,j,t}^{\Delta P}$ cannot be positive at the same time. In the "Released Production" model, the objective function has changed. The minimization of the sum of $b_{p,j,t}^{\Delta P}$ and $e_{p,j,t}^{\Delta P}$ cannot guarantee that only one of $b_{p,j,t}^{\Delta P}$ and $e_{p,j,t}^{\Delta P}$ can be positive at the same time. For example, we compare the case that $b_{p,j,t}^{\Delta P}$ equals to 2 and $e_{p,j,t}^{\Delta P}$ equals to 5 with the case that $b_{p,j,t}^{\Delta P}$ equals to 0 and $e_{p,j,t}^{\Delta P}$ equals to 7. There is possibility that for both cases objective RP.14 is satisfied. However, $b_{p,j,t}^{\Delta P}$ equals to 2 and $e_{p,j,t}^{\Delta P}$equals to 5 at the same time are unrealistic. That is why constraints RP.9-RP.11 have been added.

3.3 Transportation models

Similar to production model, we develop transportation models to represent the behavior of the transportation planning component of transportation DMU. Transportation models also have different purposes to serve. Therefore, this section will present a basic transport model and its variation according to different purposes.

The transportation models are based on the main hypotheses as the following ones:

- Transport operator is a third party logistic provider. We do not explore in detail all the activities it performs such as dispatching, grouping of products at logistic platforms.
- The **transportation service is without inventory** over multiple time periods and its transportation capacity is shared among different customer zones.
- A depot is the location where trucks are parked when not in use. We suppose that the depot of transport operator is near producer, the travel time from depot to producer is thus neglected. **The trip of a truck is arranged as follows**: a truck departs from depot, picks up products at the producer, delivers products at customers and then comes back to depot in order to make another shipment.
- **The transport operator uses a fleet of homogeneous trucks** to transport the multiple products from the producer to the numerous customer zones. **Each truck has only one destination after departure so no vehicle routing** decisions are considered in this research.
- As we consider a tactical planning problem, the transportation resource unit is the truck. Consequently, the **transportation capacity is globally defined by a number of trucks**. The transportation decisions include the pickup quantities and the number of trucks used at each time instant, even if some trucks are not full.
- When transportation capacity gets shortage, transport operator may seek help from external environment. It could either outsource its transportation tasks or rent external transport resources. To focus on the decisions of transport operator's own activities, we only consider the case with **renting external transportation resource**.
- We suppose transportation cost consists of two parts: **destination related cost** (e.g. depreciation of truck, fuel cost) and **product related cost** (e.g. assurance of products). We suppose there is no product loss during the transportation.
- We suppose producer and transport operator have the same reference of products and customers and we also suppose they adopt **the same lengths of planning horizon and period** thus the information has the same degree of accuracy.

The hypotheses defined above make it possible to take into account simple real transportation situations with a limited modeling complexity. Let us remind that beyond the modeling of transportation and production DMUs, the goal of this work is the study of coordination between production and transportation activities.

Three transportation models are presented in the next sections. The first one is a general transportation planning oriented towards the achievement of a transportation plan maximizing the profit of the transport operator. The second and the third transportation models inherit of the main characteristics of the first one with a slight variation: the second one aims at providing the best service to its customers; the third one is able to partially release the profit which is obtained in the first model. Referring to Figure 3.1, the first and the second model correspond to transportation planning while the third one corresponds to transportation replanning. The difference of the first and the second model is only the objective: profit maximization or customer satisfaction maximization.

The indices used in transportation models are the same as those of production models and are recalled below.

Sets

T	Set of periods composing the planning horizon
P	Set of products
J	Set of customers

Indices

t	$t \in T$	Index of planning period
p	$p \in P$	Index of products
j	$j \in J$	Index of customers

3.3.1 Best Profit Transportation model (BPT model)

The basic elements of transportation planning are shown in Figure 3.6. The output pickup plan indicates transportation decisions based on the delivery plan received from producer.

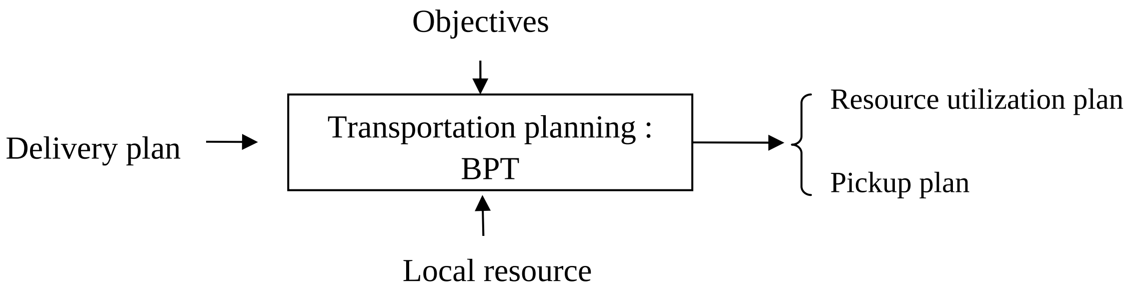


Figure 3.6 General view of transportation planning (BPT model)

The principle of a “Best Profit Transportation” model is to make pickup decisions with an objective of maximizing its profit. Transport operator’s profit is the difference between revenue and its total costs that include distance related cost, product related cost and penalty costs that must be paid to producer when the pickup quantities of the products have small deviations from the delivery plan. Let us notice that in this transportation model, the early and late pickup are evaluated compared with the delivery plan received from a producer. Both early pickup and late pickup trigger a penalty cost. So penalty costs in transportation model express a preference in priority of serving customers. The higher penalty cost is, the higher priority a customer to be served. Basic elements of a transportation model are presented in this section, including input parameters, local resource constraints, objectives and output decisions variables.

3.3.1.1 *Parameters and decision variables*

We identify some necessary parameters for the execution of the transportation model which include shared information which is identical to production model, the external information such as delivery plan received from producer, internal information such as the transportation lead time, capacity limitation and economic related information. All the parameters used in the transportation model are listed below:

External information

- Shared parameters

DT_j Transportation lead time to customer j

TP_j Transportation price per ton to customer j

v_p Unitary scalar of product p; this scalar represents weight or volume after packaging

- Demand parameters

$l_{p,j,t}$ Delivery quantity of product p required to be launched in transportation to customer j at period t

- External resource parameters

cap_{extra} Load capacity of an external truck

FC_extra_j Destination related cost per external truck

$M\_extra_{j,t}$ Limit of the number of external trucks at period t to customer j

Internal information

- Transportation system parameters

D_j Transportation lead time of a round trip from depot though customer j back to depot

- Economic parameters

FC_j Destination related transportation cost to customer j per truck

VC_p Unitary product related transportation cost of product p

$EC_{p,j}$ Unitary penalty cost per period of product p delivered earlier than the due time to customer j

$BC_{p,j}$ Unitary penalty cost per period of product p delivered later than the due time to customer j

- Operator-owned resource parameters

cap Load capacity of a truck

R Number of trucks initially available: initial transportation capacity of transport operator

Concerning the transportation system parameters presented above, we specify two kinds of lead time: DT_j indicates the transportation lead time from depot to a specific customer which is the shared information with producer; D_j indicates the round trip time which is the lead time from depot to a specific customer and then back to depot. Obviously there is $D_j > DT_j$. Let us remind that the time from depot to producer is neglected. During the lead time from customer to depot D_j - DT_j, the trucks are empty but the resources are still occupied and cannot be used to execute other transportation tasks. Therefore, DT_j is used to calculate the pickup time in order to deliver products at right time at customer as presented in production model while D_j is used to precisely calculate the availability of resources.

Concerning the operator-owned and external resource parameters defined above, the capacity of a truck can be defined by a scalar such as the maximum of weight or volume. As mentioned in the transportation modeling hypotheses, if the transportation capacity gets shortage, we consider that it rents external transportation resource.

As a transportation system, it is important to specify how many products can be transported and how many trucks are needed at each time period. As there is transportation lead time, the pickup decisions should indicate the starting period of transportation activities. It should also be able to specify how many external resources are required, specifically how many external trucks need to be rent. As a consequence, we have mainly two kinds of decisions, pickup plan and corresponding resource allocation plan. A list of decision variables is defined as follows:

Decision variables

$q_{p,j,t}$ Pick up quantity of product p to be launched in transportation from producer at time period t to customer j

$m_{j,t}$ The number of trucks launching transportation from producer at time period t to customer j

$m\_extra_{j,t}$ The number of external trucks launching transportation from producer at time period t to customer j

$tb_{p,j,t}$ Late pickup quantities of product p at time period t to customer j

$te_{p,j,t}$ Early pickup quantities of product p at time period t to customer j

For the same reason as in the production model, in order to have practical meaning, these decision variables are defined as integers.

3.3.1.2 *Constraints and objectives*

The decisions taken by transport model are subject to the constraints of the transportation system, such as the availability of transportation resource. The constraints that we have identified for a transportation model are listed below.

Deviation from delivery plan

$$q_{p,j,t} - te_{p,j,t} + tb_{p,j,t} = \; l_{p,j,t} - te_{p,j,t-1} + tb_{p,j,t-1} \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(BPT.1)}$$

This constraint expresses the difference between delivery plan sent by producer and pickup quantities proposed by transport operator which is similar to constraint BPP.2. The pickup quantities can be less or a little more than the delivery plan quantities according to the limitations of transportation capacity. Therefore the difference can be sometimes positive and sometimes negative. That is why two separate secondary variables are added to ensure that all variables are positive.

Transportation resource capacity

$$\sum_p v_p \cdot q_{p,j,t} \leq m_{j,t} \cdot cap + m\_extra_{j,t} \cdot cap_{extra} \qquad \forall t \in T, \forall j \in J. \qquad \text{(BPT.2)}$$

$$\sum_j \sum_{i=1}^{D_j} m_{j,t-i+1} \leq R \qquad \forall t \in T. \qquad \text{(BPT.3)}$$

$$m\_extra_{j,t} \leq M\_extra_{j,t} \qquad \forall t \in T, \forall j \in J. \qquad \text{(BPT.4)}$$

These constraints guarantee the transportation loads respect transportation resource capacity. There are two kinds of resource: operator-owned trucks and external trucks. The operator-owned trucks have fixed capacity and the total number of operator-owned trucks is limited; the external trucks have certain flexibility so that each time period, transport operator can seek for them if they are needed. Constraint BPT.2 expresses these limitations. Constraint BPT.3 ensures the respect of operator-owned transportation resources. As we mentioned above, D_j represents the transportation lead time of a round trip. Although the trucks are empty after delivery they are still occupied. Thus the calculation of occupied trucks at time period *t* has to consider the sum of $m_{j,t}$ over i periods $1 \leq i \leq D_j$. Constraint BPT.4 ensures the respect of external resource limitations. Let us remark that by setting the limitation of external resources $M\_extra_{j,t}$ to be 0, it expresses the situation where there is no possibility to use external transportation resource. Hence, this parameter enables the transportation model to get a certain flexibility existing in a real world environment.

Demand limitation

$$\sum_p \sum_t q_{p,j,t} \leq \sum_p \sum_t l_{p,j,t} \qquad \forall j \in J. \qquad \text{(BPT.5)}$$

The constraint BPT.1 expresses that at each time period the pickup quantities can have small deviations from delivery plan quantities while this constraint ensures that the accumulated pickup quantities over the planning horizon of all products to each customer must not exceed the corresponding accumulated delivery plan quantities of this customer.

Non-negative variables

$$q_{p,j,t}, tb_{p,j,t}, te_{p,j,t}, m_{j,t}, m\_extra_{j,t} \geq 0 \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(BPT.6)}$$

This constraint ensures that all the variables in the model are positive. To remind, all the variables are integers too.

Objective

The last part characterizes the objective of the transportation model. One of the most general objectives is to maximize transportation profit. The objective function of "Best Profit Transportation" model, labeled "*T_profit*", is presented as follows:

Max T_profit=Transportation revenue received from producer– Distance related cost –Product related cost– Penalty cost – External cost (BPT.7)

Transportation revenue $=\sum_p \sum_j \sum_t TP_j \cdot v_p \cdot q_{p,j,t}$ (BPT.8)

Distance related cost $= \sum_j \sum_t FC_j \cdot m_{j,t}$ (BPT.9)

Product related cost $= \sum_p \sum_j \sum_t VC_p \cdot q_{p,j,t}$ (BPT.10)

Penalty cost $= \sum_p \sum_j \sum_t (BC_{p,j} \cdot tb_{p,j,t} + EC_{p,j} \cdot te_{p,j,t})$ (BPT.11)

External cost $= \sum_j \sum_t FC\_extra_j \cdot m\_extra_{j,t}$ (BPT.12)

The maximization of this objective function ensures the best transportation profit takes into account the revenue by transportation price (*TP*), the corresponding cost of distance related cost (*FC*), product related cost (*VC*) and the penalty cost of not on time pickup quantities (*BC* and *EC)* and also the external resource cost (*FC_extral*). The optimization model tries to avoid not on time pickups in order to well satisfy producer's delivery plan, furthermore to minimize the penalties costs. And also it tries to increase the utilization rate of local trucks instead of using external resource especially make full use of the capacity of each truck.

The ideal solution is as follows:

$te_{p,j,t} = 0 \quad \forall p \in P, \forall t \in T, \forall j \in J.$

$tb_{p,j,t} = 0 \quad \forall p \in P, \forall t \in T, \forall j \in J.$

$q_{p,j,t} = l_{p,j,t} \quad \forall p \in P, \forall t \in T, \forall j \in J.$

$m\_extra_{j,t} = 0 \quad \forall t \in T, \forall j \in J.$

This solution corresponds to zero penalty cost and zero external cost solution.

3.3.1.3 *Numerical example*

In order to have an impression of the decisions of transportation model, a small numerical example is presented as follows. In this example, two products and two customers are considered for transport operator. The cost of using external transportation resource is 100 times more than local resource. The planning horizon is 7 days. Because of this expensive cost, transport operator can only use local resource. The parameters of BPT model are shown in Table 3-5 to Table 3-7.

Table 3-5 Parameters of BPT model (Part 1)

	Late Delivery Penalty Cost		**Early Delivery Penalty Cost**		**Handling Cost**
	$BC_{p,j}$		**$EC_{p,j}$**		**VC_p**
	Customer 1	Customer 2	Customer 1	Customer 2	
Product 1	40	45	20	25	2
Product 2	50	55	30	35	3

Table 3-6 Parameters of BPT model (Part 2)

	Destination Related Transportation Cost (euro/ truck)	**Extra Transportation Cost / Truck (euro)**	**Transportation Lead Time (day)**	**Transportation Roud Trip Lead Time (day)**	**Transportation Price (euro/ ton)**
	FC_j	**FC_extra_j**	**DT_j**	**D_j**	**TP_j**
Customer 1	600	60000	1	2	12
Customer 2	800	80000	1	3	10

Table 3-7 Parameters of BPT model (Part 3)

Limit of Extra Capacity (unit)	**Number of Truck (unit)**	**Load Capacity of a Truck (weight)**
$M\_extra_{j,t}$	**R**	**Cap**
0 ($\forall j, \forall t$)	115	100

The experiment results are shown in Table 3-8.The bold rows show the output of BPT model which correspond to pickup plan and resource utilization plan. In this example, the producer's delivery plans of both customers are not been satisfied in some periods as shown in blue cells. The pickup quantity has a deviation from delivery plan quantities in these periods. Because of transportation lead time, the product launched in transportation at period t can be delivered at customer at period $t+1$. The symbol "-" in the table represents the not available information which requires information out of planning horizon in the future. This numerical example is a preliminary validation of BPT model and gives output plans of a simple test case.

Table 3-8 Results of BPT model

Customer 1							
Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Product1							
Delivery plan	0	130	150	170	130	170	179
Pickup quantity	**0**	**132**	**151**	**167**	**130**	**170**	**179**
Early pickup quantity	0	2	3	0	0	0	0
Late pickup quantity	0	0	0	0	0	0	0
Product 2							
Delivery plan	0	110	120	110	130	130	108
Pickup quantity	**0**	**113**	**118**	**108**	**131**	**130**	**108**
Early pickup quantity	0	3	1	0	0	0	0
Late pickup quantity	0	0	0	1	0	0	0
Total load	0	1564	1699	1699	1698	1890	1759
Number of trucks needed	**0**	**16**	**17**	**17**	**17**	**19**	**18**
Customer 2							
Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Product 1							
Delivery plan	0	150	130	170	200	170	120
Pickup quantity	**0**	**150**	**132**	**168**	**200**	**170**	**120**
Early pickup quantity	0	0	2	0	0	0	0
Late pickup quantity	0	0	0	0	0	0	0
Product 2							
Delivery plan	0	200	210	170	200	150	120
Pickup quantity	**0**	**205**	**205**	**170**	**200**	**150**	**120**
Early pickup quantity	0	5	0	0	0	0	0
Late pickup quantity	0	0	0	0	0	0	0
Total load	0	2390	2300	2200	2600	2050	1560
Number of trucks needed	**0**	**24**	**23**	**22**	**26**	**21**	**16**

3.3.2 Best Service Transportation model (BST model)

“Best Profit Transportation” model searches to maximize transport operator’s profit. However, the transport operator may also have other performance to improve, such as quality of service. That is what “Best Service Transportation” model (BST model) serves. It searches for a pickup plan which is considered as the best response to producer’s delivery plan under transportation capacity constraints. A general view of BST model is presented in Figure 3.7.

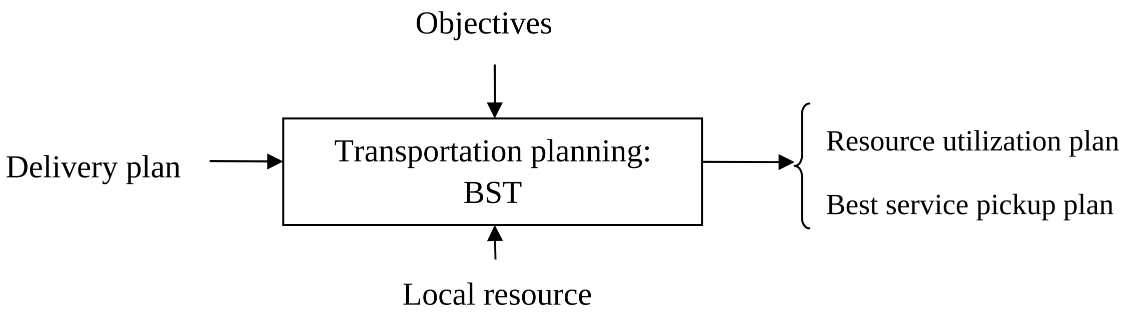


Figure 3.7 General view of transportation planning (BST model)

“Best Service Transportation” model is a variation of “Best Profit Transportation” model. The parameters and decision variables of BST model are the same as those in BPT model; constraints BST.1 to BST.6 are identical to constraints BPT.1 to BPT.6. Only objective functions are different.

Objective function

Min (Total not on time deliveries + The number of extra trucks) (BST.7)

Total not on time deliveries$=\sum_p \sum_j \sum_t (tb_{p,j,t} + te_{p,j,t})$ (BST.8)

The number of extra trucks$=\sum_t \sum_j (m\_extra_{j,t})$ (BST.9)

The “Best Profit Transportation” model (BPT model) searches to maximize transportation profit. In order to save distance related cost, the transport operator may make full use of the capacity of each truck which may cause more deviation of pickup quantities from delivery plan. The “Best Service Transportation” model (BST mode) searches for the pickup plan which is the closest to the delivery plan. Of course, it may take more cost than the pickup plan decided by “Best Profit Transportation” model (BPT model). In the BPT model, the objective function maximizes transportation profit and minimizes implicitly the number of extra trucks. In BST model, there is no constraint which limits the utilization of extra trucks so that we need to express it explicitly in the objective function of the “Best Service Transportation” model (BST.7).

3.3.3 Released Transportation model (RT model)

RT model is used to progressively release certain constraints of BPT model in order to respond to producer’s demand. RT model takes into account best service pickup plan and tries to search for a solution which minimizes the deviation from best service pickup plan but with an expected profit which should not be lower than certain level labeled “release lower profit bound of transport operator”. Figure 3.8 shows a general view of RT model.

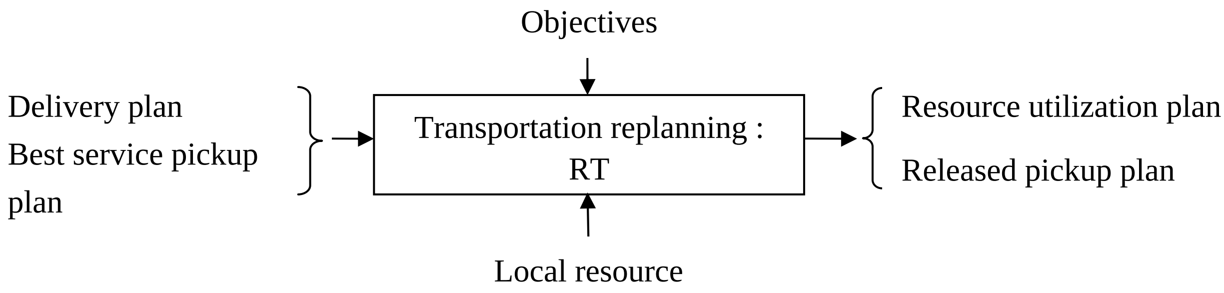


Figure 3.8 General view of transportation replanning (RT model)

Besides the parameters of BST model, RT model adds some other parameters.

$q^{*}_{p,j,t}$	Best service pickup plan, quantities of product p in time period t delivered to customer j
M	Very big integer number
$minT$	Release lower profit bound of transport operator

The following additional decision variables are used:

$b^{\Delta T}_{p,j,t}$	Difference between best service pickup plan $q^{*}_{p,j,t}$ and released pickup plan $q_{p,j,t}$; max $(q^{*}_{p,j,t} - q_{p,j,t}, 0)$
$e^{\Delta T}_{p,j,t}$	Difference between best service pickup plan $q^{*}_{p,j,t}$ and released pickup plan $q_{p,j,t}$; max$(q_{p,j,t} - q^{*}_{p,j,t}, 0)$
$b\_control^{T}_{p,j,t}$	Binary control variable which indicates whether $b^{\Delta T}_{p,j,t}$ is positive, equals to 1 if $b^{\Delta T}_{p,j,t}$>0; otherwise equals to 0
$e\_control^{T}_{p,j,t}$	Binary control variable which indicates whether $e^{\Delta T}_{p,j,t}$ is positive, equals to 1 if $e^{\Delta T}_{p,j,t}$>0; otherwise equals to 0

Similar to RP model, $b^{\Delta T}_{p,j,t}$ and $e^{\Delta T}_{p,j,t}$ are integer variables. Figure 3.9 shows the relation between best service pickup plan $q^{*}_{p,j,t}$ and the released pickup plan $q_{p,j,t}$.

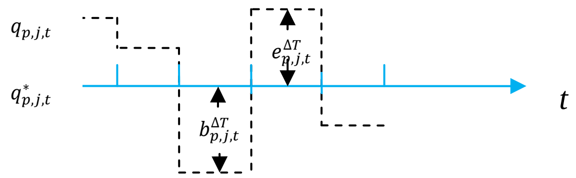


Figure 3.9 Relation between variables in “Released Transportation” model

Constraints RT.1 to RT.6 are identical to constraints BPT.1 to BPT.6. The following new constraints are added:

Deviation of released pickup plan from best service pickup plan

$$q_{p,j,t} = q^{*}_{P,j,t} - b^{\Delta T}_{p,j,t} + e^{\Delta T}_{p,j,t} \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(RT.7)}$$

$b^{\Delta T}_{p,j,t}$ and $e^{\Delta T}_{p,j,t}$ represent the deviations of released pickup plan $q_{p,j,t}$ from best service pickup plan $q^{*}_{P,j,t}$. We use these two separated variables to ensure that all decision variables are positive.

Deviation control

$$b^{\Delta T}_{p,j,t} \leq M \cdot \text{b\_control}^{\text{T}}_{p,j,t} \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(RT.8)}$$

$$e^{\Delta T}_{p,j,t} \leq M \cdot \text{e\_control}^{\text{T}}_{p,j,t} \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(RT.9)}$$

$$b\_control^{T}_{p,j,t} + e\_control^{T}_{p,j,t} \leq 1 \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(RT.10)}$$

For the same reasons as in “Released Production” model (RP model), these three constraints ensure that $b^{\Delta T}_{p,j,t}$ and $e^{\Delta T}_{p,j,t}$ cannot be positive at the same time.

Release of profit

$$T\_profit \geq minT \qquad \text{(RT.11)}$$

T_profit corresponds to formulation in BPT.7. This constraint releases the profit of best profit transportation plan (BPT model); the profit has to be greater than a release lower profit bound labeled m*inT*.

Non-negative variables

$$b^{\Delta T}_{p,j,t}, e^{\Delta T}_{p,j,t} \geq 0 \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(RT.12)}$$

Besides non-negative variables limited in non-negative constraint RT.6, the new adding variables are also non-negative variables.

Objective

$$\text{Min} \sum_{p} \sum_{j} \sum_{t} (b^{\Delta T}_{p,j,t} + e^{\Delta T}_{p,j,t}) \qquad \text{(RT.13)}$$

As we mentioned above the objective of “Released Transportation” model is to minimize the deviation from best service pickup plan. Constraint RT.11 limits the expect profit so as to limit the utilization of external transportation resource since it is more expensive than the local one. Therefore we do not minimize the external resource in the objective function RT.13 as what we have done in the objective function BPT.7.

3.4 Principle and specification of coordination based on negotiation

The different actors in charge of executing production and transportation activities both pursue the maximization of their own benefits. Conflicts often arise between them. Negotiation should be an efficient way to resolve conflicts of interest and reach an agreement potentially acceptable for all involved partners. Until now we have defined production models and transportation models with different purposes which correspond to the “Models” component of production and transportation DMUs respectively. The output of these models serves as input to “Control” components. In this section, we will present “Control” component which is the other component of DMU as shown in Figure 3.1 and is responsible for making negotiation decisions. We will explain how “Control” component functions; how “Control” component interacts with “Models” component within the same DMU; how “Control” component interacts with other DMU. In brief, we explain what to negotiate and how to negotiate in this section which corresponds to the notion “negotiation objects” and “negotiation protocol” as defined in section 2.2.2.3 in chapter 2.

In this section we focus especially on one-to-one negotiation, one producer and one transport operator. An extension of this principle to “one-to-many” negotiation will be discussed in the chapter 5 which will focus on the coordination between one producer and many transport operators.

3.4.1 Hypotheses

Contract imposes a legal obligation between partners of the supply chain. Negotiation could occur before or after contract. For instance, the supplier selection requires negotiation. After contracting, when there is disagreement which is not defined in the contract, negotiation can also be used. Therefore in this thesis, the first thing we need to decide is whether the production and transportation activities take place before contracting or after contracting. The decisions varies in the two cases, before contracting the decisions are such as selecting partners, negotiating price while after contracting the negotiation space is narrowed by terms in contract.

Before contracting

If negotiation process takes place before contracting, a producer has to select transport operators to accomplish transport activities among many transport operators in market which offer their services. It is a supplier selection problem. In this case, it means a supply chain has not been established. The decisions regarding supplier selection and strategic partnering are decisions made at strategic level.

After contracting

If negotiation process takes place after contracting, it means that a producer already found its transport operators to accomplish transport activities and signed contract with them. The terms in the contract should specify transportation prices, responsibility and penalty, payments transfer type and a global demand, which are negotiable before contracting. But the concrete demand quantities required during each time unit which are expressed by transportation or production plans are determined later and may be negotiable within a certain range defined in contract by partners during the operation process. They are tactical decisions to determine rough quantities and time for the flows and resources in a given supply chain. To face uncertainty on delivery plan, the transport operators has to find extra transportation resource when their capacity is insufficient to accomplish all required transportation tasks. In this situation, it is assumed that transport operator is responsible for the cost of extra transportation resources.

Consequently, we consider the problem in which the partnership relations already exit. Producer and transport operator have signed a global contract to define the framework of collaboration and detail all necessary information such as price, global quantity for a long period, each partner’s responsibility and penalty. But the demand quantities for more detailed time period are not specified in contract and are regularly negotiated during the operation process.

Referring to section defining the coordination by contract of chapter 2, we assume that contract signed between producer and transport operator defines:

- **Horizon length**: we suppose that in our case the contract is valid in one year.
- **Pricing**: transportation price is measured per ton to a given customer. Not on time delivery penalties are defined according to products and customers.
- **Information sharing**: transport operator share information of transportation price and transportation lead time regarding different destinations.
- **Quantity**: the required delivery quantities in each time period is not defined.

3.4.2 Notations in negotiation protocol

Several models were defined in the production and transportation DMUs. In the environment of negotiation, information is exchanged between models. To facilitate the explanation, we present some notations first.

The following notations, shown in Table 3-9, are adopted to mention planning models, output plan and corresponding profit (objective function) of a given model.

Table 3-9 Notations

	Production			**Transportation**		
Model Name	**BPP**	**EP**	**RP**	**BPT**	**BST**	**RT**
Output Plan Name	Delivery plan	Feasible delivery plan	Released delivery plan	Best profit pickup plan	Best service pickup plan	Released pickup plan
	P_{BPP}	P_{EP}	P_{RP}	P_{BPT}	P_{BST}	P_{RT}
Profit	G_{BPP}	G_{EP}	G_{RP}	G_{BPT}	G_{BST}	G_{RT}

In the following part, in order to simplify the notation and the description of the negotiation protocol, we introduce the notation $P_T \in \{P_{BST}, P_{BPT}, P_{RT}\}$ which denotes the pickup plan received from transport operator and $G_T \in \{G_{BST}, G_{BPT}, G_{RT}\}$ which denotes the corresponding profit.

The objective functions of different models express the problem-solving strategy. Profits assessment allows evaluating the individual performance of each partner in planning their activities. No matter the models we select, profits are calculated following the same logic that is expressed in the objective function in corresponding "Best Profit" models: *P_profit* or *T_profit*

Profit of producer *P_profit*

G_{BPP}, G_{EP} and G_{RP} are profits related to producer's solutions, they are calculated by the same formula of *P_profit* as presented below using the parameters of corresponding solutions:

P_profit =

$$\sum_t \sum_p \sum_j (SP_{p,j} \cdot l_{p,j,t}) - \sum_t \sum_p (CP_p \cdot f_{p,t}) - \sum_t \sum_p (CS_p \cdot i_{p,t}) - \sum_t \sum_p \sum_j (CR_{p,j} \cdot b_{p,j,t} + CE_{p,j} \cdot e_{p,j,t}) - \sum_t \sum_p \sum_j (TP_j \cdot v_p \cdot l_{p,j,t})$$

Profit of transport operator *T_profit*

G_{BPT}, G_{BST} and G_{RT} are transport operator's solutions, similarly they are calculated by the following formula of *T_profit* using the parameters of correspond solutions:

$$T\_profit = \sum_p \sum_j \sum_t TP_j \cdot v_p \cdot q_{p,j,t} - \sum_j \sum_t FC_j \cdot m_{j,t} - \sum_p \sum_j \sum_t VC_p \cdot q_{p,j,t} - \sum_p \sum_j \sum_t (BC_{p,j} \cdot tb_{p,j,t} + EC_{p,j} \cdot te_{p,j,t}) - \sum_j \sum_t FC\_extra_j \cdot m\_extra_{j,t}$$

3.4.3 Negotiation protocol

Negotiation protocol is the most critical part to define in this thesis. An efficient negotiation protocol may lead to win-win situation for both partners. In the following sections, we will propose a negotiation protocol between one producer and one transport operator based on the various hypotheses presented above.

3.4.3.1 *Global view of negotiation protocol*

Globally the negotiation process between producer and transport operator may consist in several iterations as shown in Figure 3.10. Producer sends an initial delivery plan to transport operator and transport operator responds by a pickup plan; during negotiation, each partner intends to maximize his own profit.

When a pickup plan totally matches with a delivery plan, a converged solution comes up. Otherwise, producer may reject the pickup plan proposed by transport operator, considering that its own profit is too low or all production constraints cannot be respected according to the received plan. Producer first refuses to modify its initial delivery plan; transport operator so needs to make a new pickup plan, called released pickup plan, by releasing some economic constraints (i.e. iteration 2).

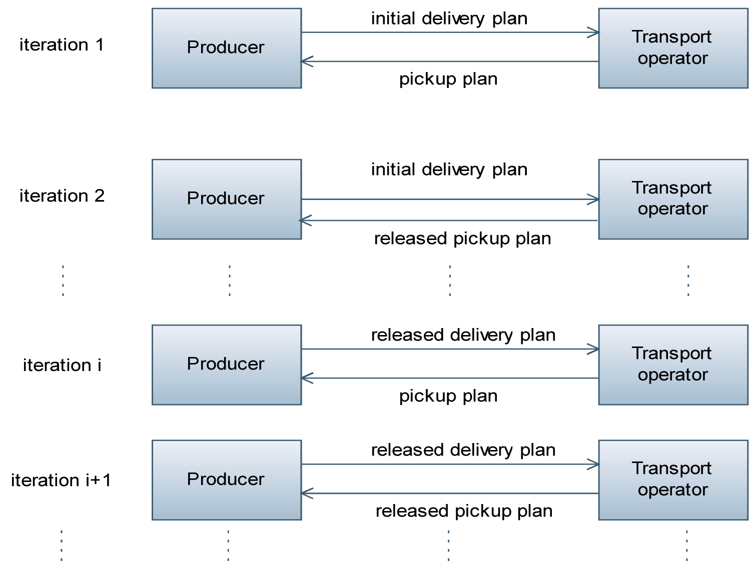


Figure 3.10 Negotiation iterations

It may happen that transport operator cannot release anymore while any proposed pickup plan has never been considered as acceptable by producer (in this particular one-one relation); producer then has to adapt his production to the constraints expressed by the transport operator, so as to generate a released delivery plan (i.e. iteration i). In this case, a new round negotiation repeats the same process until a converged solution is found. The transport operator progressively reduces its economic conditions (in term of profit), intending to send an acceptable pickup plan to the producer.

The negotiation process consumes time and cost. Therefore it should be controlled and be viewed as a failure if it cannot converge within certain iterations.

Figure 3.11 shows the DMUs of the two partners. The main decision path (thin arrow) within a DMU and the information exchanged (bold arrow) between DMUs are presented. The blue blocks represent models element inside “Models” component and the yellow ellipses show control elements inside “Control” component according to the general cooperation framework presented at the beginning of this chapter (Figure 3.1).

Broadly speaking, the negotiation process starts with the calculation of the production plan (made by the “Best Profit Production” model), from which delivery plan is deduced and sent to the transport operator. Transport operator estimates the delivery plan of producer through the elaboration of two plans, best profit pickup plan P_{BPT} and best service pickup plan P_{BST}, which respectively characterize the upper and lower limits of his profit. The defined value domain thus is called “negotiation space” of transport operator which will be discussed later.

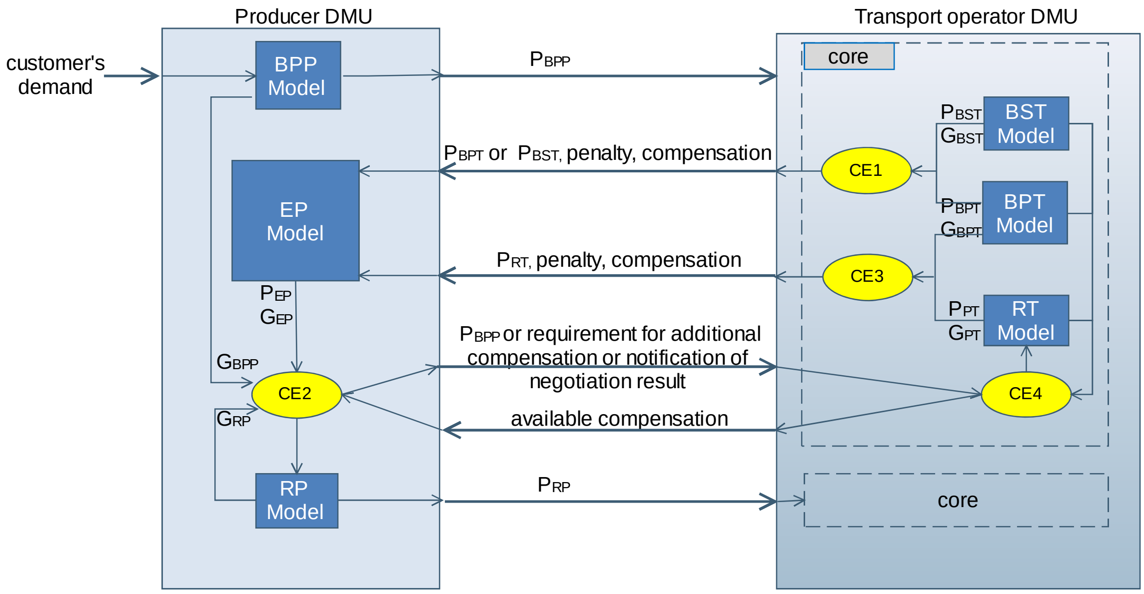


Figure 3.11 One-to-one negotiation process between DMUs

The transport operator then decides on what kind of pickup plan can be proposed to producer and calculates financial compensation and penalties. This set of decisions is represented on the scheme by a “control element”, called CE1.

After receipt of this proposition from transport operator, producer evaluates (with “Evaluation Production” model) whether pickup constraints are consistent with production capacities, and whether the received plan enables him to have enough benefits. In case of no sufficient profit, producer may require more additional compensation; if the received pickup plan is considered as unacceptable and transport operator cannot release anymore, producer has to release some financial constraints and modify its initial delivery plan. This decision making process concerns a new control element, called CE2.

Decision made by the transport operator then depends on the producer requirement, evaluated through the control element CE4. When necessary, a released pickup plan is calculated by the transport operator, and new values of compensation and penalties are assessed based on decisions made in the control element CE3 before these data were dispatched to the producer.

Each time the producer releases delivery plan, the transport operator will repeat the same process of the block labeled “core” which shows the main process of transport operator.

Having presented the elementary principle of negotiation, we will detail the different elements (i.e. model and control) of the negotiation, starting with the key determinants of the negotiation protocol.

3.4.3.2 *Key determinants of negotiation protocol*

No negotiation really exists if no decisional flexibility exists between the two involved partners. The objective of negotiation is to use this flexibility and information exchange to achieve a win-win situation as possible as they can. The negotiation protocol proposed in this thesis uses some fundamental notions which must be presented: negotiation space, plans acceptance criterion, compensation and release degree. Particularly the notion of compensation plays an important role to achieve a win-win negotiation result.

Negotiation space

As previously mentioned, the negotiation space is a range of possible values on a one dimension axis representing the profit for each partner. In our case, the two partners negotiate on any delivery and pickup plan which makes the profit as higher as possible for each partner.

Transport operator: considering the transport operator, the negotiation space shown in Figure 3.12 is defined by upper and lower bounds, respectively denoted by $\overline{G}^T$ and $\underline{G}^T$, representing the profit obtained when the pickup plan corresponds to the maximization of the profit of transport operator (calculated by the BPT model) or when the plan is the one that serves the producer demand as best as possible (elaborated by the BST model). The profit of RT model G_{RT} is included in $[G_{BST},\ G_{BPT}]$

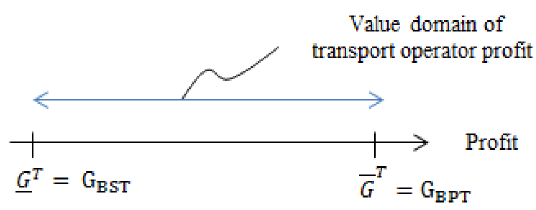


Figure 3.12 Negotiation space of the profit of transport operator

Producer: Figure 3.13 shows the negotiation space of the producer. When the initial delivery plan requested by the producer cannot be completely performed by the transport operator, the latter has to propose a pickup plan with early and late pickup comparing with the pickup time required by producer. In this context, the producer must estimate if this proposition is feasible, taking into account all constraints ("Evaluation Production" model) and if it is financially interesting for him.

A principle similar to the one used by the transport operator may be used to define the value domain of profit considered as acceptable by the producer. The expected profit value $\overline{G}^P$ corresponds to benefits G_{BPP} or G_{RP} that producer has respectively estimated through the calculation of initial delivery plans ("Best Profit Production" model), or through the calculation of a released delivery plan ("Released Production" model). This value, strictly speaking, does not limit the profit of producer and cannot be assimilated to an upper bound. This expected profit value is only used to estimate the lower profit bound, above which the producer's profit is considered acceptable.

The lower bound is more difficult to define, considering the following hypotheses:

- Taking into account the fact that producer has no available additional capacity to produce as close as possible to customer's demand, it is possible that profit maximizing plan and customer service rate maximizing plan are close to each other. The profit gap between these two plans is not sufficient to define a negotiation space large enough to give flexibility to producer's decisions.
- The transport operator's impossibility of performing a pickup plan which is consistent with producer's delivery plan leads the latter to accept to degrade its own performance because producer has no other alternative but one transport operator to deliver the products to customers. When transportation capacities are strongly constrained, the final producer's profit can be under the expected profit when he intends to calculate a released delivery plan which is close to the customer's demand and is adapted to transportation capacity at meanwhile.

On these evidences, the lower bound $\underline{G}^P$ i.e. the minimum of profit expected by the producer, is then defined relative to the expected profit value $\overline{G}^P$, based on the following expression:

$$\underline{G}^P = \overline{G}^P \cdot R_G$$

where R_G expresses the percentage reduction in the expected profit value.

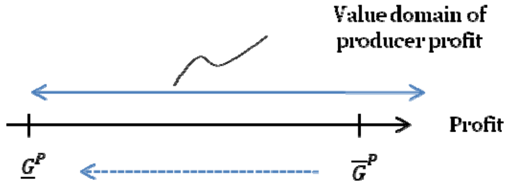


Figure 3.13 Negotiation space of the profit of producer

Compensation

Compensation is as an incentive mechanism only used by the transport operator to persuade the producer to accept the pickup plans he proposes.

Transport operator: the transport operator may try to propose a pickup plan as close as possible to the producer's delivery plan, or can decide to maximize its profit even if the resulting plan does not timely respect the delivery quantities. The profit gap, denoted ΔG, is then defined as the difference of the profits corresponding to each of these plans, considering that $G_{BPT} \geq G_{BST}$, and may be expressed by:

$$\Delta G = G_{BPT} - G_{BST} \text{ or } \Delta G = G_{RT} - G_{BST}$$

The transport operator can decide to share a part of this profit gap with the producer to motivate its acceptance of a pickup plan. The sharing principle is controlled by a specific parameter called compensation percentage (*pp_compen*) which defines the percentage of profit gap that the transport operator intents to pay to the producer.

