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# A game theory approach for the collaborative planning of production and transportation activities in the supply chain

Yiting Wang

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POUR OBTENIR LE GRADE DE  
**DOCTEUR DE**  
**L'UNIVERSITÉ DE BORDEAUX**

ÉCOLE DOCTORALE SPI

SPÉCIALITÉ Automatique, Productique, Signal et Image, Ingénierie cognitive

Par Yiting WANG

**A game theory approach for the collaborative planning of  
production and transportation activities in the supply chain**

Sous la direction de : Rémy DUPAS  
(co-directeur : Jean-Christophe DESCHAMPS)

Soutenue le 04 Mai 2018

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**Titre : Une approche basée sur la théorie des jeux pour la planification collaborative des activités de production et de transport dans la chaîne logistique**

**Résumé :**

L'étude de la planification entre partenaires coopérant au sein d'une chaîne logistique au niveau tactique fait l'objet de cette thèse. Le présent travail se focalise plus particulièrement sur la coordination des processus de planification des activités de transport et de production, autour d'une nouvelle approche fondée sur la théorie des jeux. Deux situations de coopération sont considérées, selon le caractère homogène ou hétérogène des partenaires ; ainsi une première étude est menée sur un ensemble d'opérateurs de transport pour ensuite être étendue à la relation entre l'entreprise manufacturière et les transporteurs qui travaillent avec elle. L'expérimentation s'appuie sur des modèles mathématiques en programmation linéaire pour simuler les processus de planification des différents groupes de partenaires (également appelés coalitions), un protocole de coopération utilisant certaines propriétés liées à la théorie des jeux et sur une répartition équitable des gains / coûts telle que préconisée par la valeur de Shapley. Les modèles et l'ensemble du protocole sont appliqués à deux cas d'étude basés sur des jeux de données réalistes.

**Mots clés :** production, distribution, coopération en planification, programmation linéaire, théorie des jeux, valeur de Shapley

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**Title : A game theory approach for the collaborative planning of production and transportation activities in the supply chain**

**Abstract :**

This thesis focuses on the collaboration between partners inside supply chain at the tactical level of planning. This work aims to develop a new approach based on game theory to solve the problem of coordinating processes concerned by production and transportation planning decision making. Two types of coalitions cooperative games are implemented according to the nature of partners: the cooperation between homogeneous partners concerns multiple transport operators while the other case is more on the relationships between heterogeneous partners including one manufacturer and multiple transport operators. The coordination is supported by mathematical models implemented in linear programming which simulate the planning process within the various possible pools of partners, also called "coalitions". These models are used in a gains/costs sharing protocol between the partners which is based on the Shapley value. Some basic properties are checked in order to verify if the cooperation is valid. The models and the protocol are assessed on theoretical test cases based on realistic data sets.

**Keywords :** production, distribution, cooperation planning, linear programming, game theory, Shapley value

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# General introduction

- Context

This thesis focuses on the collaboration between partners inside Supply Chain. Collaboration is a mutually beneficial and well-defined relationship between one or more organizations to achieve common goals, which is necessary for obtaining the best solution in terms of efficiency. As managing capabilities and resources across enterprise boundaries becomes increasingly important, collaboration is considered as an essential issue to deal with Supply Chain performance improvement. The coordination of planning decision making at the tactical level is a major problem in this context. On this basis, our work intends to develop a new approach to solve the problem of coordinating production and transportation planning decision making.

- Problem studied and objective

The current work is focused on the decentralized planning at the mid-term planning decision level, between partners having different roles in Supply Chain. Indeed in our work, each partner has its own decision so that each manager can decide to keep some private confidential information or can decide to share some information with others. Two types of partners are considered for planning: production and distribution/transport. The production planning aims to propose a production plan on a midterm planning horizon according to the delivery plan, production capacity, inventory capacity of finish products and required production lead time for products etc., while taking into account various costs. The distribution planning provides a midterm delivery plan according to the customer demand and the production plan. The transport operator offers a pickup plan according to the delivery plan and its transportation capacity.

The road transportation activity studied in this work mainly concerns the chartering activity. Any truck used in the transportation planning process is dedicated to only one shipper and one customer destination. Pricing we adopt is classically decomposed in a fixed term and a variable term and the estimation of their values is based on the French Road National Committee (CNR) recommendation.

- Methodology and contribution

In the modern production and distribution systems, the market competition reduces regularly the revenues and the potential reduction of the costs for fulfilling customers is more and more limited. Hence, increasing the level of competition between the

partners does not seem the most interesting way to go. On the other hand, the global competitiveness could be increased if the partners cooperate in order to share their costs or their profits. Consequently, in this thesis, the collaboration problem between transport and production is based on game theory which aims to offer a logical method to predict outcomes in various contexts. More precisely in our work, we approach the collaboration problem as a cooperative game in which groups of players ("coalitions") may enforce cooperative behavior. For instance, this is the case when players choose the strategies by a consensus decision-making process. In this context, Shapley value is known to provide a good mechanism to share costs or allocate possible profit between partners searching efficient and fair solutions in a collaborative way. Consequently the Shapley value is used to tackle the planning cooperation at a tactical level between transport operators as well as between manufacturers and transport operators.

Two kinds of cooperative games are studied according to the character, homogeneous or heterogeneous of the partners involved in the cooperation. As far as the homogeneous game is concerned, we consider multiple transport operators that cooperate in order to satisfy the delivery requests of a manufacturer. Concerning the heterogeneous game, a manufacturer and multiple transport operators cooperate in order to satisfy the customer demand. These games are combined with linear programming models that simulate the planning process of each partner. The cooperation between the various actors is modeled by a specific process in which the execution of the linear programming models is used to calculate the Shapley values for each partner of the game. These Shapley values represent the target values for sharing the costs or the profits in a fair way.

- Content

The context of this thesis, general definitions and notions of supply chains will be introduced in chapter 1. Supply chain planning and the game theory especially cooperative game theory will be introduced in chapter 2. The planning models of the production and transportation activities as well as cooperation protocols will be described in chapter 3. The interest of our cooperative approaches will be evaluated in chapter 4. Consequently, numerical experiments will be designed and implemented to evaluate the performance of the cooperation solution based on game theory.

# Chapter 1

## Supply chain context and problem definition

### 1.1 Introduction

This chapter presents the background of this thesis which is related to the design and management of supply chain (SC), the collaboration in the supply chain and the transportation activities in the supply chain. It is made up of the following sections. Section 1.2 presents the context of the problem, the background is described from the logistics to supply chain and then supply chain management. The collaboration in supply chains is introduced in section 1.3, discussing the collaborative modes and approaches. In section 1.4, transportation activities in the supply chain are described, including the transportation mode, services and performance. At last, a conclusion is given in section 1.5. It is worth to mention that the position of our work is defined gradually.

### 1.2 Definition of the context

In this section, the context of our research is introduced. First, it is necessary to present the logistics, which is related with supply chain. Second, supply chain and its actors are introduced. The difference between logistics and supply chain is described in (Hugos 2010). *“Logistics typically refers to activities that occur within the boundaries of a single organization and supply chains refer to networks of companies that work together and coordinate their actions to deliver a product to market. Also, traditional logistics focuses its attention on activities such as procurement, distribution, maintenance, and inventory management.”* Third, supply chain management – SCM is presented.

#### 1.2.1 What are logistics? Definition and meaning

Logistics is a multi-layered concept, depending on the viewpoint of authors concerned by this topic. In this way, logistics is defined by (Coyle, Langley et al. 2016) as *“getting the right product, to the right customer, in the right quantity, in the right condition, at the right place, at the right time, and at the right cost”*. From this point of view, logistics is not quite different from the notion of supply chain management (SCM) - as it will be discussed shortly after - and this definition includes an implicit notion of flow control and a business dimension.

Over the past years, some authors have tried to position this concept in relation to supply chain management, since many years. Proof of this are the work of (Cooper, Lambert et al. 1997) untitled “Supply Chain Management: more than a new name of Logistics” or the survey of (Larson and Halldorsson 2004) that present logistics as a part of SCM. For instance, (Cooper, Lambert et al. 1997) have identified that logistics do not include some business dimensions, such as the product development process, and others functions that are considered in Supply Chains in an integrated point of view.

(Council-of-Logistics-Management 1991) defines the logistics as a “*part of the supply chain process that plans, implements and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers’ requirements*”.

(Rutner and Langley Jr 2000) mention the “Seven Rs” as a simple definition of logistics, which refer to the definition given by (Shapiro and Heskett 1985). These latter consider logistics as “*ensuring the availability of the right product, in the right quantity and the right condition, at the right place, at the right time, for the right customer at the right cost*”.

More recently, (Lummus, Krumwiede et al. 2001) propose an interesting analysis of the relationships between logistics and supply chain management which will be presented in section 1.2.3. These authors first specified that logistics “*involve the movement of physical goods from on one location to another, and received much attention from the military during both world wars*”. They also highlighted that (Cavinato 1982) defines logistics as “*the management of all inbound and outbound materials, parts, supplies, and finished goods. Logistics consists of the integrated management of purchasing, transportation, and storage on a functional basis*”. Thus, (Lummus, Krumwiede et al. 2001) have concluded that the term of logistics as “*relating essentially to the movement and transmittal of goods, services and information*”.

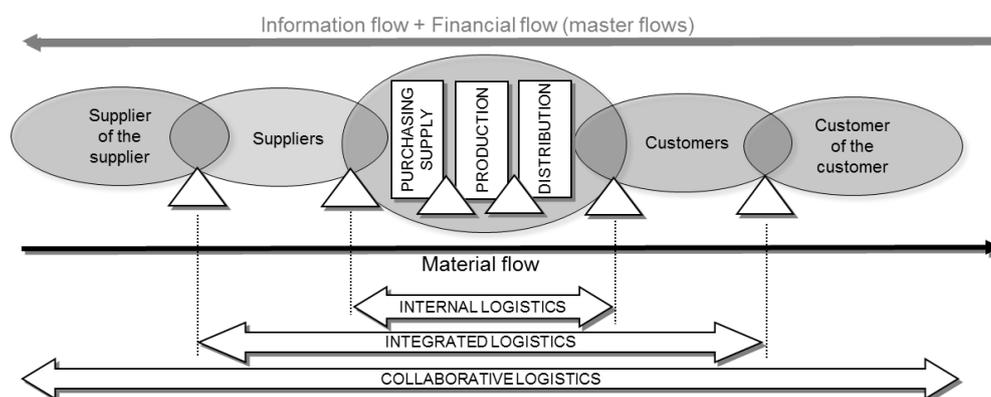
(Tseng, Yue et al. 2005) point out that “*logistics is a process of moving and handling goods and materials, from the beginning to the end of the production, sale process and waste disposal, to satisfy customers and add business competitiveness*”. They also conclude that “*logistics is customer-oriented operation management*”.

We retain the following notions of these definitions:

Logistics define joint activities of one or more companies more concerned by the moving and handling of materials, parts and finished products, from raw-material suppliers to end consumers.

Based on this definition and Figure 1-1, we assume that:

- *Internal logistics* concern the move of materials flows within a same company, including procurement, reception, storage, transfer and preparation for shipment. Procurement logistics is to obtain materials, services or products at the best possible cost which satisfy the needs and time restrictions. Procurement logistics include such activities as market research, requirements planning, buying decisions, supplier management, ordering, and order controlling. The procurement processes consist of bids, price negotiations, assuring proper quantities and specifications, shipping and delivery. Distribution logistics plan the delivery of the finished products to the customer. It consists of order processing, warehouse management, and transportation management. Distribution logistics is essential since the delivery time, place, and products quantity should be agreed between manufacturer and consumer.
- *Integrated logistics* is a system-wide management of transportation and handling activities integrating the company and its tier-one suppliers and customers in a single entity
- *Collaborative logistics* characterize long-term partnerships between more than tier-one organizations intending to optimize the move of materials by sharing equipment, information and costs.