Plans acceptance

Plans acceptance criterion is a general mechanism used to decide if a plan can be acceptable for a given partner. However by taking into account the modeling differences of the negotiation spaces of both partners which have been explained above, this mechanism is implemented in a slightly different way on the transportation side and on the production side. These implementations are described hereunder:

Transport operator: the plan acceptance is based on a criterion noted AC^T which is used to decide which plan should be sent to producer between P_{BST} and P_{BPT}. It is defined as a ratio which is always greater than or equals to 1. The ratio of $\frac{G_{BPT}}{G_{BST}}$ is used to compare with the value of AC^T. This comparison expresses how much the gain obtained by performing the best profit pickup plan must be better than profit of best service pickup plan in order to accept to negotiate. Thus, if the ratio is less than AC^T, even if P_{BPT} can bring more profit, this gain is considered more than the costs induced by negotiation. Therefore, P_{BST} is sent to producer without considering negotiating on P_{BPT} or P_{RT}.

Producer: in order to judge whether a received pickup plan is acceptable, the producer uses the percentage R_G. The producer's profit corresponding to the execution of the received pickup plan should be over the lower bound $\underline{G}^P$. However, with received compensation from transport operator, the producer's profit could exceed the expected profit value $\overline{G}^P$. Therefore, producer considers that any received pickup plan whose related profit is greater than $\overline{G}^P \cdot R_G$ is acceptable as shown in Figure 3.14 where $\overline{G}^P \in \{G_{BPP}, G_{RP}\}$. Once a pickup plan is accepted by producer, the negotiation process is terminated.

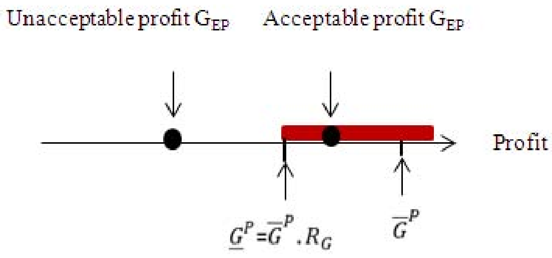


Figure 3.14 Value domain of acceptable and unacceptable profit of producer

Release degree

When, after one or several attempts, a partner cannot persuade the other one to precisely respond to its requests, he must release some financial constraints in order to propose a new feasible delivery plan or pickup plan. Without considering this principle, the negotiation can go on infinitely if each partner maintains its position in term of expected profits.

In this context, release degree, labeled "RD", defines the released profit in order to generate released delivery plan or pickup plan which is more likely to be accepted by the other partner.

Transport operator: The released degree is considered when producer insists on his delivery plan. Release degree is calculated by the following formula: $RD^T = (G_{BPT} - G_{BST})/MaxNego$. *MaxNego* is a parameter defined by transport operator which represents the maximum number of iterations that transportation operator can release its profit based on the same delivery plan. The less *MaxNego* is, the larger RD^T is, the faster the negotiation progresses. Thus, *MaxNego* controls the convergence speed.

The range of possible values for profit of a released pickup plan at each step *i* of negotiation of transport operator is then defined by $[G_{BPT} - i * RD^T, G_{BPT}]$. Let us remark *minT* in Figure 3.15-a is used in "Released Transportation" model and $minT = G_{BPT} - i * RD^T$. Each time a pickup plan is rejected by the producer, a released pickup plan is calculated by the transport operator though "Released Transportation" model (Figure 3.15-a). This one intends to find a new pickup plan which is a compromise between the maximization of its own profit and the satisfaction of the producer requests. The use of the release degree to progressively increase the value domain of the transport operator's profit allows promoting the convergence towards a plan which ensures to find a consensual solution in a win-win relation. At each step of negotiation transport operator reduces its expected profit by the value of the release degree.

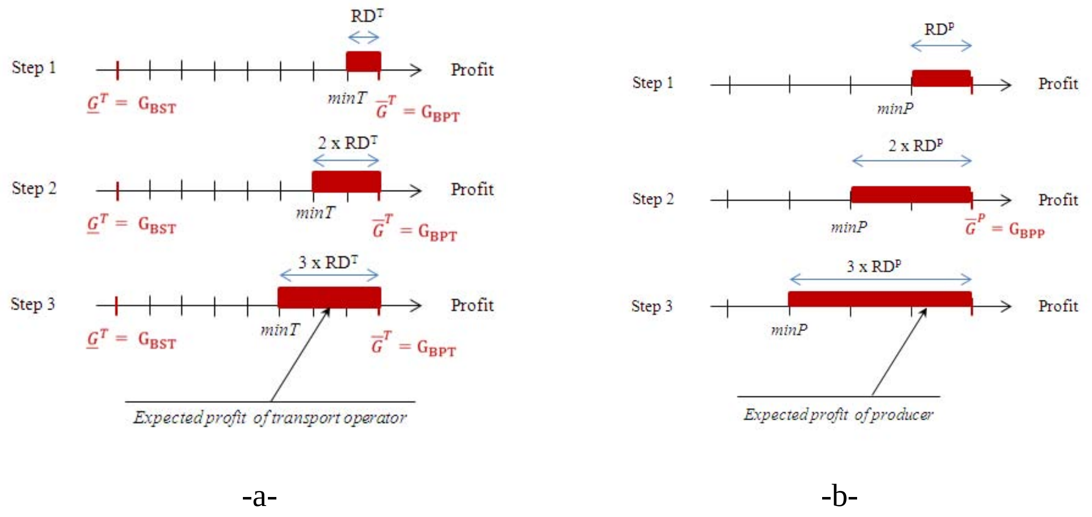


Figure 3.15 Release degree of transport operator and producer

Producer: the principle is quite identical (Figure 3.15-b) and is only used in case of execution of the “Released Production” model; when a delivery plan cannot be satisfied by any pickup plan sent by the transport operator, release degree is calculated by the following formula: $RD^P = pp\_release * G_{BPP}$. Parameter *pp_release* defined by the producer represents the percentage of production profit that producer releases. Thus, the range of possible values for profit of a released delivery plan at each step k of negotiation of producer is defined by $[G_{BPP} - k * RD^P, G_{BPP}]$. Let us remark *minP* in Figure 3.15-b is used in “Released Transportation” model and $minP = G_{BPP} - k * RD^P$.

3.4.3.3 *Detailed view of negotiation protocol*

We have presented a global view of the negotiation between the DMU of producer and transportation operator. In this section, how the “Models” component and “Control” component interact in detail will be explained.

3.4.3.3.1 *“Models” components*

Models presented in section 3.2 and section 3.3 of this chapter are interrelated and some input parameters of these models such as *minP* or m*inT* are based on output of other models which have to be precisely defined in negotiation context. Let us detail some input information and some connections about these models:

<u>EP model</u>

As shown in Figure 3.11 the feedback information from transport operator which could be one of the following plans P_{BPT}, P_{BST} or P_{RT} is the input information of EP model.

RP model

Producer may receive a pickup plan from transport operator which indicate that the delivery plan cannot be accomplished even transport operator tries his best. The received pickup plan could be P_{BST}, which is a best service pickup plan or P_{RT} which is a released pickup plan however equals to best service pickup plan. In this particular case, producer needs to release certain constraints in order to find a less constrained delivery plan to adapt to transport operator's capacity. The lower profit bound in released constraint is deduced from the expected profit G_{BPP}, by using the concept of released degree. RP model uses release degree to specify the input "released lower profit bound of producer" by the following formula*: minP* = $G_{BPP} - k * RD^{P}$ where k is the current producer iteration number.

RT model

Producer may reject the received pickup plan from transport operator. In this case, transport operator needs to release certain constraints in order to find a less constrained pickup plan which has more possibility to be accepted by producer. Similar to the principle of RP model, RT model specifies the input "released lower profit bound of transport operator" by the following formula *minT* = $G_{BPT} - i * RD^{T}$ where "i" is the current transport operator iteration number (i ≤ MaxNego).

Important note: considering the various key determinants of negotiation protocol, and the general principle of negotiation described in the previous parts, we can observe that:

- Each time the producer proposes a delivery plan to transport operator, the latter has a maximum of *MaxNego* iterations to propose a pickup plan that can be accepted or not by the producer.
- Each time any plan sent by the transport operator cannot be accepted, the producer must release some constraints in order to find a delivery plan consistent with transportation capacities. By defining the parameter *pp_release* as the percentage of production profit that producer accepts to release, we ensure that producer has a maximum of *1/pp_release* iterations in trying to find a consensual solution with the transport operator. Thus, we can define that a successful negotiation must be finished in less than *MaxNego/pp_release* iterations
- When producer has to evaluate the feasibility of a new production plan, given the pickup plan proposed by the transport operator, the value domain he considers as

acceptable for profit is defined by $[\overline{G}^{P} \cdot R_G\ ,\ \infty\ ]$; if any pickup plan received from transport operator cannot be accepted (i.e. profit is not included in the given interval), producer releases a percentage of production profit ("Released Production" model) in order to find a less financially constrained delivery plan in the value domain $[G_{BPP} - k * RD^P, G_{BPP}]$. Let us remark that $RD^P = pp\_release * G_{BPP}$, the value domain can also be denoted as $[(1 - k * pp\_release) * G_{BPP}, G_{BPP}]$ by replacing RD^P. The value domain of released delivery plan should cover the value domain of acceptable pickup plan. Therefore, the following condition should be satisfied $R_G \geq (1 - pp\_release)$.

3.4.3.3.2 *"Control" component*

The yellow ellipses show the control elements inside "Control" components of the two DMUs. There are three control elements blocks referring to Figure 3.11. The control logic inside each block is shown in Figure 3.16 to Figure 3.18.

<u>Control Element 1</u>

Control element 1 shown in Figure 3.16 is on the transport operator side. Once receiving the delivery plan, transport operator makes two plans: the first one is the optimal pickup plan by "Best Profit Transportation" model (BPT model) but because of local interests and capacity limits, this pickup plan may be varied from delivery plan from producer; transport operator also makes a second plan which is best service pickup plan (BST model). The gap between the two profits labeled G_{BPT} and G_{BST} respectily is measured by a ratio $\frac{G_{BPT}}{G_{BST}}$ and is compared with plans acceptance criterion AC^T. The transport operator sends the chosen pickup plan and pays penalty and compensation to producer based on the comparison result. Parameter pp_compen represents the percentage of profit gap that transport operator will compensate producer for its profit loss of accepting the proposed pickup plan. The larger the parameter AC^T is, the more likely the condition $\frac{G_{BPT}}{G_{BST}} \geq AC^T$ is false.

- If the condition $\frac{G_{BPT}}{G_{BST}} \geq AC^T$ is true, then transport operator will propose plan P_{BPT} and pay penalty and the following compensation $pp\_compen * (G_{BPT} - G_{BST})$ to producer.

- If the condition is false, then it is not interesting to negotiate on P_{BPT}, transport operator will propose plan P_{BST} and specify this is the best service pickup plan and pay penalty to producer since in this case the compensation equals to 0.

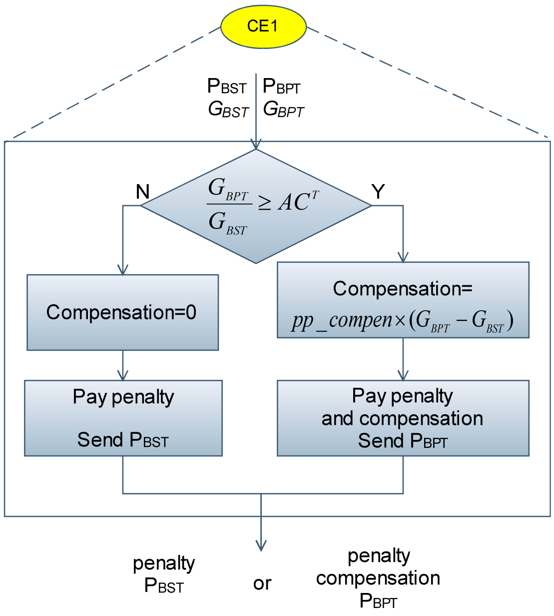


Figure 3.16 Decision making process inside control element 1

Control Element 2

Figure 3.17 shows the decision making process inside control element 2 where *Max= 1 / pp_release* represents the maximum run number of RP model which guarantees that even without finding a convergence solution, the negotiation process could finish. This may help to prevent unnecessary negotiation cost.

Control element 2 is on the producer side. It has two kinds of input. One kind of input comes from models and the other kind of input comes from transport operator. They are detailed as follows.

- From models

Once producer receives a pick up plan (P_{BPT} or P_{BST} or P_{RT}), the first task is to evaluate with EP model whether this plan is feasible for the producer. The output of EP model is the input of control element 2. There exist some decision branches:

- If the output plan of EP model P_{EP} is not feasible (i.e. P_{EP} ok? in Figure 3.14), then producer should check further whether this plan equals to the best service pickup plan.
  - If it equals to a best service pickup plan, since there is only one transport operator, producer has no choice but to adapt to this constraint and trigger "Released Production" planning (RP model) to find a counter delivery plan.

If the RT model has been run for its maximum run number, the negotiation process stops with failure. Producer sends the notification "failure" to transport operator.

- Otherwise producer insists on sending delivery plan P_{BPP}.

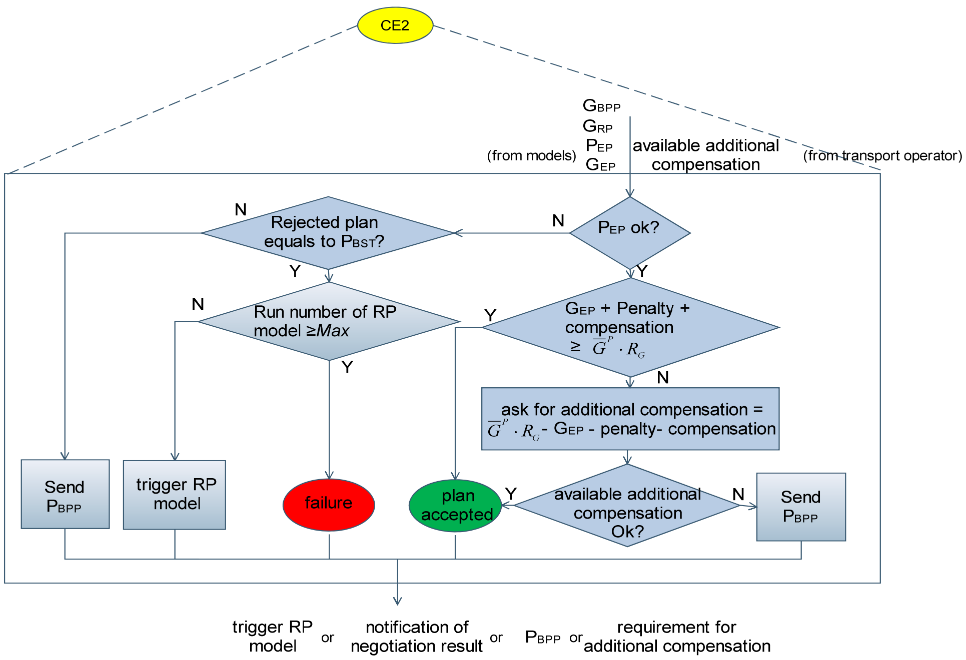


Figure 3.17 Decision making process inside control element 2

– If P_{EP} is feasible and if the following equation is satisfied (G_{EP} + penalty + compensation $\geq \overline{G}^P \cdot R_G$), where $\overline{G}^P \in \{G_{BPP}, G_{RP}\}$, which means that with the received penalty and compensation, the profit of producer is superior to the lower bound of acceptable solutions value domain, producer will agree on this pick up plan and the negotiation process stops with success. Producer sends the notification "Plan accepted" to transport operator; otherwise producer will calculate with how much additional compensation this plan is acceptable. The required additional compensation sent to the transport operator is calculated as follows: $\overline{G}^P \cdot R_G - G_{EP}$ − compensation − penalty.

➢ From transport operator

Producer may require additional compensation to accept the received pickup plan. Hence the input from transport operator indicates the available compensation it can provide.

– If available compensation can satisfy the required additional compensation, the negotiation process stops with success. Producer sends the notification "Plan accepted" to transport operator.
– Otherwise, producer insists on sending delivery plan P_{BPP}.

Control Element 3

The control element 3 shown in Figure 3.18 is on the transport operator side. The decision making process is similar to CE1. After several iterations of release of transportation profit by RD^T which indicates the released quantity of profit in each iteration, the transportation profit will finally attain G_{BST}. The output plan of RT model P_{RT} will be identical to P_{BST}. In this case, the compensation paid by transport operator to producer will be 0. Transport operator sends P_{RT} and indicates that it equals to a best service transportation plan. Otherwise the profit of output plan G_{RT} is more than G_{BST} and less than G_{BPT}. In this case the compensation is calculated by formula $pp\_compen * (G_{RT} - G_{BST})$. Transport operator sends P_{RT} and pays corresponding penalty and compensation to producer.

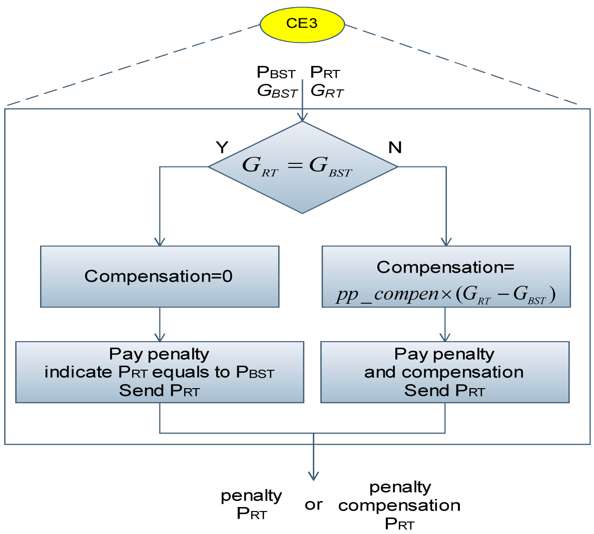


Figure 3.18 Decision making process inside control element 3

Control Element 4

The control element 4 shown in Figure 3.19 exists on the transport operator side as well.

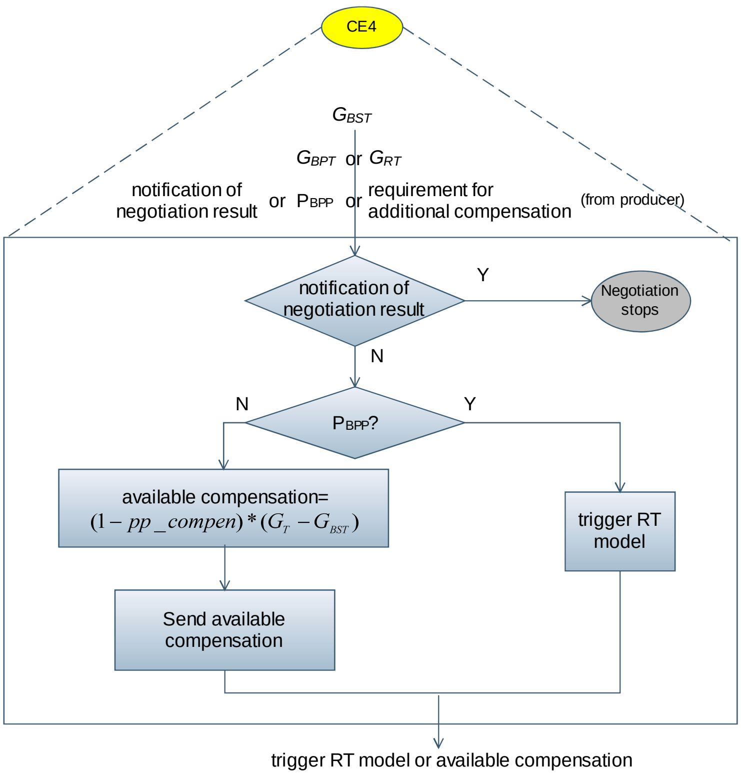


Figure 3.19 Decision making process inside control element 4

Once receiving information from producer, CE4 takes charge of deciding to stop the negotiation or to trigger RT model or to provide available compensation based on received information from producer.

- If the received information is the notification of negotiation result, the negotiation process stops on transport operator side.
- If P_{BPP} is the received information, it means that producer insists on its delivery plan. In this case transportation operator has to trigger RT model to generate a released pickup plan which may have more chance to be accepted by producer.
- If the received information is neither the notification of negotiation result nor P_{BPP}, it must be the requirement for additional compensation. Transport operator will calculate the available compensation. Available compensation of transport operator is the remainder of the profit gap and the proposed compensation, calculated by formula $(1 - pp\_compen) * (G_T - G_{BST})$ where G_T represents the profit of the sent pickup plan which could be G_{BPT} or G_{RT}.

3.4.3.4 *Example of negotiation protocol*

This section presents a given negotiation scenario with information exchanges between producer and transport operator by using UML[1]sequence diagrams in Figure 3.20. A sequence diagram shows an interaction arranged in time sequence. In particular, it shows the instances participating in the interaction by their "lifelines" and the information they exchange arranged in time sequence. The rectangles on top represent the objects which are in our case transportation or production operator. The dash line is called the lifeline of the object which represents that the object is active. The horizontal arrows represent the messages exchanged between objects, in the order in which they occur. In this scenario, producer does not accept the released pickup plan even it is already the best service pickup plan proposed by transportation operator. If the producer still would like to keep working with this transport operator or in a transport monopoly situation, producer will run "Released Production" model (RP model) to find a released delivery plan and restart the negotiation process.

1. Customer sends demands to producer which triggers the negotiation process;
2. Producer runs "Best Profit Production" model (BPP model) to get a best profit production plan and an initial delivery plan P_{BPP};
3. The initial delivery plan P_{BPP} as the output of BPP model serves as input to transport operator;
4. Transport operator runs "Best Service Transportation" model (BST model);
5. Transport operator runs "Best Profit Transportation" model (BPT model);
6. Transport operator evaluates the profit gap between the best service pickup plan and best profit pickup plan. In this particular scenario, the profit gap is more than plans acceptance criterion AC^T which means it is interesting to negotiate on the best profit pickup plan;
7. Transport operator proposes best profit plan P_{BPT} to producer and pays **penalty and compensation**. Compensation is calculated according to the difference between G_{BPT} and G_{BST};
8. Producer runs "Evaluation Production" model (EP model) to evaluate the received pickup plan;
9. The pickup plan is not feasible by producer;
10. Producer rejects the pickup up plan and insists on sending the same initial delivery plan;
11. Transport operator runs "Released Transportation" model (RT model). The output of RT model(release pickup plan) equals to a best service plan;

[1] UML : Unified Modeling language : http://www.omg.org/spec/UML/

12. Transport operator sends released pickup plan $\mathrm{P_{RT}}$ to producer, proposes to pay **penalty** and indicates that the initial delivery plan cannot be accomplished even transport operator tries his best. In this case, no compensation is proposed to producer;
13. Producer runs EP model to evaluate plan $\mathrm{P_{RT}}$ and takes into account the received penalty from transport operator;
14. The released pickup plan $\mathrm{P_{RT}}$ is not feasible. Producer is informed that the released pickup plan is a best service pickup plan;
15. Producer runs "Released Production" replanning (RP model);
16. A released delivery plan $\mathrm{P_{RP}}$ is sent to transport operator;
17. Transport operator runs "Best Service Transportation" model (BST model);
18. Transport operator runs "Best Profit Transportation" model (BPT model);
19. Best profit pickup plan is more interesting to negotiate after comparing with plan acceptance criterion AC^T;
20. Transport operator proposes best profit plan $\mathrm{P_{BPT}}$ to producer and pays **penalty and compensation**;
21. Producer runs "Evaluation Production" model (EP model) to evaluate the received pickup plan;
22. The pickup plan is feasible by producer;
23. Condition $\mathrm{G_{EP}} + \text{penalty} + \text{compensation} \geq G_{RP} \cdot R_G$ is satisfied;
24. Producer notices the success of negotiation to transport operator;

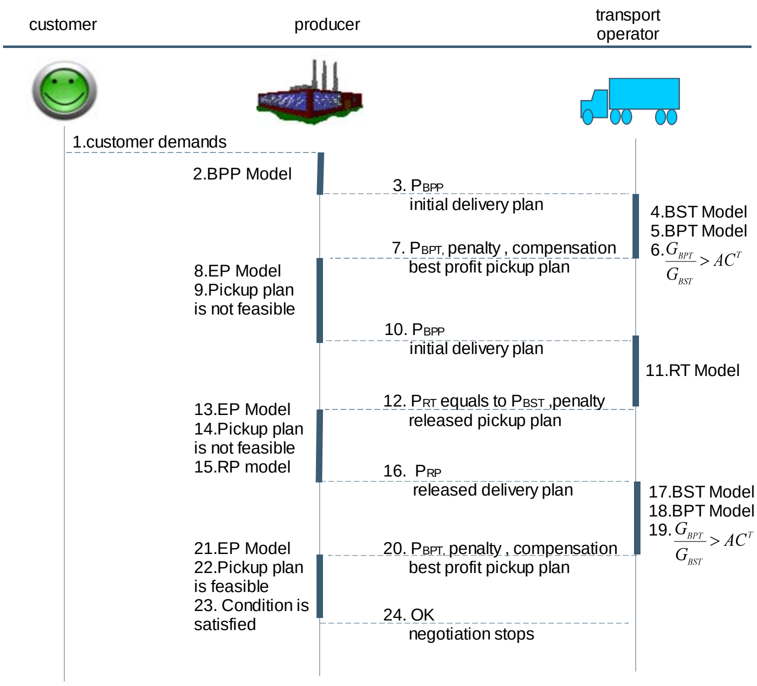


Figure 3.20 Sequence diagram of a negotiation scenario

3.4.3.5 *Synthesis of negotiation protocol*

To conclude, the two main points to consider in defining the negotiation protocol are the objects of negotiation (i.e. what) and the way to negotiate (i.e. how).

What to negotiate

Four kinds of information that transport operator can receive from producer are identified:

1. An initial delivery plan

The first time transport operator receives an initial delivery plan, it will trigger the running of BST model and BPT model. The other case is when producer insists on sending its initial delivery plan, transport operator has to run replanning (RT model).

2. A released delivery plan

If transport operator receives a released delivery plan, it will be considered as a new round of initial delivery plan. Transport operator repeats the negotiation process from beginning and run BST model and BPT model.

3. Requirement of additional compensation

If producer asks for additional compensation, transport operator will respond producer an available additional compensation which may satisfy or not the required additional compensation. In the case that there are still enough gap of profit between best service plan and proposed pickup plan for the increase of compensation, transport operator will accept this increase.

4. Notification of negotiation process

The end of negotiation process is decided by producer by noticing transport operator the success or failure of the negotiation process. The negotiation process finishes with success when and only when a pickup plan is evaluated as feasible by EP model and if the required additional compensation required by producer can be satisfied by transport operator.

There are two kinds of information that producer can receive from transport operator

1. Pickup plan P_T

The received pickup plan could be any plan among P_{BPT} or P_{BST} or P_{RT} which are the output of different transportation models. P_{BST} is the output of “Best Service Transportation” mode and P_{RT} is the output of “Released Transportation” model. If the received plan is P_{BST} or a P_{RT}

which is equals to P_{BST}, the producer will also receive a notice from transportation operator which indicates this pickup plan equals to a best service pickup plan.

2. Financial information

Producer could also receive some financial information such as penalty and compensation or available additional compensation. Producer evaluates the feasibility of the received pickup plan and takes into account received penalty and compensation. Once producer requires additional compensation, it receives information of available additional compensation from transport operator.

How to negotiate

To conclude, there are two kinds of information to negotiate: pickup quantity in each period and compensation to producer. If the optimal producer's delivery plan is not optimal for transport operator and if there is a much better pickup plan for transport operator in terms of profit, transport operator can negotiate pickup quantity and propose compensation to producer to motivate it to accept the deviation from the delivery plan. Certainly, transport operator has to pay producer penalties when there are deviations of pickup quantities from delivery plan. So that, besides penalty, producer may receive compensation from transport operator. The two partners firstly negotiate on pickup quantities to make sure both partners have enough capacity to execute this plan; secondly they negotiate on compensation after they reach an agreement about quantity. The compensation proposed to the producer is calculated by following formula: $\mathrm{pp\_compen} * (G_T - G_{BST})$. But the producer may require for additional compensation for the purpose of accepting the received pickup plan. If transportation operator accepts this increase of compensation, the negotiation process stops with success.

The negotiation protocol proposed here, involves distributed decision making. As shown in Figure 3.11, the decisions are made clearly separately by different partners. This section explained how the DMUs of producer and transport operator coordinate by negotiation and also how "Control" component interact with "Models" component within the same DMU and between DMUs. Some parameters are involved in the negotiation protocol such as pp_compen which can be defined according to the specific situation of operators and give a certain flexibility to our negotiation protocol.

3.5 Conclusion

Two components "Models" and "Control" of a DMU are defined and specified in this chapter. The "Models" component is composed by some mathematic models which have different purpose to serve; the “Control” component conduct the decision making process within DMU and follows a negotiation protocol to coordinate with other DMUs.

Model component

We have defined six mathematical models in this thesis which characterize the main principles of decisional processes involved in the “Models” component. It supports the decision making of the producer or the transport operator. They take into account the technical factors of production and transportation system (e.g. capacity parameters in BPP model) and also economic factors. Based on different decision objectives, a generic model and its variants are modelized. The models are general and flexible as well. They can be applied to the SC partners who allow early and late supply or the utilization of external resource. Many parameters in these models show the management preference such as penalty costs or the lower profit bound, etc. These parameters are defined by expert and managers according the dynamic environment information or experience of the corresponding party. These models help make tactic decisions to plan the production and transportation activities over a non sliding time horizon and suppose the planning time unit are the same. They are linear integer problems. The output of the models is optimal or near optimal solutions with the given input parameters.

Control component

We also proposed a negotiation protocol for the “Control” components which interacts with “Models” component and other DMUs. The objective of the negotiation protocol is to reach a win-win situation for one-to-one producer transport operator negotiation. We use the notion of compensation to motivate the acceptance of a pickup plan and make win-win situation possible. We suppose the negotiation process takes place after contracting so that the most part of parameters are well defined, for example the economic parameters. Transport operator and producer negotiate the pickup quantities. Transport operator has stronger willing to improve its profit and pay compensation to producer to motivate the acceptance of a pickup plan by producer. Producer releases delivery plan only when the transport operator cannot accomplish delivery plan with its best effort. The negotiation takes place only between producer and transport operator without the involvement of customer. However the negotiation result may cause more late or early supplied products to customer. The customer’s tolerance for these not on time deliveries limits the flexibility of negotiation.

The negotiation proposed in this research is designed for decentralized decision making structure, especially in a supply chain which cannot gather all information of SC members or without a third part mediator. This negotiation protocol coordinates two parties with minimal information exchange without exploring private information which makes it suitable for small and medium manufacturing enterprises. Although we illustrate it in a production transportation problem, it can be extended to other supply chain problem as long as there are coordination problems because of conflicts of members.

In the next chapter, numerical results will be presented in order to illustrate and evaluate the coordination performance of the proposed negotiation protocol.

Chapter 4

Performance evaluation of the one-to-one production transportation case

Chapter 4 Performance evaluation of the one-to-one production transportation case

4.1 Introduction

After having presented analytical models in chapter 3, the coordination performance of production and transportation activities based on a negotiation protocol must be evaluated and analyzed. The aim of this chapter focuses on the evaluation case of an elementary SC restricted to one producer and one transport operator. In this context, numerical experiments are defined and performed to assess the performance of the supply chain and the negotiation protocol. Indeed, many parameters and decision variables in production and transportation models may affect the responses of the system so that, decisions of models vary and SC performances vary as well depending on values of different parameters. Thus, the objective of this chapter is to investigate the process as a whole and identify a list of main parameters which can affect the process by their importance, from the most influential to the least influential so as to provide some advices for coordinating production and transportation activities by negotiation. For example, the main question to answer is: how to define the parameters values of models to achieve better profit or better service level?

The experimental study carried out in this chapter is based on the design of experiments (DOE) well-known as a systematic method to determine the relationship between input parameters affecting a process and the output of that process. A design of experiment (DOE) is the laying out of a detailed experimental array which is composed of several experiment trials. DOE is performed in advance of doing the experiment. Each experiment trial changes one or more input parameters in order to observe the effect that the changes have on output. It is helpful to manage input in order to optimize the output. Some essential terms used in DOE such as factor, response and interactions are defined as follows (Box et al., 2005):

- A factor is the input of a process, also called controlled independent variable; the levels of a factor define the possible values of input and are set by the experimenter.
- A response characterizes the output of a process, sometimes called dependent variable.
- An interaction occurs when dependence between the effects of two or many factors can be observed.

DOE begins with determining the objectives of an experiment (responses) and selecting the factors for the study. By identifying the responses, factors and levels of factors, experimental array is defined as a consequence. In this chapter, the factors of production and transportation models and also the factors which control the negotiation process such as plan acceptance criterion will be specified in the experimental array. The responses will show performances of producer and transport operator and also will present the performance gap before and after negotiation. Based on the observation of output, it is possible to discover which set of input can strongly affect output and how they affect the coordination performance.

Main notions used in this chapter refer to elements of the Taguchi method for DOE whose main contribution is to provide methods and tools to facilitate the use of experimental arrays in the field of quality improvement. The Taguchi method for design of experiments is briefly synthesized in the following four steps:

1. Identify the responses, factors, their levels and design an experimental array.

2. Run experiments.
3. Analyze results.
4. Perform a confirmation experiment.

The construction of an experimental array at the end of step one proves to be a difficult step that cannot be achieved without relying on a method. The design of experiments proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and their levels; it allows collecting necessary data to detect factors that most affect experiment responses with a minimum amount of experiment trials, thus saving time and resources. For this purpose, it is worth recalling some properties related to the design of experiments (Box et al., 2005):

- **A full factorial design** is a design of experiments which consists of two or more factors, each with discrete possible values or "levels", and whose experiment trials take on all possible combinations of these levels across all such factors. For example, with five factors, three at two levels and four at three levels, the experiment is denoted as $2^3 3^4$, there are 648 possible combinations. The problem with a full-factorial design is that, for most practical situations, it is too costly and tedious to have all possible combinations. For this reason, researchers often use fractional-factorial designs.

- **A fractional-factorial design** only studies a subset of all possible combinations. It has fewer trials than a full factorial design. The disadvantage of having fewer trials is that some effects become confounded. Two effects are confounded or aliased when they are not distinguishable from each other.

- A special type of fractional-factorial design is the **orthogonal array**, in which all estimable effects are uncorrelated. Orthogonal arrays are two dimensional arrays of numbers which possess the interesting quality that by choosing any two columns in the array you receive an even distribution of all the pair-wise combinations of values in the array. This allows studying the effects of each factor independently.

The experiments carried out in this chapter first will be based on Taguchi orthogonal array which allows significantly reducing the number of trials to be performed while getting almost as effective information as the full factorial design. In a second step, the full factorial design will be used when the complexity of the plan is limited.

The following sections of this chapter are organized according to the main steps defined above. Section 4.2 firstly defines factors and responses of experiment. This section also presents the experimental platform supporting the implementation of experiments. In section 4.3, a preliminary experimental array is defined by specifying the levels of each factor. Performance evaluation is carried out without considering interactions in order to find important factors affecting responses. Section 4.4 defines furthermore two experimental arrays: the first one is oriented toward the study of interactions between main factors identified in section 4.3. The second experimental array focuses on the factors which are related to negotiation protocol. Reduced size experimental array is made to study the effects of these factors on the responses in order to study how these factors affect negotiation protocol. At the end, section 3.5 will synthesize all the evaluation and analysis conclusions.

4.2 Experimental framework

This section presents the experimental framework which supports our experiment assessment. This framework is made up of two parts. The first one is a preliminary work which aims to build and define the factors and responses of the experiment. The second part consists in specifying the software architecture of the platform used for implementing the experiments.

4.2.1 Factors and responses definition

The identification of factors and responses is the first step of DOE. Responses define the output of experiment that we want to evaluate and the factors represent the elements which may affect the output. The identification step is referred to the performance indicators presented in section 2.2.3.

4.2.1.1 *Responses definition*

Based on the mathematical models presented in chapter 3, the responses are divided into two groups: economic responses and service quality responses.

4.2.1.1.1 *Economic responses*

The objectives of producer and transport operator are to maximize their own profits. Therefore, the profit of producer (PPR_{out}), the profit of transport operator (PTR_{out}) and the total profit (TOP_{out}) after negotiation of both partners are identified as the most significant economic responses.

Three complementary economic responses (DPP_{out}, DPT_{out}, DTP_{out}) are evaluated by comparing the initial (i.e. before negotiation) and final (i.e. after negotiation) economic performances of each partner. These differences are evaluated by percentage and demonstrate the performance improvement of the proposed negotiation protocol. For each economic response labeled X_{out}, this difference is calculated as follows: (X_final_{out} - $X\_initial_{out}$) / $X\_initial_{out}$. Table 4-1 synthesizes the different economic responses and defines how their values are calculated.

Table 4-1 Economic responses definition

Name	Response Label	Value
Profit of producer	PPR_{out}	G_{EP}+compensation+penalty
Profit of transport operator	PTR_{out}	(G_{BST} or G_{BPT} or G_{RT})-compensation
Total profit	TOP_{out}	G_{EP}+ penalty+(G_{BST} or G_{BPT} or G_{RT})
Difference of profit of producer	DPP_{out}	G_{EP}+compensation+penalty-G_{BPP} / G_{BPP}
Difference of profit of transport operator	DPT_{out}	(G_{BST} or G_{BPT} or G_{RT})-compensation- G_{BST} / G_{BST}
Difference of total profit	DTP_{out}	G_{EP}+ penalty+(G_{BST} or G_{BPT} or G_{RT})- (G_{BPP}+G_{BST}) / (G_{BPP}+G_{BST})

4.2.1.1.2 *Service quality responses*

At the meanwhile, the service quality is another important aspect of performance. Table 4-2 shows the service quality responses grouped into 3 parts: production responses, transportation responses and negotiation responses. The service quality responses show the level of satisfaction of partners and correspond to the performance after negotiation. The column labeled "Value" defines how to calculate these responses by the experiment output of models. Let us remark that the response called "total iteration number" TIN_{out} is the output directly observed during experimentation (the number of executions of "Evaluation Production" model), and is not calculated from output of models. Thus, there is no corresponding calculation formula for this response in Table 4-2.

Production responses

The producer provides products to satisfy customer demands. Its service quality is evaluated through the calculation of accumulated early supplied quantity (ESQ_{out}), accumulated late supplied quantity (LSQ_{out}) over the planning horizon and backorders to customer (BOC_{out}) at the end of planning horizon.

Transportation responses

Similar to producer, transport operator provides transportation service to satisfy producer delivery demands. Its service quality is estimated by accumulated early pickup quantity (EPQ_{out}), accumulated late pickup quantity (LPQ_{out}) over the planning horizon and backorders to producer (BOP_{out}) at the end of planning horizon.

Negotiation responses

In addition, in order to evaluate the performance of negotiation protocol, two negotiation responses are indentified: the compensation FCP_{out} that transport operator pays to producer at the end of negotiation and the total number of iterations TIN_{out} that the negotiation process really takes.

Table 4-2 Service quality responses definition

Name	Response Label	Value
Production		
Accumulated early supplied quantity	ESQ_{out}	$\sum_{p,j,t} e_{p,j,t}$
Accumulated late supplied quantity	LSQ_{out}	$\sum_{p,j,t} b_{p,j,t}$
Accumulated backorders to customer	BOC_{out}	$\sum_{p,j} b_{p,j,t}$ (t is the last period of planning horizon)
Transportation		
Accumulated early pickup quantity	EPQ_{out}	$\sum_{p,j,t} te_{p,j,t}$
Accumulated late pickup quantity	LPQ_{out}	$\sum_{p,j,t} tb_{p,j,t}$
Accumulated backorders to producer	BOP_{out}	$\sum_{p,j} tb_{p,j,t}$ (*t* is the last period of planning horizon)
Negotiation		
Final compensation	FCP_{out}	*pp_compen**(G_{BPT}-G_{BST}) or *pp_compen**(G_{RT}-G_{BST})
Total iteration number	TIN_{out}	-

4.2.1.2 *Factors definition*

In this part, we will define the input of experiment, i.e. the factors employed in the experimental arrays. The methodology used to structure the current analysis is based on three steps represented in Figure 4.1. Some primary factors are firstly identified by brainstorming followed by factors combination and selection to establish the final factors list.

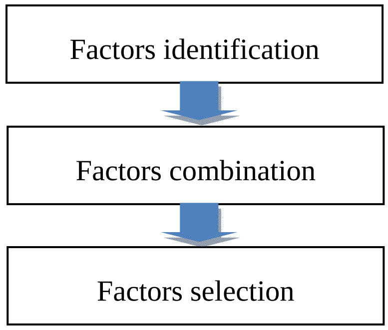


Figure 4.1 Factors definition process

Let us notice that the following notation of factor levels is used in the rest part of this chapter: each value of a factor containing m levels is labeled Li, i ∊ {1…m}.

4.2.1.2.1 *Factors identification*

In order to identify the possible factors which may have effects on economic and service quality responses, an Ishikawa diagram is adopted to identify factors affecting the responses. These factors can be classified in three groups depending on their nature: production related factors defined in production model, transportation related factors defined in transportation model, and negotiation related factors (Figure 4.2).