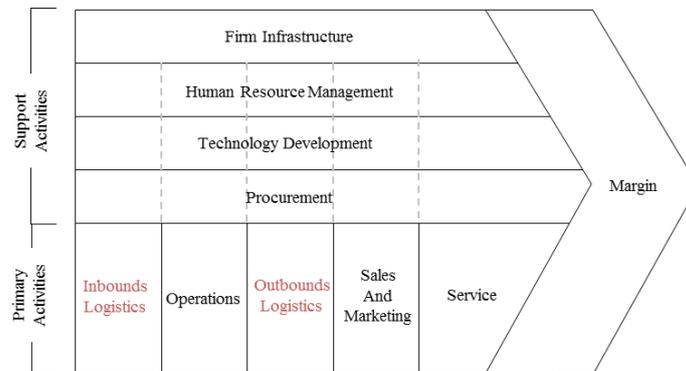


**Figure 1-1 Scope of Logistics**

## 1.2.2 From logistics to Supply Chains

The previous definitions outline that Supply Chain Management (SCM) is a wider concept than logistics. (Porter 1985) was one of the first researchers in economy to

consider inbound and outbound logistics as primary activities in creating value (Figure 1-2). Inbound logistics refer to activities of receiving, storing and manage incoming raw materials to use in production. Outbound logistics concern activities of shipping produced goods and transportation from the company to customers. This work represents one of the key steps in removing barriers between businesses functions of enterprises involved in a same production network.



**Figure 1-2 The Value Chain (Porter 1985)**

Many researchers assume this proposition as one of the foundations of studies where activities from suppliers to consumers (end-users) is considered as a whole system called Supply Chain. Since then, many definitions have been proposed in the literature. Obviously, the chronological list of definitions proposed hereafter is not exhaustive, but shows some interesting orientations in supply chains researches.

(Stevens 1989) has thus considered a supply chain 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.*”

(Lee and Billington 1995) defines a supply chain as “*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*”.

(Chopra and Meindl 2001) recognizes that a supply chain “*consists of all stages involved, directly or indirectly, in fulfilling a customer request. The supply chain not only includes the manufacturer and suppliers, but also transporters, warehouses, retailers, and customers themselves.*”

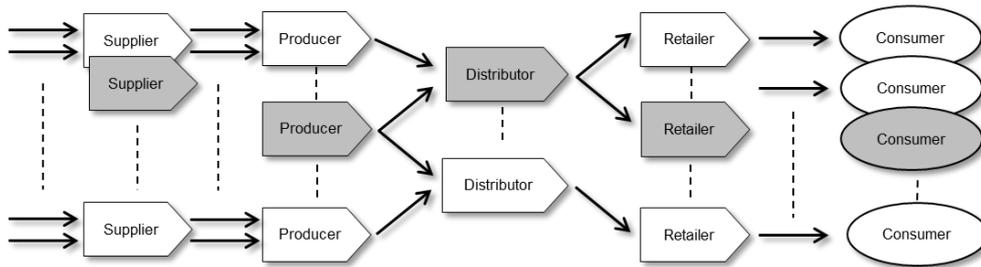
A supply chain also concerns “*all activities associated with the flow and transformation of goods from the raw materials stage, through to the end user, as well as the associated information flows. Material and information flow both up and down the supply chain.*” (Handfield and Nichols 2002)

(Waters 2007) defines the supply chain focusing on transfer of the materials and information. “A *supply chain* is the series of activities and organizations that materials – both tangible and intangible move to their journeys from initial suppliers to final customers.”

(Christopher 2016) defines the value of the supply chain. “*Supply Chain* is the 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”.

Based on the above definitions, some common elements characterizing the notion of Supply Chain (SC) have to be more detailed.

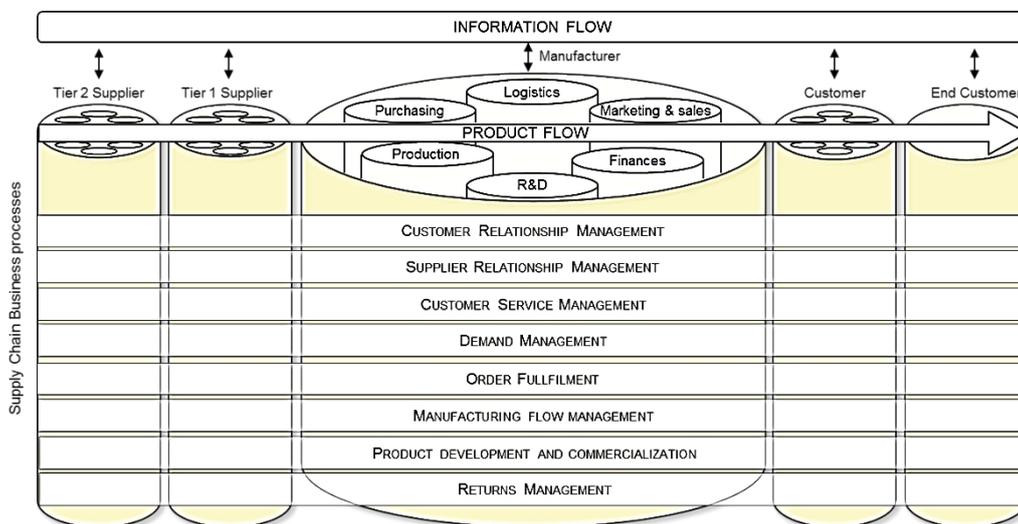
1. The partners of the supply chain are customers, retailers, distributors, transporters, and suppliers (see Figure 1-3).
  - A *customer* is a company or a person that purchases and uses a product. The company may purchase a product in order to incorporate it into another product that they in turn sell to other customers. Indeed, a customer may also be the final end-user of a product who buys the product in order to consume (also called end-consumer).



**Figure 1-3 Scheme of a supply chain (grey color) within a network of supply chains**

- A *retailer* is a business company or person that sells products directly to end-consumers. To realize a profit, retailers search for products that match with their business objectives and find suppliers with the most competitive prices. Generally, a retailer can buy small quantities of an item from a distributor or a wholesaler. For instance, a retail merchant who wants to purchase a dozen lamps could contact lighting distributors to inquire about pricing.
- *Distributors* are companies that store products bought to manufacturers in order to deliver parts of these related products to the retailers or end-consumers. They typically purchase products to supply plants in larger quantities than an individual consumer would usually buy. Thus, distributors can “absorb” the fluctuation of retailer’s demands, by stocking products to ensure the availability of products for any customer. Distributors are also known as wholesalers.

- *Manufacturers*, also called manufacturing plants or production are companies that manufacture a product. The manufacturer makes a good through a physical process involving raw materials, components, or assemblies, usually on a large scale with different operations divided among different workers.
  - Raw material *Suppliers* are parties that mine for minerals, drill for oil and gas, and cut timber. It also includes organizations that farm the land, raise animals, or catch seafood.
2. The function of the supply chain establishes the processing and distributing channels.
  3. The products stream in the supply chain starts from the sourcing (raw materials) and ends with the delivery to the final consumer, and its management is supported by many functions, as presented in Figure 1-4 (Cooper, Lambert et al. 1997, Tseng, Yue et al. 2005).



**Figure 1-4 Integrating and managing business processes across the supply chain**

A supply chain concerns the regular flows of information, product, and finance between different stages and comprises many functions, such as new product development, marketing, operations, distribution, finance, and customer service. Thus, the main business processes identified across the Supply Chain shown in Figure 1-4 are detailed in the following:

- *Customer Relationship Management* consists in developing one-to-one relationships with customers in order to have sustainable business relations with added value for the firm.

- *Supplier Relationship Management* intends to rationalize business processes that connect a firm with its suppliers. It notably increases the efficiency of procurement of goods, services and stocks management, and allows controlling the production costs.
- *Customer Service Management* follows up customers who have problems and litigations. The main objective of this function is to find solutions to these problems, to answer any technical questions on the product, and to try to satisfy customers as best as possible.
- *Demand Management* concerns a set of management processes that support the planning and the estimation of the forecast demand (based on history of sales on markets) of goods and services. Processes through the SC are often integrated into sales and operations planning.
- *Order Fulfillment* combines all processes involved in receiving, processing and delivering orders to end customers.
- *Manufacturing Flow Management* is “the supply chain management process that includes all activities necessary to move products through the plants and to obtain implement and manage flexibility in the supply chain” (Goldsby and Garc ía-Dastugue 2003).
- *Product development and commercialization* is “the supply chain management process that provides structure for developing and bringing to market new products jointly with customers and suppliers” (Rogers, Lambert et al. 2004).
- *Returns management* deals with activities associated with returns and reverse logistics. This function controls the reverse product flow, intends to reduce unwanted returns and manage reusable assets.

4. The supply chain produces value in the form of products and services in the hands of the ultimate consumer. This, in the definition of the supply chain, supply chain value plays an important role. The objective of every supply chain should be to maximize the overall value generated. This value, also known as supply chain surplus, which is generated by a supply chain, is the difference between what the value of the final product is to the consumer (consumer value) and the costs the supply chain brings about to respond the customer’s request (supply chain cost). The consumer value is the value that the consumer pays for the products or service. The costs the supply chain are the costs to serve the consumers, including the cost of raw materials, the production cost, the inventory cost of raw materials and finish product, the transport cost, and the labor cost etc.

Based on the various points discussed before, we assume that:

A supply chain is a network of interdependent entities, which are retailers, distributors, transporters, storage facilities, and suppliers, establishing the processing and distributing channels of the product from the sourcing (raw materials) to delivery to the final consumer, meanwhile producing value in the form of products and services.

### **1.2.3 Supply chain management: Levels of decisions and decisional functions**

Many definitions emphasize the main concepts of Supply Chain Management, for more than 40 years now. Through some of these definitions, we intend to highlight these main concepts related to SCM in order to synthesize them by giving our own definition.

*“The objective of managing the supply chain is to synchronize the requirements of the customer with the flow of materials from suppliers in order to effect a balance between what are often seen as conflicting goals of high customer service, low inventory management, and low unit cost.”* (Stevens 1989). The notions of material flow, value creation, and customer satisfaction are those that are most interesting to retain first.

The idea of networks of relationships is given in (La Londe and Masters 1994). SCM is defined that *“A concept whose primary objective is to integrate and manage the sourcing, flow and control of materials using a total systems perspective across multiple functions and multiple tiers of suppliers”*.

(Cooper, Lambert et al. 1997) define that *“SCM is an integrative philosophy to manage the flow of a distribution channel from supplier to the ultimate user”*. The concept of physical flow in supply chain is clearly expressed, but only with a unidirectional characteristic.

The material, finances and information flows are illustrated in (Nishat Faisal, Banwet et al. 2006), *“SCM requires a complex flow of information, materials and funds for several functional areas within and between organizations”* as well as the internal and external networks of relationships. Whereas, the function of customer services in SCM is missing.

(Tang 2006) describes SCM included three profiles, such as the material, information and financial flows, networks of relationships, and component parts. Supply chain management is defined as *“the management of material, information and financial flows through a network of organizations (i.e., suppliers, manufacturers, logistics providers, wholesalers/distributors, retailers) that aims to produce and*

*deliver products or services for the consumers.*” Nevertheless, the ideas of value creation and customer satisfaction are missing.

The idea of coordination in supply chain and supply chain efficiency are mentioned in (Hugos 2010). *“SCM refers to the coordination of production, inventory, location, and transportation among the participants in a supply chain to achieve the best mix of responsiveness and efficiency for the market being served.”*

Finally, the Council of Supply Chain Management Professionals (CSCMP), which is a nonprofit organization of business personnel, offers a definition of SCM based on logistics management. They defined: *“The logistics management is that part of the business that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers’ requirements.”* On the other hands, supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. CSCMP defined that *“Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the Logistics Management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finances and information technology.”*

According to these definitions, several common points of SCM can be pointed out:

- Material, finances and information flows in the SC;
- Customer services and satisfaction;
- Internal and external networks of relationships;
- Value creation;
- SC efficiency;
- Component parts of SC.

Based on these six points, we define SCM as:

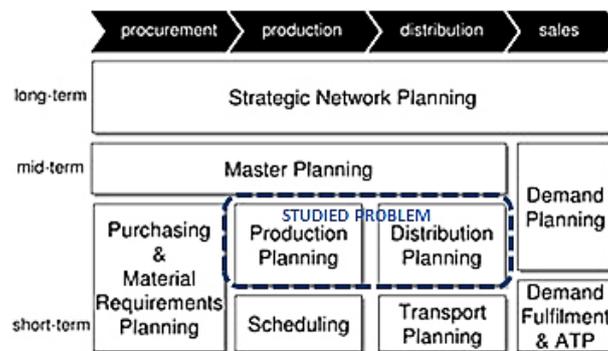
The management of material, information and financial flows through a network of organizations, that support the coordination the supply chain partners in producing and delivering products or services to the customers. The main objective of SCM is to guarantee the customer satisfaction and to create an added value at each stage of the SC.

After the definition of SCM has been given, the supply chain decisions must be discussed, in order to understand how its main functions operate to fulfil the objectives previously presented. According to the hierarchical dimension, supply chain decision phases may be categorized as design, planning, or operational, depending on the time frame during which the decisions are applied. Design decisions constrain or enable good planning, which in turn constrains or enables effective operation.

- Supply Chain Design – Strategic Decision Level: During this phase, how to constitute the supply chain over the next several years is decided by company. The chain's configuration, the resources allocated, and processes performing in each stage are decided. Strategic decisions which are made by companies consist of whether to outsource a supply chain function or fulfil it internally, the location and capacities of production and warehousing facilities, the locations of the products to be manufactured and stored, the modes of transportation, and the type of information system utilized.
- Supply Chain Planning – Tactical Decision Level: During this phase, the time horizon for decisions made is considered as a quarter to a year. Thus, it is supposed that the supply chain's configuration determined in the strategic phase. This configuration builds constraints for necessary planning. The purpose of planning is to maximize the supply chain surplus that can be generated over the planning horizon which is established during the strategic or design phase. The planning phase is started by companies with a forecast for the coming year (or a comparable time frame) of demand and other factors such as costs and prices in different markets. Making decisions concerning each aspect are involved in planning, such as which markets will be supplied from which locations, the subcontracting of manufacturing, the inventory policies to be subjected, and the timing and size of marketing and price promotions.
- Supply Chain Operation – Operational Decision Level: The time horizon is considered weekly or daily during this phase. The decisions of companies are focused on individual customer orders. At the operational level, supply chain configuration is fixed, and planning policies are already defined. To handle incoming customer orders in the best possible way is the goal of supply chain operations. Companies allocate inventory or production to individual orders, set a date when an order is to be fulfilled, generate pick lists at a warehouse, allocate an order to a particular shipping mode and shipment, set delivery schedules of trucks, and constitute replenishment orders. There is less uncertainty about demand information of operational decisions, since they are being made for the short term (minutes, hours, or days). Given the constraints founded

by the configuration and planning policies, reducing the uncertainty and optimizing performance is the purpose during the operation phase.

Our work focuses on the tactical decision level, i.e., supply chain planning, hence, it is necessary to present this part more in deep. Supply chain planning is made up of several functions according to supply chain process (procurement, production, transportation and sales) and hierarchy, such as strategic network planning, master planning, purchasing and material requirements planning, production planning and scheduling, distribution planning and transport planning etc. A planning matrix (Meyr, Wagner et al. 2002) is shown in Figure 1-5, where the main SCM functions are integrated along with two dimensional axes -- planning process and hierarchy levels.



**Figure 1-5 A supply chain planning matrix**

Strategic network planning

Strategic network planning comprises several decisions, such as the procurement decision, production decision, distribution decision and sales at long term level, especially plant location decisions and distribution structure design. Which products allocate to which markets is determined under the consideration of strategic sales planning. The supply chain design and the materials flow paths between suppliers and customers are defined in this function.

Master planning

Master planning consists of procurement, production and distribution decisions on a midterm planning level. These decisions include not only the use of production, transport, supply capacities, stock space, but also the balance between supply and demand. When the total costs of inventory, overtime, production and transportation are minimized, synchronously the decisions of production and transport quantities are acquired. The planning horizon should be sufficiently long to compose entire demand peaks.

### Purchasing and Material Requirements Planning (MRP)

Purchasing and material requirements planning, for short purchasing & MRP, composes both aspects, such as managing the decisions on short-term level, making the orders of replenishment and production for components and parts in a multi-stage production context. Based on a time series of primary demands -- generally finished products, demands of components and parts are included in secondary time-phased plans in MRP. Purchasing orders are sent to the corresponding suppliers when the demand of components and parts are identified.

### Production planning and scheduling

Production planning consists of making the plans for manufacturing in a company, where the facilities needed are determined and arranged (Fargher and Smith 1996). With the purpose of well serving different customers, the resource allocation of employees, materials and production capacity are decided in the production plan. A production plan is made periodically for a specific time period, which is named the planning horizon. The production planning is made based on the demand planning, and it comprises three tasks, such as lot-sizing, machine scheduling and shop floor control whose targets are generating specific production schedules for the shop floor over a relatively short interval time. Production planning concerns the decisions of mid-term level, and production scheduling pays attention to the decisions of short-term level. Depending on the industry sector, it varies from one day to a few weeks that the planning interval for production planning and scheduling. The decisions are strongly depending on the production system at this detailed short term level. Thus, for different companies, production planning and scheduling are specialized. Multi-stage production processes and product structures are arranged in an integrative manner when they exist.

### Distribution planning and transport planning

Distribution and transport planning covers respectively the mid-term and short-term decisions.

(SteadieSeifi, Dellaert et al. 2014) propose an interesting and helpful literature review to support the distinction between these operations. The authors base their analysis on the decision horizon of the planning problem, considering the strategic, tactical and operational decision-making levels. The tactical planning problems more deal with the best choice of services and transportation modes, the allocation of resources, the definition of aggregated delivery quantities and the planning of itineraries. The operational level is still concerned by the same objectives as the tactical level, with

new considerations on real-time requirements, dynamic short-term problems. According to this proposition, we assume that:

- Distribution is more identified as a planning function implemented at the tactical level that defines quantities to move per time period from shippers to customers along a time horizon, or as a location-covering problem. The time horizon at this level can be one month, a few days or one day.
- Transportation planning is an operational function in charge to define and rationalize itineraries to ensure the best service quality for the customers.

Important note: In spite of the differences discussed before, and considering transport operators as main partners in our supply chain study, we decide to use both terms “Transport Planning” or “Distribution Planning” interchangeably to refer to the mid-term planning problems.

### Demand planning

Demand planning achieves the purpose to forecast the customer demand for a set of products in the future. Demand planning makes decisions on a mid-term level, mostly composing many time periods, typically 12 - 24 months. Determining the aggregation or disaggregation of data for products, customers and time is a considerable task in demand planning. Such as former planning runs, historic customer orders, shipments etc., are utilized to predict data.

### Demand fulfillment and available to promise (ATP)

Demand fulfillment & ATP (Available To Promise) identifies the way of satisfying the current customer demand on short-term level. The current and future supply and capacity are decided here in order to know whether to accept new customer orders. The demand fulfillment process improves conventional approach, which is quoting orders against inventory and supply lead-time, and offers fast and reliable order promises to the customer comparing to conventional approach which mostly leads to unfeasible order promises and the decreasing of punctual delivery.

The mid-term decisions are concerned in this work, including production planning, distribution/transport planning. The production planning proposes a production plan in the time about one month according to the delivery plan, production capacity, inventory capacity of finish product and required production lead time for product etc., while taking into account various costs. The distribution planning provides a monthly delivery plan according to the demand and constrained by production plan. Transport offers a pickup plan according to the delivery plan and the transportation

capacity. Indeed, the production planning and distribution/transport planning are considered as interdependent in this research work.

The components and parts are thought as infinite for theoretical study, thus, it is not necessary to replenish them. Consequently, purchasing and material requirements planning are not concerned in my work. The manufacturer receives a deterministic monthly demand from the customer, thus the demand planning is not the research object in this work.

Tactical decisions are the object to study in this work. Consequently, supply chain planning is concerned, particularly, production planning, distribution planning. Transportation activities and production activities are coordinated to propose the consistent production plan, delivery plan and pickup plan for the manufacturer and the transport operators.

### **1.3 Collaboration in Supply Chain**

Collaboration is necessary for obtaining the best solution in terms of efficiency for all the SC partners in supply chain. If the collaboration is insufficient or inefficient in a supply chain, inefficient production, superfluous inventory, and inflated costs will occur (Li 2007). Supply chain collaboration handles the inter-organizational relationships so that its members accept to invest resources, to mutually achieve goals, to share information, resources, rewards and responsibilities as well as jointly make decisions and to solve problems (Soosay, Hyland et al. 2008). In this section we introduce the supply chain as a decentralized system; then we discuss the general notion of collaboration and describe the various collaboration modes and the main collaborative approaches in supply chain management; at last the position of our work is given regarding collaboration.

#### **1.3.1 Supply Chain as a decentralized control system**

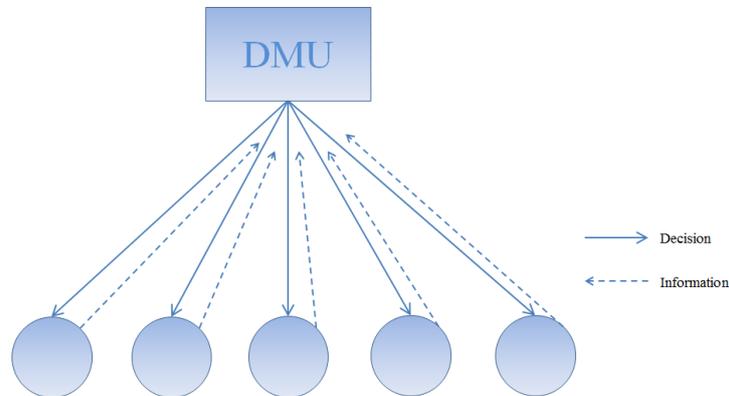
In order to understand the notion of collaboration, it is indispensable to begin with the presentation of the concepts of centralized architectures and decentralized architectures. Even if these concepts are generic in the field of control systems, the presentation below is limited to their application to the supply chain context.