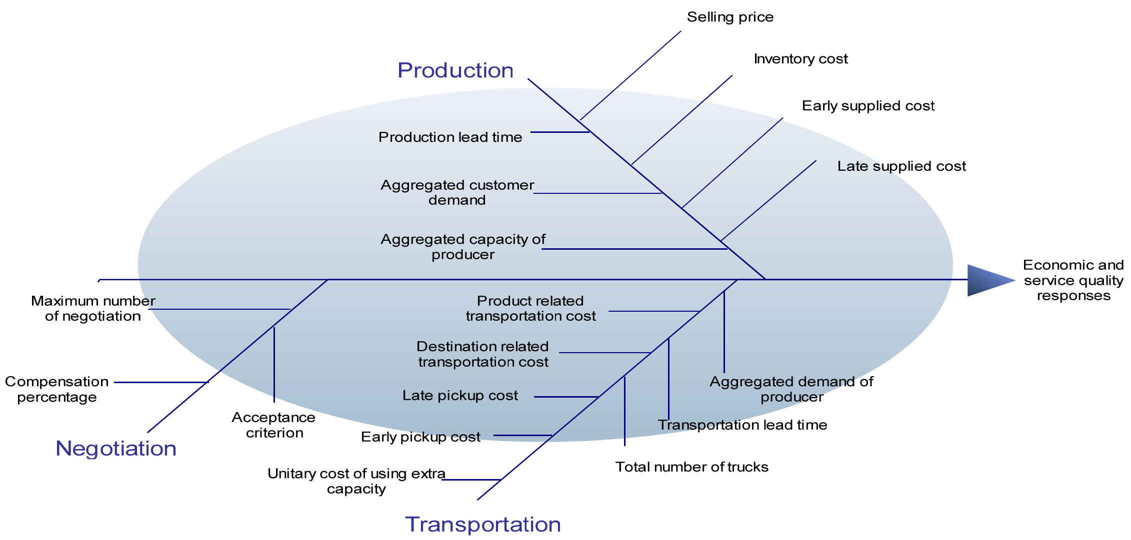


Figure 4.2 Factors identification

The negotiation related factors identified here are only representative of the transport operator behavior. This choice is motivated by the importance that we intend to give to the transport operator in the negotiation protocol, in such a way to avoid observing an impact on negotiation which only results from producer. Therefore, negotiation factors that impact the producer's behavior during the negotiation process (lower bound parameter R_G and release parameter *pp_release*) are fixed in the experimental arrays.

A preliminary list of 18 factors obtained by Ishikawa diagrams is shown in Table 4-3.

Table 4-3 Initial list of factors

Name	Factor label	Factor definition	Importance	Type
Production				
Aggregated resource requirement of customer demand	ADC_{in}	$\sum_{p,j,t} u_p * d_{p,j,t} * DP_p$	2	Aggregated
Aggregated capacity of producer	ACP_{in}	$\sum_{t} Pcap_t$	2	Aggregated
Inventory cost	ICP_{in}	$\{CS_p, \forall p \in P\}$	2	Set
Selling price of product	SPP_{in}	$\{SP_{p,j}, \forall p \in P, \forall j \in J\}$	2	Set
Production lead time	LTP_{in}	$\{DP_p, \forall p \in P\}$	1	Set
Early supplied cost	ESP_{in}	$\{CE_{p,j}, \forall p \in P, \forall j \in J\}$	2	Set
Late supplied cost	LSP_{in}	$\{CR_{p,j}, \forall p \in P, \forall j \in J\}$	2	Set
Transportation				
Total number of trucks	TNT_{in}	R	2	
Aggregated demand of producer	ADP_{in}	$\sum_{p,j,t} v_p * l_{p,j,t}$	2	Aggregated
Unitary cost of using extra capacity	CET_{in}	$\{FC\_extra_j, \forall j \in J\}$	2	Set
Destination related transportation cost	CDT_{in}	$\{FC_j, \forall j \in J\}$	2	Set
Product related transportation cost	CPT_{in}	$\{VC_p, \forall p \in P\}$	2	Set
Transportation lead time	LTT_{in}	$\{DT_j, \forall j \in J\}$	1	Set
Early pickup cost	EPT_{in}	$\{EC_{p,j}, \forall p \in P, \forall j \in J\}$	2	Set
Late pickup cost	LPT_{in}	$\{BC_{p,j}, \forall p \in P, \forall j \in J\}$	2	Set
Negotiation protocol				
Acceptance criterion	ACR_{in}	AC^T	3	Elementary
Compensation percentage	CPP_{in}	*pp_compen*	3	Elementary
Maximum number of negotiation	MNN_{in}	*MaxNego*	3	Elementary

This table contains two important columns:

- The column labeled "Factors definition" specifies each factor. This specification shows that three types of factors are considered:

  - Elementary factors such as ACR_{in} correspond directly to a given parameter of the mathematical models or of the negotiation protocol described in chapter 3.

  - Aggregated factors such as ADC_{in} are obtained by calculation (see symbol ∑ in column entitled "Factor definition") merging different parameters.

  - Set factors such as ICP_{in} correspond to a list of parameters (see symbol {} in column entitled "Factor definition")

- The column labeled "Importance" contains the importance level associated to each factor. Later it will be used as a criterion to make a selection of remarkable factors by eliminating the factors with less importance. The importance indicates the estimated influence that a factor may have on the response. It increases from 1 to 3. The influence of production lead time and transportation lead time on the responses is not so evidence than other factors so that they are assigned importance value "1". All cost related factors and capacity related factors affect directly the economic and service quality responses. Therefore, they are assigned importance value "2". Since the experiment is designed to evaluate the performance of negotiation protocol, the negotiation factors are assigned the highest importance value "3".

4.2.1.2.2 *Factors combination and mapping*

In DOE methodology, factors must be independent from each other. So, this step aims at identifying couples of factors which are linked so as to combine each couple into a new one. This combination step also makes it possible to decrease the number of factors so as to decrease the size of experimental array. However this combination requires some additional specification, if set or aggregated factors are concerned. Hence a two-step process is performed in order to define these new factors and map them with parameters of our models.

Table 4-4 Factors combination

	ADC_{in}	ACP_{in}	ICP_{in}	SPP_{in}	LTP_{in}	ADP_{in}	TNT_{in}	CPT_{in}	CET_{in}	CDT_{in}	LTT_{in}	LPT_{in}	ESP_{in}	EPT_{in}	LSP_{in}	ACR_{in}	CPP_{in}	MNN_{in}
ADC_{in}		X																
ACP_{in}	X																	
ICP_{in}													X					
SPP_{in}				X														
LTP_{in}																		
ADP_{in}																		
TNT_{in}																		
CPT_{in}																		
CET_{in}										X								
CDT_{in}									X									
LTT_{in}																		
LPT_{in}															X			
ESP_{in}			X											X				
EPT_{in}													X					
LSP_{in}												X						
ACR_{in}																		
CPP_{in}																		
MNN_{in}																		

The first step is the identification of combinations which is summarized in the following Table 4-4. This symmetric matrix table (see Table 4-4) presents the grouping choices between couples of factors depending on intuitive reasoning; symbol "X" indicates a combination of factors.

The second step is the mapping between each new factor and the parameters of models. This mapping is performed in order to clearly specify the levels of these factors. The combinations and mappings between two factors are represented by ratios which are described hereunder:

- R_CAP_{in} : Capacity ratio

The aggregated resource requirement of customer demand (ADC_{in}) has a strong link with aggregated production capacity (ACP_{in}). If this aggregated resource requirement of customer demand is superior to the aggregated production capacity over the planning horizon, producer would have difficulty to supply right quantity of products at right time. It will obviously cause backorders at the end of planning horizon. This ratio is defined as follows:

$$R\_CAP_{in} = ADC_{in} / ACP_{in}$$

- R_INV_{in} : Inventory ratio

The comparison of inventory cost (ICP_{in}) and early supplied penalty cost (ESP_{in}) will affect delivery decisions, so these two factors are dependent. In the case where there is early production, if the early supplied penalty cost is less than inventory cost ($ESP_{in} < ICP_{in}$), producer will prefer to make early delivery if it is allowed by customer. If the early supplied penalty cost is more than inventory cost ($ESP_{in} > ICP_{in}$), producer will make inventory instead of making early delivery. If $ESP_{in} = ICP_{in}$, the decisions will depend on other factors.

Both factors ICP_{in} and ESP_{in} correspond to a set of parameters. Early supplied cost (ESP_{in}) corresponds to parameter $CE_{p,j}$ in the production model which is indexed by products and customers while the inventory cost (ICP_{in}) corresponds to parameter CS_p which is only denoted by products. To overcome this difficulty, we apply the definition of inventory ratio to $ICP_{in}/\overline{ESP_{in}}$, in which $\overline{ESP_{in}}$ represent the average early supplied cost of different customers, indexed by products. Thus ICP_{in} and $\overline{ESP_{in}}$ factors have the same index. The mapping is defined as follows: the value of factor $\overline{ESP_{in}}$ is supposed to be known and the value of factor ICP_{in} (see grey cells in Table 4-5) is set in order to get a given level of inventory ratio R_INV_{in}. Table 4-5 shows an example made up of two products and two customers. For product 1, the $\overline{ESP_{in}}$ is calculated as follows: $CE_{1,1}$+$CE_{1,2}$/2=(5+15)/2=10. Then, the value of factor ICP_{in} for product 1 will be chosen according to the explanation above. In the proposed example of Table 4-5, the value of ICP_{in} is set to be 10 (respectively 12), if the level value of factor R_INV_{in} must equal to 1 (respectively 1.2).

Table 4-5 Mapping example of inventory ration (R_INV_{in})

Factor	Levels	Parameters	Product 1		Product 2	
			Customer 1	Customer 2	Customer 1	Customer 2
R_INV_{in}	L1=1.0	ESP_{in} (known)	5	15	15	25
		$\overline{ESP_{in}}$(calculated)	10		20	
		ICP_{in} (chosen)	10		20	
	L2=1.2	ESP_{in} (known)	5	15	15	25
		$\overline{ESP_{in}}$(calculated)	10		20	
		ICP_{in} (chosen)	12		24	

- R_SELL_{in} : Selling ratio

SPP_{in} is a factor corresponding to a set of parameters indexed by products and customers ($SP_{p,j}$) in planning models. In our study case, the selling price can differ depending on business dealings between the producer and its various customers. It can be interpreted in certain degree as the relative priority of products to be served when the production capacity cannot accomplish all customer demands. The more the product's selling price to a customer is, the higher the producer's profit is, the higher this customer would be served for this product.

The ratio R_SELL_{in} considers the relation between $SP_{p,1}$ and $SP_{p,2}$ which represent the selling price to customer 1 and customer 2 respectively. Let us consider for instance the definition of "L1" of ratio R_EXT_{in}, this level corresponds to a ratio of parameters which equals to 1 as follows:

R_SELL_{in}=L1$\Rightarrow \forall p \in P$ $SP_{p,1}/SP_{p,2}$=1

- R_EXT_{in} : Extra capacity ratio

The comparison of the cost of using extra transportation capacity (CET_{in}) with destination related transportation cost (CDT_{in}) affects the decisions of whether and how much extra transportation capacity is required. The more the cost of using extra transportation capacity is, the more this extra transportation capacity should be avoid.

Both CET_{in} and CDT_{in} are of type "Set" in Table 4-3 which respectably correspond to parameters FC_extra_j and FC_j indexed by customers. In order to build ratio R_EXT_{in}, the combination is made to each pair of factors. Let us consider for instance the definition of value "L1" of ratio R_EXT_{in} corresponds to a numerical value which equals to 1 as follows:

R_EXT_{in}=L1 $\Rightarrow \forall j \in J$, FC_extra_j/FC_j= 1

- R_EAR_{in}: Early ratio and R_LAT_{in} : Late ratio

Producer pays penalty cost to customers if there are products supplied early or late than customers' demands. Transport operator pays penalty cost to producer if there are products picked up early or late than delivery demands. Therefore, some penalty costs of producer are compensated by the penalty cost received from transport operator.

The ratio of both early and late penalty costs of the two actors affect the profit distribution between the two actors. If transport operator proposes to make early pickup, it will cause producer making early supplied quantities to customer. If $ESP_{in} \leq EPT_{in}$, the early supplied penalty that producer pays to customer will be less than or equals to the early pickup penalty that transport operator pays to producer. Producer is promoted to accept the early pickups of transport operator. If $ESP_{in} > EPT_{in}$, the received early pickup penalty from transport operator is less than the early supplied penalty that producer pays to customer. Therefore, any early pickup caused by transport operator will decrease producer's profit. LSP_{in} and LPT_{in} affect the decision in the same way. If $LSP_{in} \leq LPT_{in}$, producer is promoted to accept the late pickups proposed by transport operator.

The early ratio R_EAR_{in} (ESP_{in} v.s. EPT_{in}) and late ratio R_LAT_{in} (LSP_{in} v.s. LPT_{in}) are factors of type "Set" in Table 4-3 which are all indexed by products and customers. They have the same indexation of the model parameters from which they are made up. Thus the mapping is achieved at this detailed indexation level. Let us consider for instance the definition of "L1" of ratio R_EAR_{in} corresponds to a numerical value which equals to 1 as follows:

$$R\_EAR_{in}=L1 \Rightarrow \quad CE_{1,1}/EC_{1,1}=1 \text{ and } CE_{1,2}/EC_{1,2}=1$$

$$\text{and } CE_{2,1}/EC_{2,1}=1 \text{ and } CE_{2,2}/CE_{2,2}=1$$

These ratios which are the combinations of two factors are called "ratio factors". All other factors which are not involved in a combination (i.e. LTP_{in}, ADP_{in}, TNT_{in}, LTT_{in}, ACR_{in}, CPP_{in}, MNN_{in}) are not concerned by this mapping step. Let us remark that each negotiation factor (ACR_{in}, CPP_{in}, MNN_{in}) corresponds to a parameter defined in section 3.4.3.2 of chapter 3.

4.2.1.2.3 *Factors selection*

After the combination step, the initial list of factors is now reduced to a list of total 14 factors including some ratio factors. This initial list is then transformed to a selection list as shown in Table 4-6.

Table 4-6 Selection list of factors

Label	Importance	Technical difficulty
R_CAP_{in}	2	+
R_INV_{in}	2	++
R_SELL_{in}	2	+
R_EXT_{in}	2	+
R_EAR_{in}	2	+
R_LAT_{in}	2	+
LTP_{in}	1	+
ADP_{in}	2	+++
TNT_{in}	2	+
CPT_{in}	2	+
LTT_{in}	1	+
ACR_{in}	3	+
CPP_{in}	3	+
MNN_{in}	3	+

Two selection criteria are associated to each factor: importance and technical difficulty.

- The criterion importance is the same as in Table 4-3. The calculation of this criterion may be hard if ratio factors are concerned; fortunately, in our case, they correspond to the combination of factors with the same importance levels. Therefore the importance levels for ratio factors keep the same as their component factors.

- The other criterion indicates the technical difficulty of presenting or employing the factors in the experiments. We use label "+" to present the difficulty in Table 4-6. The difficulty is ranged increasingly in three degrees from "+" to "+++". In Table 4-6, the aggregated delivery demand of producer, labeled ADP_{in}, is the output of production model. It is not possible to define it before the running of the production model. Thus we assign it highest technical difficulty. The ratio factor R_INV_{in} which is the comparison of inventory cost with the early supplied cost is assigned technical difficulty "++" because of the inconsistency of the indices of ICP_{in} and ESP_{in}. Inventory cost (ICP_{in}) is indexed by products while early supplied cost is indexed by products and customers.

By taking into account the two selection criteria importance and technical difficulty, this selection list can be simplified by eliminating LTP_{in} and LTT_{in} which have the lowest importance level and ADP_{in} which has the highest technical difficulty. Particularly product related transportation cost CPT_{in} is eliminated because destination related cost as a representative transportation cost is already considered in a ratio factor. At the end of this selection step, the list of factors is reduced to10 factors.

4.2.2 Experimental platform

In order to facilitate the execution of the experiment, an experimental platform is helpful. This section explains the development environment and the architecture of the platform.

4.2.2.1 *Development environment*

Our experimental platform involves two main software components: Xpress-MP and Visual Basic for Applications (VBA).

- Xpress-MP

Xpress-MP is a mathematical modeling and optimization software suite, providing tools for the formulation, solution and analysis of linear, quadratic and integer programming problems. It contains several components among which we only use the three following: Xpress-Mosel, Xpress-Optimizer and Xpress-IVE.

Xpress-Mosel provides a high level modeling and programming language, which allows us to formulate our problem, solve it using the Xpress-Optimizer, and analyze the solution.

Xpress-Optimizer is at the core of the Xpress-MP suite which represents decades of research and development in solution methods for linear programming (LP), quadratic programming (QP) and mixed integer programming (MIP) problems.

Xpress-IVE, the Xpress Interactive Visual Environment, is a complete modeling and optimization development environment running under Microsoft Windows. Presenting Mosel in an easy-to-use Graphical User Interface (GUI), with built-in text editor, IVE can be used for the development, management and execution of multiple model programs.

- VBA

Visual Basic for Applications (VBA) is a programming language that provides the ability to extend office applications such as Excel. We adopt VBA in the platform in order to implement the process of transferring information between producer and transport operator. It simulates the dynamic aspect of information flow in the SC.

4.2.2.2 *Architecture of the platform*

The architecture of the designed experimental platform is presented in Figure 4.3.

Excel files are used to store the input such as the values of parameters, the levels of factors and output which corresponds to the results after Xpress-MP calculation such as production plan, delivery plan and pickup plan. In these excel files, the input and output entities of the model are stored in form of tables which contain one or a set of values.

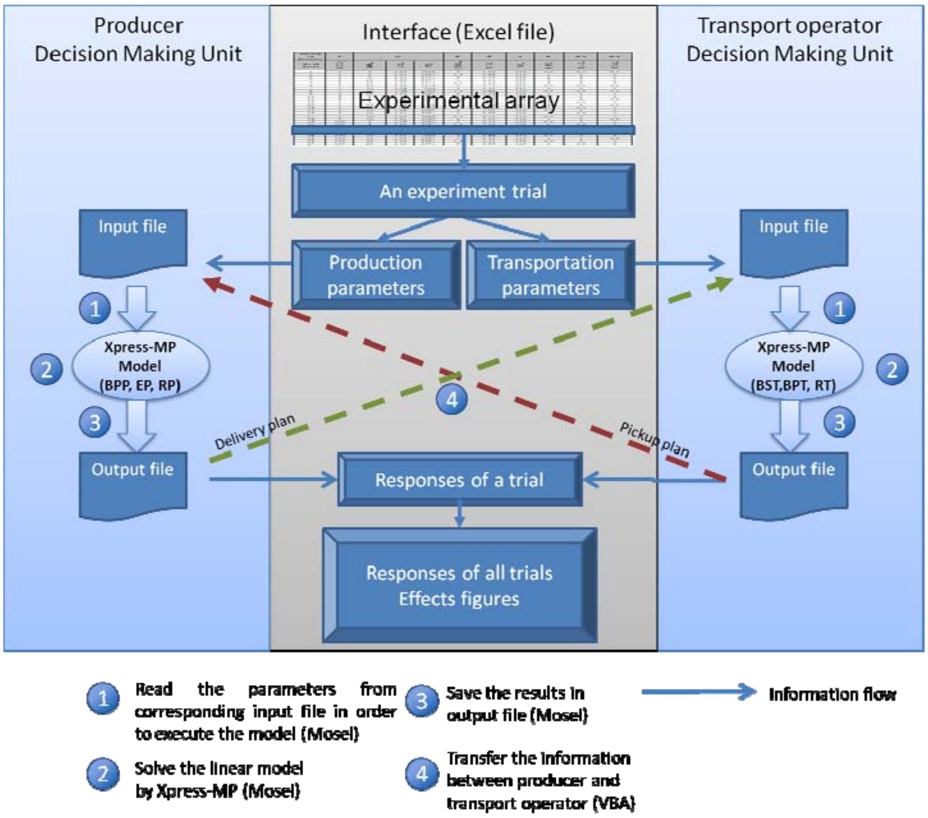


Figure 4.3 Architecture of experimental platform

In this platform architecture, each actor has his own input and output files. By using this way, the information privacy of each actor is guaranteed. Producer and transport operator coordinate by transferring information between their independent input and output files. The decentralized aspect of SC is respected.

A user interface is designed for two main purposes:

- Provide a way for inputting the experimental array and all other required parameters. Let us remind that in the experimental array, some factors are ratio factors. Hence certain parameters of models are deduced from the selected values of ratio factors. The production parameters on the interface will be stored in the input files of production model (BPP, EP, RP). Transportation parameters on the interface will be stored in the input files of transportation model (BST, BPT, RT).

- Display all the responses of the experiment as defined in section 4.2.1.1 such as PPR_{out}. After running each trial of experiment, the platform can extract the responses from the output files of both operators and display them on the interface. Although the interface accesses the information system of both operators, this does not violate the decentralized aspect of SC because doing it by this way is just for the purpose of evaluation.

At the beginning of the experiment execution, an experimental array is inputted on the interface. The program will sequentially execute all the experiment trials in this experimental array. At the beginning of the execution of each trial, an experiment trial setting which is a combination of the values of factors will be read to the interface from the experiment array. These values of factors will be used to deduce some production or transportation parameters which will be stored in the corresponding input files. Xpress-MP model reads the input file, makes calculation and save the results to the output file. The output of one partner will serve as the input of the other partner. There is information transfer between interface and the input files of operators and also between the input and output files of different operators. After the execution of all the experiment trials, the responses of all the trials will be used to calculate the effects of all factors in order to draw effects figures.

Xpress-MP can solve the linear programming models by providing exact optimized solution. However with the increasing of problem complexity, the time for searching the solution is too cost. That is why we use a Mosel parameter to limit the time of model execution. Therefore the solutions are not always optimized in our work. We focus on the performance of negotiation protocol in this thesis, thus a non-optimal solution within a reasonable execution time is acceptable.

4.3 Preliminary performance evaluation

The objective of this section is to analyze how all kinds of factors can affect the responses by first considering a preliminary experimental array which takes into account all factors and responses defined in section 4.2.1. Thus, in section 4.3.1, an experimental array is built by using Taguchi method which considers no interactions between factors. Levels of each factor are specified in the experimental array. The output based on this experimental array is then evaluated in section 4.3.2. As we have defined more than one response, the evaluation is performed response by response. For each response, the influences of all factors are compared. Therefore, it is possible to find out the most influential factors for each response. Because the experimental array defined in section 4.3.1 is based on the premise that no interaction between factors exists, conformation experiment is required to verify the influence effects that are observed in section 4.3.1. The conformation experiment is presented in section 4.3.3. At the end of section 4.3, a list of influential factors to all the responses, also called important factors, is identified based on the results of preliminary experiment and confirmation experiment.

4.3.1 Experimental array

In order to design an experimental array, two important steps should be explained: levels definition and orthogonal design.

4.3.1.1 *Levels definition*

We have previously seen how the total number of factors can be finally reduced from 18 to 10. Table 4-7 lists the final factors that are retained after combination and selection steps. The upper part of this table contains all ratio factors, and its lower part contains all the rest factors. In this section, the levels of factors which are the possible values of input are defined as shown in Table 4-7. Each factor has 3 levels labeled: L1, L2, and L3. The principles of defining the value of these levels are presented by two groups, ratio factors and the rest factors, as follows:

- The levels defined for ratio factors do not following the same principle, there are presented by four cases hereunder:

  - Case of ratio factor R_INV_{in}, R_EAR_{in}, R_LAT_{in}: each ratio factor expresses the dependent relation between its two component factors. Thus, in general, the possible values for each ratio factor express the three possible orders between the two component factors: “less than”, “equal to” and “more than”. The corresponding values in Table 4-7 are “0.5”, “1” and “2”.
  - Case of ratio factor R_CAP_{in} (ADC_{in} v.s. ACP_{in}): the defined values “1.01”, “0.96” and “0.75” in Table 4-7 express the cases where the aggregated resource requirement of customer demand is more than, almost at the same level or less than aggregated capacity of producer. The choice of an almost same level demand-capacity relation can reflect the tension of demands and leave flexibility to allow leveling as well.
  - Case of ratio factor R_SELL_{in}: the defined values “1”, “1.5” and “5” in Table 4-7 express the cases where the two products have the same prices or one product is a little more expensive or much more expensive than the other.

- Case of ratio factor R_EXT_{in}: the defined values “2”, “5” and “100” in Table 4-7 express the cases where the cost of using extra capacity is a little more expensive or much more expensive or extremely more expensive than the own destination related transportation cost. Especially, the value “100” corresponds to the cases without using extra capacity implicitly.

• The levels defined for the rest factors represent three possible values: a low value, an average value and a high value.

- Acceptance criterion ACR_{in} is used to be compared with $\frac{G_{BPT}}{G_{BST}}$ which are the ratio of the profits of “Best Profit Transportation” model and “Best Service Transportation” model. The values of ratio $\frac{G_{BPT}}{G_{BST}}$ in the experiment trials performed in this chapter are no more than 1.04. We intend to focus on the effect of ACR_{in} in the situation where there is negotiation interest of transport operator. Hence, the values of the levels for ACR_{in} are chosen no more than 1.04, corresponding to “1.01”, “1.03” and “1.04” in Table 4-7. The less the ACR_{in} is, the more the possibility that the condition $\frac{G_{BPT}}{G_{BST}} \geq ACR_{in}$ is true, the more the possibility of negotiating on the pickup plan.
- Compensation percentage CPP_{in} is set at an average value “50%”, a low value “30%”and a high value “70%.” The values defined for CPP_{in} reflect in certain degree the relation between producer and transport operator. By setting CPP_{in} a big value for instance “70%”, transport operator is more willing to work with producer.
- The MNN_{in} affects the convergence speed of negotiation process. If the value of MNN_{in} is small, the negotiation will finish soon and the profit improvement of both actors would not be remarkable. Considering an efficient negotiation process is expected to be finished within 20 iterations, the values for MNN_{in} are set to “5”, “10” and “20”.
- The aggregated delivery demand from producer in our study case requires almost 110 trucks for transport operator. As the delivery demand of producer is the output of production model which cannot be obtained before the execution of production model. This requirement for transportation capacity is deduced from the customer demand profile shown in Table 4-8. Thus the value defined for total number of trucks TNT_{in} express three cases: 1) transportation capacity is not enough (i.e. value “105”), so that to cause remarkable early and late pickup quantities and backorders to producer; 2) transportation capacity is almost enough (i.e. value “110), it may cause few early and late pickup quantities in order to well utilize transportation capacity over the planning horizon; 3) transportation capacity is enough (i.e. value “115”), producer’s delivery demand have more chance to be satisfied.

Table 4-7 Final factor list and levels of factors

Name	**Label**	**Levels**		
		L1	**L2**	**L3**
Capacity ratio	R_CAP_{in}	1.01	0.96	0.75
Extra capacity ratio	R_EXT_{in}	2	5	100
Inventory ratio	R_INV_{in}	0.5	1	2
Selling price ratio	R_SELL_{in}	1	1.5	5
Late ratio	R_LAT_{in}	0.5	1	2
Early ratio	R_EAR_{in}	0.5	1	2
Acceptance criterion	ACR_{in}	1.01	1.03	1.04
Compensation percentage	CPP_{in}	30%	50%	70%
Maximum number of negotiation	MNN_{in}	5	10	20
Total number of trucks	TNT_{in}	115	110	105

Let us remark that ACR_{in}, CPP_{in}, MNN_{in} are negotiation protocol related factors. The other factors are production model or transportation model related factors.

All ratio factors (i.e. R_EXT_{in}, R_SELL_{in}, R_CAP_{in}, $R\_INV_{in,}$ R_LAT_{in},R_EAR_{in}) which are used in our experiment are defined according to the explanation of section 2.1.2.2 in the mapping step. Once the factors levels are chosen (see Table 4-7) and given some known parameters of the transport operator and producer, some remaining parameters have to be deduced. They are calculated as follows:

- Production capacity ($Pcap_t$)

The production capacity parameter, labeled $Pcap_t$, is considered as constant over the planning horizon and is defined based on customer demands and ratio factor R_CAP_{in}. Table 4-8 shows customer demands profile and the aggregated resource requirement of customer demand ADC_{in}. Referring to the definition of ADC_{in} in Table 4-3, ADC_{in} is calculated based on all the values in gray cells. Customer demands vary from period to period. Because transportation and production lead times both equal to 1 period in our study case, any customer's demand expressed before period 3 cannot be served if no production and transportation have been launched before period 0. We make therefore the assumption that no in-process activities exist at the beginning of planning. Thus no customer demands are considered in the first 2 periods considered as a transient period. The effective period (stationary period) for production is 20 periods.

As defined in section 2.1.2.2, $R\_CAP_{in} = ADC_{in}/ADP_{in}$. ADP_{in} is the accumulated production capacity over the planning horizon. Hence, the production capacity of each period $Pcap_t$ is calculated as $Pcap_t = ADC_{in}/R\_CAP_{in}/20$ shown in Table 4-9. The grey cells show the levels of ration factors. The known input values of parameters are shown in bold cells and the white cells show the value of corresponding parameters which are deduced from ratio factors and known parameters.

Table 4-8 Customer demands profile

Product 1 required resource/unit u_1=**1**	**Demand (unit)** $d_{p,j,t}$		**Product 2** required resource/unit u_2=**2**	**Demand (unit)** $d_{p,j,t}$		**Inventory Capacity (ton)** $Icap_t$
Period	Customer 1	Customer 2	Period	Customer 1	Customer 2	
1	0	0	1	0	0	4000
2	0	0	2	0	0	4000
3	130	150	3	110	200	4000
4	150	130	4	120	210	4000
5	170	170	5	110	170	4000
6	130	200	6	130	200	4000
7	170	170	7	130	150	4000
8	179	120	8	108	120	4000
9	200	150	9	140	200	4000
10	170	170	10	180	190	4000
11	150	190	11	140	210	4000
12	200	200	12	110	220	4000
13	230	150	13	100	160	4000
14	201	170	14	130	220	4000
15	150	100	15	105	130	4000
16	160	130	16	123	200	4000
17	130	170	17	125	200	4000
18	121	150	18	132	190	4000
19	150	150	19	125	200	4000
20	169	170	20	155	133	4000
21	100	150	21	200	150	4000
22	151	120	22	132	190	4000
SUM	3211	3110	SUM	2605	3643	88000
Aggregated resource requirement of customer demand (unit) ADC$_{in}$						**18817**

Table 4-9 Parameters of production capacity

	R_CAP$_{in}$		
	L1	L2	L3
	1.01	0.96	0.75
ADC$_{in}$	Pcap$_t$		
18817	931	980	1254

- Unitary selling price to customer 1($SP_{p,1}$)

The parameter unitary selling price to customer 1, labeled $SP_{p,1}$, is deduced from unitary selling price to customer 2 (i.e. $SP_{p,2}$) and factor R_SELL$_{in}$ by equation $SP_{p,1}$ = $SP_{p,2}$* R_SELL$_{in}$ shown in Table 4-10.

Table 4-10 Parameters of selling price

		R_CAP$_{in}$		
		L1	L2	L3
		0.5	1	2
$SP_{p,2}$		$SP_{p,1}$		
Product 1	250	125	250	500
Product 2	300	150	300	600

- Late and early supplied penalty cost ($CR_{p,j}$, $CE_{p,j}$)

Unitary late (early) supplied penalty cost of producer (i.e. $CR_{p,j}$, $CE_{p,j}$) is deduced from unitary late (early) pickup penalty cost of transport operator (i.e. $BC_{p,j}$, $EC_{p,j}$) and factor R_LAT_{in} (R_EAR_{in}) shown in Table 4-11.

Table 4-11 Parameters of unitary late and early supplied and pickup penalty cost

			R_LAT_{in}					
			L1		L2		L3	
			0.5		1		2	
	$BC_{p,j}$		$CR_{p,j}$					
	Customer 1	Customer 2	Customer 1	Customer 2	Customer 1	Customer 2	Customer 1	Customer 2
Product 1	40	45	20	22.5	40	45	80	90
Product 2	50	55	25	27.5	50	55	100	110
			R_EAR_{in}					
			L1		L2		L3	
			0.5		1		2	
	$EC_{p,j}$		$CE_{p,j}$					
	Customer 1	Customer 2	Customer 1	Customer 2	Customer 1	Customer 2	Customer 1	Customer 2
Product 1	20	25	10	12.5	20	25	40	50
Product 2	30	35	15	17.5	30	35	60	70

- Unitary mean inventory cost (CS_p)

The parameter unitary mean inventory cost labeled CS_p in production model corresponds to factor ICP_{in} and is deduced from unitary early supplied penalty cost labeled $CE_{p,j}$ (i.e. ESP_{in}) and factor R_INV_{in}. Table 4-11 shows three sets of possible values of unitary early supplied penalty cost ($CE_{p,j}$). Following the same way of calculation, there will be nine sets of parameters CS_p by considering the three levels of factor R_INV_{in}.

- Cost of using extra capacity

The cost of using extra capacity is deduced from destination related transportation cost and factor R_EXT_{in} shown in Table 4-12.

Table 4-12 Parameters of destination related transportation cost and cost of using extra capacity

		R_EXT_{in}		
		L1	L2	L3
		2	5	100
	FC_j	FC_extra_j		
Customer 1	600	1200	3000	60000
Customer 2	800	1600	4000	80000

As mentioned before, we focus on the impact of transport operator negotiation factors in the preliminary experiment by fixing the producer negotiation factors as shown in Appendix I, Table a. 4. Other parameters which are necessary for the execution of production and transportation models can be found in Appendix I as well, see Table a. 1 to Table a. 3. The destination related transportation cost of using a truck takes more than 50% transportation cost.

4.3.1.2 *Orthogonal design*

A full-factorial design with 10 factors at 3 levels without interactions requires 3^{10} trials of experiment. In order to reduce the number of trials, orthogonal array proposed by Taguchi method are used in order to design an experiment with 10 factors at 3 levels and furthermore evaluate the effects of factors.

A three-step procedure should be followed in design of experiments:

1. Find out the total degree of freedom (DOF).

How to calculate DOF of an experiment? Total degree of freedom of experiment equals to the sum of degrees of freedom of all the elements which are overall mean, factors and interactions in the experiment.

- The overall mean always uses 1 degree of freedom.
- The degree of freedom of a factor equals to the number of levels of this factor minus 1. For example factor A, if the number of levels are n_{A},, the degree of freedom of factor A = n_A-1;
- For an interaction between factor A and factor B, the degree of freedom of interaction AB = (n_A-1)(n_B-1).

Thus, the DOF of experiment with 10 three-level factors is calculated in Table 4-13.

Table 4-13 Total degree of freedom of preliminary experiment

Factors	Degree of freedom
Overall mean	1
10 three-level factors	10*(3-1)=20
DOF	**1+20=21**

2. Select a standard orthogonal array by respecting the following two rules:
   - The number of trials in the orthogonal design should be greater than total DOF;
   - The selected orthogonal array should be able to accommodate the factor level combinations in the experiment.

Table 4-14 Taguchi standard orthogonal arrays (Ranjit, 2001)

Orthogonal array	No. trials	Max Factors	2-level	3-level	4-level	5-level
L_4	4	3	3			
L_8	8	7	7			
L_9	9	4		4		
L_{12}	12	11	11			
L_{16}	16	15	15			
L'_{16}	16	5			5	
L_{18}	18	8	1	7		
L_{25}	25	6				6
L_{27}	27	13		13		
L_{32}	32	31	31			
L'_{32}	32	10	1		9	
L_{36}	36	23	11	12		
L'_{36}	36	16	3	13		
L_{50}	50	12	1			11
L_{54}	54	26	1	25		
L_{64}	64	63	63			
L'_{64}	64	21			21	
L_{81}	81	40		40		

Denoting T as the number of trials in the orthogonal design which corresponds to the number of rows in experimental array, the above two rules can be expressed as follows:

- T≥ DOF;
- T=k* LCM (n_i*n_j), with the following notations, k is an integer which is more than or equal to 1; LCM is defined as the least common multiple; i and j are any two different factors of the experiment.

In our experiment design, the experiment is composed by10 factors at 3 levels. Thus,

- T≥21
- T= k*LCM(3*3, 3*3, …,3*3)=9k
- So the minimum number of trials in the orthogonal design T equals to 27.

Referring to Table 4-14, the corresponding orthogonal array is L_{27} which can evaluate at most 13 factors at 3 levels.

3. Assign factors to appropriate columns using the following rules:
   - Assign factors and interactions according to the linear graph of Taguchi;
   - Assign factors which are the most difficult to change in frontal columns; let us notice that this constraint is not significant in the context of simulated design of experiments.

The selected orthogonal array L_{27} contains 13 columns. Since we only have 10 factors, we only use the first 10 columns of the orthogonal array. In physical systems, the factors which are not easy to change are assigned to frontal columns. Concerning our experiment, we can assign arbitrarily the factors to columns.

An experimental array with 27 trials is shown in Table 4-15. The factors can be divided into different groups, production factors (P), transportation factors (T), negotiation factors (N) and inter-model factors (P/T).

Table 4-15 Experimental array L_{27}

Group of factors	T		N			P			P/T	P/T
N° of trial	R_EXT_{in}	TNT_{in}	MNN_{in}	ACR_{in}	CPP_{in}	R_SELL_{in}	R_CAP_{in}	R_INV_{in}	R_LAT_{in}	R_EAR_{in}
1	2	115	5	1.01	30%	1	1.01	0.5	0.5	0.5
2	2	110	5	1.01	30%	1.5	0.96	1	1	1
3	2	105	5	1.01	30%	5	0.75	2	2	2
4	2	115	10	1.03	50%	1	1.01	1	1	1
5	2	110	10	1.03	50%	1.5	0.96	2	2	2
6	2	105	10	1.03	50%	5	0.75	0.5	0.5	0.5
7	2	115	20	1.04	70%	1	1.01	2	2	2
8	2	110	20	1.04	70%	1.5	0.96	0.5	0.5	0.5
9	2	105	20	1.04	70%	5	0.75	1	1	1
10	5	105	5	1.03	70%	1	0.96	0.5	1	2
11	5	115	5	1.03	70%	1.5	0.75	1	2	0.5
12	5	110	5	1.03	70%	5	1.01	2	0.5	1
13	5	105	10	1.04	30%	1	0.96	1	2	0.5
14	5	115	10	1.04	30%	1.5	0.75	2	0.5	1
15	5	110	10	1.04	30%	5	1.01	0.5	1	2
16	5	105	20	1.01	50%	1	0.96	2	0.5	1
17	5	115	20	1.01	50%	1.5	0.75	0.5	1	2
18	5	110	20	1.01	50%	5	1.01	1	2	0.5
19	100	110	5	1.04	50%	1	0.75	0.5	2	1
20	100	105	5	1.04	50%	1.5	1.01	1	0.5	2
21	100	115	5	1.04	50%	5	0.96	2	1	0.5
22	100	110	10	1.01	70%	1	0.75	1	0.5	2
23	100	105	10	1.01	70%	1.5	1.01	2	1	0.5
24	100	115	10	1.01	70%	5	0.96	0.5	2	1
25	100	110	20	1.03	30%	1	0.75	2	1	0.5
26	100	105	20	1.03	30%	1.5	1.01	0.5	2	1
27	100	115	20	1.03	30%	5	0.96	1	0.5	2

4.3.2 Result evaluation and analysis

Producer and transport operator intend to find a consensual solution according to the negotiation protocol, as described in chapter 3. The different combinations of factors levels cause various experiment responses. In this part, the results of experimental array L_{27} will demonstrate how these factors affect the experiment responses, and which factor affects the most the responses. At the end of analysis, a list of factors will be identified regarding their influence to the production-transportation negotiation. It then allows producer and transport operator to identify a subset of factors whose value should be paid more attention and qualitatively estimate the impact on the optimization of the performance of each partner.

4.3.2.1 *Results and observations*

The results of this experiment are organized from two different aspects. At first, the analysis is focused on the economic responses regarding the profit of each partner and total profit for all the performed experiment trials. The analysis then considers customer satisfaction. Economic responses and service quality responses are respectively shown in Table 4-16 and Table 4-17.

Table 4-16 Preliminary experiment results of economic responses

N° of trial	PPR_{out} (euro)	PTR_{out} (euro)	TOP_{out} (euro)	DPP_{out} (%)	DPT_{out} (%)	DTP_{out} (%)
1	2 063 533.5	267 618.0	2 331 151.5	0.10%	1.95%	0.31%
2	2 965 848.1	261 722.9	3 227 571.0	0.07%	2.28%	0.24%
3	9 279 230.7	250 098.3	9 529 329.0	-0.01%	2.04%	0.04%
4	2 065 019.5	266 777.5	2 331 797.0	0.17%	1.63%	0.34%
5	2 966 458.5	260 057.5	3 226 516.0	0.09%	1.63%	0.21%
6	9 287 080.0	251 341.5	9 538 421.5	0.07%	2.55%	0.13%
7	2 065 353.8	265 234.2	2 330 588.0	0.19%	1.04%	0.28%
8	2 970 358.0	258 583.5	3 228 941.5	0.22%	1.05%	0.29%
9	9 288 746.5	248 842.5	9 537 589.0	0.09%	1.53%	0.13%
10	2 079 875.1	191 571.9	2 271 447.0	0.89%	4.52%	1.19%
11	2 972 486.5	256 830.0	3 229 316.5	0.29%	1.56%	0.39%
12	9 286 431.4	228 977.1	9 515 408.5	0.06%	1.10%	0.09%
13	2 068 610.4	202 609.1	2 271 219.5	0.35%	10.54%	1.18%
14	2 967 934.3	263 545.2	3 231 479.5	0.14%	4.21%	0.46%
15	9 284 203.0	235 181.0	9 519 384.0	0.04%	3.84%	0.13%
16	2 075 354.0	197 090.5	2 272 444.5	0.67%	7.53%	1.23%
17	2 970 390.0	260 502.0	3 230 892.0	0.22%	3.01%	0.44%
18	9 287 387.5	233 771.5	9 521 159.0	0.07%	3.21%	0.15%
19	2 050 347.0	269 308.0	2 319 655.0	-0.54%	5.97%	0.17%
20	2 665 063.5	267 412.0	2 932 475.5	-10.08%	19.32%	-8.01%
21	9 281 535.0	266 434.0	9 547 969.0	0.01%	0.00%	0.01%
22	2 044 354.3	270 774.7	2 315 129.0	-0.83%	6.55%	-0.02%
23	2 919 795.0	275 826.0	3 195 621.0	-1.49%	23.07%	0.24%
24	9 282 385.5	267 653.5	9 550 039.0	0.02%	0.46%	0.03%
25	2 055 739.5	269 308.0	2 325 047.5	-0.28%	5.97%	0.41%
26	2 874 130.0	276 520.0	3 150 650.0	-3.03%	23.38%	-1.17%
27	9 280 613.1	269 567.9	9 550 181.0	0.00%	1.18%	0.03%
MAX	9 288 746.5	276 520.0	9 550 181.0	0.89%	23.38%	1.23%
MIN	2 044 354.3	191 571.9	2 271 219.5	-10.08%	0.00%	-8.01%
AVERAGE	4 755 491.3	253 079.9	5 008 571.2	-0.46%	5.23%	-0.04%

Table 4-17 Preliminary experiment results of service quality responses

N° of trial	Transport operator			Producer			Negotiation	
	LPQ_{out} **(Unit)**	EPQ_{out} **(Unit)**	BOP_{out} **(Unit)**	LSQ_{out} **(Unit)**	ESQ_{out} **(Unit)**	BOC_{out} **(Unit)**	TIN_{out} **(Unit)**	FCP_{out} **(euro)**
1	11	15	0	7	15	4	3	2 196.0
2	5	18	0	4	18	1	3	2 498.1
3	6	14	0	2	12	2	4	2 144.7
4	9	25	0	6	25	3	4	4 283.5
5	5	18	0	4	18	1	5	4 163.5
6	3	31	0	3	31	0	4	6 247.5
7	8	32	0	6	32	2	6	6 393.8
8	3	23	0	3	23	0	8	6 275.5
9	3	31	0	3	31	0	7	8 746.5
10	20	19	3	17	19	3	4	19 315.1
11	3	9	0	3	9	0	3	9 184.0
12	10	1	1	9	1	1	5	5 793.9
13	20	19	3	17	19	3	7	8 277.9
14	9	15	0	6	15	3	4	4 564.8
15	3	7	0	2	6	0	8	3 723.0
16	20	19	3	17	19	3	12	13 796.5
17	9	15	0	6	15	3	7	7 608.0
18	6	9	0	6	9	0	14	7 277.5
19	0	0	0	306	7	2	7	0
20	179	0	2	4 812	15	64	56	0
21	28	1	0	28	1	0	1	0
22	13	26	0	313	31	4	14	3 422.3
23	0	0	0	1 882	8	61	22	0
24	23	21	0	23	21	0	6	2 845.5
25	0	0	0	306	7	2	21	0
26	0	0	0	2 275	8	62	42	0
27	25	22	0	24	22	1	10	1 343.1
MAX	179	32	3	4 812	32	64	56	19 315.1
MIN	0	0	0	2	1	0	1	0
AVERAGE	15.6	14.4	0.4	373.7	16.2	8.3	10.6	4 818.5

From the all the results, we get some general remarks as follows:

- The performance of the negotiation protocol behaves as expected: the profit of transport operator PTR_{out} is maximized on average 5.23% without decreasing significantly the profit of producer PPR_{out} (average decrease of 0.46%). The total profit TOP_{out} resulting from the negotiation protocol is only slightly impacted, with an average decrease of 0.04%. The transport operator tries to convince the producer to deliver his customers early or late by sharing the increase of profit resulting from leveling of transportation load. There is a financial exchange in the negotiation: if the profit of transport operator increases, it does not mean that producer loss its profit. The early or late supplied penalties that producer pays to its customers could be compensated by the shared profit increase of transport operator and by similar penalties that transport operator has to pay to producer.
- The responses focus on the performance of producer and transport operator. The risk of losing a customer by late deliveries is not analyzed here.