##### **1.3.1.1 Centralized architecture of supply chain**

First, let us introduce the DMU (Decision Making Unit) which includes a decision maker (human or artificial intelligence) and potentially a number of humans and machines, which receives information from partners, meanwhile generates information within itself, processes information and produces the decision. Notice that,

the minimum DMU is the decision maker himself. A larger unit can include the decision maker, system analysts and computing instruments. Before making decisions, the DMU collects information from its subordinated sub-systems.

Applying this paradigm to the Supply Chain, the partners must be coordinated by a central decisional center (DMU). The partners in the supply chain then perform actions in respect with the decision frames received from this DMU. Centralized architecture of supply chain can contain a unique control center (Chankong and Haimes 2008), which entirely controls and coordinates the whole set of partners in the supply chain through the managing all the information and decisions. centralized architecture is shown in Figure 1-6, where a circle represents a partner, the rectangle represents the DMU, the dashed arrows represent the information sent from the partner to DMU, and the continuous line arrows represents the decision of the DMU. The advantages of the centralized architecture are twofold: the DMU has an entirely control of the supply chain and optimal decisions can be made, achieving the objective of the chain. However, the DMU needs to collect a huge amount of information for analyzing and processing. The supply chain, which uses the centralized architecture, is sensitive to any failure or error occurring during the information exchange or decisions making.



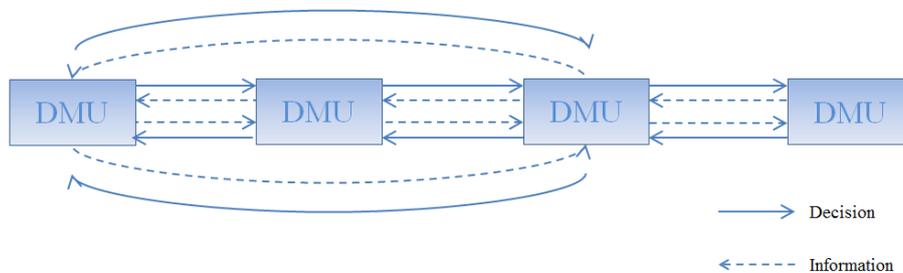
**Figure 1-6 Centralized decision making system**

### 1.3.1.2 Decentralized architecture of supply chain

A centralized decision making system ignores the independence of its members, thus, most of supply chain systems are decentralized (Wang, Guo et al. 2004). Decentralized architecture involves more than one partner containing a DMU. In other words, each partner makes its own decision. A possible proposition of decentralized architecture is shown in Figure 1-7, where a rectangle represents a partner assimilated to a DMU in the decentralized architecture and the dashed arrows represent the

information sharing. Partners can establish a partnership with others or not, i.e. each partner can decide to share information with another partner or not. Each partner makes its local optimal decisions, and is responsible for its own development.

In the decentralized architecture of supply chains there is no DMU controlling all partners. Thus, it cannot be guaranteed that the local decisions of partners will converge to a global optimum solution of the supply chain. In order to solve the conflict problems, the partners who establish a partnership exchange information of transaction orders and feedback decisions to negotiate on their decisions. The partnership of partners will break down when they cannot find a converged solution. The decentralized architecture is flexible, and the privacy information of each enterprise is well protected. Nevertheless the decisions are locally optimal but not globally optimal.



**Figure 1-7 Decentralized decision making system**

In our work, each partner can have its own decision. From this point of view, the supply chain is mainly considered as a decentralized decision making system. Certainly, the information sharing is necessary for the cooperation. Particularly, the manager can have the personal information of each partner and keeps it confidential from other partners.

In this context, information sharing is an important requirement for achieving the cooperation. Each partner can decide to share some of its personal information with other partners or, it can also decide to keep it confidential from other partners. In the next section, the principles of collaboration in the decentralized supply chain are presented, which can solve the drawback of the decentralization.

### 1.3.2 Notion of collaboration

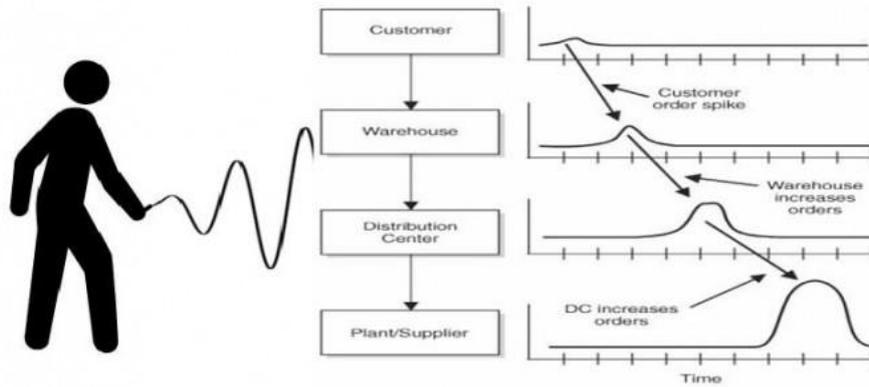
A decentralized supply chain consists of several self-interested partners, thus, competition between partners brings the system efficiency down, and the decision of competition generally is not optimal (Wang, Guo et al. 2004). Collaboration is a significant way to improve efficiency of supply chain. The enterprise is forced to seek

the efficient collaborative approach to coordinate the materials flows in the globalization of supply chain management. “*Collaboration is a mutually beneficial and well-defined relationship entered into by one or more organisations to achieve common goals. The relationship includes a commitment to: a definition of mutual relationships and goals, a jointly developed structure and shared responsibility; mutual authority and accountability for success; and sharing of resources and rewards.*”(Mattessich and Monsey 1992) In conclusion, collaboration is required for helping supply chain partners to work efficiently together and to achieve high supply chain performance, which refers to delivering on time and offering products and service with low cost etc.

The following two points are important for a successful collaboration in the supply chain. Firstly, the partners are ensured that the gain of each partner is not lower than before supply chain cooperation, and the total cooperative gain is shared properly. Secondly, the partners do not have enough incentives to deviate from the system optimal solution of cooperation.

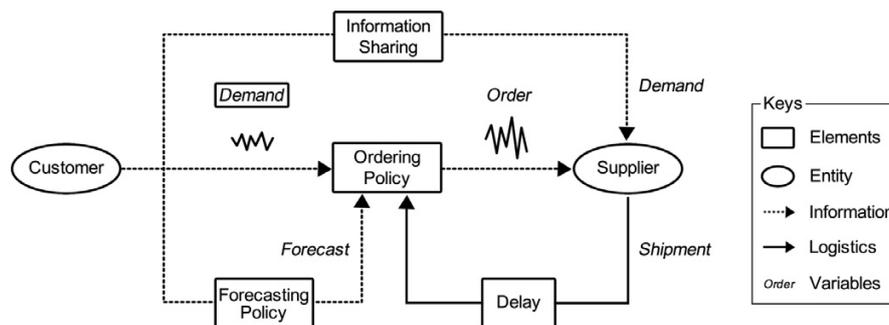
Decisions on logistics, inventory management, forecasting, production, transportation require SC collaboration, which focuses on synchronizing inter-organizations flows. In distributed system, there are always different and conflicting objectives in the different partners. However, the decisions made by each partner should be synchronized. For example, the manufacturer’s delivery decisions and transport operator’s pickup decisions should be consistent. If the manufacturer cannot supply enough products or the transport operator cannot totally pick up required products, the inconsistency will occur. The needs of coordination are enhanced by dynamic aspects in the supply chain.

At that stage of the presentation, it is interesting to shortly present the bullwhip effect which originates from a lack of collaboration and which refers to the amplification of upstream demand variance influencing the downstream in a multiple firm supply chain (Metters 1997). Sometimes, the bullwhip effect is known as ‘demand amplification’ or ‘variance amplification’. The slow moving of customer demand creates large swings in production/suppliers at the other end of the supply chain, as represented in Figure 1-8. Indeed when there is a small increase of customer demand, the upstream supply chain – warehouse, distribution center and supplier will adopt the corresponding solutions to keep stocks avoiding the potential increase of customer demand in the future. This effect is led by the insufficient sharing information, which is a result of lack of collaboration.



**Figure 1-8 Bullwhip effect**

Many modelling approaches to measure the bullwhip effect have been proposed. Elements in bullwhip model can involve demand, forecasting, time delay, ordering policies, and information sharing (Wang and Disney 2016), as in Figure 1-9. These elements can have either positive or negative impacts on demand amplification.

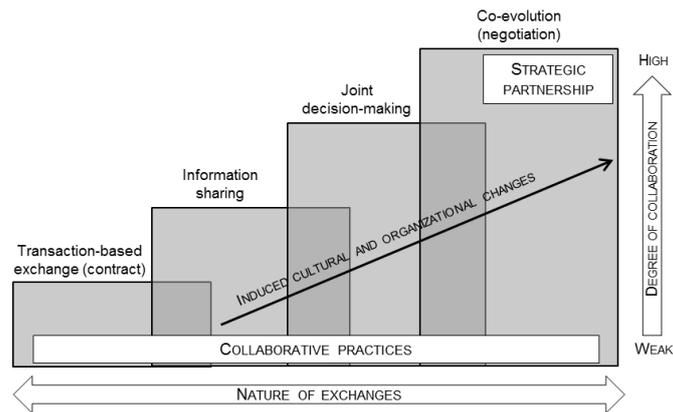


**Figure 1-9 A typical bullwhip model**

Reducing the number of nodes of supply chain can be a way to solve bullwhip. Supply chain integration can be a possible way to achieve this goal. Notice that this solution is implemented through the Vendor Managed Inventory (VMI) which is one of the well-known collaborative approaches presented in the following section 1.3.4.

### 1.3.3 Collaboration modes

A collaboration mode defines how the supply chain partners collaborate effectively. Different levels of information quantities are transferred in each particular collaboration mode. A collaboration mode also states a set of rules specifying the actions of different collaborative partners in a supply chain. Four kinds of collaboration mode are shown in Figure 1-10 according the nature of information exchanges: contract, information sharing, joint decision making and negotiation.



**Figure 1-10 Degree of collaboration / Nature of exchanges**

### Contract

In general, a contract is a voluntary arrangement between two or more parties that is enforceable by law as a binding legal agreement (Ryan 2006). In supply chain, a contract is an agreement which stipulates the precise acts to perform or forbid, and/or services and/or pending delivery products between two or more partners (Pawar, Rogers et al. 2016). In order to increase total SC profit, reduce overstock/under stock costs and share the risks among the partners of supply chain, different kinds of contract are proposed by (Cachon 2003, Amrani-Zouggar, Deschamps et al. 2009), such as buyback contract, revenue-sharing contract and quantity flexibility contract.

### Information sharing

The involved SC partners mutually sharing their confidential information, such as cost, quality and schedule, during any stage of collaboration, is called information sharing. The SC partners can collaborate with information sharing concerning demands, orders, inventory, POS (Point Of Sale) data, etc. (Francois, Deschamps et al. 2006). Inventory reductions and cost savings could be advantages of information sharing policy.

### Joint decision making

The SC partners making decisions in partnership instead of individually is joint decision making. The SC performance regarding such as human, technology, strategies is improved with joint decision making of the involved partners. The characteristic examples of joint decision making are VMI (Vendor Manage Inventory) and CPFR (Collaborative Planning, Forecasting and Replenishment) detailed in the section 1.3.4.

### Negotiation

Negotiation is a way to obtain a compromising solution for the partners who have

conflicting targets.