The observations and explanations of other response are presented as below:

- Difference of profit of producer, DPP_{out}.

After negotiation, the profit of producer is increased by maximum 0.89% and in some cases decreases as well. The worst case decreases by 10.08%. There are two reasons to explain the decrease of production profit: 1) Producer accepts profit decrease to a lower bound R_G*G_{BPP}. As long as the production profit after negotiation is more than this lower bound, the received pickup plan is considered acceptable (i.e. trial N°3 in Table 4-16); 2) Profit of producer decreases because producer releases his profit in order to adapt to transport operator's capacity, trials N°19, 20, 22, 23, 25, 26 in Table 4-16. For each released production planning, producer releases 1% of his profit by using parameter *pp_release*. The more the number of released production planning is, the more production profit decreases.

- Difference of profit of transport operator, DPT_{out}.

After negotiation, profit of transport operator is improved much more than profit of producer. The maximum increase of profit of transport operator is 23.38% corresponding to trial N°26 in Table 4-16. In the trials N°20, 23, 26 in the same table, the cost of using extra capacity is extremely high. The local transportation capacity is 105 trucks which is less than the requirement of delivery demand. So that producer's delivery demand will not be satisfied. Producer may only release his profit by accepting the decrease of delivery demands. Therefore, transport operator pays less early and late pickup penalties to producer than executing the initial delivery plan so that the profit of transport operator significantly increases.

- Difference of total profit, DTP_{out}.

After negotiation, the trials with the maximum and minimum differences of total profit (TOP_{out}) correspond to the same trials with the maximum and minimum difference of profit of producer (PPR_{out}), because the profit of producer is almost 10 times of that of transport operator. The average compensation will cause about 0.1% increase to the average profit of producer.

- Early and late pickup quantity $EPQ_{out,}$ LPQ_{out} and early and late supplied quantity, LSQ_{out}, ESQ_{out}.

The experiment trial with maximum value of EPQ_{out} corresponds to the same trial with maximum value of ESQ_{out}. It is the same situation for LPQ_{out} and LSQ_{out}. It can be explained by the fact that any early or late pickup quantity of transport operator will directly cause early or late supplied quantities of producer.

- Backorders to producer, BOP_{out} and backorders to customer, BOC_{out}.

BOP_{out} is always less than BOC_{out} because any backorders caused by transport operator will directly affect the deliveries to customers and further cause producer's backorders to customer.

- Final compensation, FCP_{out}.

There are six trials with compensation 0, trial N°19, 20, 21, 23, 25, 26 in Table 4-17. In these cases, the negotiation process converges finally on the BST plan of transport operator.

- Total number of iterations

We note that, in general, the total number of iterations (run times of EP model) is no more than 20 when the profits of both partners increase after negotiation. The negotiation process searches for maximizing performance and for respecting transportation constraints at the same time. Hence a large number of iterations are rather revealing the limitations of transportation capacity.

4.3.2.2 *Effects of factors on responses*

We have presented all the results of this preliminary experiment and some analysis remarks. In this part, we will evaluate the effects of the ten factors in order to know their influence to the responses. The analysis is carried out according to Taguchi method.

For each response, denote:

$\overline{D}$: average value of the considered response on all trials.

$\overline{A_n}$: average value of the considered response when factor A at level n

E_{An}: effect of factor A at level n.

The formula to calculate the effect of factor A at level n is $E_{An} = \overline{A_n} - \overline{D}$. By using this formula, we evaluate hereunder the effects of factors by two parts as defined in section 4.2.1.1: economic responses and service quality responses.

4.3.2.2.1 *Economic responses*

There are totally six economic responses as defined in section 4.2.1.1.1: profit of producer PPR_{out}, difference of profit of producer DPP_{out}, profit of transport operator PTR_{out}, difference of profit of transport operator DPT_{out}, total profit TOP_{out}, and difference of total profit DTP_{out}.

In this section we will not present all the factor effects graphs but consider response PTR_{out}, profit of transport operator, as an example to analyze which factors have significant effects on the responses. Figure 4.4 shows that four factors have great effects on profit of transport operator:

- The ratio between cost of using extra capacity and destination related transportation cost (R_EXT_{in})
- The ratio between selling price to customer 1 and selling price to customer 2 (R_SELL_{in})
- The ratio between aggregated resource requirement of customer demand and aggregated capacity of producer (R_CAP_{in})
- The total number of trucks (TNT_{in})

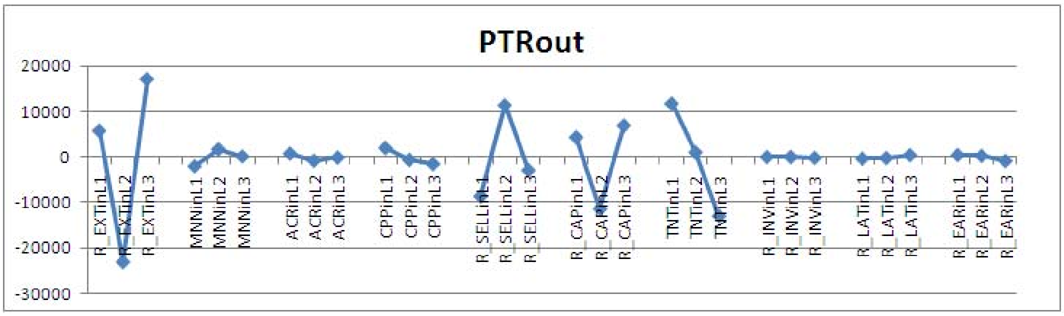


Figure 4.4 Effects on response of profit of transport operator

All the effects graphs of preliminary experiment can be found in Appendix II. Table 4-18 synthesizes the most important factors which impact economic responses. "X" indicates that there is a factor which has effect on the corresponding response. Four factors are identified which have significant effects on economic responses.

Table 4-18 Influential factors on economic responses

		Responses					
		PPR_{out}	DPP_{out}	PTR_{out}	DPT_{out}	TOP_{out}	DTP_{out}
Factors	R_SELL_{in}	X	X	X	X	X	X
	R_EXT_{in}		X	X	X		X
	R_CAP_{in}		X	X	X		X
	TNT_{in}		X	X	X		

4.3.2.2.2 *Service quality responses*

The service quality responses are divided into three groups: production responses, transportation responses and negotiation responses, as proposed in section 4.2.1.1.2. Similar to economic responses, the figures of effects on service quality responses can be found in Appendix II. We only present the response ESQ_{out} which is the accumulated early supplied quantity as a representative example. Figure 4.5 shows that all factors can be considered as significant in analyzing their effects on response of ESQ_{out} except factor ACR_{in}.

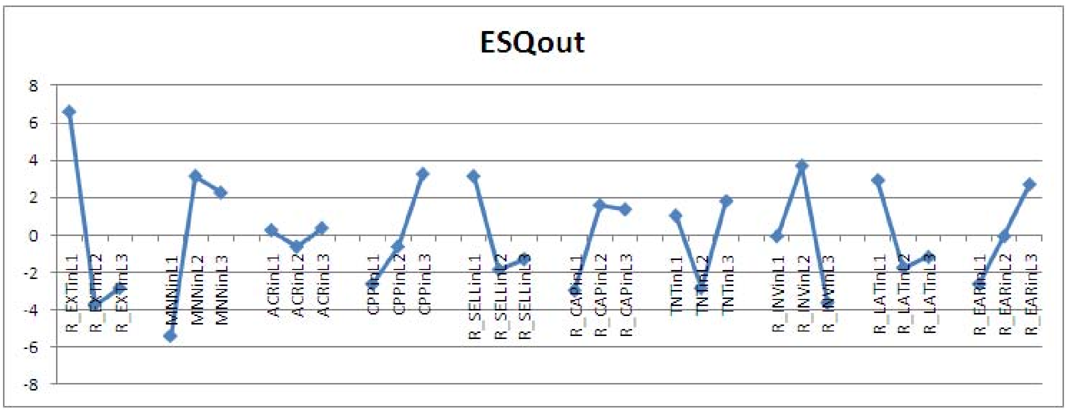


Figure 4.5 Effects on response of accumulated early supplied quantity

Table 4-19 synthesizes the factors which have great effects for each service quality response.

Table 4-19 Influential factors on service quality responses

		Responses							
		ESQ_{out}	LSQ_{out}	BOC_{out}	EPQ_{out}	LPQ_{out}	BOP_{out}	FCP_{out}	TIN_{out}
Factors	R_CAP_{in}	X	X	X	X	X	X	X	
	R_INV_{in}	X			X	X			
	R_SELL_{in}	X	X	X	X	X	X	X	
	R_EXT_{in}	X	X	X	X	X	X	X	X
	R_EAR_{in}	X			X	X			
	R_LAT_{in}	X			X	X			
	ACR_{in}					X			
	CPP_{in}	X			X	X			
	MNN_{in}	X			X	X			
	TNT_{in}	X	X	X	X	X	X	X	

4.3.2.2.3 *Synthesis of effects*

Table 4-20 synthesizes the number of responses which are impacted by each factor and displays a ranked list of factors from most influential to least influential.

Table 4-20 Factors and the number of affected responses

Factors	The number of response affected
R_SELL_{in}	**13**
R_EXT_{in}	**12**
R_CAP_{in}	**11**
TNT_{in}	**10**
CPP_{in}	3
MNN_{in}	3
R_INV_{in}	3
R_LAT_{in}	3
R_EAR_{in}	3
ACR_{in}	1

4.3.3 Confirmation experiment

The previous experiment array supposes the interactions between any couple of factors have minor effects on the results. Let us also recall that this preliminary experiment is based on a fractional experimental array which contains a reduced number of experiment trials. Consequently it is necessary to verify this hypothesis through the implementation of a new experiment, called "confirmation experiment". This confirmation must be done for each response studied. For each response, it consists in choosing the level for each factor. The chosen level will orient the concerned response toward the best value. The level settings of factors in confirmation experiment are based on the results of preliminary experiment and are shown for each response in Table 4-21.

The confirmation experiment can be analyzed in two different ways: the first concerns the validation of the effects of factors observed in preliminary experiment and the second concerns the interpretation of these results on the transportation and production point of view.

Table 4-21 Factor settings of confirmation experiment

	Responses \ Factors	R_EXT_{in}	MNN_{in}	ACR_{in}	CPP_{in}	R_SELL_{in}	R_CAP_{in}	TNT_{in}	R_INV_{in}	R_LAT_{in}	R_EAR_{in}
Economic	PPR_{out}	L2	L2	L1	L3	L3	L2	L1	L3	L2	L1
	TOP_{out}	L2	L2	L1	L3	L3	L2	L1	L3	L2	L1
	PTR_{out}	L3	L2	L1	L1	L2	L3	L1	L2	L3	L1
	DPP_{out}	L2	L2	L1	L3	L1	L2	L1	L3	L2	L1
	DPT_{out}	L3	L2	L1	L1	L2	L1	L3	L2	L3	L1
	DTP_{out}	L2	L2	L1	L3	L1	L2	L1	L3	L2	L1
Service quality	ESQ_{out}	L2	L1	L2	L1	L2	L1	L2	L3	L2	L1
	LSQ_{out}	L1	L2	L1	L3	L3	L2	L1	L3	L2	L1
	BOC_{out}	L1	L3	L2	L3	L3	L2	L2	L1	L3	L1
	EPQ_{out}	L3	L1	L2	L1	L2	L1	L2	L3	L2	L1
	LPQ_{out}	L1	L3	L2	L1	L1	L3	L2	L1	L3	L1
	BOP_{out}	L1	L2, L3	L1	L1	L3	L3	L1	L1	L2, L3	L1
	FCP_{out}	L3	L2	L3	L1	L2	L1	L2	L3	L3	L1
	TIN_{out}	L1	L2	L1	L3	L3	L2	L1	L3	L2	L1

Concerning the validation process, the response value of the confirmation experiment is compared with the response values obtained in the preliminary experiment containing 27 trials. The confirmation results are synthesized in Table 4-22 for all the responses. In this table, the second column, labeled "confirmation success rate", contains a ratio calculated as the number of trials in the preliminary experimental array which have a response worse than the confirmation trial. For instance, in the second line of this table, the response total profit (TOP_{out}) is confirmed in 24 trials among the total number of trials (i.e 27). If the confirmation success rate equals one, the full validation of the design of experiment is obtained. The following remarks can be done about Table 4-22:

- The confirmation success rate is superior to 85 % (23/27) for 12 responses which are in bold in this table and it is 100 % for six responses. However the two responses, profit of transport operator labeled PTR_{out} and late supplied quantity labeled LSQ_{out}, have a low confirmation success rate (21/27 and 19/27). Hence the experimental design that we proposed can encompass the large set of responses which are considered in this study.

- The main important response considered in this study, i.e. the total profit TOP_{out}, has a high confirmation success rate 89% (24/27).

Table 4-22 Comparison results of conformation experiment

Responses	Confirmation success rate	Verification result	MAX	MIN	AVERAGE
Economic response					
PPR_{out}	**27/27**	**9 289 196.5**	**9 288 746.5**	**2 044 354.3**	**4 755 491.3**
TOP_{out}	**24/27**	**9 546 026.5**	**9 550 181.0**	**2 271 219.5**	**5 008 571.2**
PTR_{out}	21/27	269 279.5	276 520	191 571.9	253 079.9
DPP_{out}	**25/27**	**0.44%**	**0.89%**	**-10.08%**	**-0.46%**
DPT_{out}	**26/27**	**23.07%**	**23.38%**	**0%**	**5.23%**
DTP_{out}	**24/27**	**0.56%**	**1.23%**	**-8.01%**	**-0.04%**
Service quality response					
ESQ_{out}	**27/27**	**1**	**32**	**1**	**16.2**
LSQ_{out}	19/27	6	64	0	8.3
BOC_{out}	**27/27**	**0**	**32**	**1**	**16.2**
EPQ_{out}	**27/27**	**0**	**32**	**0**	**14.4**
LPQ_{out}	**23/27**	**3**	**179**	**0**	**15.6**
BOP_{out}	**27/27**	**0**	**3**	**0**	**0.4**
FCP_{out}	**27/27**	**0**	**19 315.1**	**0**	**4 818.5**
TIN_{out}	**23/27**	**4**	**56**	**1**	**10.6**

- On the production and transport point of view, the following remarks can be done:
  - There is a strong coupling between the two economic responses, profit of production (PPR_{out}) and total profit (TOP_{out}); this can be observed in Table 4-21 where the factors settings for these two responses in the confirmation experiment are identical for all factors. A similar observation can be done between the difference of profit of producer DPP_{out} and the difference of total profit DTP_{out}. This strong coupling can be explained by the important weight of the production profit in the total profit.
  - The level value of early ratio factor (R_EAR_{in}) equals to L1 in all the confirmation experiment trials. It means that all the responses performances are better when the early supplied cost is less than the early pickup cost. This encourages the producer to accept the early supplied quantity induced by early pickup quantity of transport operator.

The confirmation experiment achieved in this section shows that the effects of factors are validated in most of the responses studied. Hence, the preliminary experimental array of the previous section is confirmed in their ability to identify the most important factors. However considering that two responses (i.e. $PTR_{out,}$ LSQ_{out}) were not fully validated, we investigate in the next section the existence of interactions between the important factors.

4.4 Refined performance evaluation

In the previous section, a preliminary experimental array has been performed in order to study the effects of a large number of factors (i.e. 10 factors) without interactions. In this section, two refined experimental arrays are achieved. The first one aims to study the effects of possible interactions between the important factors identified in the preliminary performance evaluation process (i.e. R_EXT_{in}, R_CAP_{in}, R_SELL_{in}, TNT_{in}). The second refined experiment focuses on the analysis of the negotiation process which is the main concern of our research.

4.4.1 Interactions study

The confirmation experiment in the preliminary performance evaluation step show that the preliminary experimental array is not fully validated regarding the response of profit of transport operator (PTR_{out}) and response of accumulated late supplied quantity (LSQ_{out}). This could be caused by interactions. In order to study the effects of interactions, since wide ranging interactions can be observed for all these 10 factors, we decide to study only the interactions of the most important factors. We have identified four factors which have strong impacts on responses in section 4.3.2.2.3. Now the new experiment focuses on these four factors and invests their interactions on responses.

4.4.1.1 *Experimental array*

Six pairs of any two factors among the set of four factors compose 6 two-factor interactions (i.e. first order interactions). The full-factorial design with four factors at 3 levels and full interactions may be studied through more than 27 experiment trials. In order to decrease the number of experiment trials, we have two choices: decrease the number of levels or decrease the number of interactions. Thus, the analysis can be made by defining:

- an experimental array with four factors and complete interactions but at 2 levels,
- or an experimental array with four factors at 3 levels but with incomplete interactions.

Since we would like to study the effects of interactions, we choose to decrease the number of levels. Using the same principle of total degree of freedom, we choose orthogonal array L_{16} to construct the new experimental array which can be used to study at most five 2-level factors with complete interactions. Referring to the linear graph of L_{16}, see Figure a. 43 in Appendix V, we assign factors to corresponding columns in the Table 4-23.

Table 4-23 Factors and corresponding columns in experimental array L_{16}

Factors	Label	Column
R_EXT_{in}	A	1
R_CAP_{in}	B	2
R_SELL_{in}	C	8
TNT_{in}	D	15
	AB	3
	AC	9
	AD	14
	BC	10
	BD	13
	CD	7

In order to define the levels of each factor in this new experimental array, we chose the smallest and biggest value in the previous experimental array (i.e. L1, L3) as shown in Table 4-24. Table 4-25 shows the new experimental array. Let us remark that L_{16} table contains 15 columns and some columns are unused because only 10 columns are concerned in our experimental array. As shown in Table 4-26, for the rest factors in experimental array L_{27} which are not taken into account in experimental array L_{16}, we choose the levels which achieve the best response on total profit referring to the corresponding effects figure of TOP_{out} in Appendix II, Figure a. 5.

Table 4-24 Levels of factors in experimental array L_{16}

Factors	Levels		
	L1	L2	L3
R_CAP_{in}	**1.01**	0.96	**0.75**
TNT_{in}	**115**	110	**105**
R_INV_{in}	0.5	1	2
R_SELL_{in}	**1**	1.5	**5**
R_LAT_{in}	0.5	1	2
R_EAR_{in}	0.5	1	2
ACR_{in}	1.01	1.03	1.04
MNN_{in}	5	10	20
CPP_{in}	30%	50%	70%
R_EXT_{in}	**2**	5	**100**

Table 4-25 Experimental array L_{16} with interactions

N° of trial	**A**	**B**	AB	CD	**C**	AC	BC	BD	AD	**D**
1	**2**	**1.01**	1	1	**1**	1	1	1	1	**115**
2	**2**	**1.01**	1	1	**5**	2	2	2	2	**105**
3	**2**	**1.01**	1	2	**1**	1	1	2	2	**105**
4	**2**	**1.01**	1	2	**5**	2	2	1	1	**115**
5	**2**	**0.75**	2	2	**1**	1	2	1	2	**105**
6	**2**	**0.75**	2	2	**5**	2	1	2	1	**115**
7	**2**	**0.75**	2	1	**1**	1	2	2	1	**115**
8	**2**	**0.75**	2	1	**5**	2	1	1	2	**105**
9	**100**	**1.01**	2	2	**1**	2	1	2	1	**105**
10	**100**	**1.01**	2	2	**5**	1	2	1	2	**115**
11	**100**	**1.01**	2	1	**1**	2	1	1	2	**115**
12	**100**	**1.01**	2	1	**5**	1	2	2	1	**105**
13	**100**	**0.75**	1	1	**1**	2	2	2	2	**115**
14	**100**	**0.75**	1	1	**5**	1	1	1	1	**105**
15	**100**	**0.75**	1	2	**1**	2	2	1	1	**105**
16	**100**	**0.75**	1	2	**5**	1	1	2	2	**115**

Table 4-26 Other factors not defined in experimental array L_{16}

Factor	MNN_{in}	ACR_{in}	CPP_{in}	R_INV_{in}	R_LAT_{in}	R_EAR_{in}
Level	10	1.01	70%	2	1	0.5

4.4.1.2 *Result evaluation and analysis*

After execution of the experimental array with four factors and full interactions defined in section 4.4.1.1, we get the results of 16 experiment trials shown in Table 4-27 and Table 4-28.

Table 4-27 Experiment results of economic responses of interaction study

N° of trial	PPR_{out} (euro)	PTR_{out} (euro)	TOP_{out} (euro)	DPP_{out} (%)	DPT_{out} (%)	DTP_{out} (%)
1	2 066 830.4	265 064.1	2 331 894.5	0.26%	0.98%	0.34%
2	9 287 703.5	248 905.5	9 536 609.0	0.08%	1.56%	0.12%
3	2 069 703.5	248 905.5	2 318 609.0	0.40%	1.56%	0.52%
4	9 284 470.4	265 064.1	9 549 534.5	0.04%	0.98%	0.07%
5	2 069 703.5	248 905.5	2 318 609.0	0.40%	1.56%	0.52%
6	9 284 470.4	265 064.1	9 549 534.5	0.04%	0.98%	0.07%
7	2 066 830.4	265 064.1	2 331 894.5	0.26%	0.98%	0.34%
8	9 287 703.5	248 905.5	9 536 609.0	0.08%	1.56%	0.12%
9	2 016 262.5	275 411.0	2 291 673.5	-2.19%	22.88%	0.27%
10	9 283 793.0	267 653.5	9 551 446.5	0.03%	0.46%	0.05%
11	2 064 713.0	267 653.5	2 332 366.5	0.16%	0.46%	0.19%
12	9 235 950.0	275 826.0	9 511 776.0	-0.48%	23.07%	0.07%
13	2 064 713.0	267 653.5	2 332 366.5	0.16%	0.46%	0.19%
14	9 237 000.0	275 826.0	9 512 826.0	-0.47%	23.07%	0.09%
15	2 016 542.5	276 211.0	2 292 753.5	-2.18%	23.24%	0.31%
16	9 283 793.0	267 653.5	9 551 446.5	0.03%	0.46%	0.05%
MAX	9 287 703.5	276 211.0	9 551 446.5	0.40%	23.24%	0.52%
MIN	2 016 262.5	248 905.5	2 291 673.5	-2.19%	0.46%	0.05%
AVERAGE	5 663 761.4	264 360.4	5 928 121.8	-0.21%	6.51%	0.21%

Table 4-28 Experiment results of service quality responses of interaction study

N° of trial	LPQ_{out} (Unit)	EPQ_{out} (Unit)	BOP_{out} (Unit)	LSQ_{out} (Unit)	ESQ_{out} (Unit)	BOC_{out} (Unit)	TIN_{out} (Unit)	FCP_{out} (euro)
1	9	25	0	6	25	3	4	5 996.9
2	8	32	0	6	32	2	4	8 893.5
3	8	32	0	6	32	2	4	8 893.5
4	9	25	0	6	25	3	4	5 996.9
5	8	32	0	6	32	2	4	8 893.5
6	9	25	0	6	25	3	4	5 996.9
7	9	25	0	6	25	3	4	5 996.9
8	8	32	0	6	32	2	4	8 893.5
9	0	0	0	2 005	10	56	23	0
10	23	21	0	23	21	0	6	2 845.5
11	23	21	0	23	21	0	6	2 845.5
12	0	0	0	1 894	12	61	11	0
13	23	21	0	23	21	0	6	2 845.5
14	0	0	0	1 834	12	61	11	0
15	0	0	0	1 989	10	56	23	0
16	23	21	0	23	21	0	6	2 845.5
MAX	23	32	0	2 005	32	61	23	8 893.5
MIN	0	0	0	6	10	0	4	0
AVERAGE	10	19.5	0	491.4	22.3	15.9	7.8	4 434.0

In order to evaluate the effects of factors and their interactions, we present first the calculation formula defined in Taguchi method.

Denote:

I_{AnBm} : effect of interaction of factor A at level n and factor B at level m;

E_{An} : effect of factor A at level n;

E_{Bm} : effect of factor B at level m;

$\overline{A_n B_m}$: average value of the considered response when factor A at level n and factor B at level m;

$\overline{D}$: average value of the considered response on all trials.

Then,

$$I_{AnBm} = \overline{A_n B_{\mathrm{m}}} - \overline{D} - E_{An} - E_{Bm}$$

We present all the figures which show the effects of factors and their interactions on all responses in Appendix III. In the following parts, we only present some of them as examples.

- Economic responses

The effects of factors and their interactions are evaluated on economic responses including profit of producer (PPR_{out}), profit of transport operator (PTR_{out}), total profit (TOP_{out}) and their difference before and after negotiation (DPP_{out}, DPT_{out}, DTP_{out}). Figure 4.6 presents the effects of factors on response of profit of transport operator. This figure shows that interaction AD significantly impacts the response of profit of transport operator. Lets us remind that column A corresponds to $R\_EXT_{in,}$ representing the extra capacity ratio and column D corresponds to TNT_{in}, which is the total number of trucks. If the cost of using extra capacity is not significant expensive, and if the number of trucks that transport operator owns decreases, its transportation capacity will decrease as well. Transport operator may require more extra transportation capacity to satisfy producer’s delivery demand. By paying more extra transportation cost, profit of transport operator will decrease. However, if the cost of using extra capacity is significantly expensive and transport operators’ transportation capacity cannot satisfy delivery requirement, transport operator will not require extra capacity. In this case producer has to adapt to the limitation of transportation capacity. By this way, transport operator pays fewer penalty and his profit increases consequently. Therefore, an interaction between R_EXT_{in} and TNT_{in} exists.

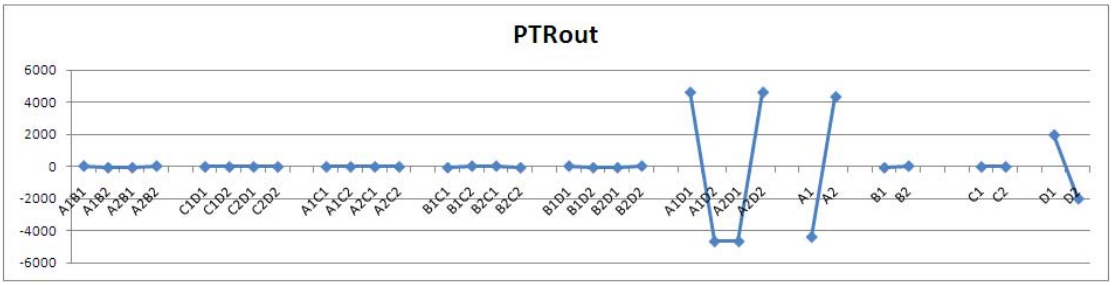


Figure 4.6 Effects of interactions on response of profit of transport operator

Table 4-29 summarizes all the effects of interactions on the six economic responses. It shows that interaction AD is the most significant interaction, which has effect on most (4/6) of economic responses.

Table 4-29 Synthesis of effects of interactions on economic responses

		Responses					
		PPR_{out}	PTR_{out}	TOP_{out}	DPP_{out}	DPT_{out}	DTP_{out}
Interactions	AB						
	CD				X		X
	AC				X		X
	BC						
	BD						
	AD		X		X	X	X

- Service quality responses

We evaluate service quality responses considering the three groups: production responses, transportation responses and negotiation responses.

a. Production responses

The effects of interactions on the responses of producer service quality include late supplied quantity (LSQ_{out}), early supplied quantity (ESQ_{out}) and backorders to customer (BOC_{out}). The corresponding effects figures can be found in Appendix III. Interaction AD has an still effect on all these three responses.

b. Transportation responses

Accumulated late pickup quantity (LPQ_{out}), early pickup quantity (EPQ_{out}), backorders to producer (BOP_{out}) are three transport operator service quality responses. The corresponding effects figures can be found in Appendix III. Interaction AD has an effect on accumulated late pickup quantity and early pickup quantity.

c. Negotiation

Figure 4.7 shows that interaction AD has effect on response of final compensation after negotiation (FCP_{out}). Figure 4.8 shows the effects of interactions on response of total iteration number (TIN_{out}). Interactions CD, AC and AD have effects on total iteration number. Lets us remind that column A corresponds to $R\_EXT_{in,}$ representing the extra capacity ratio, column C corresponds to the selling price ratio R_SELL_{in} and column D corresponds to TNT_{in}, which is the total number of trucks.

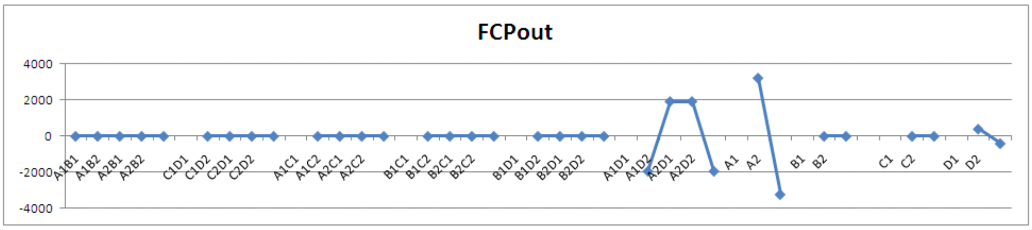


Figure 4.7 Effects of interactions on response of final compensation

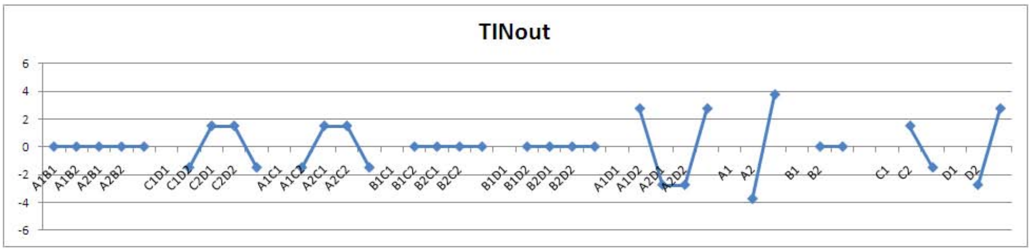


Figure 4.8 Effects of interactions on response of total iteration number

Table 4-30 summarizes all the effects of interactions on service quality responses. It shows that interaction AD have effect on most (7/8) of service quality responses.

Table 4-30 Synthesis of effects of interactions on service quality responses

		Responses							
		LPQ_{out}	EPQ_{out}	BOP_{out}	LSQ_{out}	ESQ_{out}	BOC_{out}	TIN_{out}	FCP_{out}
Interactions	AB								
	CD							X	
	AC							X	
	BC								
	BD								
	AD	X	X		X	X	X	X	X

In conclusion, from all the responses we can notice that interaction AD (i.e. interaction of extra capacity ratio R_EXT_{in} and total number of trucks TNT_{in}) has effect on most of economic and service quality responses. R_EXT_{in} and TNT_{in} are transportation related factors. This may explain why in the confirmation experiment the profit of transport operator does not get so good result in few cases.

4.4.2 Negotiation factors study

Important factors and their interactions were studied in the previous section. Since this thesis studies the coordination by negotiation, the analysis which is achieved in this section focuses on negotiation factors in order to study their effects on responses.

Considering that the negotiation protocol has been developed to enable the transport operator to increase its benefits, we propose in this section to only focus on factors specific to this partner.

Transport operator has three negotiation related factors, called acceptance criterion (ACR_{in}), maximum number of negotiation (MNN_{in}), and compensation percentage (CPP_{in}). We specify an experimental array with these three factors at 2 levels in order to construct a full factorial design. The choice of levels of each factor is shown in Table 4-31. The level of each factor is chosen to orient the solution to best total profit, referring to effects figure on response TOP_{out} (see Figure a. 5). Concerning factor "maximum number of negotiation" (MNN_{in}), we choose the smallest and biggest value (L1 and L3) in order to increase the performance gap resulting from different iteration numbers. The first two levels (L1 and L2) were randomly chosen for acceptance criterion ACR_{in} and compensation percentage CPP_{in}. A full factorial design with three 2-level factors is proposed in Table 4-32. Eight experiment trials are enough to build a complete experimental array and study the effects of negotiation factors.

Table 4-31 Levels of factors in negotiation factors study

Factors	**Levels**		
	L1	**L2**	**L3**
R_EXT_{in}	2	**5**	100
R_SELL_{in}	1	1.5	**5**
R_CAP_{in}	1.01	**0.96**	0.75
TNT_{in}	**115**	110	105
R_INV_{in}	0.5	1	**2**
R_LAT_{in}	0.5	**1**	2
R_EAR_{in}	**0.5**	1	2
ACR_{in}	**1.01**	**1.03**	1.04
MNN_{in}	**5**	10	**20**
CPP_{in}	**30%**	**50%**	70%

Table 4-32 Experimental array of negotiation factors study

N° of trial	**ACR_{in}**	**MNN_{in}**	**CPP_{in}**
1	1.01	5	30%
2	1.01	5	50%
3	1.01	20	30%
4	1.01	20	50%
5	1.03	5	30%
6	1.03	5	50%
7	1.03	20	30%
8	1.03	20	50%

In order to well evaluate the impact of the negotiation factors of transport operator, we have decided to fix the negotiation factor of producer. The values of producer negotiation factors are shown in Appendix I, Table a. 4.

Similar to preliminary performance evaluation, we classify the experiment results in two groups: economic responses and service quality responses (Table 4-33 and Table 4-34).

Table 4-33 Experiment results of economic responses of negotiation factors study

N° of trial	PPR_{out} **(euro)**	PTR_{out} **(euro)**	TOP_{out} **(euro)**	DPP_{out} (%)	DPT_{out} (%)	DTP_{out} (%)
1	9 281 141	267 619	9 548 760	0.01%	1.95%	0.06%
2	9 282 605	266 155	9 548 760	0.02%	1.39%	0.06%
3	9 281 580	268 888	9 550 468	0.01%	2.44%	0.08%
4	9 283 407	267 061	9 550 468	0.03%	1.74%	0.08%
5	9 281 141	267 619	9 548 760	0.01%	1.95%	0.06%
6	9 282 605	266 155	9 548 760	0.02%	1.39%	0.06%
7	9 281 580	268 888	9 550 468	0.01%	2.44%	0.08%
8	9 283 407	267 061	9 550 468	0.03%	1.74%	0.08%

Table 4-34 Experiment results of service quality responses of negotiation factors study

N° of trial	LPQ_{out} **(Unit)**	EPQ_{out} **(Unit)**	BOP_{out} **(Unit)**	LSQ_{out} **(Unit)**	ESQ_{out} **(Unit)**	BOC_{out} **(Unit)**	TIN_{out} **(Unit)**	FCP_{out} **(euro)**
1	11	15	0	7	15	4	3	2 195
2	11	15	0	7	15	4	3	3 659
3	8	32	0	6	32	2	6	2 740.2
4	8	32	0	6	32	2	6	4 567
5	11	15	0	7	15	4	3	2 195
6	11	15	0	7	15	4	3	3 659
7	8	32	0	6	32	2	6	2 740.2
8	8	32	0	6	32	2	6	4 567

We use the same way to evaluate the effects of factor as previous sections. Figures which show the effects of all factors on all the responses are shown in Appendix IV. We also present the effects by two groups, economic responses and service quality responses and synthesize the most influential factors for each response in Table 4-35 and Table 4-36.

Table 4-35 Synthesis of effects of factors on economic responses

		Responses					
		PPR_{out}	DPP_{out}	DPT_{out}	DPT_{out}	TOP_{out}	DTP_{out}
Factors	ACR_{in}						
	MNN_{in}	X	X	X	X	X	X
	CPP_{in}	X	X		X	X	

Table 4-36 Synthesis of effects of factors on service quality responses

		Responses							
		ESQ_{out}	LSQ_{out}	BOC_{out}	EPQ_{out}	LPQ_{out}	BOP_{out}	FCP_{out}	TIN_{out}
Factors	ACR_{in}								
	MNN_{in}	X	X	X	X	X		X	X
	CPP_{in}							X	

Referring to the effects figures in Appendix IV and also experiment results in Table 4-33 , we can conclude that:

- Maximum number of negotiation MNN_{in} which corresponds to parameter *MaxNego* of negotiation protocol is a fundamental factor to determine the minimum bound of profit. Let us remind that this bound labeled *minT* is calculated as follows: $minT = G_{BPT} - i * RD^T$, $RD^T = (G_{BPT} - G_{BST})/MaxNego$ (see section 4.3.2 in chapter 3). The transport operator uses this bound to find a released pickup plan whose profit is above this bound though “Released Transportation” model. It directly affects the final converged pickup plan. Table 4-33 shows that, each time the number of allowed iterations is increased (trial N°1 v.s. trial N°3, trial N°2 v.s. trial N°4, trial N°5 v.s. trial N°7, trial N°6 v.s. trial N°8 in Table 4-32), the profits for both business partners are better (PPR_{out}, PTR_{out}, TOP_{out}) and the profit differences before and after negotiation (DPP_{out}, DPT_{out}, DTP_{out}) are improved too. Table 4-36 confirms that this factor has effect on almost all responses except the accumulated backorders to producer (BOP_{out}) in this experiment. The disadvantage induced by the increase of iterations number remains the computation time needed to obtain the negotiation solution. Let us remark that time is not measured in our experiment.
- Compensation percentage CPP_{in} plays a role of transferring profit from transport operator to producer. It has effect on profit of producer (PPR_{out}), profit of transport operator (PTR_{out}), their differences after negotiation (DPP_{out}, DPT_{out}) and final compensation (FCP_{out}). Nevertheless, this factor does not have any impact on the plans resulting from the models in negotiation process. Table 4-34 shows that any trial leading to the same value of total profit (trials N°1, 2, 5, 6 or trials 3, 4, 7, 8) provides identical performance in terms of service quality responses. Delivery and pickup plans are the same. The probable cause of such a result is that, in the definition of the planning models and the negotiation protocol, we make a decision to not include the compensation in the objective function of any model; the profit is estimated after each partner plans their activities, is deduced from achievable benefits in applying planning decisions, and completed with the percentage of compensation which is gained or paid by each partner.
- Acceptance criterion ACR_{in} is a parameter which is considered at the beginning of negotiation. Just as a reminder, this factor defines for transport operator the admissible profit gap resulting from the implementation of both “Best Service Transportation” (BST) and “Best Profit Transportation” (BPT) models. When this gap is sufficient, transport operator intends to negotiate, starting with sending best profit pickup plan. Otherwise, he considers that profit resulting from negotiation does not sufficiently compensate costs induced by negotiation, and decides to respect the producer’s demand as close as possible. Once the negotiation works in process, this parameter has no other effect on the performance of negotiation. For all trials of Table 4-35 acceptance criterion ACR_{in} has no effect on all the responses in this experiment.

The current experiment results are somewhat disappointing, considering the lack of impact of ACR_{in} on all the responses. Based on this finding, we examined in details whether this factor may have a real impact on negotiation or not.

Indeed, we then observe that transport operator always starts with negotiating on best profit transportation plan in all the eight experiment trials above. The main reasons to explain this situation are:

- The studied factors (ACR_{in}, MNN_{in}, CPP_{in}) in the current experiment do not influence the values of parameters of production model. Therefore, for each trial, the plan resulting from the "Best Profit Production" model execution is the same, so that the transport operator works on an identical delivery plan (input) to define its performance gap between G_{BPT} and G_{BST}. The direct consequence is the constant value of this gap for any trial.
- The nature of the pickup plan that transport operator decides to send to producer depends on the respect of condition $\frac{G_{BPT}}{G_{BST}} \geq ACR_{in}$. However, considering the present experiment trials, the ratios $\frac{G_{BPT}}{G_{BST}}$ always equal to 1.046. When the level of ACR_{in} equals to 1.01 or 1.03, in any case, the condition is satisfied.

Thus, the levels of ACR_{in} are not well chosen in this experimental array. Two complementary trials are then constructed in order to observe the performance of protocol when condition $\frac{G_{BPT}}{G_{BST}} \geq ACR_{in}$ is false.