### **1.3.4 Collaborative approaches in supply chain management**

The collaboration study mainly focuses on the relations of a given partner with upstream and downstream entities inside supply chain. Regarding this kind of collaboration, the main following approaches are VMI (vendor managed inventory), CPFR (collaborative planning, forecasting and replenishment), ECR (Efficient Consumer Response), and pooling.

#### VMI

In VMI (Vendor-Managed Inventory) certain product information is sent from the buyer (customer) to a supplier (vendor) of this product. The vendor takes full responsibility for sustaining a corresponding inventory of the product, generally at the customer's consumption location (usually a store). The vendor and the customer works together to manage and optimize inventory of the product demanded by the customer. Thus, the vendor can supervise the inventory of the product and plan inventory replenishment of the customer. Though this way, the vendor can get all required data, such as sales record, promotion data and historical data to decide the optimal inventory level and make a replenishment plan. The production and consumption speed are kept same in VMI, consequently bullwhip effect is effectively prevented (Chan and Chan 2006). The customer's confidence on the vendor is necessary in the implementation of VMI, whose business depends on vendor's appropriate inventory management.

#### CPFR

CPFR (collaborative planning, forecasting and replenishment) focuses on collaboration not only for efficient replenishment as VMI, but also 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*". CPFR has been worked out as a formalized process by the standardization committee VICS (Voluntary Inter-industry Commerce Standards) and implemented within over 300 companies (VICS 2008). When both the buyer and seller collaborate through joint knowledge of sales, promotions, and relevant supply and demand information, the forecasting accuracy is facilitated for broad exchange of forecasting information.

## ECR

ECR (Efficient Consumer Response) is “*a strategy to increase the level of services to consumers through close cooperation among retailers, wholesalers, and manufacturers*”. (Reyes and Bhutta 2005) In ECR, retailers and suppliers work together to increase the service level to accomplish the requirements of consumers, and the stock and linked procedure fees are reduced at the retailer. ECR means a complete integration of information and supply chain with the implementation of information sharing and joint decision making.

The current work is focused on the decentralized collaboration at the planning decision level, between partners having different natures. Two collaboration contexts will be studied: firstly, many transport operators collaborating together to serve the deliveries demands of a manufacturer (homogenous collaboration case); secondly a manufacturer associated with many transport operators collaborating to serve the customer demands (heterogeneous collaboration case).

### **1.4 Transportation activities in the supply chain**

The collaboration between production and transportation is the study object of our work. Hence, the transportation activities are presented in this section, which is a considerable study field in the supply chain. Various transportation modes are introduced with a particular focus on the road transport operations. Different distribution chains are studied, and several indicators for measuring transportation performance are mentioned.

#### **1.4.1 Different transportation modes**

Transport in a supply chain is usually an intermediary that facilitates the physical flows of goods from a point of origin, i.e., shipper, to a point of destination, i.e., consignee (Lai, Ngai et al. 2002). Transport mode is an item for differentiating methods to perform transport. Normally, for inland transportation, rail, road and river transport can be chosen, and for oversea transportation, sea and airline transport could be the options. The infrastructure, vehicles, and operations are particular for each mode.

#### Rail

In many countries, railways play a remarkable role in economic and social development, and continue to be the major mode of transport in the field of intercity movement (Molemaker and Pauer 2014). Railway is mostly used in transporting big and heavy materials such as big machines, coal, food grain, chemicals, automobiles,

iron, steel etc. By using the rail mode, some advantages are obvious (Lun, Lai et al. 2010).

- Rail mode has high average speeds for journeys, which are peculiarly significant for providing reliable transit times.
- The railway efficiently capitalizes on land space (usually planned by a government).
- Railways are cost-efficient when dealing with volume materials, thus it can relieve a large number of heavy trucks in the road system. High fixed cost and relatively low variable cost are the features of the rail mode (Coyle, Bardi et al. 2000), as reflected below:
  - The fees of operations, maintenance, and ownership of rights of way are the major costs of the rail industry. The extensive investment in private terminal facilities is a reason for the rail industry's high fixed cost. These terminal facilities include freight yards, where trains are sorted and scheduled, and terminal areas, where shippers and connecting railways are serviced.
  - The variable cost states the cost proportionately with distance and volume. Whereas, in some kind of variable cost, such as labor cost, a certain extent of indivisibility exists, hence variable cost per unit will decrease slightly when volume increases.
  - The significant economies of scale in rail are created by the net effect of high fixed cost and relatively low variable cost. The per-unit cost is generally reduced by distributed fixed cost over greater volumes. Similarly, when the fixed cost is allocated over increasing lengths of transport, the rail ton-mile cost decreases.

Due to high fixed cost and relatively low variable cost of rail transport, huge investment of capital construction (fixed cost) is obviously a disadvantage of rail mode. Furthermore, the infrastructure investments are dedicated for a specific area and immobile after built. In the case where railways are not sufficiently used, the investments lead to wastage of huge resources. Some other disadvantages are explained in the following:

- Lack of flexibility: railway transport's routes and timings cannot be adjusted to individual requirements.
- Lack of door-to-door service: the particular tracks of railway are already built before offering service.
- Unsuitable for short distance and small loads: the investment of railway terminal facilities spends high cost. Considering the large carrying capacity of the train, full

load of the train is ideal in the view of economic operation. Trains with not full load will lead to loss of economy.

- Unsuitable for remote area: Due to the low requirement in remote areas (small quantity of population) and the high fix investment of railways, it cannot be operated economically in remote areas.

### Road

Road transport is supported with land passage by a number of vehicles, which are controlled and guided independently by a driver. Due to a higher quality of service compared with other modes of transport, road transport mode plays a primary role in the transit of higher-valued and time sensitive products. The common service characteristics of road transport mode carriers consist of accessibility, speed, reliability, frequency, and lower loss and damage rates, which offer the superiorities to road transport mode carriers over other transport modes, such as:

- The vehicles are the most flexible way of freight transport (products transiting) because of the general property of the road network. “Door-to-door” services are available offered to shippers. The alternative routes are practicable for the vehicles in any journey. The best route can be chosen by the drivers based on the information known by all the road users and their experience.
- The security of the cargo and the vehicle can be controlled more easily, since the vehicle is handled by the driver. Thus, it is easier to make delivery on time.
- The infrastructure of road transport mode is designed, built, and maintained by a government or other transport service operators. Therefore, the payment for the infrastructure is distributed to many users in the way of user fees such as a toll fee. Road transport companies can focus their full management effort on forming their major business, since the design, building, and maintenance of highways are in charge of the public organizations.

Road transport is one of the most accessible modes since the road infrastructure is for public use. A widespread road network reaches most areas of the world and has a property of high accessibility, which refers to key public infrastructure components such as highways, tunnels, and bridges.

Some drawbacks exist in the road mode. On the contrary of rail mode, the road is unsuitable for long distance due to the limitation of slow speed compared with rail mode. Furthermore, the road mode transport is not a good way for bulky traffic because of the limited carrying capacity. Additionally, the road mode is limited by some factors, for example – weather and traffic jam. During rainy season, roads

become unfit and unsafe for use. Moreover there are more chances of accidents and breakdowns in case of motor transport compared with rail mode. Besides, the charge of road mode is fluctuated closely with the price of fuel.

### River

River transport is a form of waterway transport mostly in inland case. Waterway transport is the process of transport using a watercraft, such as a boat or ship in a waterway. If a boat or other vessel can successfully pass through a waterway, it is known as a navigable waterway, which can be a natural river, a man-made canal, or an area of water closely connected to the shore. Waterway transport is suitable to transport petroleum products, chemicals, iron, machines, tools, heavy equipment, coal and several heavy goods. Water carriers are the oldest transport mode, which have promoted the development of many created cities. The water carrier system is a feasible part of the transport system, and it competes with other inland transport modes such as roads and rails. All-in-one packages are always provided by the water carriers, for example carriage from a seaport to a container inland depot and return of empty containers (European Conference and Maritime Transport Committee 2005). The low-cost feature is a superiority of river transport mode compared with other inland transport mode. For the movement of non-liquid products, the lowest-cost transport mode is generally water transport. However, a pipeline is usually the lowest-cost transport mode for transiting liquid products. Nevertheless, one of the disadvantages of water transport is slow. Compared with other transport modes, such as rail, roads, and air, water transport has the longest transit time. Accessing the waterways is necessary for customers of the water carriers. Hence, another disadvantage of the water transport is low accessibility.

### Sea

Sea transport is another form of waterway transport, normally concerning oversea cargo movement. For example, in the container transport chain, the key role of sea container carriers is customarily offering liner services.

### Air

Air transport is the fastest modern way of transport. At the beginning, only passengers, mails, perishable goods and costly light goods were transported by air transport. Whereas, nowadays air transport system has also become suitable for other industrial and commercial products. The importance of air transport has gradually growing. This is the fastest speed means for transporting passengers and goods to different parts within a country and different countries of the world.

## 1.4.2 Modes comparison

Diversities exist in the operational environment among the major transport modes (Christiansen, Fagerholt et al. 2004). Accordingly a general description is stated for the advantages and disadvantages of each transportation modes in Table 1-1.

**Table 1-1 Advantages / Disadvantages of the five transport modes**

|              | Advantages                                      | Disadvantages                         |
|--------------|---|---------------------------------------|
| <b>Rail</b>  | Speed and reliability, suited for large volumes | Heavy investment                      |
| <b>Road</b>  | Suited for short and middle distances           | Pollution / Saturation of the network |
| <b>River</b> | Reliability, suited for large volumes           | Slowness                              |
| <b>Air</b>   | Speed   | High cost                             |
| <b>Sea</b>   | Low cost, suited for large volumes              | Slowness                              |

Some detail characteristics of each transport mode are shown in Table 1-2, as the transport mode is suitable for which type of parcels, whether the transport mode can be combined with other transport mode, and the speed, costs of each transport mode etc.

**Table 1-2 Main freight transport modes**

| CHARACTERISTICS                    | MODES   |   |                             |   |                        |
|------------------------------------|---|---|-----------------------------|---|------------------------|
|                                    | Ground transportation                                 |   |                             | Oversea transportation                      |                        |
|                                    | Road  | Rail  | River                       | Sea   | Airline                |
| Small parcels (<50kg)              | Yes (courier services)                                | Yes (courier services)                                      | No                          | No  | Yes (courier services) |
| Large parcels                      | No (except exceptional transport)                     | Yes   | Yes                         | Yes   | Yes                    |
| Heavy parcels                      | No  | Yes   | Yes                         | Yes   | Yes                    |
| Types of flows                     | Domestics + Continental Europe + Middle East          | Domestics + Continental Europe + Middle East                | North Europe                | Inter continental                           | Inter continental      |
| Combined transport (w/t container) | Combined with rail or sea transport                   | Combined with road or sea transport                         | Combined with sea transport | Combined with sea, road and river transport | -                      |
| Door-to-door transport             | Yes   | Yes (except RCT*)   | No **                       | No **                                       | No **                  |
| Speed                              | Fast but congestion of roads & territorial boundaries | Not fast (priority to passengers, disparity of EU railways) | Not fast                    | Not fast (congestion of larger harbours)    | Very fast              |
| Costs                              | Middle  | Weak  | Weak                        | Weak  | High                   |
| Packaging                          | -   | -   | -                           | Strong                                      | Weight savings         |

\* RCT : Rail-Connected Terminal

\*\* Except plants located in a Port Area

Combined transport can gather the advantages of chosen modes, for example, rail-road combined transport, which can offer door-to-door service by road mode and

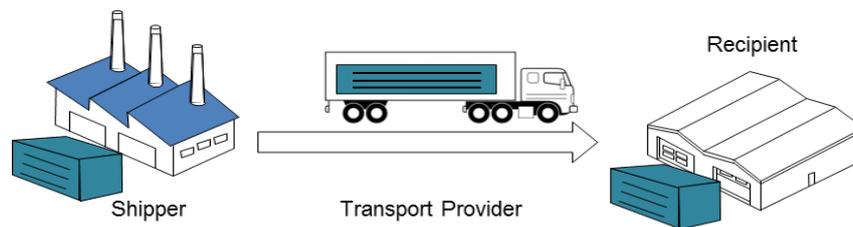
have the low ton-km price by rail mode. However, combined transport may have additional costs which are associated with moving freight by changing transport mode, at least more labor costs are required by switching the mode. Moreover, if the communication of each transport operator is not in time, the equipment may be idle sometimes, which will increase transportation costs.

### 1.4.3 Segmentation of supply and demand for road transport operations

Transport services offer is structured through many traditional segments. Each segment is characterized by the parcel size, the complexity of the service and the mode of price calculation. Four types of offers may be mainly distinguished.

#### Charter (or complete batch)

It usually consists in using the complete transportation capacity of any vehicle to serve only one shipper and provide door-to-door road transportation without any transshipment. Numerous actors with small sizes are present in this segment, and this type of offer is not known to be logistically complex. The main disadvantage is the small profit margin that any transport provider can expect in offering their services. Figure 1-11 is a concise scheme of complete batch.

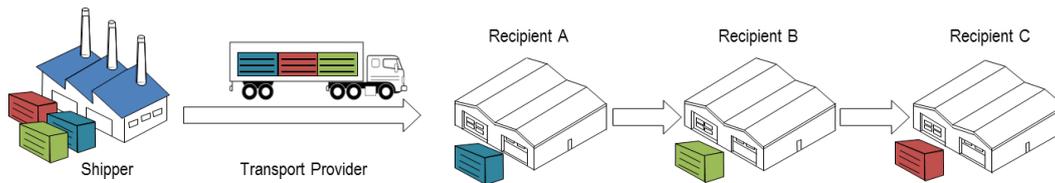


**Figure 1-11 Complete batch**

Pricing frequently used is based on a fixed term, covering the fixed expenses of the transport provider, and a variable term proportional to the number of kilometers travelled during a year.

#### Transport of batches (partial batch)

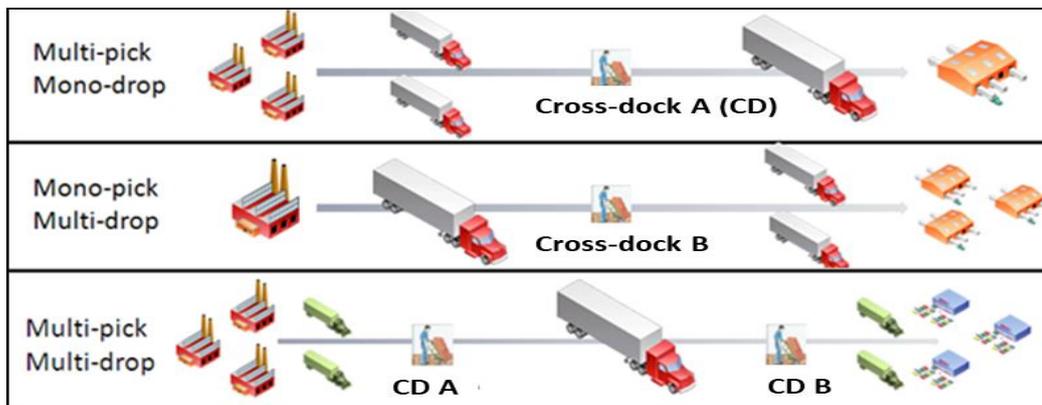
This type is a variant of the previous segment, when parcels with high dimensions do not need to use the complete capacity of a vehicle. The shipper books a part of capacity of a vehicle which is shared between several loaders, with a gradually decreasing price depending on the number of reserved linear meters. The transport provider then will serve successively the different delivery points according to a sequence and a time schedule that can be optimized or contractually defined. A simple example of partial batch is represented in Figure 1-12,



**Figure 1-12 Partial batch transportation**

The transport of partial batches may be used in many situations, shown in Figure 1-13:

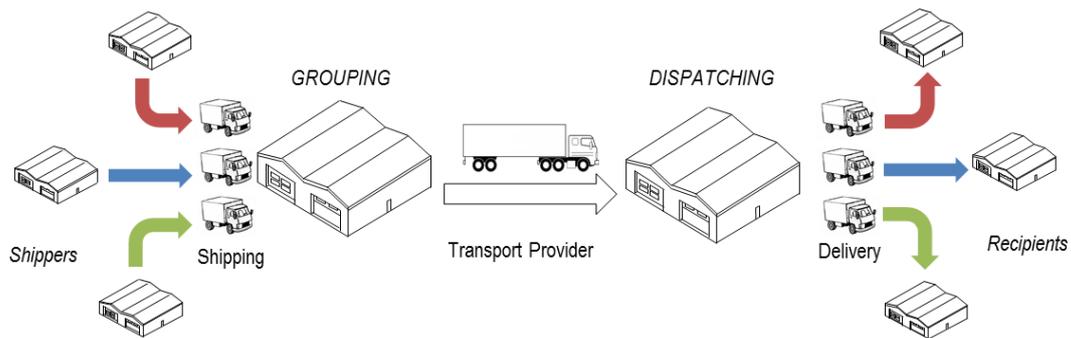
- Multi pick / Mono drop: various pickup points are visited before moving the load to one delivery point (with eventually a cross docking just after the picking),
- Mono pick / multi drop: only one pickup point is visited before serving many delivery points (with eventually a cross docking just before the delivery),
- Multi pick / Multi Drop: Many pickup and delivery points are visited.



**Figure 1-13 Three situations of partial batch transportation**

### Grouping

This segment of the transportation services offering concern parcels with a weight exceeding 3 tons. It implies that the transportation provider has bundling/unbundling platforms to perform much transshipment if necessary. The transportation activity is decomposed in : (1) a picking, (2) a cross docking at a bundling platform, (3) an online and massive transport between a bundling platform and an unbundling platform, (4) a new cross docking and (5) the distribution of parcels to customers, shown in Figure 1-14. The transport provider usually organizes its activity by developing regular line transportation activities between its owned logistics platforms. A vehicle capacity is shared between different loaders for massive transport and for pickup and delivery activities. Pricing is dependent of the number of reserved linear meters.



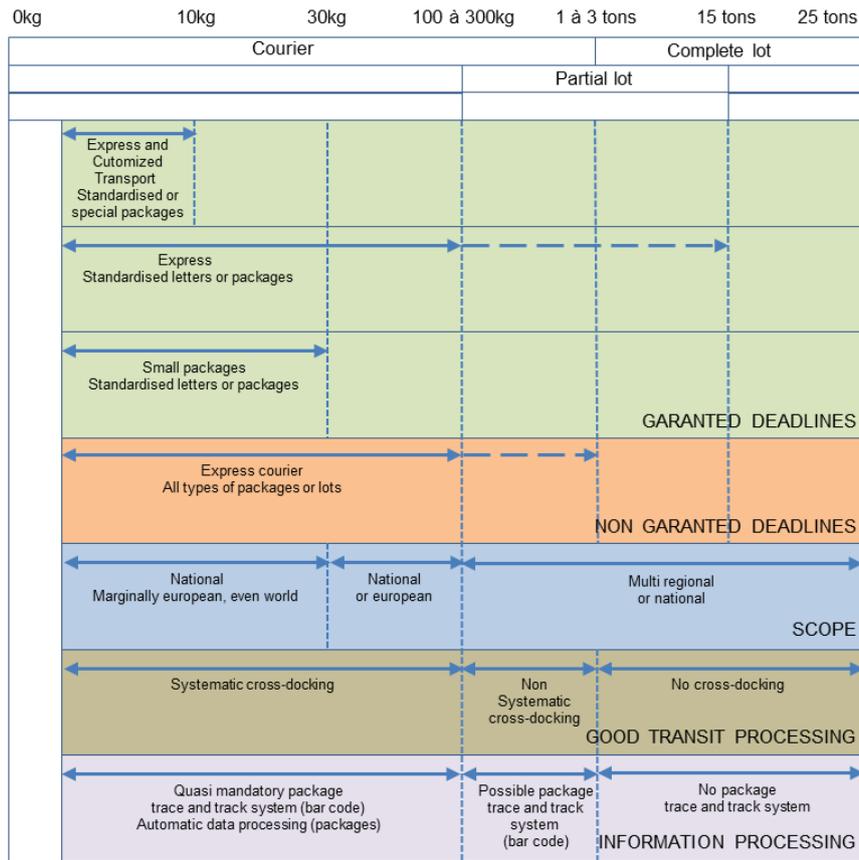
**Figure 1-14 Grouping transportation**

### Couriers services

This service concerns the shipping of parcels weighting not more than 3 tons, and has a common modus operandi with the bundling activity (three transport operations and two cross docks). Nevertheless, some differences may be highlighted in many points: first, in most cases, the picking is not requested by the shipper, but is made at a fixed schedule. Parcels processing is industrially made (cross docking) and pricing is usually estimated in relation with the barycentric distance between the pickup and delivery zones. This segment is a major market part of the transportation activity. The offering is structured on three dimensions:

- Delays: courier's services providers organize their activities by grouping delivery points in geographical zones, and define a delay from any shipping zone to each delivery zone.
- Weight scoring method: pricing is calculated according to some specific intervals of weight values (i.e. from 0 to 10kg, from 10 to 20 kg, and so on).
- Ancillary services: transport providers offer other services to their customers, such as cash-on delivery payment, parcel tracking, or the widening of the contractual liability.

The different segments of the transportation offering are synthetized in Figure 1-15, in relation with the parcel's weight, the scope of the offering, the existence of guaranteed deadlines, the transit processing mode and the information processing.



**Figure 1-15 Road transport segmentation**

We retain from these notions that:

The road transportation activity as studied in this work mainly concerns chartering. Any truck used in the transportation planning process is dedicated to only one shipper and one recipient. Pricing we adopt is classically decomposed in a fixed term and a variable term and the estimation of their values is based on the French Road National Committee (CNR) method. Notice that the main principles of CNR are defined in the experimental chapter (chapter 4) of this work.

#### 1.4.4 Transport Performances

Variable quality of transport services are provided by each transport operator (i.e. carrier). Indeed, it is not easy to make the decision of choosing one of them, but some service factors are available to help the carrier selection.

##### Transport cost

Transport cost is a considerable parameter for carrier selection in the early stage of the selection process. Rates, loading and unloading charges, and special services available (e.g., stopping in transit) from carriers are all included in the transport cost. Due to the

specific cost structures of the transport modes, transport cost is variable according to each mode, nevertheless the variation exists in the transport cost of different carriers within a transport mode (Coyle, Bardi et al. 2000). However, the importance of transport cost is weakened, since the cost trade-off between the services provided and the operations cost are more concerned in the current logistics (Gubbins 2003).