- Complementary trial 1: ACR_{in} = 1.05 and transportation capacity is considered as sufficient to meet the producer's demand (i.e. TNT_{in}=115).

Table 4-37 Factors of complementary trial 1

N° of trial	R_EXT_{in}	TNT_{in}	MNN_{in}	ACR_{in}	CPP_{in}	R_SELL_{in}	R_CAP_{in}	R_INV_{in}	R_LAT_{in}	R_EAR_{in}
9	5	115	5	1.05	30%	5	0.96	2	1	0.5

The values of factors in complementary trial 1 are shown in Table 4-37. Only ACR_{in} is reconfigured compared with the eight experiment trials above for negotiation factors study. Transportation capacity TNT_{in} is sufficient compared with the requirement of delivery quantities. In this trial, we effectively observe that transport operator sends its best service plan to producer because the profit gap is insufficient and the producer accepts the received pickup plan. The negotiation process stops with only one iteration. Table 4-38 shows the results of economic responses. In this case, the SC performance is the same as the case without negotiating.

Table 4-38 Results of economic responses of complementary trial 1

N° of trial	PPR_{out} **(euro)**	PTR_{out} **(euro)**	TOP_{out} **(euro)**	DPP_{out} (%)	DPT_{out} (%)	DTP_{out} (%)
9	2 665 023.5	267 383	2 932 406.5	0%	0%	0%

With this experiment, we are reassured concerning the utility of the factor "acceptance criteria" and its possible effect on solutions resulting from negotiation. Nevertheless, the lack of iterations during the negotiation between producer and transport operator has to be a little concerned. To consolidate the present analyze, a new trial is proposed, with the assumption that an insufficient transportation capacity should oblige the producer to release its initial delivery plan.

- Complementary trial 2: ACR_{in} = 1.15, and transportation capacity (TNT_{in}) is not sufficient to meet the producer's demand.

Table 4-39 Factors of complementary trial 2

N° of trial	R_EXT_{in}	TNT_{in}	MNN_{in}	ACR_{in}	CPP_{in}	R_SELL_{in}	R_CAP_{in}	R_INV_{in}	R_LAT_{in}	R_EAR_{in}
10	100	105	5	1.15	30%	1.5	1.01	1	0.5	2

The values of factors in complementary trial 2 are shown in Table 4-39. The value setting is totally different from complementary trial 1. We choose the levels which will orient to the most total iteration number (i.e. TIN_{out}) referring to Figure a. 13 in order to study the effect of ACR_{in} in a negotiation process with more than one iteration. We observe that the inadequacy of transportation capacity in relation with producer's demand (i.e. TIN_{out} = 105) and a high cost of using extra capacity (i.e R_EXT_{in} = 100) impact the negotiation performance. The results of economic responses are shown in Table 4-40. In this trial, transport operator sends best service pickup plan to producer. The latter adapts to the limitation of transportation capacity by RP model. At the end of negotiation, the profit of transport operator is improved by paying fewer penalties to producer.

Table 4-40 Results of economic responses of complementary trial 2

N° of trial	PPR_{out} (euro)	PTR_{out} (euro)	TOP_{out} (euro)	DPP_{out} (%)	DPT_{out} (%)	DTP_{out} (%)
10	2 665 063.5	267 412	2 932 475.5	-10.08%	19.32%	-8.01%

Thus, based on these two new observations, we can conclude that the parameter ACR_{in} does not strongly orient the solutions issued from negotiation, but may provide an interesting element of control for the negotiation protocol in determining whether the situation can be avoided when a strong time consuming negotiation should be engaged.

4.5 Conclusion

This chapter is an important step for validating of models proposed in chapter 3, and also for understanding the factors that can impact performance during the process of negotiation protocol. Analysis is so performed based on various numerical experiments. Basic experiment design principles and Taguchi method are used to specify the experimental arrays and to perform results evaluation. The evaluated responses include economic responses and service quality responses which are further grouped by production responses, transportation responses and negotiation responses.

At first, a framework is defined in order to prepare the experiment. This framework aims to specify responses, input factors and the software platform. Then following the principle of Taguchi method, several experimental arrays are studied for different purposes.

- At the beginning an experimental array is defined for preliminary evaluation which considers all indentified factors in Table 4-7 and supposes there are no interactions between factors. This experiment encompasses many factors at the same time and identifies the factors which have significant effects on responses.

- Considering the hypothesis of interaction, confirmation experiment is necessary to verify the effects of all factors on responses. The results of confirmation experiment demonstrate that for fewer responses the effects of factors are not validated. Therefore interactions are considered in the next experimental array.

- In order to study the factors interactions and to reduce the number of required trials in the orthogonal array, four important factors which are identified in preliminary experiment, extra capacity ratio (R_EXT_{in}), selling price ratio (R_SELL_{in}), capacity ratio (R_CAP_{in}), total number of trucks (TNT_{in}) and their interactions are studied. The interaction between factors R_EXT_{in} and TNT_{in} may explain the non validated responses in confirmation experiment.

- At the end, a small experiment is defined to focus on the effects of transport operator negotiation factors to study how these negotiation factors impact the performance of negotiation protocol.

The main evaluation results in this chapter are the following ones:

- A list of parameters which can affect the process is built by their importance, from the most influential to the least influential (see Table 4-20). Selling price ratio R_SELL_{in}, extra capacity ratio R_EXT_{in}, capacity ratio R_CAP_{in} and total number of trucks TNT_{in} are indentified as important factors which have effects on most responses.

- The preliminary experiment results show that profit of transport operator is improved much more than the profit of producer. Because there is only one transport operator, producer adapts to the limitation of transport operator. All the responses performances are better when the early supplied cost is less than the early pickup cost.

- Interaction between extra capacity ratio R_EXT_{in} and total number of trucks TNT_{in} are detected on responses of profit of transport operator, on all the difference of profits before and after negotiation and also on all service quality responses except backorders to producer. When the total number of trucks TNT_{in} cannot satisfy producer’s delivery requirement, extra capacity ratio R_EXT_{in} will affect the decision of using extra capacity or not and will affect the final profit of both partners consequently.

- The value of factor MNN_{in} will affect the final converged plan. If the number of allowed iterations MNN_{in} is increased, the profits of both producer and transport operator are better and the corresponding profit differences before and after negotiation are increased as well.

- Compensation percentage CPP_{in} which is a part of profit gap that transport operator pays to the producer to motivate the acceptance of a pickup plan, has effect on profit of producer, profit of transport operator, their differences before and after negotiation and final compensation. It plays a role of transferring profit from transport operator to producer.

- Acceptance criterion ACR_{in} does not affect the plans resulting from the production and transportation models in the negotiation process. But it may serve as an interesting control element to avoid strong time consuming negotiation.

These conclusions show parameters which should be paid attention for decision makers of both producer and transport operator in order to achieve better profit or better service level.

The models and negotiation protocol evaluated in this chapter concerns only one producer and one transport operator. In the next chapter a more complex and realistic situation concerning one producer and multiple transport operators will be studied.

Chapter 5

Modeling and coordinating by negotiation between one producer and multiple transport operators

Chapter 5 Modeling and coordinating by negotiation between one producer and multiple transport operators

5.1 Introduction

The coordination between one producer and one transport operator (labeled 1P-1T) is the basic and simplest form of production and transportation coordination which was studied in the last two chapters. In this chapter, we will extend the number of transport operators to encompass the coordination problem of one producer with multiple and competitive transport operators, labeled 1P-nT, in a supply chain.

As defined in chapter 3, each partner could be assimilated to a decision making unit (DMU) in charge to plan transport or production activities. Compared to the 1P-1T context, the relations between producer and transport operators are more complex (Figure 5.1), because producer has to assign “partial or total” loads to “one or many” transport operators in addition to classical planning decisions. On this point-of-view, the coordination among the DMUs is much more difficult to implement.

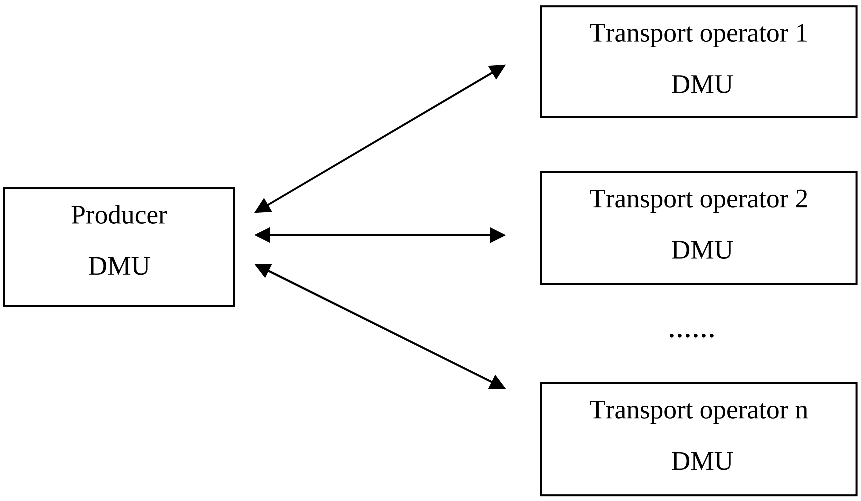


Figure 5.1 DMUs in 1P-nT context

Generally speaking, the “1P-nT” coordination problem can be decomposed to several “1P-1T” coordination problems, except that transport operators are not totally independent. They have to satisfy the delivery request expressed by a whole delivery plan proposed by the producer together. Thus, resulting from the increase of the number of transport operators, two challenges arise to coordinate “1P-nT” production transportation by negotiation.

1. How does the producer allocate delivery request to each transport operators so that the split deliveries which compose the whole delivery plan can be accomplished by each transport operator and with the lowest cost for the producer?
2. How does the producer evaluate whether separated pickup plans proposed by each transport operator are feasible?

This chapter aims to answer to these two challenging questions.

The general negotiation context between one producer and multiple transport operators is defined by the following hypotheses and corollary:

- **Hypothesis 1**: Some information is exchanged between both partners. For instance, transportation parameters such as price or capacity are shared with producer.
- **Hypothesis 2**: Producer deals with a large number of available operators in the transportation market to accomplish its delivery request. Hence, there is no more limitation of the number of transport operators.
- **Corollary 1**: Consequently to the two previous hypotheses, the producer is always able to propose split delivery requests which are consistent with the capacities expressed by the transport operators. More precisely, each split delivery request sent to a specific transport operator can be fully accomplished by him with a best service quality. This is a main difference compared with “1P-1T” context which brings out that there is no need to use the “Released Production” model (RP model).

Consequently, the generic pattern of negotiation described in the 1P-nT context is simplified, as shown in Figure 5.2. The negotiation is made up of two main phases: the first phase is the splitting of the delivery request over the possible set of transport operators; the second phase is the point-to-point negotiation (1-1 negotiation) between the producer and each transport operator.

Let us remark, in this concerned 1P-nT context, each transport operator do its best to respond to producer’s delivery request in the splitting phase. They use BST (Best Service Transportation) models to calculate pickup plans in order to get as much as possible assignments of transportation load close to the delivery request.

The splitting phase can be further broken down into three main steps:

- **Step1**: The producer intends to get the estimated capacity of each transport operator. In that aim, he broadcasts a whole delivery plan to all potential transport operators, including all deliveries requested by customers;
- **Step2**: Each transport operator proposes a pickup plan through BST model implementation which intends to answer the producer’s request as best as possible. Thus, he primarily attempts to satisfy its “customer” (i.e. the producer), even if later in the protocol, he can negotiate with producer trying to improve its own profit.
- **Step3**: Based on these answers, the producer uses a splitting method in order to dispatch the split delivery requests to each transport operator. The basic idea of the splitting is to achieve a set of split delivery plans which maximizes the profit of producer and at the same time satisfies all the constraints expressed by the estimated capacity of each transport operator.

Similarly, the 1-1 negotiation phase can also be further broken down into three others steps:

- **Step4**: Each transport operator starts a 1-1 negotiation with the producer. As described in chapter 3, in the “1P-1T” negotiation protocol, the transport operator starts with sending its best profit pickup plan or its best service pickup plan according to its own plans acceptance criterion.

- **Step5:** After all the pickup plans are received, the producer achieves a global assessment of all the answers. If the assessment result is not feasible, producer insists on the split delivery plans sent to each transport operator.
- **Step6:** Each transport operator sends a released pickup plan whose profit is between the profits corresponding to its "best service" and its "best profit" pickup plans. The expected profit of a released pickup plan gradually decreases as the negotiation progresses.

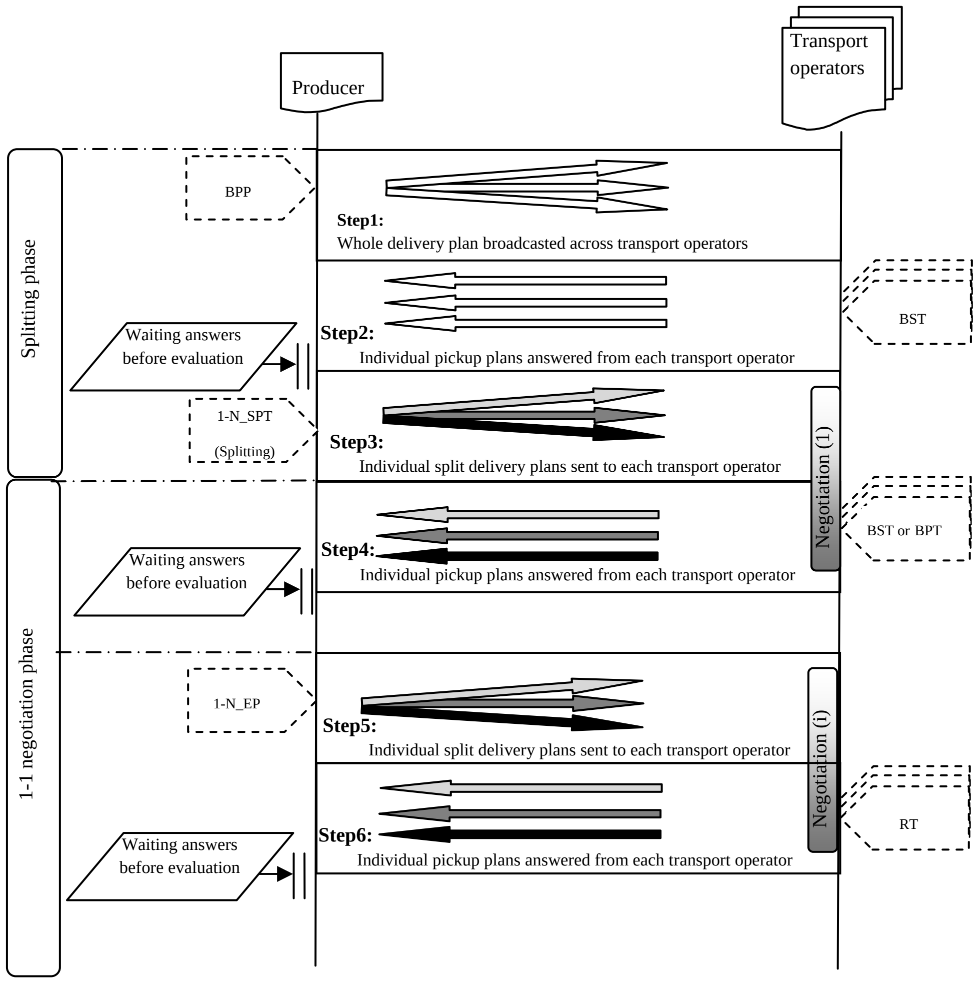


Figure 5.2 General view of the negotiation process in the multiple transport operators context

Let us remark that, while the negotiation phase is initialized on steps 3 and 4, the main pattern of negotiation consists of step 5 and step 6 which are repeated during the negotiation until the negotiation stops. The end of negotiation occurs when the global evaluation of all pickup plans together is considered as acceptable by producer as regards its expected profit definition based on the acceptance mechanism presented in chapter 3. Let us also remark that models used at each step of the negotiation are mentioned in dotted arrows in Figure 5.2; some models such are BPP, BST, BPT are previously defined in chapter 3 and others are new models specific to the current context that will be described in this chapter.

Following the same principles as described in the "1P-1T" problem, this chapter is divided into two main parts. The analytic models and the negotiation protocol are presented respectively. Within each part, test cases are carried out in order to validate the models or the proposed negotiation protocol. Let us remark that, in the negotiation protocol part, the main steps of negotiation presented above will be refined.

5.2 1P-nT models

Compared with the "1P-1T" problem, the producer has to deal with multiple transport partners, while the transport operator decision making process does not really change. Indeed, each transport operator deals with only one producer and the relation is the same as "1P-1T" problem from the transport operator's point of view. Thus, only the models which concern producer need to be changed. That is why this chapter only focuses on explaining production models.

The negotiation protocol integrates all production and transportation analytic models and defines the rules of how these models can interact. This "1P-nT" protocol is based on the "1P-1T" protocol which has been adapted to integrate particularities of the context of multiple transport operators.

Facing the two challenges mentioned in the introduction, two new models will be presented: the 1P-nT "split delivery production" model (labeled 1-N_SPT) and the 1P-nT "evaluation production" model (labeled 1-N_EP). 1-N_SPT model is in charge of splitting the whole delivery plan to multiple transport operators, according to estimated transportation capacities; 1-N_EP model evaluates the received pickup plans from multiple transport operators. These two models will be presented in the following sections.

In order to present these two models, this section is made up of three parts: firstly, some general requirements of the splitting phase are presented as they impact the following modeling of producer and negotiation; secondly the two models 1-N_SPT model and 1-N_EP model are specified; finally the 1-N_SPT model will be validated by some numerical examples.

5.2.1 General requirements of splitting

The main difference between "1P-nT" problem and "1P-1T" problem is the splitting phase as presented in Figure 5.2. Thus, let us present here the general requirements of the 1-N_SPT model in the "1P-nT" negotiation context. The 1-N_SPT model is based on "Best Profit Production" model, as described in chapter 3. It extends BPP model by taking into account the transport resource allocation decisions. The main goal of 1-N_SPT model is to split the whole delivery plan to a set of partial delivery plans, also called split delivery plans, to different transport operators by respecting their capacity constraints. The difficulty of 1-N_SPT model lies on the following question: "**how to express and respect the transportation capacity of each transport operator**".

In the "1P-1T" negotiation, producer receives a pickup plan which expresses an effective products quantity that can be picked up by the transport operator during each time period. However in the "1P-nT" context, the information received from transport operator is presented in a quite different way which will be described in the following part. Producer considers the received information as the expression of transport operators' capacity which he has to respect in order to propose achievable split delivery plans.

In what follows, we attempt to show that, in the current context, pickup quantities are however not sufficient to accurately characterize the transportation capacity, so that accumulated transportation load must be considered to achieve this goal.

Pickup quantities

By only considering the pickup quantities, the producer can make wrong transportation capacity estimation, based on an inappropriate analysis. This evidence can be shown through a basic example of an instantiation of the splitting process (see Figure 5.3).

Some hypotheses are made for this example:

- The studied problem includes one producer, two transport operators (T1, T2), one product, and one customer.
- Each transport operator has only two trucks.
- The unitary capacity of a truck is 100 tons.
- The round trip transportation lead time equals two time periods.
- The unitary weight of product is 1 ton.

The splitting process is carried out as follows.

1) Producer sends a whole delivery plan to both transport operators which expresses the quantity of products expected to be picked up in each time period.
2) Any transport operator cannot accomplish the producer's delivery plan with its own transportation capacity. Because of transportation lead time, the transportation capacity used in a specific period may be still occupied in the subsequent period. Therefore, the pickup quantities for both transport operators in period 2 and period 4 equal to 0, due to in-process transportation activities.
3) Both transport operators send their pickup plans to producer. Producer interprets the received pickup quantities as the transportation capacity of corresponding transport operator in each time period.

After the splitting process, the results are presented in step 4:

4) Considering there is no available transportation capacity in period 2 and period 4, producer only assign delivery quantities to both transport operators in period 1 and period 3 which causes early supplied quantities, shown in gray cells.

Splitting process

Step 1)	Delivery Plan	Periods				
		1	2	3	4	5
Producer	(unit)	200	200	200	200	200

Step 2)	Pickup Plans	Periods				
		1	2	3	4	5
Transport operators	T1 (unit)	200	0	200	0	200
	T2 (unit)	200	0	200	0	200

Step 3)	Received Capacity	Periods				
		1	2	3	4	5
Producer	T1 (unit)	200	0	200	0	200
	T2 (unit)	200	0	200	0	200

Splitting result

Step 4)	Split Delivery plans	Periods				
		1	2	3	4	5
Producer	T1(unit)	200	0	200	0	200
	T2(unit)	200	0	200	0	200

Ideal result

	Ideal Split Delivery Plans	Periods				
		1	2	3	4	5
Producer	T1(unit)	200	0	200	0	200
	T2(unit)	0	200	0	200	0

Figure 5.3 Example of respecting transportation capacity by pickup quantities for each time period

However, the splitting result is unsatisfied considering an ideal result presented in Figure 5.3.

The ideal splitting result for producer working with these two transport operators would be that producer assigns delivery quantities to T1 in period 1. So, T2 can retain its transportation capacities to transport products in period 2; it takes the same logic of assigning delivery quantities for the following periods.

The reason for this unsatisfactory splitting result (i.e. split delivery plans) comes from the facts that:

- Each transport operator intends to do their best to respond to delivery request through BST model, without knowing others operators' responses. Each of them proposes a pickup plan where transportation activities are executed as early as possible, That's why each operator proposes to serve the producer on period 1, leading to consider that no trucks are available on the subsequent period.
- Although the transportation capacity of T2 are interpreted as 0 in period 2 as shown in table of step 3 (see Figure 5.3), if the capacity of T2 is not used in period 1, it becomes available in period 2. Therefore, by receiving these pickup plans, the producer has no way to make a correct interpretation of this information, and considers the pickup quantities as the expression of real capacity of each transport operator.

To overcome this limitation, transport operators could express their transportation capacity by considering the accumulated load over the round trip transportation lead time and send this information to producer.

Accumulated transportation load

This new principle is illustrated by considering the same example, except that accumulated transportation load are sent to producer in order to make split delivery plans, as shown in Figure 5.4.

The first two steps in executing the splitting process are the same as those described before so that we start the explanation from step 3.

> Because the round trip transportation lead time takes two periods, the accumulated transportation load in a current period should take into account the load in the previous period. In others words, the transportation capacity is not expressed by pickup quantities but must correspond to the in-process transportation load. For instance, contrary to Figure 5.3, in the second time period, the values “200 ton” in the T1 and T2 lines denote the transportation load in this time period. This load is resulting from the use of 2 trucks to execute a transportation activity which is started at the beginning of period 1 and finished at the end of period 2 to transport 200 tons of products required by customer.

The splitting results corresponding to this principle could be the ones by respecting the constraint that accumulated delivery load (what need to be done) over the round trip transportation lead time should not exceed the corresponding accumulated transportation load (what can be done). One possible solution is shown in the first table of step 4. Let us remark that this solution is the best possible expected split delivery plans.

Splitting process

Step 1)	Delivery Plan	Periods				
		1	2	3	4	5
Producer	(unit)	200	200	200	200	200

Step 2)	Pickup Plans	Periods				
		1	2	3	4	5
Transport operators	T1 (unit)	200	0	200	0	200
	T2 (unit)	200	0	200	0	200

Step 3)	Received Capacity	Periods				
		1	2	3	4	5
Producer	T1 (ton)	200	200	200	200	200
	T2 (ton)	200	200	200	200	200

Splitting result

Step 4)	Expected Split Delivery Plans	Periods				
		1	2	3	4	5
Producer	T1(unit)	200	0	200	0	200
	T2(unit)	0	200	0	200	0

Or

Step 4)	Possible Split Delivery Plans	Periods				
		1	2	3	4	5
Producer	T1(unit)	20	180	200	0	200
	T2(unit)	180	20	0	200	0

Figure 5.4 Example of respecting transportation capacity by accumulated transportation load over round trip transportation lead time

Nevertheless, the simple use of accumulated transportation load is not sufficient to guarantee achievable delivery plans. To prove it, the second table of step 4 presents another possible solution of splitting. This splitting result respects the accumulated transportation load constraints but is unfeasible because it violates, in fact, the capacity of both transport operators. In period 2, the accumulated delivery load of the first two periods to T1 equals 200 tons (i.e. 20 tons on time unit 1 and 180 tons on time unit 2) which satisfy the constraint of the accumulated transportation load. However, one truck of T1 is used in period 1 and only one truck is available in the second period. Due to the fact that transport operator T1 has only 2 trucks with a maximum individual capacity of 100 tons, it is impossible for him to pick up 180 units of product in period 2.

Therefore, expressing transportation capacity by the accumulated transportation load is not enough to guarantee the transportation capacity constraint because the integrity of the truck is not taken into account.

Consequently, the transportation capacity is expressed as **the number of accumulated trucks** of transport operator in 1-N_SPT model.

Let us recall that in "1P-1T" negotiation, all delivery quantities have to be allocated to one transport operator; producer may significantly decrease its own profit each time he adapts to transportation operator's capacity. However in "1P-nT" context, producer can adjust delivery quantities among different transport operators by considering their transportation capacities without decreasing its own profit.

5.2.2 Definition of models

We will present in detail the production models (1-N_SPT and 1-N_EP) in "1P-nT" context in this section.

Production and transportation planning decisions are modeled as linear integer programming. Different integer sets and indices are commonly used by all models presented in this section which extend the notations defined in chapter 3 in order to take into account the multiple transport operators. These sets and indices are labeled as follows:

<u>Set and indices</u>

Sets

T	Set of periods composing the planning horizon
P	Set of products
J	Set of customers
N	Set of transport operators

Indices

t	$t \in T$	Index of planning period
p	$p \in P$	Index of product
j	$j \in J$	Index of customer
n	$n \in N$	Index of transport operator

Following the same principles as “1P-1T” problem, we present hereunder the splitting and evaluation models through the definition of their parameters, constraints and objective function.

5.2.2.1 *1P-nT split delivery production model (1-N_SPT)*

A planning is done by the producer in order to satisfy customers’ demands and split delivery quantities among different transport operators. The general view of “1P-nT split delivery production” model is presented in Figure 5.5. This model is an extension of the “Best Profit Production” model which takes into account the allocation of transportation load (splitting) to the multiple transport operators.

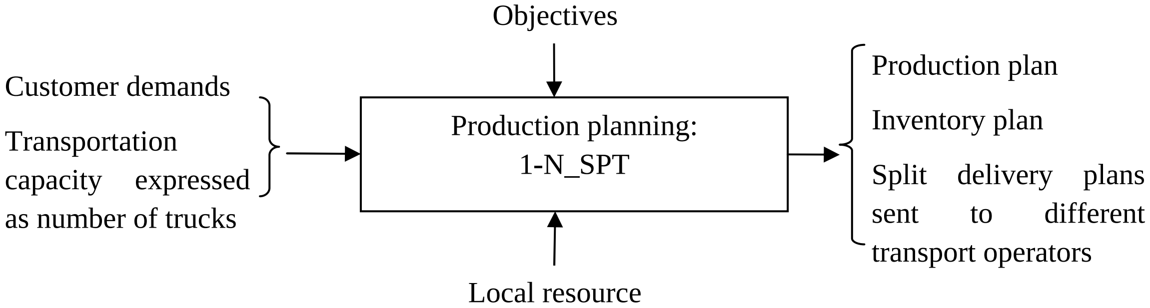


Figure 5.5 General view of production planning (1-N_SPT model)

- Parameters

The list of parameters used in this model is presented below:

$TP_{j,n}$	Transportation price per ton of transport operator n to customer j
cap_n	Unitary capacity of truck of transport operator n
$TC\_NBR_{j,n,t}$	Transportation capacity of transport operator n, expressed as the number of trucks at each time period
$minLoad_{j,n}$	Minimum load assigned to transport operator n to customer j for each time period over the horizon
F_n	Cooperation cost of working with transport operator n
M	A very big number

Transportation price (TP) and truck capacity (cap) are the same parameters as in chapter 3, which have been adjusted by adding the transport operator index. The remaining parameters are new ones defined as follows:

- $TC\_NBR_{j,n,t}$ represents the estimated transportation capacity defining the number of available trucks at each time period. It is the number of in-process trucks (see section 5.2.1) accumulated over the transportation lead time. This lead time is defined as a round trip time D_j from a producer through customer j back to this producer.

$TC\_NBR_{j,n,t}$ is used in defining the transportation capacity constraints to control the splitting of the whole delivery plan to requested transport operators.

- Parameter $minLoad_{j,n}$ is the minimal load that must be assigned to a transport operator. The use of a transportation resource (i.e. truck) generates a cost. This parameter is used to ensure that the producer works with a specific transport operator only if at least a certain amount of products are allocated to this one.
- Parameter F_n is the cooperation cost which tends to limit the number of transport operators that the producer selects to achieve his whole delivery request. F_n is a fixed cost for each transport operator. The total cooperation cost increases if producer works with more transport operators.

As mentioned in the first hypothesis stated in the introduction of this chapter, let us recall that there are some parameters that are shared between producer and transport operators. Hence, parameters $TC\_NBR_{j,n,t}$, cap_n, and $minLoad_{j,n}$ are all transportation related parameters which are shared by transport operators with producer.

- Decision variables

The decision variables are described hereunder. The first one is identical to the one used in chapter 3, except the addition of a new index that references transport operators. Others are new decision variables.

$l_{p,j,t,n}$	Delivery quantity of product p to be launched in transportation to customer j at period t using transport operator n
$NbrTruck_{j,n,t}$	Number of trucks required to launch transportation at period t to customer j using transport operator n
$hasLoad_{j,n,t}$	Binary variable equals to 1 when load is assigned to customer j at time t by using transport operator n, otherwise equals to 0.
K_n	Binary variable equals to 1 when transport operator n is chosen, otherwise equals to 0. K_n must equal to 1 as long as at least one parameter in the set $hasLoad_{j,n,t}$ equals to 1.

- Constraints

Complementary to the constraints of BPP model (BPP.1 to BPP.7), some new constraints are added. All constraints are presented as below.

$$i_{p,t} = i_{p,t-1} + f_{p,t-DP_p} - \sum_j \sum_n l_{p,j,t,n} \qquad \forall p \in P, \forall t \in T. \qquad \text{(1-N \_SPT.1)}$$

$$\sum_n l_{p,j,t,n} + b_{p,j,t} - e_{p,j,t} = d_{p,j,t+DT_j} + b_{p,j,t-1} - e_{p,j,t-1} \qquad \forall p \in P, \forall t \in T, \forall j \in J. \qquad \text{(1-N \_ SPT.2)}$$

$$\sum_p (u_p \cdot \sum_{\tau=1}^{DP_p} f_{p,t-\tau+1}) \le Pcap_t \qquad \forall t \in T. \qquad \text{(1-N \_ SPT.3)}$$

$$\sum_p (v_p \cdot i_{p,t}) \le Icap_t \qquad \forall t \in T. \qquad \text{(1-N \_ SPT.4)}$$

$e_{p,j,t} \leq Emax_{p,j}$ $\quad \forall p \in P, \forall t \in T, \forall j \in J.$ (1-N _ SPT.5)

$\sum_t \sum_n l_{p,j,t,n} \leq \sum_t d_{p,j,t+DT_j}$ $\quad \forall p \in P, \forall j \in J.$ (1-N _ SPT.6)

$i_{p,t}, b_{p,j,t,} e_{p,j,t,} f_{p,t}, l_{p,j,t}, NbrTruck_{j,n,t} \geq 0$ $\quad \forall p \in P, \forall t \in T, \forall j \in J.$ (1-N _ SPT.7)

$\sum_p v_p \cdot l_{p,j,t,n} \geq hasLoad_{j,n,t} \cdot minLoad_{j,n}$ $\quad \forall t \in T, \forall j \in J, \forall n \in N$ (1-N _ SPT.8)

$\sum_p v_p \cdot l_{p,j,t,n} \leq hasLoad_{j,n,t} \cdot M$ $\quad \forall t \in T, \forall j \in J, \forall n \in N$ (1-N _ SPT.9)

$\sum_j \sum_t hasLoad_{j,n,t} \leq K_n \cdot M$ $\quad \forall n \in N$ (1-N_SPT.10)

$\sum_p v_p \cdot l_{p,j,t,n} \leq NbrTruck_{j,n,t} \cdot cap_n$ $\quad \forall t \in T, \forall j \in J, \forall n \in N$ (1-N_SPT.11)

$\sum_j \sum_{i=1}^{D_j} NbrTruck_{j,n,t-i+1} \leq \sum_j TC\_NBR_{j,n,t}$ $\quad \forall t \in T, \forall n \in N, t \geq DT_j.$ (1-N_SPT.12)

Constraint 1-N_SPT.1 to constraint 1-N_SPT.7 are identical to those in BPP model, except replacing $l_{p,j,t}$ by $\sum_n l_{p,j,t,n}$, because all the delivery quantities are now accomplished by *n* transport operators. Constraint 1-N_SPT.8 and constraint 1-N_SPT.9 are used together to define whether load is assigned to a transportation operator. When there is a load assigned to transport operator, $l_{p,j,t,n}$ is positive. By respecting constraint 1-N_SPT.9, the value of $hasLoad_{j,n,t}$ should be equal to 1. Thus, the load should be more than minimum load in Constraint 1-N_SPT.8. Constraint 1-N_SPT.10 expresses that if there is a load assigned to a transport operator, this transport operator is then chosen to work with. Thus corresponding cooperation cost should be considered in the objective function (see hereunder). Constraint 1-N_SPT.11 expresses the relation between loads and the number of trucks. The loads is calculated by the left part of constraint, where v_p represents the unitary weight of corresponding product. Constraint 1-N_SPT.12 limits the split delivery plan should not exceed estimated transportation capacity in terms of the number of trucks of corresponding transport operators.

- Objective function

The objective of 1-N_ SPT model is to maximize producer's profit which is presented as follows:

Max profit = Revenue of selling product - Production cost - Inventory cost - Penalty cost - Cooperation cost - Transportation fee (1-N_SPT.13)

Revenue of selling product=$\sum_t \sum_p \sum_j \sum_n SP_{p,j} \cdot l_{p,j,t,n}$ (1-N_SPT.14)

Production cost=$\sum_t \sum_p (CP_p \cdot f_{p,t})$ (1-N_SPT.15)

Inventory cost =$\sum_t \sum_p (CS_p \cdot i_{p,t})$ (1-N_SPT.16)

Penalty cost = $\sum_t \sum_p \sum_j (CR_{p,j} \cdot b_{p,j,t} + CE_{p,j} \cdot e_{p,j,t})$ (1-N_SPT.17)

Cooperation cost=$\sum_n K_n \cdot F_n$ (1-N_SPT.18)

$$Transportation\ fee = \sum_t \sum_p \sum_j \sum_n TP_{j,n} \cdot l_{p,j,t,n} \cdot v_p \qquad \text{(1-N\_SPT.19)}$$

The objective function is quite similar as BPP model, except a complementary index added to some decision variables and the integration of the cooperation cost of transport operators (i.e. F_n) which expresses the cost of working with a partner. By adding F_n in objective function, other things being the same, model will choose as few as possible transport operators to finish as much as possible delivery work with as much as possible production profit.

5.2.2.2 *1P-nT evaluation production model (1-N_EP)*

The EP model (as described in chapter 3) serves for evaluating whether a delivery plan is feasible while the purpose of 1-N_EP model is to judge whether several pickup plans are feasible. A general view of 1-N_EP model is presented in Figure 5.6.

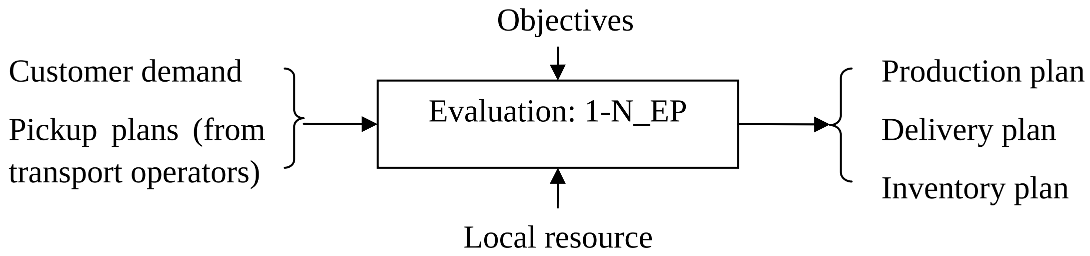


Figure 5.6 General view of evaluation (1-N_EP model)

- Parameter

Parameter $q_{p,j,t,n}$ represents the pickup quantities that producer obtains from pickup plans sent by transport operator *n*. They are the results achieved from "Best Service Transportation" or "Best Profit Transportation" models execution.

- Constraints

1-N_EP model is similar to EP model. The only difference is a new index n is added in the constraint 1-N_ EP.8.

$$l_{p,j,t,n} = q_{p,j,t,n} \qquad \forall p \in P, \forall t \in T, \forall j \in J, \forall n \in N. \qquad \text{(1-N\_ EP.8)}$$

In this constraint, the split delivery plan $l_{p,j,t,n}$ should be equal to parameter $q_{p,j,t,n}$, which is the received pickup quantity of transport operator. Model 1-N_EP searches for a feasible production plan which can produce enough products for transport operator pickup request. If no solution is found, the received pickup plans are not feasible.

5.2.3 Validation of 1-N_SPT model

The objective of the 1-N_SPT model is to find a best way to split the whole delivery plan among different transport operators in order to maximize the profit of producer. The profit of producer referring to 1-N_SPT model is mainly influenced by the splitting decisions. Thus, a better splitting result generates lower transportation fees, fewer early and late supplied quantities and involves fewer number of transport operators. The essence of the 1-N_SPT is to make trade-offs, e.g. a trade-off between working with one transport operator with leveling (i.e. transportation quantities pickup in advance or late) or using two transport operators but with more significant cooperation cost. Therefore, the following validation scenarios are constructed mainly focusing on this trade-off aspect.

Several test cases are generated to validate the 1-N_SPT model with different sets of parameters. Let us remark that the test cases presented in this section are not designed according to a structured experimental approach. Although the value of some parameters may not be always realistic, they are chosen for validation purposes in order to highlight observable behaviors and verify the main functions of the 1-N_SPT model.

Some common parameters of all the test cases are presented in the following tables Table 5-1 and Table 5-2. Other parameters for production and transportation models can be found in Appendix VI.

Table 5-1 Common parameters of all scenarios (Demands and AL)

Demand of Product 1 (unit)			**Demand of Product 2 (unit)**		
Unitary Scalar of Product 1 *v_1=5 (ton)*	**$d_{1,j,t}$**		*Unitary Scalar of Product 2* *v_2=8 (ton)*	**$d_{2,j,t}$**	
Period	Customer 1	Customer 2	Period	Customer 1	Customer 2
1	0	0	1	0	0
2	0	0	2	0	0
3	130	150	3	110	200
4	150	130	4	120	210
5	170	170	5	110	170
6	130	200	6	130	200
7	170	170	7	130	150
8	179	120	8	108	120
9	200	150	9	140	200
10	170	170	10	180	190
11	150	190	11	140	210
12	200	200	12	110	220
13	230	150	13	100	160
14	201	170	14	130	220
15	150	100	15	105	130
16	160	130	16	123	200
17	130	170	17	125	200
18	121	150	18	132	190
19	150	150	19	125	200
20	169	170	20	155	133
21	100	150	21	200	150
22	151	120	22	132	190
SUM	3211	3110	SUM	2605	3643

Accumulated load $AL_j = \sum_p \sum_t v_p \cdot d_{p,j,t}, \forall j$	Customer 1	Customer 2
	5*3211+8*2605=36895	5*3110+8*3643=44694

Table 5-2 Common parameters of all scenarios (Penalty costs)

	Customer 1		Customer 2	
	Product 1	Product 2	Product 1	Product 2
Late supplied penalty $CR_{p,j}$	40	50	10	12.5
Early supplied penalty $CE_{p,j}$	45	55	15	17.5
Average late and early supplied penalty	30			

Let us remark that:

-The accumulated load (labeled AL_j) shown in Table 5-1 is calculated from accumulated quantity of products and the corresponding unitary scalar of product v_p which corresponds to unitary weight of product in our test cases. It will be used later to calculate the estimated transportation fees of producer in the analysis of scenarios.

- The average late and supplied penalty shown Table 5-2 is an average value of all eight values in gray cells. It serves for the approximate calculation of estimated penalty costs for not on time deliveries in the analysis process.

- In all test cases, the delivery quantities require 117 trucks in the period of peak demand. This value is used to estimate the number of insufficient trucks and the not on time delivery quantities. It depends on the capacity of each truck labeled cap which is equal to 100 tons and also depends on required number of trucks at each time period to customer j which is calculated by formula $\sum_p v_p * d_{p,j,t}/cap$. The total required number of trucks at each time period can be obtained by accumulating the required number of trucks to different customers over the round trip transportation lead time

The test cases are divided into four groups according to the number of transport operators necessary to complete the deliveries. Transportation price can strongly influence the solution of the model. Thus by considering transportation price, each group can be expanded to several scenarios. The parameter settings for all the scenarios are shown in Table 5-3. The gray cells show the difference of parameters of a current scenario (line n) compared with the previous one (line n-1).

Table 5-3 Transportation parameters of scenarios

Group	Scenario	Transport operator	Transportation Price (euro/ ton) TPj Customer 1	Transportation Price (euro/ ton) TPj Customer 2	Number of trucks R	Cooperation cost F_n
Group 1	Scenario 1-1	T1	8	10	50	100 000
		T2	10	12	70	100 000
		T3	20	22	120	100 000
	Scenario 1-2	T1	8	10	50	100 000
		T2	10	12	70	100 000
		T3	10	12	120	100 000
Group 2	Scenario 2-1	T1	8	10	50	400 000
		T2	10	12	70	400 000
		T3	12	14	115	400 000
	Scenario 2-2	T1	8	10	70	400 000
		T2	10	12	30	400 000
		T3	12	14	90	400 000
	Scenario 2-3	T1	8	10	70	400 000
		T2	10	12	45	400 000
		T3	20	24	90	400 000
	Scenario 2-4	T1	8	10	30	100 000
		T2	10	12	40	100 000
		T3	20	24	90	100 000
Group 3	Scenario 3-1	T1	8	10	30	100 000
		T2	10	12	60	100 000
		T3	12	14	40	100 000
Group 4	Scenario 4-1	T1	8	10	30	100 000
		T2	10	12	50	100 000
		T3	12	14	25	100 000

- Group 1: One transport operator among the three has enough capacity to complete all delivery quantities. The cooperation costs of all transport operators are identical and are the same in all scenarios in this group.

  There are two interesting scenarios to be considered taking into account transportation prices. These two scenarios are presented in detail as follows:

  - Scenario 1-1: the transport operator (T3) has enough capacity to complete the whole delivery plan but with transportation price (per ton) significantly higher than other transport operators (T1 and T2).
  - Scenario 1-2: one transport operator (T3) has enough capacity to complete the whole delivery plan with a transportation price at the same level as transport operator (T2).

  Only transportation price of T3 is changed comparing the settings of parameters in these two scenarios. The comparison of results of these two scenarios will show the impact of **transportation price** on the splitting results.

- Group 2: Any one transport operator can not complete the whole delivery plan alone but at least two of them together can. The cooperation costs of all transport operators are identical but are not the same in all scenarios in this group. The cooperation costs of scenario 2-4 are different from those in scenario 2-1 to scenario 2-3.

There are four interesting scenarios to be considered taking into account transportation price, transportation capacity, and also the cooperation cost.

- Scenario 2-1: compared with scenario 1-2, cooperation cost is increased from 100 000 to 400 000; the transportation price of T3 is increased from 10/12 (customer 1 / customer 2) to 12/14 which is a little higher than other transport operators (T1 and T2); the transportation capacity of T3 is decreased from 120 to 115 which is not enough compared with required trucks 117. The results of scenario 2-1 show the impact of **cooperation cost** on the splitting result. In other words, producer either chooses to work with transport operator T3 with a little higher transportation price, a little insufficient capacity (i.e.115 trucks), lower cooperation cost (i.e. 1*400 000) or he chooses two transport operators T1 and T2 with lower transportation price, enough transportation capacity (i.e. 50+70=120 trucks together) but more cooperation cost (i.e. 2*400 000).
- Scenario 2-2: compared with scenario 2-1, only the transportation capacity profile of transport operators change. The sum of the capacities of two transportation operators with cheapest transportation price T1 and T2 cannot complete the whole delivery plan (i.e. 70+30<117). The results of scenario 2-1 will show the impact of the distribution of **transportation capacities** to the splitting result.
- Scenario 2-3: compared with scenario 2-2, the sum of the capacities of T1 and T2 is sufficient to complete the whole delivery plan (i.e. 70+45>117). In other words, the sum of capacities of any two transport operators can complete the whole delivery plan. Transportation price of T3 is significantly higher than other transport operators (T1 and T2). The result of this scenario show the impact of **transportation price** on choosing the transport operators as any combination of two transport operators can complete the whole delivery plan.
- Scenario 2-4: Similar to the scenario 2-2, the sum of the capacities of the two cheapest transport operators T1 and T2 is less than required capacity (30+40<117) however the cooperation cost is decreased. The result of this scenario show the impact of **cooperation cost and transportation prices** in choosing the transportation capacities to complete the whole delivery plan.

* Group 3: Any two transport operators can not complete the whole delivery plan but three together can.

  There is only one scenario in this group.

  - Scenario 3-1: All the three transport operators should be used to complete the delivery request. This scenario concerns the verification of whether transportation prices can affect the assignments to each transport operator.

- Group 4: All the three transport operators together cannot complete the whole delivery plan.

  There is only one scenario in this group.

  - Scenario 4-1: All the three transport operators should be used to make the transportation. This scenario is designed to test the robustness of 1-N_SPT model by considering the situation that it may have backorders at the end of planning horizon.

For each scenario, the validation principle is made up of three steps:

1) Analyze the scenario and identify some possible solutions. Before the execution of 1-N_SPT model, some possible solutions can be identified intuitively. However we need to identify which solution is the expected result of the 1-N_SPT model for validation purpose.
2) The possible cost of each solution is "manually" estimated and compared with others in order to identify the expected result. The cost estimation is a rough calculation based on the information in Table 5-1 to Table 5-3. The estimated cost of each possible solution considers all the producer's costs of working with multiple transport operators including transportation fees, cooperation costs and the late or early penalty costs caused by transport operators' not on time deliveries. The comparison of estimated costs shows the expected result of 1-N_SPT model.
3) The 1-N_SPT model is then implemented and the main conclusions on splitting results will be presented and compared with expected result in order to verify the functionality of 1-N_SPT model.

We only present here the analysis process of scenario 2-1 as an example in the following part. The analysis of other scenarios can be found in Appendix VII.

Analysis of scenario 2-1:

Scenario analysis:

In this scenario, in order to satisfy customer demand, producer may work with T1 and T2 together or T3 alone. Producer should make a trade-off between working with two transport operators (T1 and T2) with lower transportation prices but more cooperation cost or working with one transport operator (T3) with less cooperation cost but higher transportation price. Especially if producer works with only T3, because its transportation capacity is a little tight compared with delivery quantities, it may cause not on time deliveries of producer. Thus, producer should pay penalty cost to customer in this solution.

Estimated cost of each solution:

We calculate the transportation fee of working with each transport operator supposing it can complete the whole delivery plan alone. The transportation fee of working with each transport operator alone is shown in Table 5-4 by using the information in Table 5-1.

Table 5-4 Transportation fee of working with each transport operator alone

Transport operators	Transportation fee= $\sum_j TP_j * AL_j$
T1	8*36 895+10*44 694=742 100
T2	10*36 895+12*44 694=905 278
T3	12*36 895+14*44 694=1 068 456

The cost of working with T1 and T2, labeled “T1&T2”, is considered as the average transportation fee of the two transport operators (see Table 5-4) plus the operation costs (see Table 5-3) calculated as below:

T1&T2 = (742 100+905 278)/2+400 000+400 000 = 1 623 689

The cost of working with T3 alone, calculated as 1 068 456 +400 000 which is 1468456.

T3 has only 115 trucks. There is capacity gap of 2 trucks in the period of peak demand. The capacity of each truck is 100 tons and the unitary scalar of product can be found in Table 5-1. So each truck can transport a maximum number of 20 (i.e. 100/5) units of product 1 or 12 (i.e.100/8) units of product 2. In order to estimate the maximum penalty cost, we take the value “20” (maximum value between 20 and 12) as the not on time delivery quantities of all proudut s for each truck. The capacity gap is 2 trucks in a period of demand peak. Thus, the estimated late or early delivery quantities in a period of demand peak are 40 (i.e. 2*20) units of product and 800 (i.e. 20*40) for the planning horizon of 20 periods. Producer may pay penalty cost to customer by working with T3 alone. The average unitary late and early supplied penalty cost is 30 according to the input parameters in Table 5-2. Thus the estimated penalty cost is 30*800=24 000. So the estimated cost of working with T3 is calculated as 1 468 456+24 000 which is 1 492 456.

Comparison of estimated costs:

Table 5-5 Comparison result of possible solutions

Solutions options	Transportation cost	Choice
T1+T2	1 623 689	
T3	1 492 456	√

The comparison result in Table 5-5 shows that the favorable solution for producer is working with T3 alone.

Expected result:

Producer assigns delivery quantities to T3 only.

Splitting result of 1-N_SPT model:

All delivery quantities are assigned to T3.

The splitting results of all the scenarios are presented in Table 5-6.

Table 5-6 Splitting result of all scenarios

Scenarios	Splitting results
Scenario 1-1	Although the cooperation cost of working with T1 and T2 together is more than working with T3 alone, because of the high transportation fee of working with T3, producer prefers to work with two transport operators T1 and T2 together. There are no early pickup or late pickup quantities in splitting result.
Scenario 1-2	Compared with scenario 1-1, producer prefers to work with only one transport operator T3 by considering the high cooperation cost of working with T1 and T2 together. There are no early pickup or late pickup quantities in splitting result.
Scenario 2-1	Compared with scenario 1-2, although T3 has high transportation price and insufficient transportation capacity, producer still prefers to work with only one transport operator T3 because of a high increase of cooperation cost F_n from 100 000 to 400 000. There are some early and late supplied quantities in the result.
Scenario 2-2	Because the sum of the capacities of the two transportation operators with cheapest transportation price (i.e. T1 and T2) cannot complete the whole delivery plan, T3 should also be used. As the cooperation cost F_n is high (i.e. 400 000), working with T1, T2 and T3 together is not the best solution. Considering the combination of two transport operators, although the transportation price of T3 is high, producer prefers to work with the two transport operators T1 and T3 rather than T2 and T3 as the transportation price of T2 is more expensive than T1. There are no early pickup or late pickup quantities in splitting result.
Scenario 2-3	When the combination of any two transport operators can complete the whole delivery plan, producer prefers to work with the two transport operators with cheapest transportation prices T1 and T2. There are no early pickup or late pickup quantities in splitting result.
Scenario 2-4	Unlike scenario 2-2, with a low cooperation cost for all transport operators, producer prefers to work with T1 T2 and T3 together rather than working with T1 and T3. As the transportation price of T3 is the most expensive, producer prefers to fully load T1 and T2 and takes T3 as complementary capacity.
Scenario 3-1	In this scenario, producer has little flexibility in choosing transport operators but prefers to work with all of them. There are no early pickup or late pickup quantities in splitting result. T1 and T2 are fully loaded because of their lower transportation price.
Scenario 4-1	In this scenario, all transport operators should be used and there are backorders at the end of planning horizon. Producer should pay penalties to customers.

The splitting results are consistent with the expected results (see Appendix VII) of all the scenarios. Therefore, these splitting results validate the splitting logic of 1-N_SPT model focusing on the trade-off aspect that producer should make by considering the transportation price, transportation capacity and the cooperation cost.

5.3 1P-nT negotiation protocol

We have defined two analytical models (i.e. 1-N_SPT and 1-N_EP) specific to the multiple transport operators context. In this part, we will present the negotiation protocol and also valid it by several numerical experiments.

The proposed protocol can be used to coordinate one producer with multiple transport operators. Without the lost of generality, we present in this section the coordination between one producer and three transport operators for presentation reasons.

We make the hypotheses that total transportation capacity of the three transport operators is superior to the delivery request of a whole delivery plan over the planning horizon. This choice can be justified by the fact that a producer can contract with as many transport operators as he need to serve customers' demand, and is not limited in terms of transportation capacity.

5.3.1 Description of protocol

In this part, an instance of the negotiation process is firstly presented with a UML sequence diagram in order to have a glance at possible exchanges of information and plans in the negotiation process. The detailed explanation of the negotiation protocol will be presented after.

One producer and two transport operators are considered as an example in the sequence diagram presented in Figure 5.7. The main exchanges are explained below. Let us remark that before the negotiation process, there are information sharing activities at the initialization phase.

1. Producer calculates a whole delivery plan by BPP model (i.e. P_{BPP}) which expresses the delivery request and sends P_{BPP} to transport operator 1.
2. Producer sends P_{BPP} to transport operator 2.
3. Transport operator 1 answers by sending its accumulated number of trucks (i.e $TC\_NBR_{j,1,t}$) to producer. It is calculated based on the output $m_{j,t}$ of BST model.
4. Transport operator 2 answers by sending its accumulated number of trucks (i.e $TC\_NBR_{j,2,t}$) to producer. It is also calculated based on the output $m_{j,t}$ of BST model.
5. After the execution of 1-N_SPT model, producer sends a split delivery plan to transport operator 1 which respects well the latter's capacity constraint expressed by the accumulated number of trucks.
6. Similarly, producer sends a split delivery plan to transport operator 2.
7. Transport operator 1 compares the profit gap of best service pickup plan and best profit pickup plan with its acceptance criterion in order to decide which one between these two plans should be sent to producer. A chosen pickup plan of transport operator 1 is sent to producer.
8. Similarly, a chosen pickup plan of transport operator 2 is sent to producer.
9. Producer evaluates the received pickup plans of both transport operators with 1-N_EP model. The received pickup plan of transport operator 1 satisfies exactly the delivery request without any early or early pickup quantities. And the pickup plan proposed by transport operator 2 has deviation from the delivery request. Thus, producer insists on sending the initial delivery request to transport operator 2.
10. Transport operator 2 answers a released pickup plan with the help of RT model.

11. Producer evaluates the latest received pickup plans of both transport operators and they are acceptable. Thus, producer sends a notification of negotiation result “OK” to transport operator 1.
12. Producer sends “OK” to transport operator 2. Negotiation process stops.

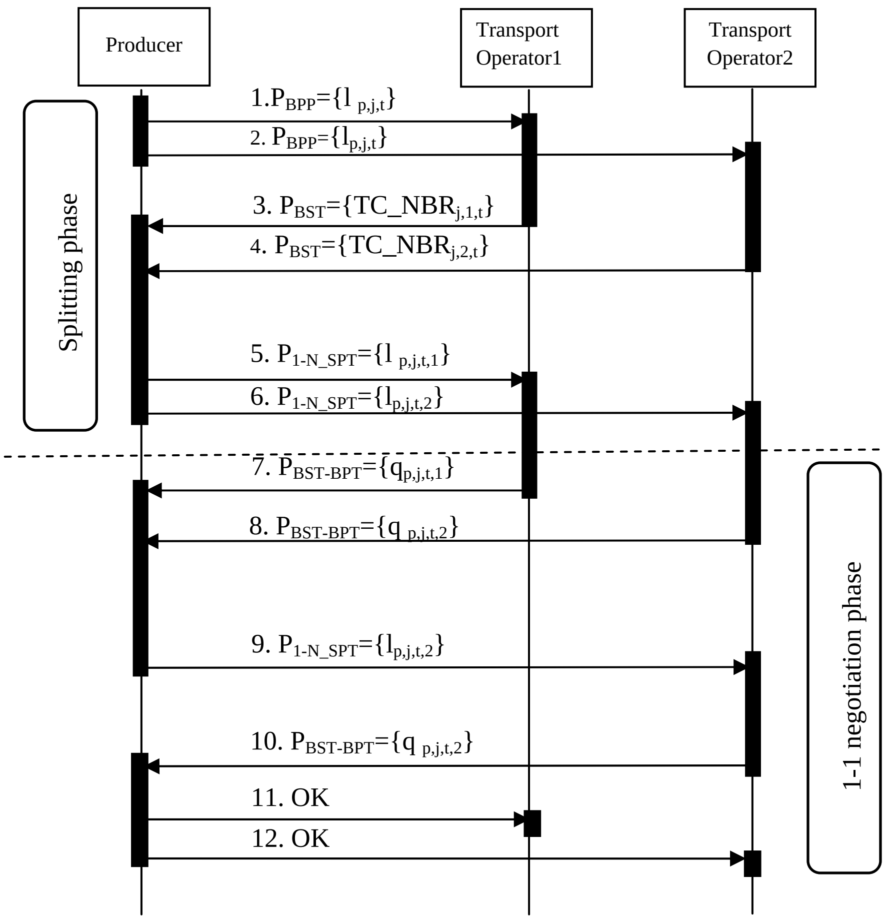


Figure 5.7 Sequence diagram of negotiation process with two transport operators

Let us remarks that producer evaluates received pickup plans to identify whether they are acceptable. Before the evaluation with 1-N_EP model, producer waits until receiving all pickup plans from transport operators and evaluates the feasibility of all pickup plans together.

The detailed and generic explanation of the negotiation protocol is presented hereunder by considering the splitting and 1-1 negotiation phases:

- **Splitting phase**

This phase is characterized by the following sequence:

– The role of this phase is to split delivery quantities among transport operators by respecting their estimated capacities. This phase starts from the generation of a whole delivery plan generated by “Best Profit Production” model (BPP model).

This output delivery plan ($l_{p,j,t}$) expresses the total delivery quantities requirement which is sent to all transport operators.

– Each transport operator responds to this delivery plan using its "Best Service Transportation" model in order to primarily satisfy its own customer (i.e. the producer). As explained in section 5.2.1, transport operator transforms the output plan of BST model into accumulated in-process trucks plan for mutual interest reasons. This accumulated in-process trucks plan expresses the available number of trucks at each time period $TC\_NBR_{j,n,t}$. It is calculated by formula $TC\_NBR_{j,n,t} = \sum_{i=1}^{Dj} m_{j,t-i+1}\ \forall n$ where $m_{j,t}$ is the trucks utilization plan of the corresponding transport operator. Then finally each transport operator informs the producer of its capacity with this plan. In that way, there is a guaranty that the split delivery plans sent to transport operators can be accomplished by transport operators without violating the limitation of the available number of trucks of each transport operator.

– The producer uses 1-N_SPT model to achieve the split delivery plans for each transport operator.

Let us notice that producer and transport operator exchange information only in one iteration (request/answer) in the splitting phase. Once the splitting phase finishes, the negotiation process moves forward to 1-1 negotiation phase without turning back.

- **1-1 negotiation phase**

The "1P-nT" negotiation phase is made up of a set of individual negotiations "1P-1T". This individual negotiation between the producer and one of its partners is a simplified 1P-1T negation protocol without using "Released Production" model. The producer is in charge of the consistency of the global negotiation results issued from each individual negotiation. This phase is characterized as regards both sides of partners:

– *Transport operator.* At the beginning of each individual negotiation, the transport operator runs the "Best Service Transportation" model BST and "Best Profit Transportation" model BPT and compares the results of the two models. As described in 1P-1T negotiation context, one of the two pickup plans is chosen to be sent to producer. During negotiation process, the "Released Transportation" model (RT model) could be triggered if the producer does not accept the pickup plan proposed by the transport operator.

– *Producer*. He is responsible for deciding whether the set of received pickup plans is acceptable.

- The model 1-N_EP is used to perform this evaluation. In order to carry out this global evaluation, a condition is required: the pickup plans from all transport operators must be received. Denote $q^{K}_{p,j,t,n}$ as the pickup plan of transport operator n at iteration number k (n: transport operator index; k: iteration number). Producer evaluates split pickup plans from transport operators by the 1P-nT evaluation production (1-N_EP) model in which the following set of constraints is imposed: $l_{p,j,t,1} = q^{1}_{p,j,t,1}$, $l_{p,j,t,2} = q^{1}_{p,j,t,2}$, $l_{p,j,t,3} = q^{1}_{p,j,t,3}$.

- Each pickup plan can be considered as "perfect" or "imperfect" depending on whether it corresponds to the split delivery plan or not. A pickup plan is considered as "perfect" only if this pickup plan has no deviation from the corresponding split delivery plan. In other words, the pickup quantities at any time period can respond exactly the required delivery quantities in the corresponding time period; more precisely, the condition $q_{p,j,t,n} = l_{p,j,t,n}\ \forall p, \forall j, \forall t, \forall n$ should be satisfied. Otherwise a split pickup plan is considered as "imperfect".

- Two kinds of alternative output from the 1-N_EP are possible:
  - The set of all pickup plans evaluated together is feasible and any pickup plan in this set is "perfect", the negotiation stops.
  - The set of all pickup plans evaluated together is not feasible and at least one pickup plan is imperfect. The negotiation goes on. The transport operators whose split pickup plans have deviation from the corresponding split delivery plan run "Released Transportation" model (RT) to replanning. Other transport operators just wait without running RT model. Their "perfect" split pickup plans can be retained by producer to next iteration. Negotiation process repeats model 1-N_EP with constraints $l_{p,j,t,n} = q^{K}_{p,j,t,n}$ until 1-N_EP model gets a feasible solution.

5.3.2 Validation of negotiation protocol

In the following experiments, the structured experimental approach of DOE is not adopted because the number of factors is increased compared with 1P-1T context. It needs more experiment trials than the 1P-1T context. We take three transport operators as example. All transportation related factors should be multiplied by 3. Considering early pickup penalty cost, late pickup penalty cost, transportation price, number of trucks, destination related cost, cooperation cost, plans acceptance criterion, maximum number of negotiation, compensation percentage, these parameters or factors will compose 27 factors. There are also production cost parameters, early supplied penalty cost, late supplied penalty cost, selling price, inventory cost, there would be at least 31 factors. A full factorial design will consist of 3^{31} trials having 3 levels for each factor. Even the orthogonal array will consists of at least 32 trials considering each factor at 2 levels without interactions in an experimental array (see Table 4-14).

Therefore, in this section, we just test the 1P-nT negotiation protocol with some numerical experiments. One producer and three transport operators are still considered in these experiments without losing the generality of multiple transport operators.

5.3.2.1 *Preliminary experiments*

The splitting model has been validated by several scenarios in section 5.2.3. In this section, we evaluate the performance of 1P-nT negotiation protocol focusing on the 1-1 negotiation phase. When splitting phase is finished, the profit of each partner before and after 1-1 negotiation phase is evaluated in order to verify that the proposed negotiation protocol can lead to a win-win situation. All the test cases are implemented through simulation in the experimental platform.

Let us remind that it is more interesting to negotiate on best profit transportation plan P_{BPT} when the condition $\frac{G_{BPT}}{G_{BST}} \geq AC^T$ is true. Thus, the test cases are divided into two groups, $\frac{G_{BPT}}{G_{BST}} \geq AC^T$ and $\frac{G_{BPT}}{G_{BST}} < AC^T$ as shown in Table 5-7 in order to observe the performance difference in these two conditions. In case 1 to case 4, condition $\frac{G_{BPT}}{G_{BST}} \geq AC^T$ is true. Transport operators start negotiation with producer by sending P_{BPT} while in case 5, condition $\frac{G_{BPT}}{G_{BST}} \geq AC^T$ is not satisfied, transport operators send P_{BST} to producer at the beginning of 1-1 negotiation phase. In order to guarantee the two conditions, the parameter settings are tested and verified by simulation.

Table 5-7 Two groups of test cases

<table>
<tr><th>Groups</th><th>Cases</th><th>Transportation prices TP_j</th><th>Number of trucks R</th></tr>
<tr><td rowspan="4">Group 1: $\frac{G_{BPT}}{G_{BST}} \geq AC^T$</td><td>Case 1</td><td rowspan="3">T1=T2=T3</td><td>T1=160; T2=45; T3=45;</td></tr>
<tr><td>Case 2</td><td>T1=160; T2=160; T3=160;</td></tr>
<tr><td>Case 3</td><td>T1=45; T2=45; T3=45;</td></tr>
<tr><td>Case 4</td><td>T1<T2<T3</td><td>T1=30; T2=50; T3=45;</td></tr>
<tr><td>Group 2: $\frac{G_{BPT}}{G_{BST}} < AC^T$</td><td>Case 5</td><td>T1<T2<T3</td><td>T1=30; T2=50; T3=45;</td></tr>
</table>

Some common parameters of the five test cases are presented in Table 5-8. Acceptance criterion AC^T, also labeled ACR_{in} in chapter 4, is set as the smallest value (i.e. 1.01) of levels of factor ACR_{in} as shown in Chapter 4. This value guarantees that the transport operator has more possibility to negotiate on best profit pickup plan. Maximum number of negotiation *MaxNego*, also labeled MNN_{in} in chapter 4, is the maximum number iterations during which transport operator may respond to the same delivery plan by gradually releasing its profit. It is set differently for the three transport operators. As parameter *MaxNego* is set to a smaller value for T3 (i.e. 5) than for T1 and T2, T3 reaches more rapidly the best service pickup plan which is considered as "perfect" during the releasing process. By *MaxNego* setting, it is possible to test how the negotiation protocol functions in the case that the received pickup plan from T3 is "perfect" while the received pickup plans from T1 and T2 are "imperfect". Load capacity of a truck and cooperation cost are respectively identical for all transport operators, so that the preference for choosing transport operators is not based on theses parameters. The customer demand profile is the same as the one used in the validation of 1-N_SPT model shown in Table 5-1. Let us remind that the requirement of trucks at period of peak demand equal to 117 trucks.

Table 5-8 Common parameters of all the test cases

	Load Capacity of a truck (ton)	**Cooperation cost (€)**	**Acceptance criterion ACR_{in}**	**Maximum number of negotiation MNN_{in}**
	Cap	**F_n**	AC^T	*MaxNego*
T1	100	10000	1.01	10
T2	100	10000	1.01	10
T3	100	10000	1.01	5

The main setting differences of the five test cases are shown in Table 5-7. The first three cases have the same transportation prices settings for all transport operators. Only the settings of transportation capacities are different. The objectives of these test cases are explained hereunder:

- In test case 1, after the splitting phase, producer will only work with one transport operator T1. This case can validate the 1P-nT negotiation protocol by the simplest 1P-1T negotiation.
- Case 2 and case 3 are carried out to observe the negotiation behaviors when the transport operators are identical.
- In case 4 and case 5, all the three transport operators should be used. These two cases will illustrate the main behaviors of one producer negotiating with multiple transport operators in the negotiation process. Particularly, in case 4, the 1-1 negotiation phase will start with sending best profit pickup plan to producer while in case 5, transport operators send best service pickup plan to producer.

The performances of the 1P-nT negotiation are presented by two groups of performance indicators: economic performance and service quality performance. By taking into account all the responses defined in chapter 4, particularly we also evaluate the penalty and the number of negotiation iterations of each transport operator.

<u>Group 1: case 1 to case 4</u>

As the settings of some parameters of case 1 to case 3 are the same, they are presented together as follows shown in Table 5-9 to Table 5-12. In these three cases, only the transportation capacities are different as shown in Table 5-7.

Table 5-9 Production parameters – basic setting of case 1 to case 3

Producer	**Selling Price (euro)**	**Maximum Quantity of Early Supplied Quantity (unit)**	**Unitary Required Resource (unit)**	**Unitary Scalar of Product p (ton)**	**Unitary Mean Production Cost (euro)**	**Production Lead time (Day)**	**Unitary Mean Inventory Cost**

	$SP_{p,j}$		$Emax_{p,j}$		u_p	v_p	CP_p	DP_p	CSp
	Customer 1	Customer 2	Customer 1	Customer 2					
Product 1	270	270	4	4	1	5	70	1	22.5
Product 2	360	360	4	4	2	8	90	1	32.5

Table 5-10 Production parameters - penalty cost of case 1 to case 3

	Unitary Late Supplied Cost (euro)		Unitary Early Supplied Cost (euro)	
	$CR_{p,j}$		$CE_{p,j}$	
	Customer 1	Customer 2	Customer 1	Customer 2
Product 1	40	45	20	25
Product 2	50	55	30	35

Table 5-11 Transportation parameters – basic setting of case 1 to case 3

T1/T2/T3	Destination related Transportation Cost (euro/ truck)	Transportation Lead Time (day)	Round trip time (day)	Transportation Price (euro/ ton)	Minimum Load (ton)
	FC_j	DT_j	D_j	TP_j	$minLoad_{j,n}$
Customer 1	600	1	2	12	100
Customer 2	800	1	3	10	100

Table 5-12 Transportation parameters – penalty cost and handling cost of case 1 to case 3

T1/T2/T3	Late Pickup Penalty Cost (euro)		Early Pickup Penalty Cost (euro)		Handling Cost (euro)
	$BC_{p,j}$		$EC_{p,j}$		VC_p
	Customer 1	Customer 2	Customer 1	Customer 2	
Product 1	40	45	20	25	2
Product 2	50	55	30	35	3

Case 1: One transport operator (T1) has enough capacity (160 available trucks v.s. 117 required ones)

The responses are presented in Table 5-13 to Table 5-15. The results of splitting phase and 1-1 negotiation phase are explained separately as below:

- In the splitting phase, all delivery quantities are sent to T1 which has enough transportation capacity because the cooperation cost would significantly increase if working with two transport operators.
- In the 1-1 negotiation phase, producer only negotiates with T1. The negotiation process converges after 4 iterations (see Table 5-15, column TIN_{out}) which is the value of how many times 1-N_EP model is executed. RT model of T1 runs 3 times (see Table 5-14, column "Iteration RT" and line "T1"). Finally producer and transport operator T1 converge on a released pickup plan. The profits before negotiation, which are corresponding to best service pickup plan and best profit pickup plan, are evaluated after splitting phase. The difference of profit of transport operator is evaluated compared with G_{BST}. As best profit pickup plan could not be accepted by producer, G_{BST} is considered as the profit of transport operator if the negotiation process is not implemented. Table 5-13 shows that profit of producer, profit of transport operator T1 and total profit are increased which is consistent with the performance of 1P-1T negotiation protocol.

Table 5-13 Economic performance of case 1

	Profit of producer	Profit of T1			Profit of T2	Profit of T3	Total profit
Before negotiation	2 051 480.0	G_{BST}	G_{BPT}	G_{BPT}/ G_{BST}	0	0	2 317 174
		265 694.0	274 734.0	1.03			

After negotiation	**PPR_{out}**	**PTR_{out}**	**PTR_{out}**	**PTR_{out}**	**TOP_{out}**
	2 055 415.5	267 603.5	0	0	2 323 019.0
Difference	**DPP_{out}**	**DPT_{out}**	**DPT_{out}**	**DPT_{out}**	**DTP_{out}**
	0.19%	0.72%	0	0	0.25%

Table 5-14 Transport operator service quality performance of case 1

	Compensation CPP_{out}	**Penalty**	**Early pickup quantity EPQ_{out}**	**Late pickup quantity LPQ_{out}**	**Backorders BOP_{out}**	**Iteration RT**
T1	4 455.5	1 035	29	3	0	3
T2	0	0	0	0	0	0
T3	0	0	0	0	0	0

Table 5-15 Producer service quality and convergence performance of case 1

Early supplied quantity ESQ_{out}	**Late supplied quantity LSQ_{out}**	**Backorders to customer BOC_{out}**	**Total iteration number TIN_{out}**
29	3	0	4

Case 2: Any transport operator has enough capacity. The number of available trucks equals to 160 for each transport operator.

The performance results of case 2 are presented in Table 5-16 to Table 5-18 and are discussed as follows:

- In the splitting phase, considering the cooperation cost, producer chooses to work with only one transport operator. Because the transportation models of all the three transport operators have the same values of parameters, anyone of them could be the possible choice of producer. These results show that all delivery quantities are sent to T3 randomly.
- In the 1-1 negotiation phase, negotiation process converges after 3 iterations. RT model of T3 runs 2 times. Finally producer and transport operator T3 converge on a released pickup plan. Table 5-16 shows that both profits of producer and T3 are increased so does the total profit.

Table 5-16 Economic performance of case 2

	Profit of producer	**Profit of T1**	**Profit of T2**	**Profit of T3**			**Total profit**
Before negotiation	2 051 480.0	0	0	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	2 317 174.0
				265 694.0	274 734.0	1.03	
After negotiation	**PPR_{out}**	**PTR_{out}**	**PTR_{out}**	**PTR_{out}**			**TOP_{out}**
	2 054 712.7	0	0	267 323.3			2 322 036.0
Difference	**DPP_{out}**	**DPT_{out}**	**DPT_{out}**	**DPT_{out}**			**DTP_{out}**
	0.16%	0.00%	0.00%	0.61%			0.21%

Table 5-17 Transport operator service quality performance of case 2

	Compensation CPP_{out}	**Penalty**	**Early pickup quantity EPQ_{out}**	**Late pickup quantity LPQ_{out}**	**Backorders to producer BOP_{out}**	**Iteration RT model**
T1	0	0	0	0	0	0
T2	0	0	0	0	0	0
T3	3 801.7	970	18	6	3	2

Table 5-18 Producer service quality and convergence performance of case 2

Early supplied quantity ESQ_{out}	**Late supplied quantity LSQ_{out}**	**Backorders to customer BOC_{out}**	**Total iteration number TIN_{out}**
18	6	3	3

Case 3: Transportation capacity is enough only if the three transport operators work together for serving the producer's requests.

The performances results of case 3 are shown in Table 5-19 to Table 5-21 and are discussed below:

- In the splitting phase, all the three transport operators T1, T2 and T3 are chosen.
- In the 1-1 negotiation phase, the negotiation process converges after 9 iterations. RT model of T1 runs 8 times. RT model of T2 also runs 8 times. RT model of T3 runs 5 times and attains the best service pickup plan. When the pickup plan of T3 corresponds to the best service pickup plan, it is considered as "perfect". This logic is confirmed by observing the values of all transport operator service quality responses of T3 which equal "0" in Table 5-20, because the best service pickup plan can exactly satisfy delivery demand. However, all the pickup plans together are not considered as acceptable by producer. Therefore, the negotiation process continues. T1 and T2 continue to release their pickup plans until 1-N_EP model finds an acceptable solution. Table 5-19 shows that profits of T1 and T2 increase more than profit of producer.

Table 5-19 Economic performance of case 3

	Profit of producer	**Profit of T1**			**Profit of T2**			**Profit of T3**			**Total profit**
Before negotiation	2 031 480.0	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	2 292 774.0
		82 270.0	85 158.0	1.03	60 189.0	62 144.0	1.03	118 835.0	121 881.0	1.03	
After negotiation	$\mathbf{PPR_{out}}$	$\mathbf{PTR_{out}}$			$\mathbf{PTR_{out}}$			$\mathbf{PTR_{out}}$			$\mathbf{TOP_{out}}$
	2 031 873.8	82 509.7			60 334.5			118 835.0			2 293 553.0
Difference	$\mathbf{DPP_{out}}$	$\mathbf{DPT_{out}}$			$\mathbf{DPT_{out}}$			$\mathbf{DPT_{out}}$			$\mathbf{DTP_{out}}$
	0.02%	0.29%			0.24%			0.00%			0.03%

Table 5-20 Transport operator service quality performance of case 3

	Compensation CPP_{out}	**Penalty**	**Early pickup quantity EPQ_{out}**	**Late pickup quantity LPQ_{out}**	**Backorders BOP_{out}**	**Iteration RT**
T1	559.3	370	0	4	3	8
T2	339.5	315	9	0	0	8
T3	0	0	0	0	0	5

Table 5-21 Producer service quality and convergence performance of case 3

Early supplied quantity ESQ_{out}	**Late supplied quantity LSQ_{out}**	**Backorders to customer BOC_{out}**	**Total iteration number TIN_{out}**
9	4	3	9

Case 4: Different from case 1 to case 3, this case considers that three transport operators have different transportation price.

The detailed transportation prices are shown in Table 5-22. With this scenario, we would like to point out that small variation of transportation prices can cause a large increase in transportation fees. For this reason, we decide to vary the transportation prices of few decimals. Referring to transportation capacity parameters defined in Table 5-7, only the total transportation capacity of the three transport operators together can satisfy the whole delivery plan. All the other parameters are the same as case 1 to case 3.

Table 5-22 Transportation price of case 4

	T1 Transportation Price / ton	**T2** Transportation Price / ton	**T3** Transportation Price / ton
	TP_j	TP_j	TP_j
Customer 1	12	12.1	12.2
Customer 2	10	10.1	10.2

The total number of trucks equal to 125 which is more than the peak requirement of trucks (i.e. 117). The performances results of case 4 are shown in Table 5-23 to Table 5-25 and are discussed below

- In the splitting phase, all the three transport operators T1, T2 and T3 are chosen.
- In the 1-1 negotiation phase, the negotiation process converges after 7 iterations. RT model of T1 runs 0 times. RT model of T2 runs 6 times. RT model of T3 runs 5 times. The condition $\frac{G_{BPT}}{G_{BST}} \geq AC^T$ is false for T1. Hence, T1 sends directly best service pickup plan to producer. During the negotiation process, after 5 iterations, T3 is released to the best service pickup plan because its parameter *MaxNego* is set as 5. The negotiation process finally converges on a released pickup plan of T2 and on best service pickup plans of T1 and T3. Table 5-23 shows that the improvements of profits are even less compared with above cases.

Table 5-23 Economic performance of case 4

	Profit of producer	**Profit of T1**			**Profit of T2**			**Profit of T3**			**Total profit**
Before negotiation	2 024 610.5	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	2 296 374
		150 742.0	151 382.0	1.00	96 933.9	98 480.5	1.02	24 087.6	28 457.6	1.18	
After negotiation	PPR_{out}	PTR_{out}			PTR_{out}			PTR_{out}			TOP_{out}
	2 024 633.5	150 742.0			97 124.9			24 087.6			2 296 588
Difference	DPP_{out}	DPT_{out}			DPT_{out}			DPT_{out}			DTP_{out}
	0.00%	0.00%			0.20%			0.00%			0.01%

Table 5-24 Transport operator service quality performance of case 4

	Compensation CPP_{out}	**Penalty**	**Early pickup quantity EPQ_{out}**	**Late pickup quantity LPQ_{out}**	**Backorders BOP_{out}**	**Iteration RT**
T1	0	0	0	0	0	0
T2	445.62	530	5	4	3	6
T3	0	0	0	0	0	5

Table 5-25 Producer service quality and convergence performance of case 4

Early supplied quantity ESQ_{out}	**Late supplied quantity LSQ_{out}**	**Backorders to customer BOC_{out}**	**Total iteration number TIN_{out}**
5	4	3	7

All these four cases presented above present that the negotiation protocol finally converges after several iterations, and that profits of concerned partners and the total profit are improved after negotiation even the improvements are not always very significant. These evaluation results confirm the goal of a win-win aspect of our negotiation protocol

Group 2: case 5

Case 5: Condition $\frac{G_{BPT}}{G_{BST}} \geq AC^T$ is not satisfied for each transport operator.

This case has different input parameters setting from case 1 to case 4 presented hereunder. The gray cells in Table 5-26 to Table 5-30 show the change of parameters compared with case 1 to case 4. The selling prices of producer are decreased, as shown in Table 5-26. The penalty costs of all partners are increased, as shown in Table 5-28 and destination related transportation cost are decreased (see Table 5-29). Transport operators have different transportation prices, T1<T2<T3 (see Table 5-30). Only by using them together, transportation capacity is enough to satisfy the total delivery requirement (see Table 5-7).

Table 5-26 Production parameters – basic setting or case 5

Producer	**Selling Price (euro)**		**Maximum Quantity of Early Supplied Quantity (unit)**		**Unitary Required Resource (unit)**	**Unitary Scalar of Product p (ton)**	**Unitary Mean Production Cost (euro)**	**Production Lead time (Day)**	**Unitary Mean Inventory Cost**
	$SP_{p,j}$		**$Emax_{p,j}$**		**u_p**	**v_p**	**CP_p**	**DP_p**	**CSp**
	Customer 1	Customer 2	Customer 1	Customer 2					
Product 1	250	250	4	4	1	5	70	1	11.25
Product 2	300	300	4	4	2	8	90	1	16.25

Table 5-27 Production parameters – penalty cost of case 5

	Unitary Late Supplied Cost (euro)		**Unitary Early Supplied Cost (euro)**	
	$CR_{p,j}$		**$CE_{p,j}$**	
	Customer 1	Customer 2	Customer 1	Customer 2
Product 1	150	175	100	125
Product 2	200	225	150	175

Table 5-28 Transportation parameters – penalty cost and handing cost of case 5

T1/T2/T3	**Late Pickup Penalty Cost (euro)**		**Early Pickup Penalty Cost (euro)**		**Handling Cost (euro)**
	$BC_{p,j}$		**$EC_{p,j}$**		**VC_p**
	Customer 1	Customer 2	Customer 1	Customer 2	
Product 1	187.5	218.75	125	156.25	2
Product 2	250	281.25	187.5	218.75	3

Table 5-29 Transportation parameters – basic setting of case 5

T1/T2/T3	Destination related Transportation Cost (euro/ truck)	Transportation Lead Time (day)	Round trip time (day)	Minimum Load (ton)
	FC_j	DT_j	D_j	minLoadj,n
Customer 1	400	1	2	100
Customer 2	500	1	3	100

Table 5-30 Transportation prices of case 5

	T1 Transportation Price / ton	T2 Transportation Price / ton	T3 Transportation Price / ton
	TP_j	TP_j	TP_j
Customer 1	8.0	8.1	8.2
Customer 2	10.0	10.1	10.2

The results of case 5 are shown in Table 5-31 to Table 5-33 and are discussed below:

- In splitting phase, T1, T2 and T3 are chosen to make transportation. Because all transport operators must be chosen, the value of cooperation cost F_n has no impact on the splitting result.
- In the 1-1 negotiation phase, producer does not negotiate with T1, T2 and T3, because the profit gaps between G_{BPT} and G_{BST} are too small. The negotiation process converges after one iteration. RT models of T1, T2 and T3 run 0 times. No profit improvements can be observed in this case.

Table 5-31 Economic performance of case 5

	Profit of producer	Profit of T1			Profit of T2			Profit of T3			Total profit
Before negotiation	1 670 896.6	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	2008274
		110 965.0	111 240.0	1.00	150 241.0	150 391.0	1.00	76 171.4	76 421.4	1.00	
After negotiation	PPR_{out}	PTR_{out}			PTR_{out}			PTR_{out}			TOP_{out}
	1 670 896.6	110 965.0			150 241.0			76 171.4			2 008 274.0
Difference	DPP_{out}	DPT_{out}			DPT_{out}			DPT_{out}			DTP_{out}
	0.00%	0.00%			0.00%			0.00%			0.00%

Table 5-32 Transport operator service quality performance of case 5

	Compensation CPP_{out}	Penalty	Early pickup quantity EPQ_{out}	Late pickup quantity LPQ_{out}	Backorders BOP_{out}	Iteration RT
T1	0	0	0	0	0	0
T2	0	0	0	0	0	0
T3	0	0	0	0	0	0

Table 5-33 Producer service quality and convergence performance of case 5

Early supplied quantity ESQ_{out}	Late supplied quantity LSQ_{out}	Backorders to customer BOC_{out}	Total iteration number TIN_{out}
0	0	0	1

Important conclusion: The profits improvements after negotiation process are not very significant in test cases 1 to 4, the following reasons may help to explain this result:

- The maximum number of negotiation (i.e. *MaxNego*) settings are not the same for transport operators, thus, the one who has small value of *MaxNego* first arrive to its best service pickup plan. Consequently, without receiving compensation from this transport operator, profit of producer does not improve significantly.
- The negotiation space of transport operator is defined by G_{BST} and G_{BPT}. If the gap between G_{BST} and G_{BPT} is small, no significant profit improvements are expected at the end of negotiation. In 1P-nT context, the split delivery plans well respect the transportation capacities of transport operators by taking into account accumulated number of trucks. Thus, the best service pickup plans which can exactly respond to the split delivery plans respect the integrity of trucks. The best profit pickup obtained by BPT model only optimizes the utilization of trucks, leading to few early and late deliveries, so that the two plans are close to each other. This reason limits the negotiation space of transport operators.
- The profit gap between best profit pickup plan and best service pickup plan corresponds to the reduction of total number of required trucks to make transportation which is obtained by leveling (i.e. pickup in advance or late) in BPT model. If the penalty cost of late and early pickup is low, it incites the leveling of pickup quantities in the BPT model so as to reduce the number of required trucks and to get more potential gain.