#### Transit time and reliability

Transit time is the total duration from the time when the goods are prepared to be available for dispatch by the shipper until the time where the same goods are delivered to their destination address by the carrier. The time required for pickup, handling, and delivery is included in the transit time. The consistency of the transit time is the reliability of the carrier (Lai and Cheng 2009). When a product is perishable, transit time is a critical parameter of the decision, since fast delivery can ensure minimum loss due to the product deterioration. Let us consider another example where an urgent need is required for spare parts to repair a ship, which has to remain idle until the part is available; in this case, the loss of shipment delay will more important than the transport cost.

#### Inventory and stock out

Inventory and stock out costs are impacted by transit time and reliability. The higher inventory levels are required because of the longer or uncertain transit times. More buffer inventory is necessary for a firm when the transit time of its carrier is not consistent. The competitive advantage of a carrier stem more or less from the reliability provided to its customers. Both inventory and stock-out cost of the customers are reduced due to a reliable transit time of the carrier.

#### Availability and accessibility

Availability refers to a carrier's ability to provide required equipment and facilities to facilitate the transport of a particular type of cargo. For instance, providing a temperature-controlled container for shipping frozen cargo is a kind of availability. Accessibility is the carrier's ability to provide the service over the route. The geographical limits of a carrier's route network are an example of accessibility. Whether the required transport service can be physically accomplished by a particular carrier depends on availability and accessibility.

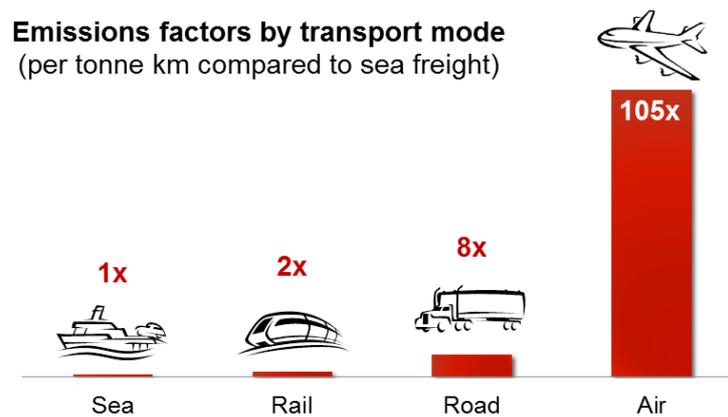
#### Security

Security is the competence of a carrier to maintain the products at the same state as when they were picked up from the customer of the carrier. The indirect transport

service cost is regarded as in the scope of security, such as damaged or lost products in transit. Considering the involved monetary loss, the damaged or lost products will impact the stock-out cost, even an unreliable transit time.

### Carbon footprint

Carbon footprint is an indispensable factor for carrier selection in the context of sustainable supply chain. The definition of carbon footprint is stated in (Wiedmann and Minx 2008), “*The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product.*” In terms of multiples of comparable carbon dioxide emission intensity, the impact of different transport modes is presented in Figure 1-16.



**Figure 1-16 Emissions factors by various transport modes**

Considering carbon dioxide emissions per ton of cargo transported during one kilometer (ton km), sea mode is recognized as the most efficient form of commercial transport. The carbon dioxide emissions of rail, road and air mode are respectively 2, 8 and 105 times the sea mode in terms of per ton km (Hoen, Tan et al. 2014).

In this work, the distance of transit is considered in the national wide, and the transit time should be known before the carriage service. In this context, we focus on the road transport, which will be the unique transport mode in the whole transit process.

## **1.5 Conclusion**

In this chapter, the notions of logistics, supply chain and supply chain management are gradually introduced, the concept of collaboration in the supply chain is presented and finally a focus is given on the transport activities. This defines the general context of our thesis work.

Tactical decisions are the object to study in this work. Indeed supply chain planning is concerned, particularly, production planning and distribution planning. Notice that both terms “Transport Planning” or “Distribution Planning” interchangeably refer to the mid-term planning problems in this thesis.

We focus on the cooperation of distribution and production partners having different natures and keeping their own decision. From this point of view, the supply chain is mainly considered as a decentralized decision making system. Certainly, the information sharing is necessary for the cooperation. Particularly, the manager needs personal information of each partner and keeps it confidential from other partners.

Notice that two collaboration contexts will be studied in chapter 3: firstly, many transport operators collaborating together to serve the deliveries demands of a manufacturer (homogenous collaboration case); secondly a manufacturer associated with many transport operators collaborating to serve the customer demands (heterogeneous collaboration case).

The transport distance considered is national wide, and the transit durations are known before the carriage service. Consequently, we focus on the road transport, which will be the unique transport mode in the whole transit process. More precisely the chartering mode of the road transportation activity is mainly concerned in our study. Any truck used in the transportation planning process is dedicated to only one shipper and one customer (destination). Transport price we adopt is classically decomposed into a fixed term and a variable term.

In the next chapter, the state of art will focus on supply chain planning and introduce the basic concepts of game theory on which rely our collaboration approach.

# **Chapter 2**

## **State of art of supply chain planning and elements of game theory**

### **2.1 Introduction**

The objective of this chapter is to propose an efficient approach to solve the problem of coordinating production / transportation planning decision making. To seek a solution of our problem, we will study the supply chain planning background in section 2.2, focusing on the coordination of partners. To solve the planning problem, game theory will be introduced in section 2.3, which involves non-cooperative game and cooperative game.

### **2.2 Main approaches of supply chain planning**

A classification for the main exponents of the supply chain planning is presented in this section, in order to offer a concise view of the domain. The main approaches can be analyzed in two main groups: centralized planning and decentralized planning.

#### **2.2.1 Centralized planning**

All supply chain members are integrated to optimize the entire supply chain in the centralized planning. Nonetheless, a trusted sharing environment is required so that the members can accept to export all needed information to implement the integration. Notice that centralized planning is not always based on full information sharing between entities.

The centralized planning approaches are based on a complete model of partners supporting the decision making for all supply chain partners (Arshinder, Kanda et al. 2011). The hypothesis of complete information sharing is necessary in this case. Then an exact approach based on mathematical programming can be used to solve these model, such as decomposition approaches (Barbarosoğlu and Özgür 1999), or approximated approaches, such as heuristics or metaheuristics. Also included in this group are the hierarchical planning which is a kind of centralized planning, where the centralized problem is undertaken through decomposed into some hierarchical but interdependent sub-problems. In reality these centralized approaches are always difficult to apply, since enterprises do not wish sharing their confidential data.

### **2.2.2 Decentralized planning**

Decentralized Planning could be defined as a type of planning where local organizations and institutions formulate, adopt, execute actions and supervise the plan without interference by the central control system. In this thesis, the objects of decentralized planning are the fully independent partners. (Taghipour and Frayret 2013) provided a general classification of decentralized coordination approaches in supply chain planning, which can be implemented in many ways such as advanced cooperation, request for actions or information exchange. For example, the production and delivery of final products are significantly impacted by the supply contracts between customers and suppliers. The supply commitments can powerfully manage and plan the product flow in a supply chain as the contract approach prescribed in (Amrani, Deschamps et al. 2012). These supply commitments can use frozen horizon or flexibility rate. In the former, the ordered quantities are regarded as fixed during this time period and cannot be changed between two planning decisions. In the later, customers can modify the ordered quantities within a certain limit and outside the frozen horizon.

Negotiation is an advanced cooperation form, which is variably defined according to the authors. It can be stated as being an exchange between two or more partners searching an agreement (Forget, D'Amours et al. 2009). Three main categories of negotiation approaches are proposed in the following:

#### *Heuristic approaches*

Partners' local initial plan is iteratively regulated according to the ability of other partners. (Dudek 2009) proposed a heuristic approach, where a negotiation-based scheme is developed. The two partners' orders and supply plans can be synchronized for planning in the supply chain due to the use of mathematical programming models to get the optimal planning. An extension of this model is presented in (Taghipour and Frayret 2013), which deal with the dynamic changes influencing planning in the supply chain environment. In the same genealogy, a theoretical scheme is formulated in (Albrecht and Stadtler 2015), which coordinate decentralized partners with the purpose of involving all supply chains functions. A negotiation mechanism is developed for collaborative planning within a supply chain based on fuzzy rules in (Yahia, Ayadi et al. 2015), which is limited to the cooperation between manufacturers and takes into account only production planning without distribution, supplier or retailers. The negotiations between partners are applied practically and easily through these approaches, however they are not mathematically proven and it is not guaranteed that they convergence toward an agreement.

### Game theory-based approaches

The best decision made by a given partner in a supply chain is found taking into account the possible decisions of others. (Simchi-Levi, Wu et al. 2004) applied the coordination and negotiation in a supply chain. Two main types of games are mentioned, which are cooperative and non-cooperative (i.e., competitive game). Powerful strategies are offered by game theory. However, the implementation of game theory to solve a practical problem, such as planning coordination, remains a delicate topic which is discussed in the second part of this chapter (section 2.3).

### Multi-agent system-based approaches

Developed in artificial intelligence problem solving, these approaches has been intensively applied to supply chain collaboration, which is particularly suited to automated negotiation due to the implementation of decision mechanisms such as auctions or bidding. A negotiation-based mechanism supported by a multi-agent system is presented in (Hernández, Mula et al. 2014), which focuses on the collaboration of demand, production and replenishment planning, and combines with the use of standard planning methods, such as the material requirement system (MRP) method. (Fischer, Chaib-Draa et al. 1999) developed a methodology and a multi-agent tool for the simulation of the transportation domain, whose negotiation-based decentralized planning approach is implemented to the scheduling of the transportation orders among an agent society involving shipping companies and their trucks. The multi-agent system-based approaches are central and powerful methods. Its application for collaborative planning is limited only by the methodology used to build the model and the decision mechanisms integrated in the agents.

### **2.2.3 Transportation and Distribution planning**

Most of the above listed works mainly deal with the production operations, while it can be helpful to investigate the planning problem concerning the logistical operations, such as distribution or transportation. These two functions do not concern the same nature of operations.

Many papers in transportation planning study automated negotiation approaches. (Sprenger and Mönch 2014) developed a decision support system for cooperative transportation planning based on a multi-agent system (MAS) and Vehicle Routing Problems (VRP) which are supported by discrete-event simulation. These same authors proposed two years before a methodology to solve large-scale cooperative transportation planning problem (Sprenger and Mönch 2012) based on a decomposition of the entire problem in a set of rich vehicle routing problems.

(Memon and Archimède 2013) present a distributed architecture planning of transportation activities for a better utilization of transport resources. Others authors (Wang, Kopfer et al. 2014), (Krajewska and Kopfer 2009), (Ziebuhr and Kopfer 2016) tackle the problem of transportation planning by combining vehicle routing and subcontracting in an integrated operational transportation planning which jointly propose optimized plans for a fleet of vehicles owned by a forwarder and subcontractors' vehicles.

Concerning the Distribution Planning, (Ivanov, Pavlov et al. 2014) mention that “it is a referenced research problem in the domain of distribution networks”. They assume that distribution planning deals with decisions on directing commodity flows, dimensioning and designing the transportation network flows under cost minimization constraints. Thus, for instance, (Rancourt, Cordeau et al. 2015) focuses on location problems of sets of distribution centers. Distribution planning becomes a central problem in cold chain management, even if this domain is relatively under-researched, as mentioned in (Hsiao, Chen et al. 2017). The authors indicate in their state-of-art that studied problems in this field consider the cost and impact of food quality deterioration in the planning models, or concern the multi-item-multi- temperature vehicle distribution problem. They proposed to study a cold chain food distribution planning problem and to make plans in order to guarantee a good quality of products under optimized cost considerations. (Crainic, Dell’Olmo et al. 2015) define the distribution planning problem as the search for optimal routes and scheduling of a fleet of vehicles making freight moves between terminals of a dry-port-based intermodal system. This paper shows that, in the literature review, some close relations exist between transportation and distribution planning problems.