5.3.2.2 *Complementary experiments*

Based on the important conclusion of the preliminary experiments, we propose to make complementary test cases by changing the settings of cost related parameters in order to find situations where profit could be more significant. The simulation results of test case 6 and test case 7 are presented as below:

Case 6: Compared with case 1-4, penalty costs of transport operators are decreased shown in Table 5-34. We also decrease transportation prices and the selling prices of products in order to be more realistic and consistent with the decreases of penalty costs shown in Table 5-35 to Table 5-36. By decreasing the penalty cost of transport operator, BPT model has more flexibility to make leveling in order to get more profit by reducing the number of required trucks. The profit gap between G_{BPT} and G_{BST} has more possibility to be increased. As the negotiation space increases, the profit improvements have more possibility to be significant.

Table 5-34 Penalty costs of transport operator of case 6

T1/T2/T3	Late Pickup Penalty Cost (euro)	Early Pickup Penalty Cost (euro)
	$BC_{p,j}$	$EC_{p,j}$

	Customer 1	Customer 2	Customer 1	Customer 2
Product 1	30	35	10	15
Product 2	40	45	20	25

Table 5-35 Selling prices of case 6

	Selling Price (euro)	
	$SP_{p,j}$	
	Customer 1	Customer 2
Product 1	250	250
Product 2	300	300

Table 5-36 Transportation prices of transport operator of case 6

	T1 Transportation Price / ton	**T2** Transportation Price / ton	**T3** Transportation Price / ton
	TP_j	TP_j	TP_j
Customer 1	8.0	8.1	8.2
Customer 2	10.0	10.1	10.2

The performance results are shown in Table 5-37 to Table 5-39 and are discussed below:

- In the splitting phase, all the three transport operators T1, T2 and T3 are chosen. T1 and T2 are almost full loaded over the planning horizon. Indeed producer intends to maximize the use of transport operators that offer the lowest transportation price. However, transport operators may have some unused capacities in certain periods, due to the inconstant delivery demand over the planning horizon. In a specific period, producer may require less transportation capacity than the sum of capacities of T1 and T2 in that period. Thus, transport operator T2 can have some flexible transport capacities to make leveling in BPT model which causes the profit gap between G_{BPT} and G_{BST} is more than that of T1.

- In the 1-1 negotiation phase, the negotiation process converges after 3 iterations before any transport operators attain its best service pickup plan. RT model of T1, T2 and T3 run 2 times. The negotiation process finally converges on released pickup plans of all transport operators. Table 5-37 shows that the improvements of profits of transport operators are significant and much more than the one of producer.

Table 5-37 Economic performance of case 6

	Profit of producer	**Profit of T1**			**Profit of T2**			**Profit of T3**			**Total profit**
Before negotiation	1 670 859.0	G_{BST}	G_{BPT}	G_{BPT}/ G_{BST}	G_{BST}	G_{BPT}	G_{BPT}/ G_{BST}	G_{BST}	G_{BPT}	G_{BPT}/ G_{BST}	1 793 874.0
		46 147.0	46 717.0	1.01	51 536.4	56 437.9	1.09	25 331.6	28 786.6	1.13	
After negotiation	**PPR_{out}**	**PTR_{out}**			**PTR_{out}**			**PTR_{out}**			**TOP_{out}**
	1 673 364.0	46 525.0			54 286.1			26 801.6			1 800 977.0
Difference	**DPP_{out}**	**DPT_{out}**			**DPT_{out}**			**DPT_{out}**			**DTP_{out}**

	0.15%	0.82%	5.34%	5.80%	0.40%

Table 5-38 Transport operator service quality performance of case 6

	Compensation CPP_{out}	Penalty	Early pickup quantity EPQ_{out}	Late pickup quantity LPQ_{out}	Backorders BOP_{out}	Iteration RT
T1	162	60	3	0	0	2
T2	1178	1010	30	10	1	2
T3	630	100	7	0	0	2

Table 5-39 Producer service quality and convergence performance of case 6

Early supplied quantity ESQ_{out}	Late supplied quantity LSQ_{out}	Backorders to customer BOC_{out}	Total iteration number TIN_{out}
40	10	1	3

Case 7: In order to confirm the impact of penalty costs of transport operators to the negotiation protocol performances, another test case is carried out by continuing decreasing the penalty costs of transport operators, as shown in Table 5-40. Other parameters are the same as those in case 6.

Table 5-40 Penalty costs of transport operator of case 7

	Unitary Late Pickup Cost (euro)		Unitary Early Pickup Cost (euro)	
	$CR_{p,j}$		$CE_{p,j}$	
	Customer 1	Customer 2	Customer 1	Customer 2
Product 1	25	30	5	10
Product 2	35	40	15	20

The performance results of case 7 are shown in Table 5-41 to Table 5-43 and are discussed below:

- In the splitting phase, all the three transport operators T1, T2 and T3 are chosen. T1 and T2 are almost full loaded over the planning horizon. Because of the decrease of the penalty costs of transport operators, they have more flexibility to making leveling the pickup quantities in order to maximize their profits. The profits G_{BPT} of all transport operators are increased a little.
- In the 1-1 negotiation phase, the negotiation process converges after 4 iterations before any transport operator attain its best service pickup plan. RT models of T1, T2 and T3 run 3 times. The negotiation process finally converges on released pickup plans of all transport operators. Table 5-41 shows that the improvements of profits of transport operators can also be observed in case 7. It confirms the impact of penalty costs of transport operators to the negotiation protocol performances. However compared with case 6, it takes one more iteration so that it causes the less final profits improvements of all partners. Indeed by decreasing the penalty cost, it increases the profit gap between G_{BPT} and G_{BST} so as to enlarge the negotiation space of transport operator. However, the final profits improvement of transport operators is not guaranteed to be increased correspondingly. The following reasons may explain this uncertainty.

Firstly, with the small penalty costs of transport operators, the proposed pickup plans are intending to have more leveling quantities which are not consistent with the producer's delivery requests. It may take more iterations for partners to finally converge on accepted pickup plans in the negotiation process.

Secondly, transport operators have no cooperation relations. Thus, they have no idea about other partners' decisions. The pickup plans of all transport operators may not be compatible with each other concerning completing the whole delivery requirement together. This also brings the uncertainty of required number of iterations for the convergence the negotiation process.

Table 5-41 Economic performance of case 7

	Profit of producer	Profit of T1			Profit of T2			Profit of T3			Total profit
Before negotiation	1 670 859.0	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	G_{BST}	G_{BPT}	G_{BPT}/G_{BST}	1 793 874.0
		46 147.0	46 732.0	1.01	51 536.4	56 437.9	1.10	25 331.6	28 786.6	1.14	
After negotiation	**PPR_{out}**	**PTR_{out}**			**PTR_{out}**			**PTR_{out}**			**TOP_{out}**
	1 672 198.5	46 535.5			52 546.4			26 801.6			1 798 082.0
Difference	**DPP_{out}**	**DPT_{out}**			**DPT_{out}**			**DPT_{out}**			**DTP_{out}**
	0.08%	0.84%			1.96%			5.80%			0.23%

Table 5-42 Transport operator service quality performance of case 7

	Compensation CPP_{out}	Penalty	Early pickup quantity EPQ_{out}	Late pickup quantity LPQ_{out}	Backorders BOP_{out}	Iteration RT
T1	166.5	45	3	0	0	3
T2	2918.2	1010	30	10	1	3
T3	630	100	7	0	0	3

Table 5-43 Producer service quality and convergence performance of case 7

Early supplied quantity ESQ_{out}	Late supplied quantity LSQ_{out}	Backorders to customer BOC_{out}	Total iteration number TIN_{out}
40	10	1	4

Based on the above performance results of 1P-nT negotiation protocol, we can conclude that:

- The results of numerical experiments confirm the principle of 1P-nT negotiation protocol.
- The profits of corresponding partners are improved after negotiation when there are negotiations between them.
- The settings of maximum number of negotiation (i.e. *MaxNego*) can affect the negotiation performance of profits improvements.
- The transport operator whose *MaxNego* has a smaller value will first attain best service pickup plan. If the total iteration number of negotiation process exceeds the value of his *MaxNego*, this transport operator has no profit improvement at the end of negotiation.

- By decreasing the penalty costs, selling price of producer, and transportation prices of transport operators, we can find in some cases in which the negotiation process can converge before any transport operator attain its best service pickup plan, thus the profits of all partners can have significant improvements after the negotiation process.
- The decreasing of penalty costs of transport operators can indeed bring significant profits improvements at the end of negotiation. But its impact is not “the more decrease, the more improvements”.
- The impact of penalty cost decreasing is also limited by the uncertainty of plans convergence.

5.4 Conclusion

This chapter extends the negotiation context to one producer and multiple transport operators. The main changes of production models are presented in 1P-nT split delivery production model and 1P-nT evaluation production model. The main particularity compared with 1P-1T negotiation is the splitting phase. 1-N_SPT model is used to split the whole delivery plan to a set of available transport operators. Transport operators respond to producer’s delivery request by their best service transportation models. In order to well represent their transportation capacity, a plan which consists of accumulated number of in-process trucks at each time period is calculated by transport operators and is sent to producer. The trade-offs in the splitting logic of 1-N_SPT model is validated by several numerical experiments by considering different transportation price, transportation capacity and cooperation cost.

1P-nT negotiation protocol is also presented in this chapter. It is validated by several numerical tests cases. Since complete and exhaustive experiment design concerns many experiment trials by considering all parameters of each partner as mentioned in section 5.3.2, a structured validation experimentation will be considered as perspectives of this work. The results of all tests case show that the profit of the partners which negotiate in the 1-1 negotiation phase will have improvements at the end of negotiation. The setting of penalty costs, transportation prices of transport operator, selling price of producer, and also the settings of maximum number of negotiation (i.e. *MaxNego*) affect the performance of all partners after the negotiation process.

General conclusion

General conclusion

The purpose of this thesis concerns the SC coordination in a decentralized decision making context. One of the starting points of this work is the consideration of SC (Supply Chain) partners performing activities of different nature, i.e. transportation and production. Within this framework, the main scientific issues have been identified as follows:

1. *How to make local decisions*
   Separated analytical models are thus developed to characterize tactical planning decision making processes, in charge of forecasting production and transportation activities execution.
2. *What to negotiate and how to negotiate*
   An efficient coordination protocol has been proposed to coordinate production and transportation decisions, so as to improve individual performances of transport operators, as well as the SC global performance.
3. *How to validate the study*
   A structured analysis, based on the design of experiments (DOE) and test cases, has been performed to assess global and local performance of the SC and identify the limitations of proposed protocol.

Scientific contributions of our work

The main contributions are highlighted hereunder by considering the models, the negotiation protocol and their performance evaluations in two different contexts separately: firstly, the one producer - one transport operator coordination problem (labeled 1P-1T) and secondly the one producer - multiple transport operators coordination context (labeled 1P-nT). Simulation is carried out through an implemented experimental platform which supports the performances measurement of economic (e.g. profit) and service quality (e.g. late deliveries) responses.

Models

Linear programming models for production planning and transportation planning have been proposed in order to simulate the planning activities. The production planning considers production, inventory, and delivery decisions. The transportation planning focuses on pickup quantities and trucks utilization decisions.

The planning models are included in a set of decisions making units, each being representative of a specific partner: they model the highly distributed nature of the decisions context and satisfy the need to guarantee the information privacy for all partners. More precisely, each partner uses a set of planning models covering the basic planning decisions. These models have the main following objectives:

- The feasibility evaluation of a given plan received from another partner,

- The generation of one or more best plans according to a partner's own objectives,
- The generation of a new plan after the previous proposed one was rejected or unfeasible.

Negotiation protocol

The negotiation protocol proposed in this work intends to provide an efficient way to resolve decision conflicts between producer and transport operator and to reach an agreement potentially acceptable by all involved partners. The proposed negotiation protocol is based on four main concepts:

- The *negotiation space, which* defines a range of possible values for profit of each partner.
- The *compensation, which can be interpreted as* an incentive mechanism used by the transport operator to persuade the producer to accept a pickup plan. This plan represents a good compromise between the profit maximization and the service quality maximization of transport operator. If the producer accepts the deal, he receives a compensation which is a part of potential gain of the transport operator.
- The plans *acceptance criterion* which proposes a general mechanism in order to decide if negotiation can lead to a sufficient profit increase, and if a planning solution can be estimated as acceptable for a SC partner or not.
- The *release degree* that allows defining the lower profit bound that each partner can expect at each step of negotiation.

(1P-1T) context

Within this background, contracting with only one transport operator is the critical point of the supply chain. It can represent the situation where the transport operator has a dominant position in relation with producer. This situation which is not frequently encountered in the real world, could appear for instance when the transportation concerns products with specific characteristics and requires scarce transportation resources which are limited in the market. It is an academic context which is a prerequisite for more complex studies.

Some experiments are carried out using Taguchi design of experiments in order to perform structured experimentation. These experiments make it possible to identify the main parameters influencing the local and global performances of the SC. Thus, it is worth to notice that, in most cases, the transport operator's profit can be increased, without affecting the producer's profit. The win-win negotiation is attained even if the gain is rather small in some cases. Lets us notice that these gains are reasonable in the field of transportation where the profit margins are generally low. Moreover, the profit of transport operator is always improved much more than the profit of producer, which is consistent with the main idea behind this research which aims to give some cooperation flexibility to the transport operator.

Concerning the negotiation protocol itself, these experiments validate the developed approach and make it possible to better understand the role of each parameter. We have observed that two parameters have a direct impact on the results of negotiation: the compensation percentage and also the maximum number of negotiation. At the meanwhile, the acceptance criterion parameter which does not affect the resulting plans in the negotiation process, may be used as an interesting control element to avoid strong time consuming negotiation.

(1P-nT) context

Concerning this more complex coordination context, as there are multiple transport operators, producer is considered that he can procure sufficient transportation capacity to perform deliveries to his customers. It can represent the situation where the producer has a dominant position in relation with transport operators, and can decide to work with as many as transport operators as needed to serve the whole customers' demand.

The performance evaluation of this protocol makes it possible to validate its main principles which can be seen as an extension of the (1P-1T) protocol; indeed, it includes an additional splitting phase in order to allocate the whole delivery plan among many transport operators. This experimentation also illustrates some performance aspects of the (1P-1T) negotiation protocol. It shows that the essence of the protocol is to find the trade-off between cooperating with fewer transport operators and important leveling (i.e. transportation quantities pickup in advance or late) or, cooperating with more transport operators but with more significant cooperation cost and less leveling penalties. The profits of both partners and also the total profit are always increased after negotiation, even if the variation is not very significant.

In conclusion, the study carried out in this thesis shows that the negotiation-based coordination approach which is proposed can improve the SC performance in terms of economic aspect (i.e. profit).

Limitations of our work

The above conclusions can be restricted to hypotheses that define the context of this study. Thus, the main limitations of our work considering successively the experimentation, the planning and finally the optimization issues are described below.

The experimentation carried out in the thesis remains limited. In the (1P-1T) context, some negotiation related parameters of the producer are fixed in the evaluation experiments. This choice is motivated by the importance that we intend to give to the transport operator in the negotiation protocol, in such a way to avoid the observation of an impact on negotiation which only results from producer. In the (1P-nT) case, experimentation were oriented toward the validation of the protocol and the models, without achieving a complete and exhaustive experiment design covering all the negotiation and all the partners characteristics of the problem. This choice is justified by the complexity of the experiment design that should have been developed.

The definitions of planning horizon/period are the same for both producer and transport operator. Thus, inconsistency problem of horizon/period is not considered in this study. The information is exchanged between producer and transport operator instantaneously, ignoring the information delay which is not considered in this study. These evaluation experiments are carried out on a non-sliding planning horizon and the customer demand is considered to be known all over the planning horizon. These restrictions are far from real world planning situations and limit the range of our conclusions.

On the optimization point of view, the implemented optimization models are limited, due to the use of exact linear programming optimization methods. These methods are very useful for specifying the planning models but their solving capacity are limited to the problems of very high computational complexity.

Perspectives

Considering the previous limitations some main perspectives can be discussed.

A complete and exhaustive experiment design for the performances evaluation in the 1P-nT context needs to be considered in order to analyze the complex impact of parameters involved in the negotiation protocol.

Considering the SC structure, the cases of multiple producers in relation with one transport operator (nP-1T) and multiple producers in relation multiple transport operators (nP-nT) relations are two interesting extended contexts to be studied. In the (nP-1T) case, transport operator should allocate his shared capacity to different producers. Decisions of multiple pickups at different producer's locations and multiple deliveries to the different destinations may be considered. In the more complex context (nP-nT), a decomposition principle could be considered to transform the initial (nP-nT) problem to (1P-nT) problems or (nP-1T) problems.

The potential inconsistent planning horizons between partners and the planning complexity inherently induced by the coordination context can be studied as well. Technical data aggregation and disaggregation over the time or over the available resources could be considered in order to coordinate the partners at a higher decision level. As regards the concerned planning, it would be also necessary to extend our approach to sliding planning horizon which is commonly used in industrial practices.

In order to tackle real world problems made up of many partners, the use of approximate optimization methods should be investigated in order to overcome the limitations of the linear programming solvers. The use of efficient heuristics or metaheuristics such as evolutionary algorithm, particle swarm optimization is a promising perspective.

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Appendices

Appendix I: Parameters of production and transportation models

Table a. 1 Parameters of production model in 1P-1T evaluation experiments

	Maximum Quantity of Early Supplied Quantity (unit)		Unitary Required Resource (unit)	Unitary Scalar of Product p (ton)	Unitary Mean Production Cost (euro)	Production Lead time (Day)
	$Emax_{p,j}$		u_p	v_p	CP_p	DP_p
	Customer 1	Customer 2				
Product 1	4	4	1	5	70	1
Product 2	4	4	2	8	90	1

Table a. 2 Parameters of transportation model in 1P-1T evaluation experiments (part 1)

	Transportation Lead Time (day)	Round Trip Transportation time (day)	Transportation Price (euro/ ton)
	DT_j	D_j	TP_j
Customer 1	1	2	12
Customer 2	1	3	10

Table a. 3 Parameters of transportation model in 1P-1T evaluation experiments (part 2)

Handling Cost (euro)		Load Capacity of a truck (ton)
VC_p		Cap
Product 1	Product 2	
2	3	100

Table a. 4 Parameters of producer negotiation factors

Release parameter (%)	Lower bound parameter (%)
pp_release	R_G
1%	99%

Appendix II: Effects of factors of preliminary experiment

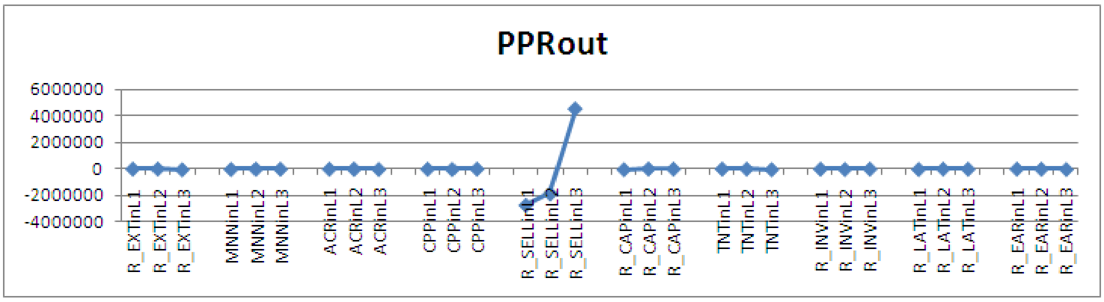

Figure a. 1 Effects of factors on profit of producer

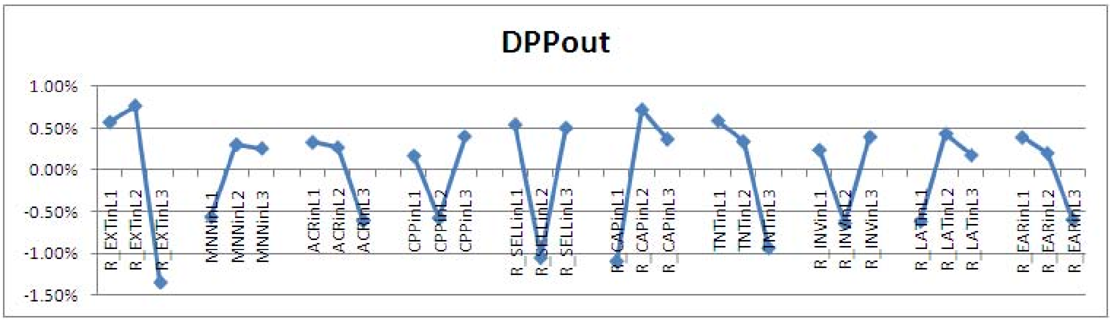

Figure a. 2 Effects of factors on difference of profit of producer

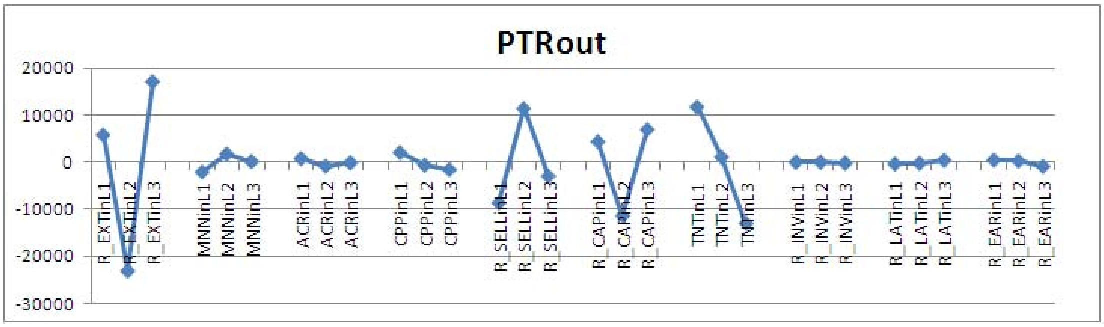

Figure a. 3 Effects of factors on profit of transport operator

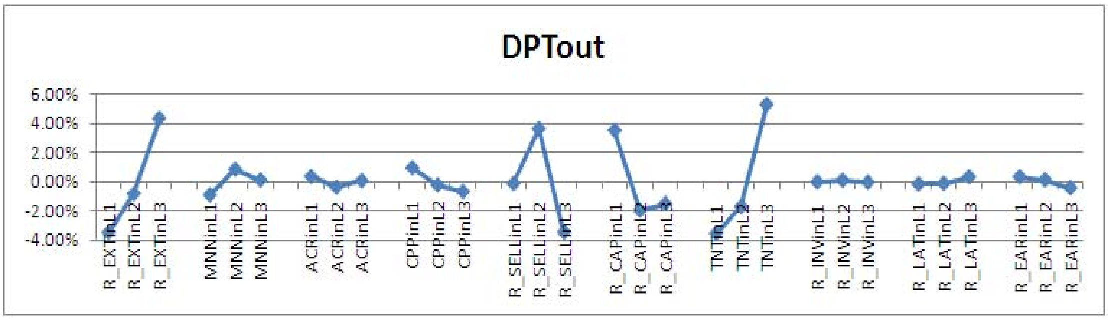

Figure a. 4 Effects of factors on difference of profit of transport operator

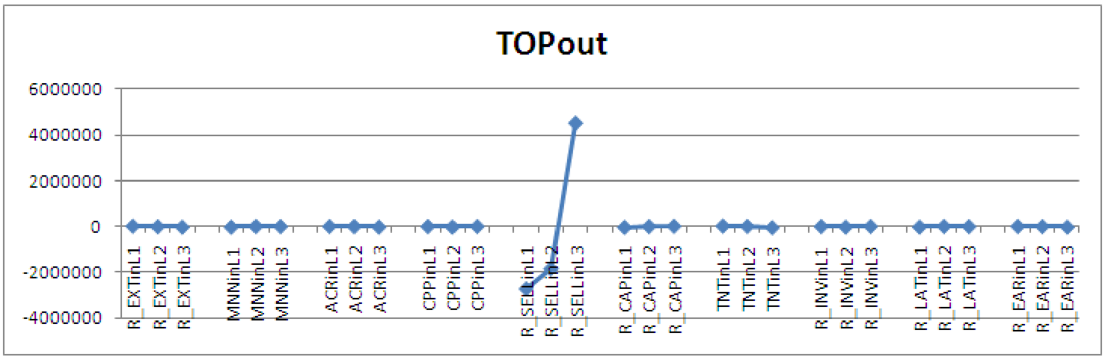

Figure a. 5 Effects of factors on total profit

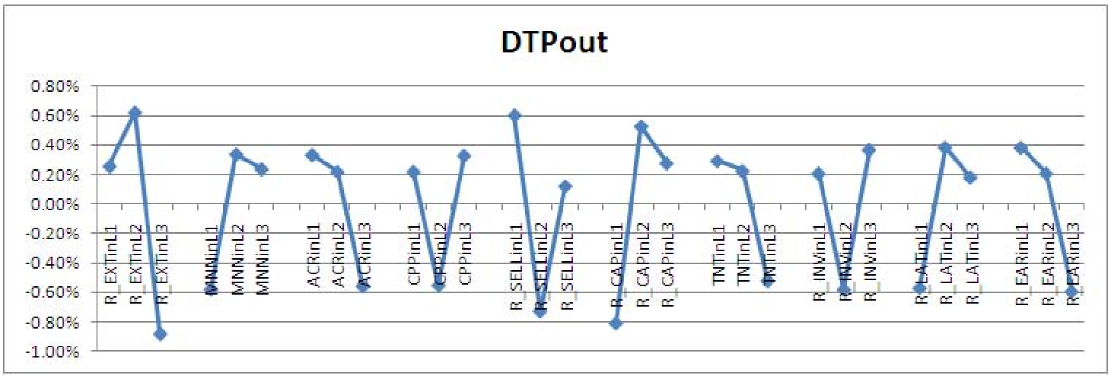

Figure a. 6 Effects of factors on difference of total profit

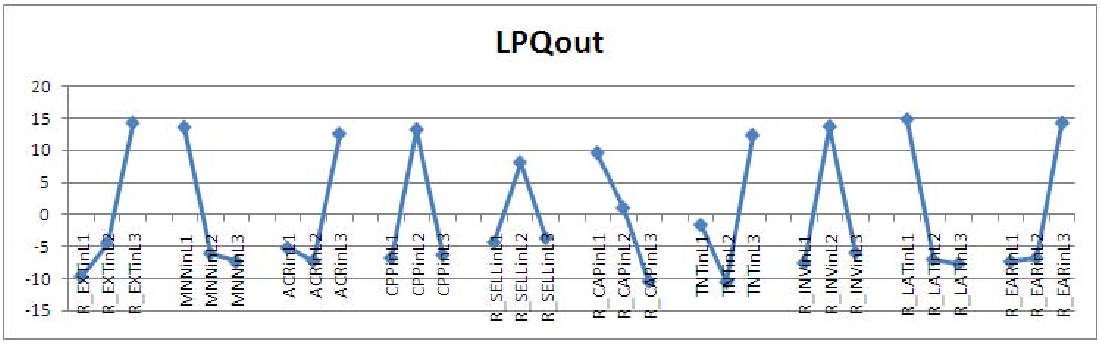

Figure a. 7 Effects of factors on accumulated late pickup quantity

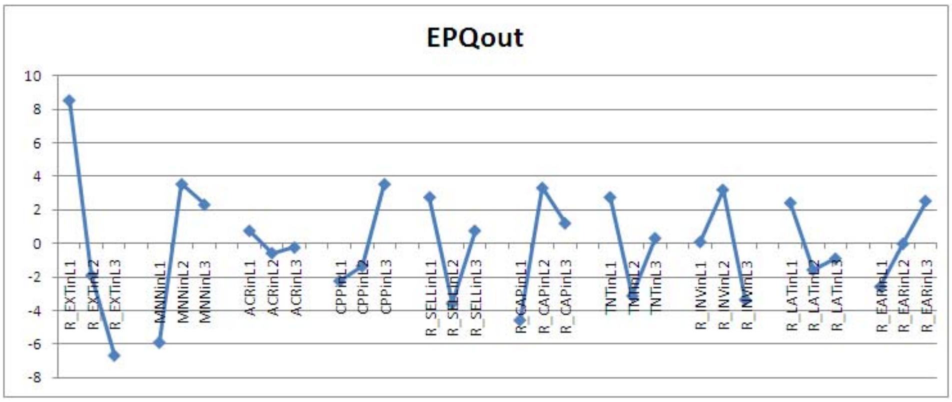

Figure a. 8 Effects of factors on accumulated early pickup quantity

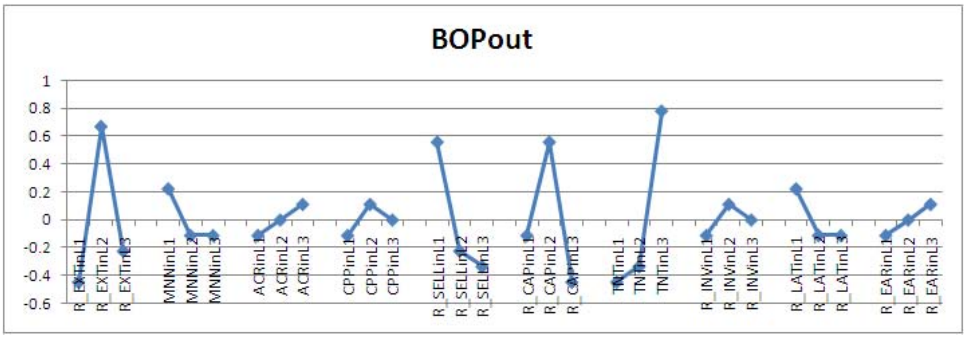

Figure a. 9 Effects of factors on backorders to producer

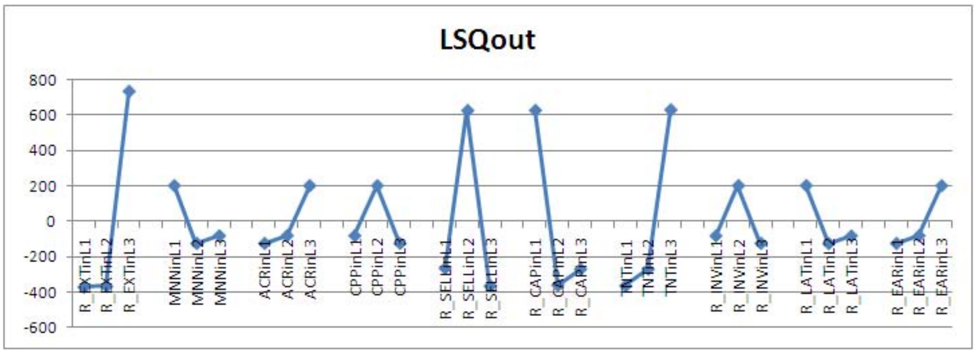

Figure a. 10 Effects of factors on accumulated late supplied quantity

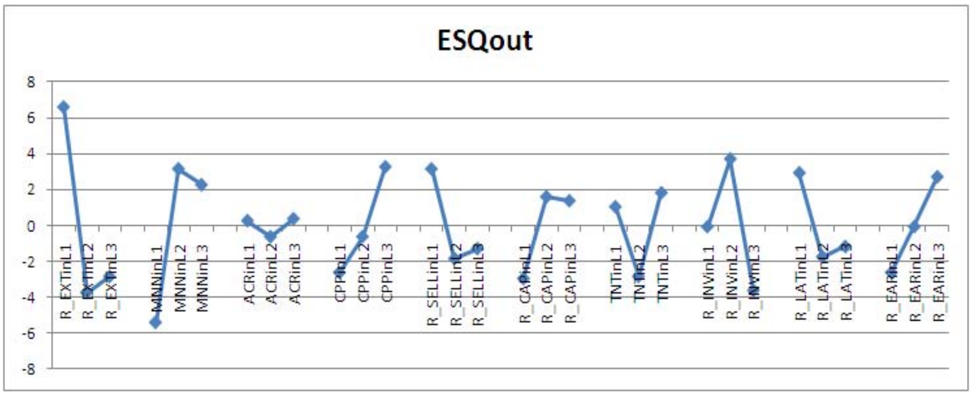

Figure a. 11 Effects of factors on accumulated early supplied quantity

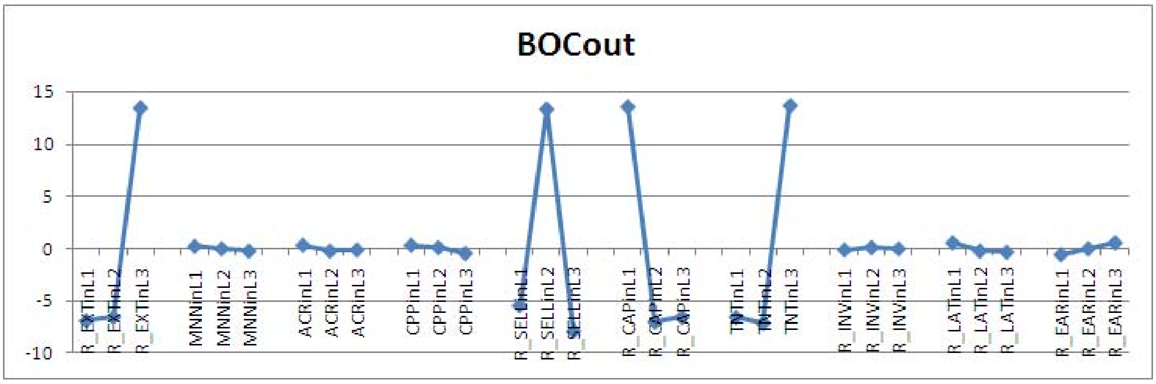

Figure a. 12 Effects of factors on backorders to customer

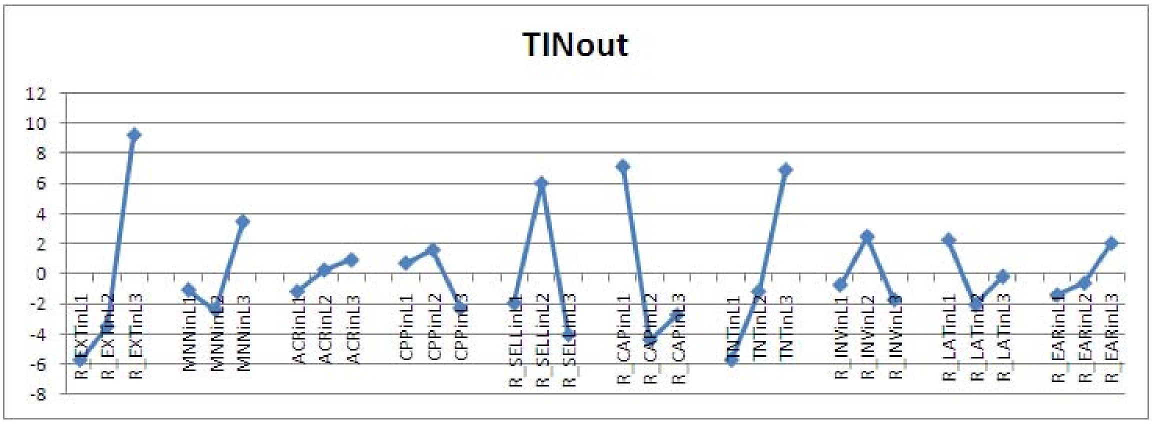

Figure a. 13 Effects of factors on total iteration number

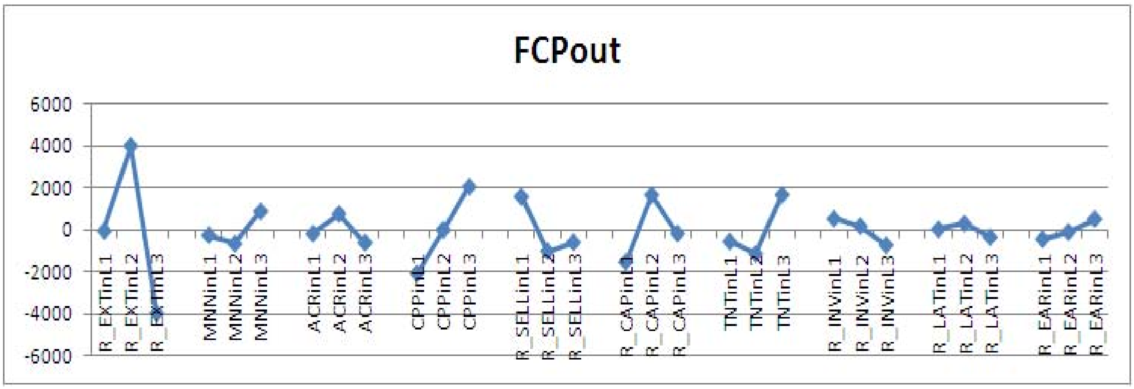

Figure a. 14 Effects of factors on final compensation

Appendix III: Effects of factors of interaction experiment

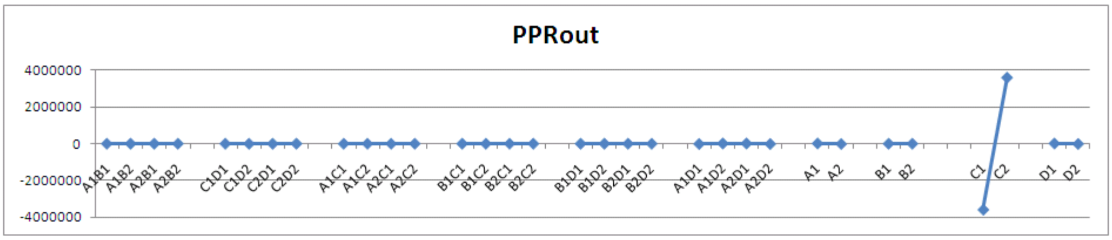

Figure a. 15 Effects of interactions on profit of producer

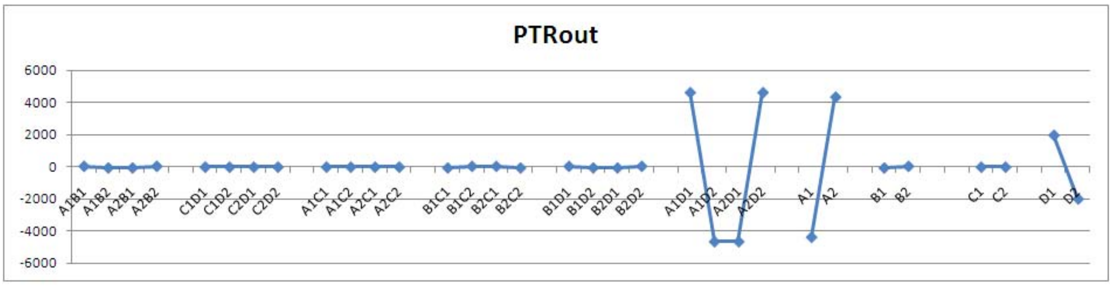

Figure a. 16 Effects of interactions on profit of transport operator

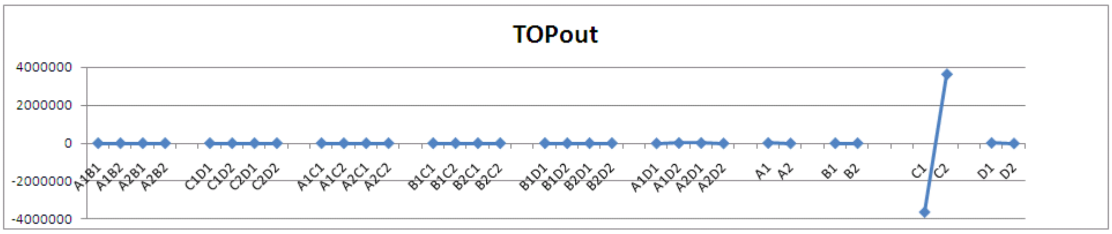

Figure a. 17 Effects of interactions on total profit

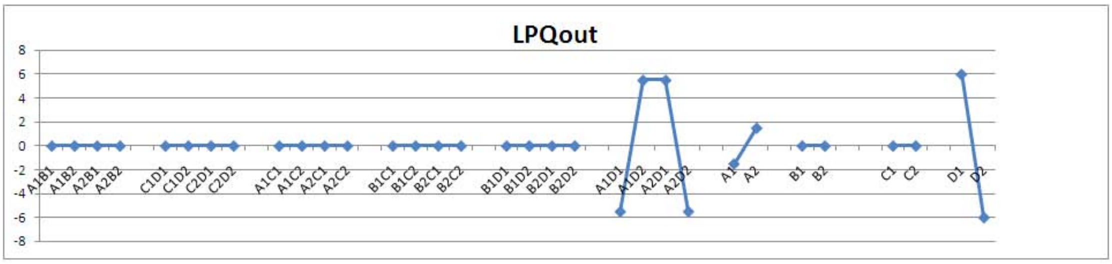

Figure a. 18 Effects of interactions on accumulated late pickup quantity

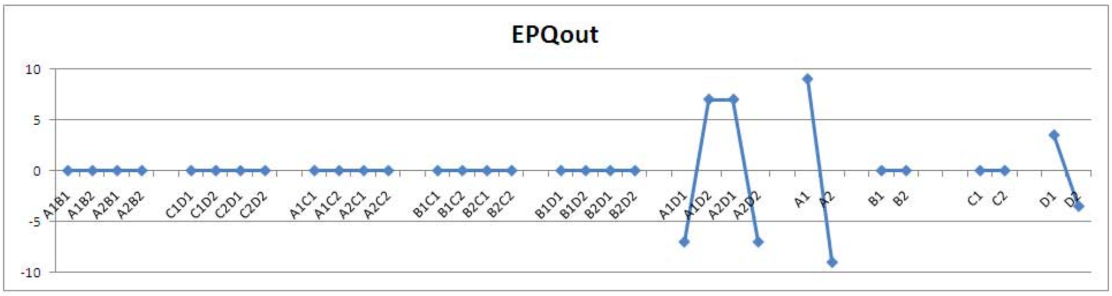

Figure a. 19 Effects of interactions on accumulated early pickup quantity

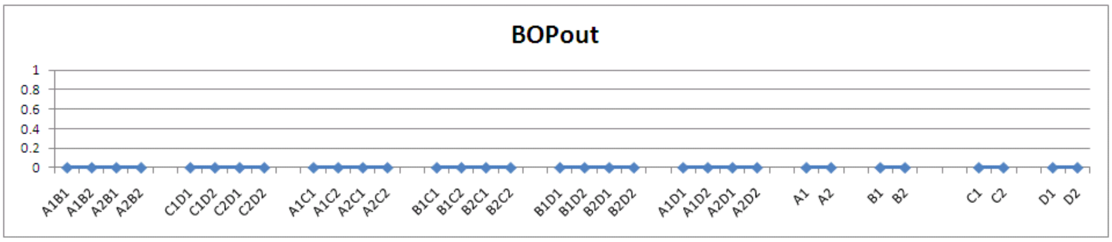

Figure a. 20 Effects of interactions on backorders to producer

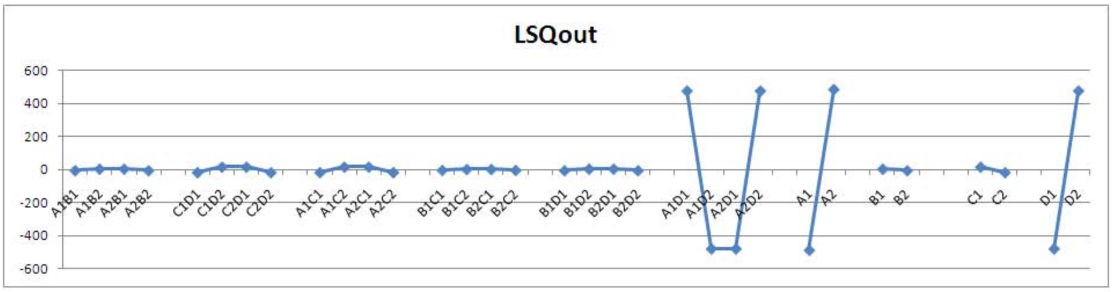

Figure a. 21 Effects of interactions on accumulated late supplied quantity

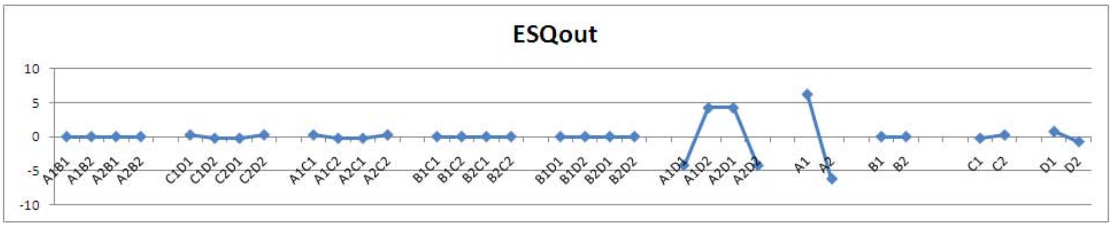

Figure a. 22 Effects of interactions on accumulated early supplied quantity

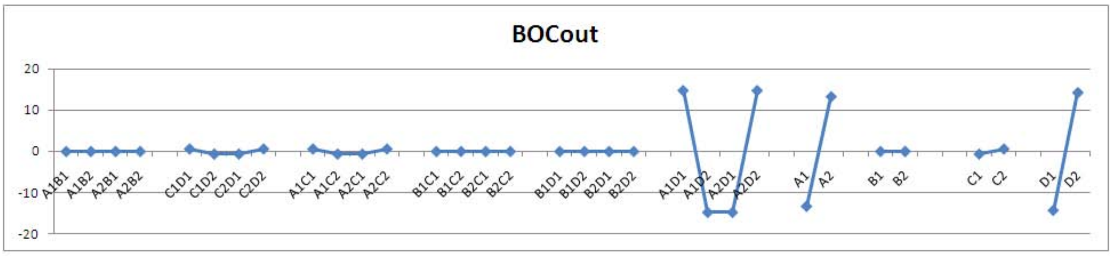

Figure a. 23 Effects of interactions on backorders to customer

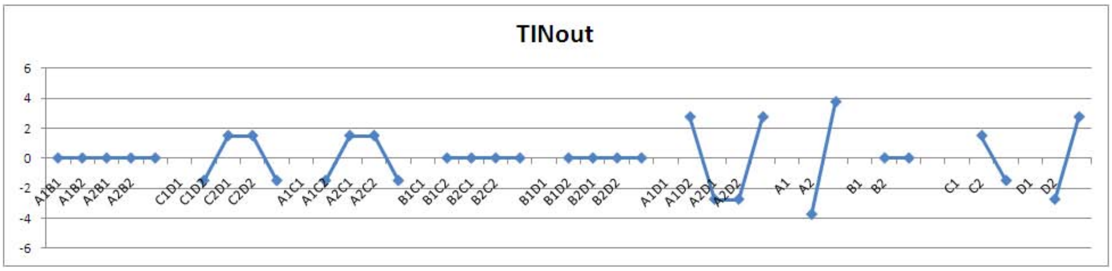

Figure a. 24 Effects of interactions on total iteration number

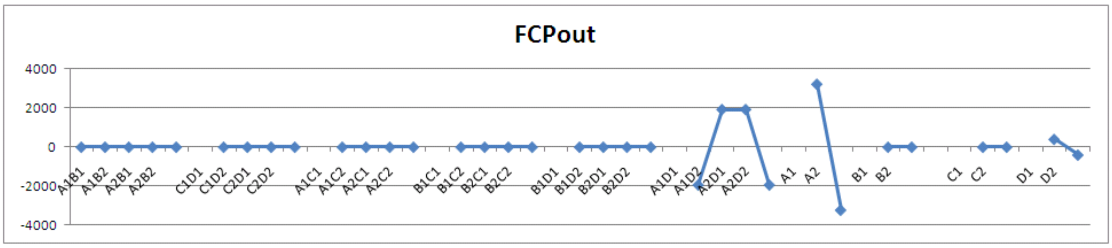

Figure a. 25 Effects of interaction on final compensation

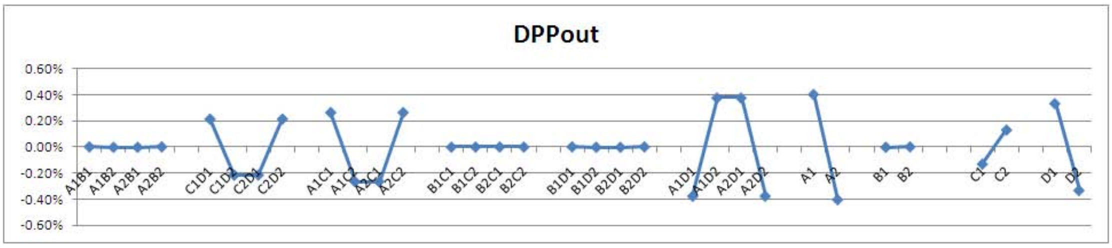

Figure a. 26 Effects of interaction on difference of profit of producer

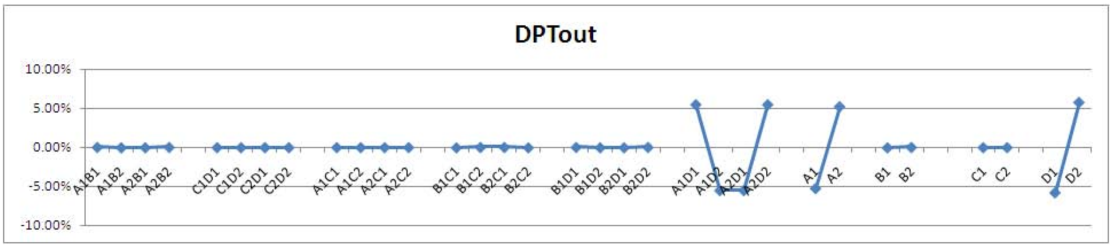

Figure a. 27 Effects of interaction on difference of profit of transport operator

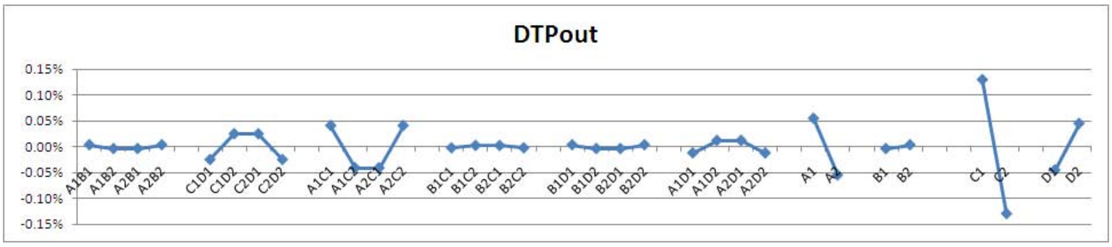

Figure a. 28 Effects of interaction on difference of total profit

Appendix IV: Effects of factors of negotiation factors experiment

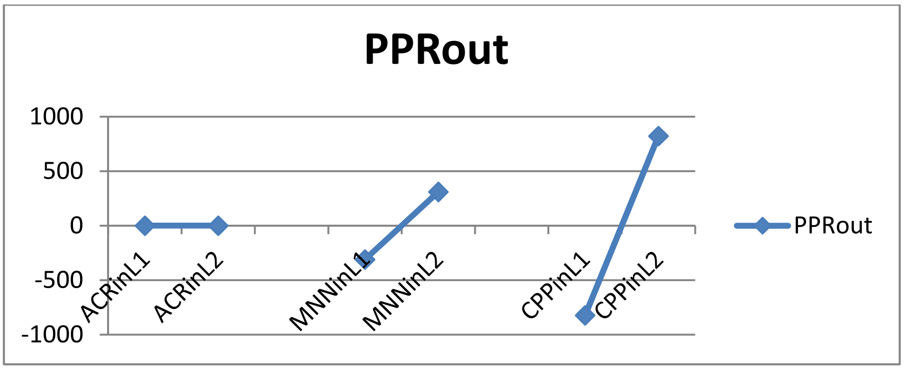

Figure a. 29 Effects of negotiation factors on profit of producer

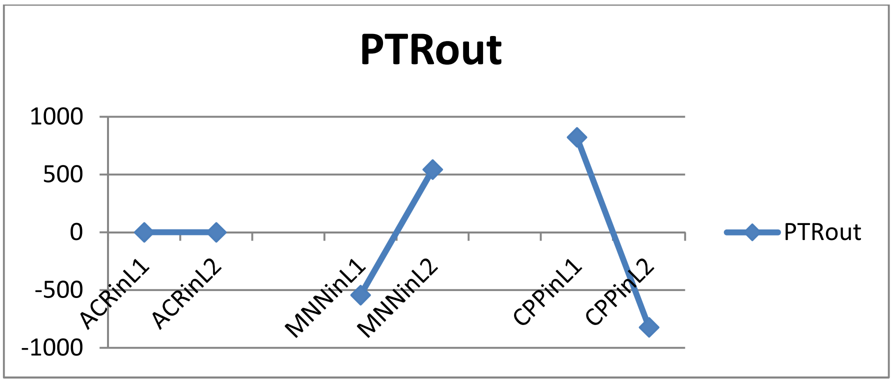

Figure a. 30 Effects of negotiation factors on profit of transport operator

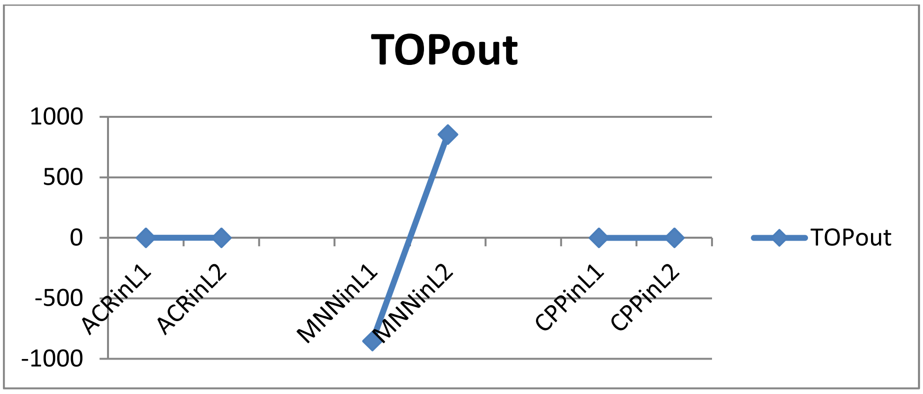

Figure a. 31 Effects of negotiation factors on total profit

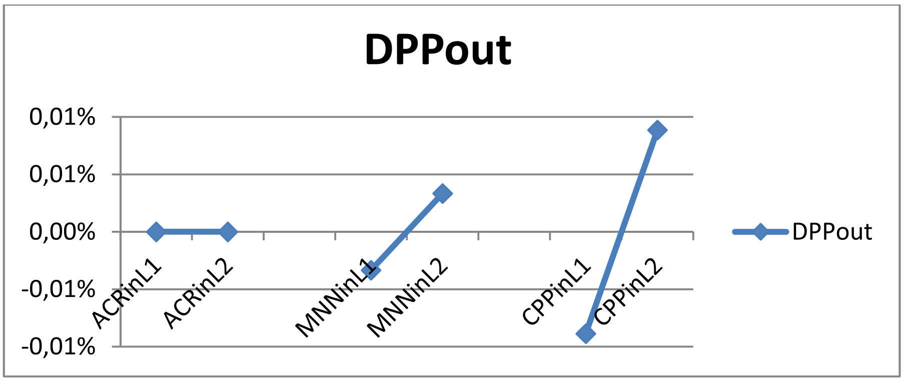

Figure a. 32 Effects of negotiation factors on difference of profit of producer

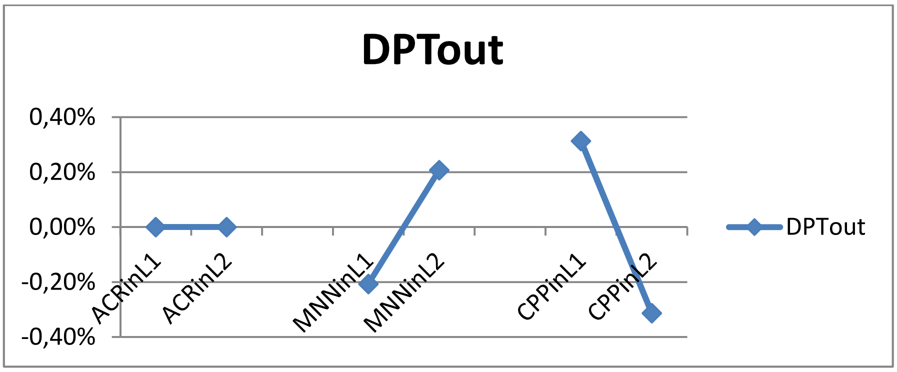

Figure a. 33 Effects of negotiation factors on difference of profit of transport operator

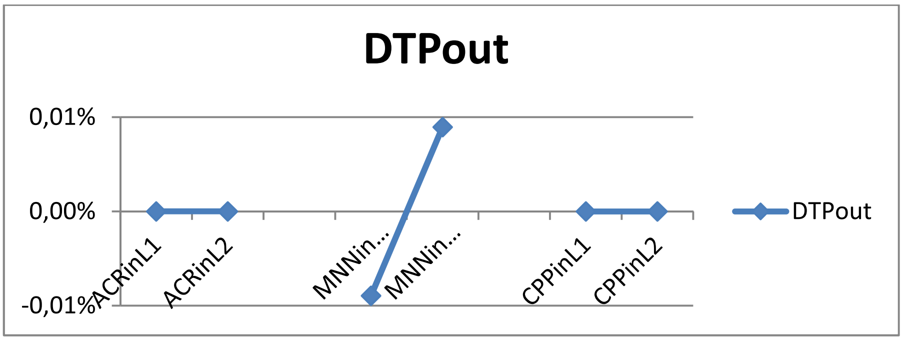

Figure a. 34 Effects of negotiation factors on difference of total profit

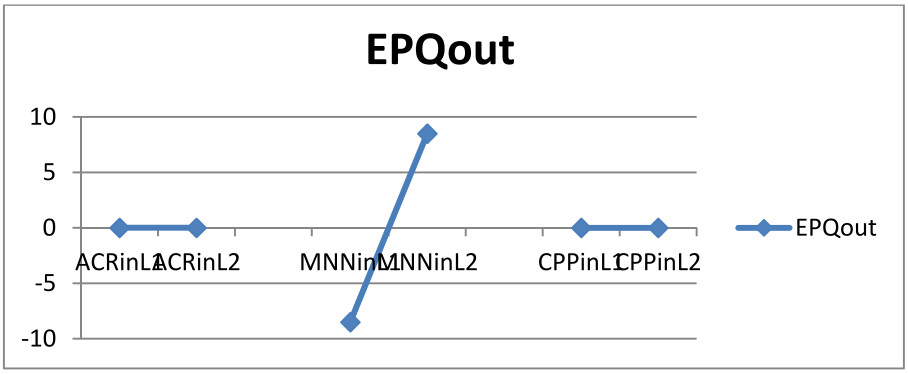

Figure a. 35 Effects of negotiation factors on accumulated early pickup quantity

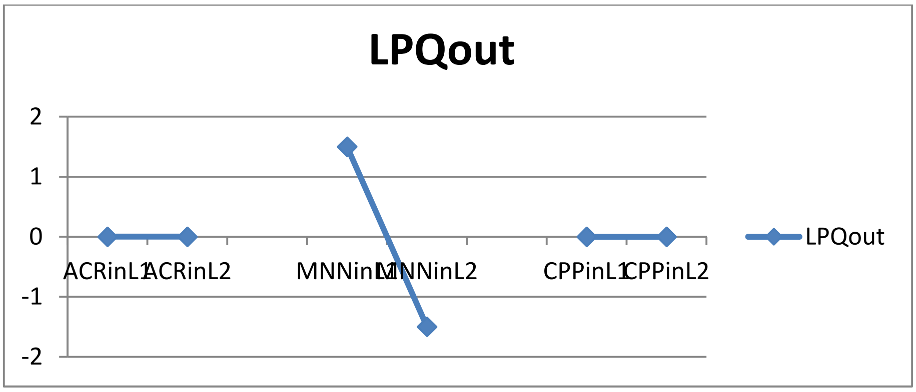

Figure a. 36 Effects of negotiation factors on accumulated late pickup quantity

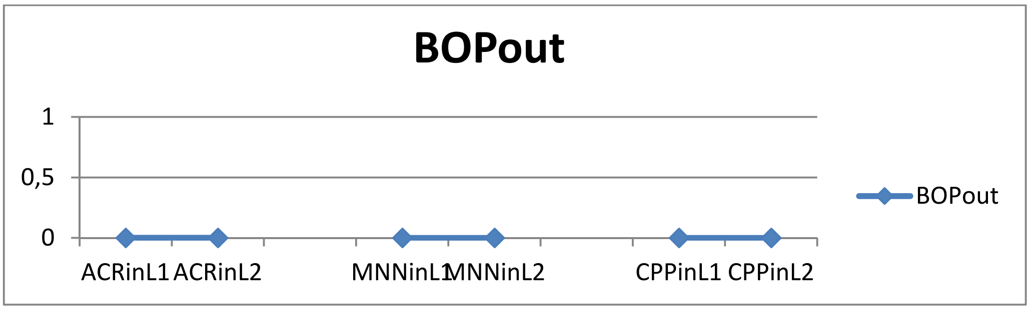

Figure a. 37 Effects of negotiation factors on backorder to producer

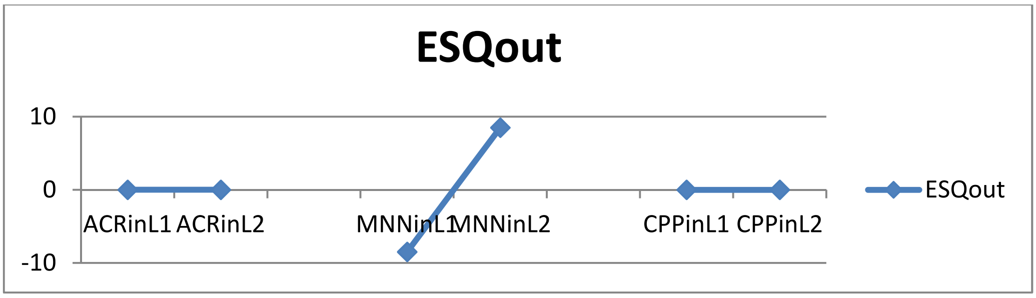

Figure a. 38 Effects of negotiation factors on accumulated early supplied quantity

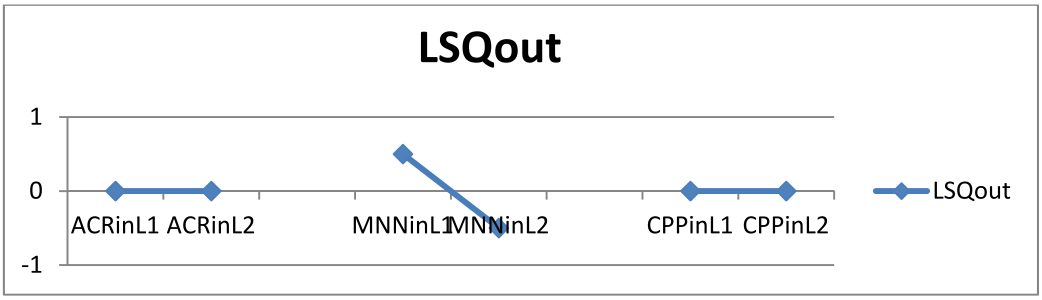

Figure a. 39 Effects of negotiation factors on accumulated late supplied quantity

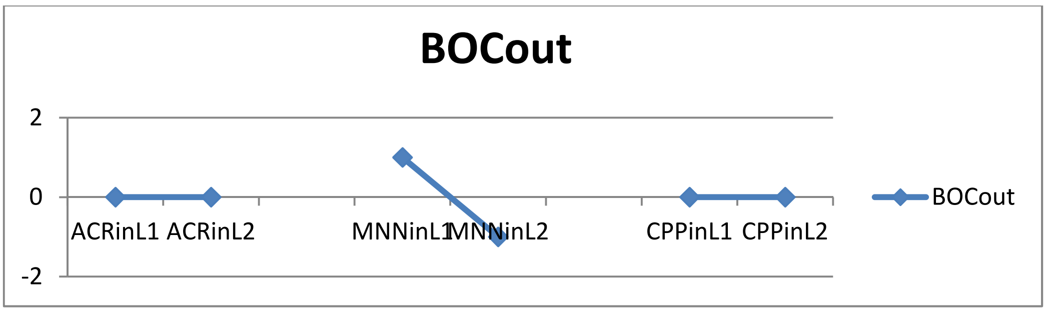

Figure a. 40 Effects of negotiation factors on backorder to customer

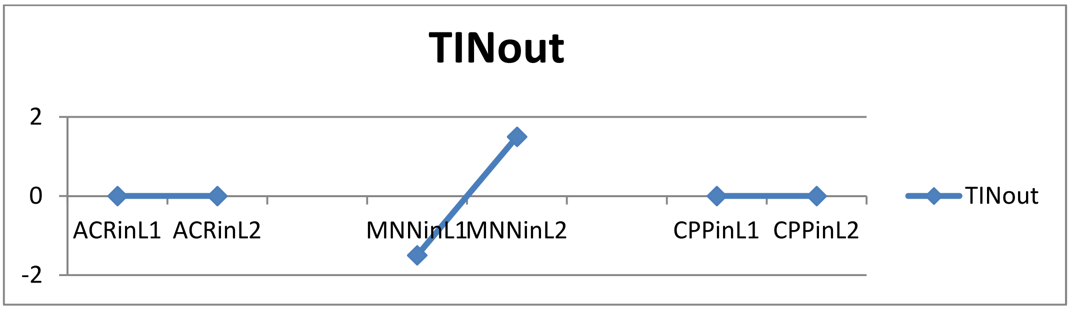

Figure a. 41 Effects of negotiation factors on total iteration number

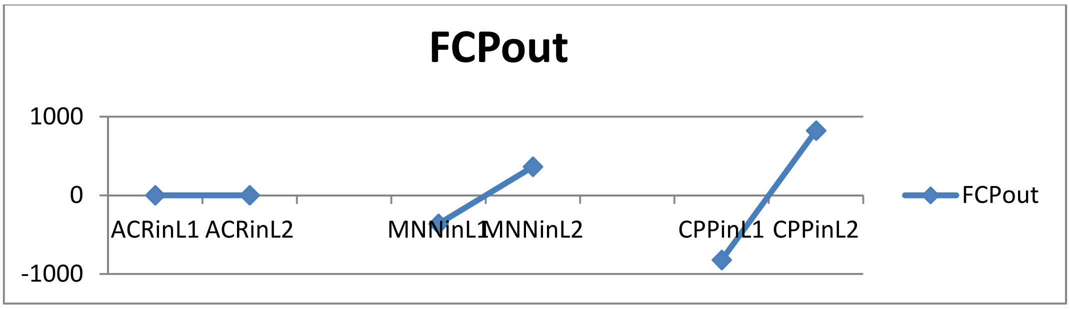

Figure a. 42 Effects of negotiation factors on final compensation

Appendix V: Linear graph of experimental array

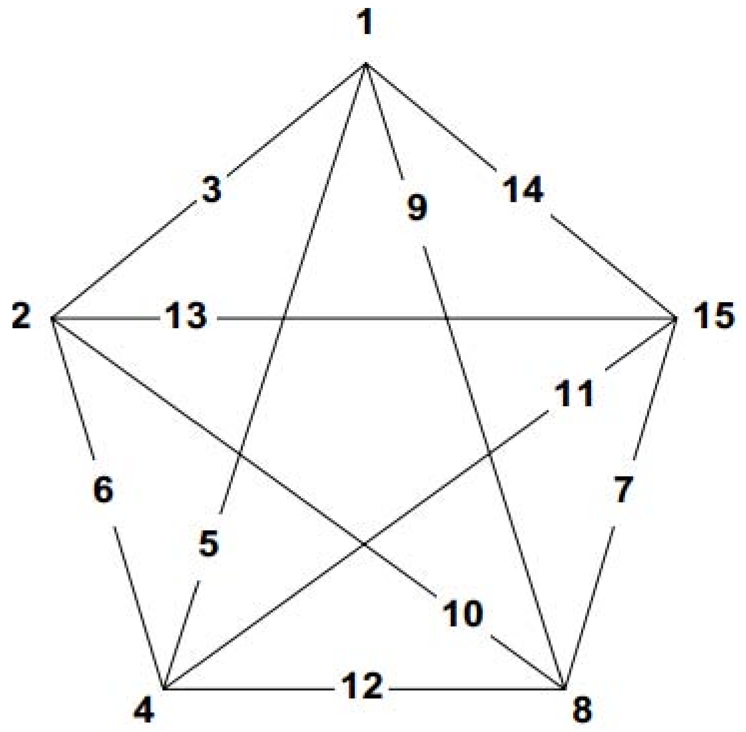

Figure a. 43 Linear graph of L_{16}

Appendix VI: Parameters for validation of 1-N_SPT model

Table a. 5 Parameters of production model in 1-N_SPT model validation experiments

Producer	**Selling Price (euro)**		**Maximum Quantity of Early Supplied Quantity (unit)**		**Unitary Required Resource (unit)**	**Unitary Scalar of Product p (ton)**	**Unitary Mean Production Cost (euro)**	**Production Lead time (Day)**	**Unitary Mean Inventory Cost**
	$SP_{p,j}$		**$Emax_{p,j}$**		**u_p**	**v_p**	**CP_p**	**DP_p**	**CSp**
	Customer 1	Customer 2	Customer 1	Customer 2					
Product 1	270	270	4	4	1	5	70	1	11.25
Product 2	360	360	4	4	2	8	90	1	16.25

Table a. 6 Parameters of transportation model in 1-N_SPT model validation experiments (part 1)

T1/T2	**Late Pickup Penalty Cost (euro)**		**Early Pickup Penalty Cost (euro)**		**Handling Cost (euro)**
	$BC_{p,j}$		**$EC_{p,j}$**		**VC_p**
	Customer 1	Customer 2	Customer 1	Customer 2	
Product 1	40	45	20	25	2
Product 2	50	55	30	35	3
T3	**Late Pickup Penalty Cost (euro)**		**Early Pickup Penalty Cost (euro)**		**Handling Cost (euro)**
	$BC_{p,j}$		**$EC_{p,j}$**		**VC_p**
	Customer 1	Customer 2	Customer 1	Customer 2	
Product 1	80	90	5	6.25	2
Product 2	100	110	7.5	8.75	3

Table a. 7 Parameters of transportation model in 1-N_SPT model validation experiments (part 2)

T1/T2/T3	**Destination related Transportation Cost (euro/ truck)**	**Transportation Lead Time (day)**	**Round trip time (day)**	**Minimum Load (ton)**	**Load Capacity of a truck (ton)**
	FC_j	**DT_j**	**D_j**	**minLoadj,n**	**Cap**
Customer 1	600	1	2	100	100
Customer 2	800	1	3	100	

Appendix VII: Analysis of scenarios

Validation of scenario 1-1:

Scenario analysis:

It is favorable for producer to work with the transport operator which has lower transportation price. In this scenario, the transport operator with the lowest transportation price has only 50 trucks that are significantly insufficient compared with the requirement of delivery quantities (i.e. 117 trucks in the period of peak demand). Thus, producer has to make a trade-off between working with two transport operators (T1 and T2) with lower transportation prices but more cooperation cost, or working with one transport operator (T3) with less cooperation cost but higher transportation price. Consequently the indentified possible solutions are either working with T1 and T2 together or working with T3 alone.

Estimated cost of each solution:

The transportation fees of working with each transport operator are evaluated supposing he can complete all the delivery quantities alone.

Transport operators	Transportation fee= $\sum_j TP_j * AL_j$
T1	8*36 895+10*44 694=742 100
T2	10*36 895+12*44 694=905 278
T3	20*36 895+22*44 694=1 721 168

The cost of working with T1 and T2, labeled "T1&T2", is considered as the average transportation fee of these two transport operators plus the operation costs see (Table 5-3) calculated as below:

T1&T2 = (742 100+905 278)/2+100 000+100 000 =1 023 689.

Similarly, the cost of working with T3 alone, calculated as:

T3=1 721 168 +100000 which is 1 821 168.

Comparison of estimated costs:

Solutions options	Estimated cost	Decision
T1+T2	1 023 689	√
T3	1 821 168	

The comparison result shows that working with T1 and T2 will cost less for producer. "√" denotes the favorable solution for producer.

Expected result:

Based on the analysis, the expected result of model is to split delivery quantities to T1 and T2.

Splitting result of 1-N_SPT model:

T1 and T2 are chosen to make the transportation.

Analysis of scenario 1-2:

Scenario analysis:

Similar to scenario 1-1, producer has to make a trade-off between working with two transport operators (T1 and T2) with lower transportation price but more cooperation cost or working with one transport operator (T3) with less cooperation cost but higher transportation price. Consequently, the indentified possible solutions are working with T1 and T2 together or working with T3 alone.

Estimated cost of each solution:

We calculate the transportation fee of working with each transport operator supposing it can complete all the delivery quantities alone.

Transport operators	Transportation fee= $\sum_j TP_j * AL_j$
T1	8*36 895+10*44 694=742 100
T2	10*36 895+12*44 694=905 278
T3	10*36 895+12*44 694=905 278

The cost of working with T1 and T2 together, labeled "T1&T2", is considered as the average transportation fee of the two transport operators plus the fix operation costs calculated as below:

T1&T2 = (742 100+905 278)/2+100 000+100 000 = 1 023 689.

Similarly, the cost of working with T3 alone, calculated as:

T3= 905 278 +100 000 which is 1 005 278.

Comparison of estimated costs:

Solutions options	Cost	Choice
T1+T2	1 023 689	
T3	1 005 278	√

The comparison result shows that the favorable solution for producer is working with T3 alone.

Expected result:

It is more interesting to work with T3 alone instead of working with T1 and T2.

Splitting result of 1-N_SPT model:

All delivery quantities are assigned to T3.

Analysis of scenario 2-2:

Scenario analysis:

Producer prefers the transport operator with cheapest transportation price (i.e. T1). However, its transportation capacity is not sufficient compared with delivery quantities. In order to satisfy customer demands, producer has to work with two transport operators T1 and T2 or T1 and T3.

Estimated cost of each solution:

Following the same principle of calculation,

Transport operators	Transportation fee= $\sum_j TP_j * AL_j$
T1	8*36 895+10*44 694=742 100
T2	10*36 895+12*44 694=905 278
T3	20*36 895+24*44 694=1 810 556

The cost of working with T1 and T2, labeled “T1&T2”, is considered as the average transportation fee of the two transport operators plus the fix operation costs plus the penalty costs.

T1 and T2 have totally 115 trucks. As calculated in scenario 2-1, the estimated penalty cost producer should pay to customer is 24 000. Thus the cost of working with T1 and T2 together is calculated as:

T1&T2 = (742 100+905 278)/2+400 000+400 000 + 24 000 = 1 647 689.

The cost of working with T1 and T3, labeled “T1&T3”, is considered as the average transportation fee of the two transport operators plus the fix operation costs calculated as below:

T1&T3 = (742 100+1 810 556)/2+400 000+400 000 =2 076 328

Comparison of estimated costs:

Solutions options	Transportation cost	Choice
T1+T2	1 647 689	√
T1+T3	2 076 328	

The comparison result shows that the favorable solution is to work with T1 and T2 together.

Expected result:

Producer assigns delivery quantities to T1 and T2.

Splitting result of 1-N_SPT model:

T1 and T2 are chosen to make the transportation. T3 is not chosen.

Analysis of scenario 2-3:

Scenario analysis:

In order to satisfy customer demand, producer may work with T1 and T3 together. This solution should be compared with other two solutions. T1 and T2 have lower transportation prices. If working with T1 and T2, producer will pay less transportation fee but should pay penalty for not on time deliveries. If working with T3 alone, producer will take less cooperation cost but should also pay penalty for not on time deliveries.

Estimated cost of each solution:

Following the same principle of calculation,

Transport operators	Transportation fee= $\sum_j TP_j * AL_j$
T1	8*36 895+10*44 694=742 100
T2	10*36 895+12*44 694=905 278
T3	12*36 895+14*44 694=1 068 456

The cost of working with T1 and T2, labeled "T1&T2", is considered as the average transportation fee of the two transport operators plus the fix operation costs plus the penalty costs.

T1 and T2 have totally 100 trucks. The transportation capacity gap is 17 trucks in period of peak demand. Each truck can transport a maximum number of 20 units of product 1 or 12 units of product 2 as mentioned in scenario 2-1. Therefore, by considering the maximum value between 20 and 12, for a period of demand peak, the estimated late or early delivery quantities of these 17 trucks are 340 units of product and 340*20=6 800 for the planning horizon of 20 periods. The average unitary late and early supplied penalty cost is 30. Thus the estimated penalty cost is 30*6 800=204 000. Thus the estimated cost of working with T1 and T2 together is calculated calculated as below:

T1&T2 = (742 100+905 278)/2+400 000+400 000 + 204 000 = 1 827 689

The cost of working with T3 alone, calculated as 1 068 456+400 000 which is 1 468 456. There would be penalty cost of working with T3 alone. The transportation capacity gap is 27 trucks in period of peak demand. Each truck can transport maximum 20 units of product 1 or 12 units of product 2. Therefore, by considering the maximum value between 20 and 12, for a period of demand peak, the estimated late or early delivery quantities of 27 trucks are 540 units of product and 540*20=10 800 for the planning horizon of 20 periods. The average unitary late and early supplied penalty cost is 30. Thus the estimated penalty cost is 30*10 800=324 000. Thus the estimated cost of working with T3 alone calculated as

T3 = 1 468 456+324 000 = 1 792 456.

The cost of working with T1 and T3, labeled "T1&T3", is considered as the average transportation fee of the two transport operators plus the fix operation costs calculated as below:

T1&T3 = (742 100+1 068 456)/2+400 000+400 000 = 1 705 278

Comparison of estimated costs:

Solutions options	Transportation cost	Choice
T1+T2	1 827 689	
T3	1 792 456	
T1+T3	1 705 278	√

The comparison result shows that working with T1 and T3 is the best solution.

Expected result:

Producer assigns load to T1 and T3.

Splitting result of 1-N_SPT model:

T1 and T3 are chosen to make the transportation.

Analysis of scenario 2-4:

Scenario analysis:

Intuitively it is not a considerable solution working with the two transportation operators T1 and T2 who have the cheapest transportation prices, because the transportation capacity is significantly insufficient compared with the requirement of delivery quantities.

The possible solutions are working with T1 and T3 or T3 alone.

Estimated cost of each solution:

Following the same principle of calculation,

Transport operators	Transportation fee= $\sum_j TP_j * AL_j$
T1	8*36 895+10*44 694=742 100
T2	10*36 895+12*44 694=905 278
T3	20*36 895+24*44 694=1 810 556

The cost of working with T1 and T3, labeled “T1&T3”, is considered as the average transportation fee of the two transport operators plus the fix operation costs calculated as below:

T1&T3 = (742 100+1 810 556)/2+100 000+100 000=1 476 328

The cost of working with T1 T2 and T3 together, labeled “T1&T2&T3” is calculated as the average transportation fee of the three transport operators plus the fix operation costs calculated as

“T1&T2&T3”=(742 100+905 278+1 810 556)/3+3*100 000= 1 452 645

Comparison of estimated costs:

Solutions options	Transportation cost	Choice
T1+T3	1 476 328	
T1+T2+T3	1 452 645	√

The comparison result shows that the best solution is to work all the three transport operators.

Expected result:

Producer assigns delivery quantities to T1, T2 and T3.

Splitting result of 1-N_SPT model:

T1, T2 and T3 are chosen. Producer makes full use of transportation capacity of T1 and T2.

Analysis of scenario 3-1:

Scenario analysis:

In this scenario the possible solutions are working with T1 and T2 or working with all the three transportation operators.

Estimated cost of each solution:

Following the same principle of calculation,

Transport operators	Transportation fee= $\sum_j TP_j * AL_j$
T1	8*36 895+10*44 694=742 100
T2	10*36 895+12*44 694=905 278
T3	12*36 895+14*44 694=1 068 456

The cost of working with T1 and T2, labeled “T1&T2”, is considered as the average transportation fee of the two transport operators plus the fix operation costs plus penalty costs.

T1 and T2 can only complete partial delivery quantities required by producer. With total capacity of 90 trucks, the transportation capacity gap is 27 trucks in period of peak demand. Each truck can transport a maximum number of 20 units of product 1 and 12 units of product 2. Therefore, by considering the maximum value between 20 and 12, for a period of demand peak, the estimated late or early delivery quantities of 27 trucks are 540 units of product and 540*20=10 800 for the planning horizon of 20 periods. The average unitary late and early supplied penalty cost is 30. Thus the estimated penalty cost is 30*10 800=324 000. Thus the estimated cost of working with T1 and T2 calculated as:

T1&T2 = (742 100+905 278)/2+100 000+100 000 + 32 4000 = 1 347 689

The cost of working with T1, T2 and T3, labeled “T1&T2&T3”, is considered as the average transportation fee of the three transport operators plus the fix operation costs calculated as below:

T1&T2&T3 =(742 100+905 278+1 068 456)/3+3*100 000=1 205 278

Comparison of estimated costs:

Solutions options	Transportation cost	Choice
T1+T3	1 347 689	
T1+T2+T3	1 205 278	√

The comparison result shows that the best solution is to work all the three transport operators.

Expected result:

Producer would assign loads to the cheapest transport operator and make full use of its capacity and then choose the second cheapest and finally the most expensive.

Splitting result of 1-N_SPT model:

T1, T2 and T3 are chosen. T1 and T2 are fully loaded.

Analysis of scenario 4-1:
All transport operators should be used no matter the comparative relation of transportation price.
Expected result:
There would be early and late supplied quantities and at the end of planning horizon, there may be backorders to customer.
Splitting result of 1-N_SPT model:
T1, T2 and T3 are chosen. Accumulated early supplied quantity is 42; accumulated late supplied quantity is 1 073; Accumulated inventory is 4. Backorder to customer is 1 at the end of planning horizon.

Thèse de Mlle Zhenzhen JIA

Titre :

Planification décentralisée des activités de production et de transport: coordination par négociation

Résumé :

Le présent travail propose d'étudier les problèmes de coordination en se plaçant dans un contexte de planification decentralisée, partant du postulat qu'une gestion centralisée n'est pas pertinente au regard des enjeux de confidentialité qu'affichent chaque partenaire d'une même chaîne logistique. Plus précisément, l'objectif du travail réside dans l'élaboration d'un protocole de négociation tendant à rechercher une solution de planification « gagnant-gagnant », i.e. l'élaboration de plans satisfaisant le producteur (clients du service transport) tout en augmentant le profit des prestataires de transport. La méthodologie suivie pour le développement de ce travail s'articule autour de deux étapes. Le contexte de planification decentralisée des activités d'un producteur avec celles d'un opérateur de transport est dans un premier temps étudié. L'objectif est de caractériser les modèles de programmation linéaire et les raisonnement nécessaires au développement du protocole de coordination et à la mise en œuvre de la simulation du comportement des deux partenaires, de manière à mettre en exergue les facteurs influant la performance globale. L'expérimentation conduite dans ce cadre s'appuie sur la notion de plans d'expériences. Le problème est dans un second temps étendu à la coordination des activités de plusieurs opérateurs de transport avec un producteur. Dans ce nouveau contexte, la résolution du problème de répartition de charges de transport entre les différents acteurs est intégrée dans le processus de négociation. Les modèles et protocole ainsi enrichis sont validés sur la base de plusieurs cas de tests.

Mots-clés :

Chaîne logistique, transport, planification, coordination, négociation, programmation linéaire.

Title:

Decentralized planning of production and transportation activities: coordination by negotiation

Abstract:

The present work aims to study the coordination problems in the context of decentralized planning, based on the postulate that centralized management is not suitable regarding the confidentiality objectives of each partner of the same supply chain. More specifically, the aim of this work is to develop a negotiation protocol seeking to reach a "win-win" planning solution, i.e. the development of plans satisfying the producer (the customer of transportation service) while increasing profit of transport operators. The development methodology of this work contains two phases. The context of decentralized planning of activities of one producer and one transport operator is firstly studied. The main objective is to characterize the linear programming models and the key determinants to develop the coordination protocol and also to implement the simulation of both partners in order to identify the factors affecting the overall performance. The conducted experimentation in this context is based on the concept of the design of experiments. The problem is extended in a second phase to the coordination of several transport operators with one producer. In this new context, the problem of allocating transport load to different transport operators is integrated into the negotiation process. The complemented models and protocol are validated based on test cases.

Keywords:

Supply chain, transport, planning, coordination, negotiation, linear programming

Laboratoire de l'Intégration du Matériau au Système(IMS)

Université Bordeaux 1.

351, Cours de la Libération – 33405 Talence Cedex.

Tél. : (33) 05 40 00 36 25

http://www.ims-bordeaux.fr