#### **2.2.4 Production and distribution planning**

Our problem belongs to the research scope of production and distribution/transport, thus, the literatures concerning the planning between production and distribution should be referred.

The centralized approaches in production and distribution planning is reviewed in (Erengüç, Simpson et al. 1999, Mula, Peidro et al. 2010, Fahimnia, Farahani et al. 2013). A mixed-integer linear programming model was developed by (Barbarosoğlu and Özgür 1999), which is solved by Lagrangian and heuristic relaxation techniques to transform the problem into a hierarchical two-stage model: one for production planning and another for transportation planning. A production-distribution problem concerning multi-firm, multi-product and multi-period was solved by a mixed-integer linear planning model in (Dhaenens-Flipo and Finke 2001), where the supply chain is

formed as a flow network. A whole supply chain in the pulp mill industry is considered in (Bredstrom and Ronnqvist 2002); production and distribution planning problems are studied, and the authors use flexible ways to aggregate time periods to find good solutions within reasonable time limits. An integrated transport and production planning model in the context of multi-plant, multi-retailer, multi-product and multi-period is presented in (Park 2005), which is based on the mixed-integer linear programming. (Selim, Araz et al. 2008) mention the uncertainty of the individual decision makers in charge of manufacturing plants or distribution centers and the author proposes a fuzzy multi-objective linear programming model is introduced. A nonlinear optimization problem is formulated for a problem in which a third party logistics (3PL) provider coordinates the distribution between suppliers and customers through a consolidation center in a distribution network (Song, Hsu et al. 2008); this model is solved by a Lagrangian method. Two approaches are compared for solving the problem of coordination between production and transport activities in (Bonfill, Espuna et al. 2008), which aim to manage the inventory profiles and material flows between the sites. One approach is an integrated model, and the other one is a solving strategy using sequentially production and scheduling models. An integrated production and distribution planning on highly perishable products is studied in (Amorim, Günther et al. 2012). Through a multi-objective framework, the advantages of integrating these two intertwined planning problems in the integrated model at an operational level are explored. (Jha and Shanker 2014) propose an iterative approach for optimizing integrated problem in a single-vendor multi-buyer supply chain, which solves the combination of an inventory problem and a vehicle-routing problem considering the transportation cost. A solution approach based on the Lagrangian Relaxation approach of integrated model is applied in a three echelons supply chain with multiple distribution centers (Nasiri, Zolfaghari et al. 2014), production sites and suppliers. (Zamarripa, Hjalila et al. 2014) proposed a linear programming model concerning the tactical planning to coordinate production and distribution in a chemical supply chain with multi-product and multi-echelon. (Zamarripa, Aguirre et al. 2013) search for the best scenario among several alternatives by comparing the integrated model with a competitive game theory-based approach.

Considering the decentralized approach, cooperation is an efficient method to solve the problems. The cooperative planning is focused on the coordination on the process and information sharing, which aims to reduce the inventory and transportation cost, and makes the supply chain more efficient. Collaborative planning in supply chains has been paid great attention for many years (Albrecht 2009, Stadler 2009). As far as the scope of production and distribution, a negotiation process is presented in (Jung

Hosang, Chen F Frank et al. 2008, Jung Hosang, Jeong Bongju et al. 2008), which propose to seek a contract for a distributor and a manufacturer in a distributor driven supply chain. However, the prices, auctions and the availability of extra resources are not considered in the negotiation principle, where the manufacturer is offered the opportunity to report shortages, thus, little flexibility is provided by this negotiation principle. A decentralized coordination mechanism is offered in (Taghipour and Frayret 2010), which utilizes negotiation concerning two enterprises within the supply chains. In fact, limited attention has been paid to the cooperation between fully decentralized production and distribution focusing on mid-term tactical planning. Considering the collaboration between production and transportation, a decentralized approach based on multistep negotiation is proposed in (Jia Zhen-Zhen, Deschamps Jean-Christophe et al. 2016), where a heuristic decentralized approach is applied. The main issues are the definitions of concepts such as negotiation space, compensation and plan acceptance. The limitation of the considered approach was nevertheless resulting in a solution more profitable for transport operators. This approach is constructed on the negotiation-based collaborative planning process, which was proposed by (Dudek 2009). The partners exchange only non-confidential data and search new compromise solutions through an iterative improvement process. In this process, an alleged “preferred plan” is used as a target plan for each partner to represent its own interest. The customers have the possibility to ask for compensation associated with a compromise proposal in this process. The relation between suppliers and customers is concerned in (Dudek 2009), however, the transport operator is explicitly considered as a partner in collaborative planning process in (Jia Zhen-Zhen, Deschamps Jean-Christophe et al. 2016).

In this thesis, we investigate a network of SC partners who look for close cooperation. Each partner accepts to exchange some information but search for keeping their own autonomy for decision making. So this problem is in relation with the study of decentralized approaches for distribution and production cooperation implemented at the tactical decision level. Distribution is studied from the planning point of view, for which decisions consist in defining quantity to move from shippers to recipients along a time horizon.

Following up on the work made in (Jia Zhen-Zhen, Deschamps Jean-Christophe et al. 2016), where the distribution-production cooperation is solved by a negotiation-based approach based on planning models and heuristics, we intend to study the problem in another perspective by applying some principles of cooperation based on the Game Theory. We intend to develop a cooperative approach that guarantee a fair repartition of gains and/or costs each partner of the supply chain.

## 2.3 Elements of Game Theory

Game theory is a general theory which aims to offer a logical method to predict outcomes for a specific game. Due to the breadth of knowledge in this field, this part of the thesis is oriented towards the utilization of the most promising concepts to contribute to the collaboration in planning according to our point of view. So the first sub section 2.3.1 presents some background definitions in this field. Then we follow the differentiation of game theory according to situations in which a decision-maker acts independently from all other decision-makers and those in which multiple decision makers can work as a group. Examples of non-cooperative games (i.e. the former case), are introduced in section 2.3.2 in which decision-makers cannot make a “binding agreement” to actualize some action on one another. The latter case is studied in section 2.3.3 which describes some of the main concepts of the cooperative game theory. We complete this overview of the game theory with the choice of the most appropriate approach as regards the solving of mixt (production/transportation) cooperative planning problems.

### 2.3.1 Basic concepts in game theory

This section presents successively the basic concepts of the game theory: the elementary notions, the mathematical definition of a normal form game, some types of game and the differences between cooperative and non-cooperative game.

#### 2.3.1.1 Elementary notions and vocabulary

Let us introduce the main notions related to the game theory. Let us consider the elementary game between two players called “matching pennies” which can be used to understand some basic vocabulary and notions. Each player has a penny and must secretly turn the penny to heads (labelled H) or tails (labelled T). The choices of the players are revealed simultaneously. If there is a matching between the pennies (both heads and both tails), then player 1 keeps both pennies, so wins one from player 2 (+1 for player 1, -1 for player 2). If the pennies do not match (one heads and one tails) player 2 keeps both pennies, so receives one from player 1 (-1 for player 1, +1 for player 2). The payoff matrix of matching pennies game is presented in Table 2-1.

**Table 2-1 Matching pennies game (matrix form)**

|          |           | Player 2  |           |
|----------|-----------|-----------|-----------|
|          |           | Heads (H) | Tails (T) |
| Player 1 | Heads (H) | +1, -1    | -1, +1    |
|          | Tails (T) | -1, +1    | +1, -1    |

### Decision-makers

Decision-makers in game theory are called players. They can be humans, organizations such as firms, which can be interpreted as acting agents. In the example of the matching pennies, obviously the two players are player 1 and player 2.

### Action /Actions profile

The actions are the available options that the players can take. In the matching penny example, the set of actions are H and T. An action profile consists of the actions of all the players at a given time of the game.

For instance, in the matching penny game if agent 1 plays H and agent 2 plays T, the action profile is (H, T).

### Strategy / Strategies profile

First, let us note that the distinction between strategy and action is quite low. The choice of an action by a player and the fact to play this action is a strategy (it is called a *pure strategy*). More precisely, strategy  $s_i$ , of player 'i' is an action plan that prescribes an action of this player each time he has to play.

Some more complex strategies exist and are based on the selection of all actions according to some probability distribution. These more complex strategies are called *mixed strategies*.

The choice of a strategy for all the players of the game at a given time is a strategy profile.

### Utility function and player objectives

For each possible set of actions, there is an outcome. A utility function (or payoff) assigns a number for every possible outcome of the game and for each player.

Note that the utility of a player depends on the strategy profile, not just its own strategy. Accordingly, the payoff of a player depends not only on its own strategy choice but also on all other players' strategy choices. The relationship is described as a payoff function from the set of all possible outcomes (i.e. the set of all possible strategies of all players) to the set of real numbers.

The utility function of the player "i" is labelled  $u_i(s)$ . For instance in the matching pennies game, the utility are  $u_1((H, T)) = 1$  for player 1 and  $u_2((H, T)) = -1$  for player 2.

A player's objective is to choose a strategy that can bring a payoff as high as possible, which is called the rationality hypothesis in game theory. We assume players/agents are expected utility maximizer so that a higher number implies that the outcome is more preferred.

Notice that an important notion is the **Pareto dominance** of a strategy for a given utility function. A strategy  $s_i$  is a strictly dominant strategy for player  $i$  if it maximizes uniquely payoff of player  $i$  for any strategy that the rivals of player  $i$  might play. So it is possible to search for Pareto optimal strategy " $s_i$ " such that there is no other strategy " $s_j$ " that dominates " $s_i$ "

### 2.3.1.2 Definition of a normal-form game

Let us give in this paragraph, the mathematic definition of normal-form game which is a classical form of game.

A (finite, n-person) normal-form game (Kevin Leyton-Brown and Shoham 2008) is a tuple  $(N, A, u)$ , where:

- $N$  is finite set of n players, indexed by  $i$ ;
- $A = A_1 \times \dots \times A_n$ , where  $A_i$  is a finite set of actions available to player  $i$ . Each vector  $a = (a_1, \dots, a_n) \in A$  is the action profile;
- $u = (u_1, \dots, u_n)$  where  $u_i: A \mapsto R$  is a real-valued utility (or payoff) function for player  $i$ .

### 2.3.1.3 Types of games

Game theory explicitly includes the effect of others' decisions/actions into one's objective function. Therefore, it is not a set of single-person optimization problems but a social optimization problem, or a complicated problem of conflicting optimizations. The informational structure that specifies what players know and what they do is an important and a mathematically complex part of a game. This structure gives birth to different type of games:

- When all players know the set of players, the set of strategies of each player, and the payoff functions of all players very well, the game is said to have **complete information** (Kline 2015).
- Otherwise, the game has incomplete information. Information crucially affects each player's decision making. If the game has incomplete information, compared with "all players know the set of players, the set of strategies of each player, and the payoff functions of all players very well" in the complete information game,

formulating a game that players do not know well all these elements of information is a complex problem (Gibbons 1992).

Complete information games can be further classified in terms of their informational structure. Whether past players' decisions are known to later player(s) affects the latter's decision making. **Perfect information games** are those in which all players know all players' past decisions at any stage of the game (Samet 2013). Otherwise, the game **has imperfect information** (Lins, Rêgo et al. 2013). For example, chess is a perfect information game, for players with good enough memory.

#### **2.3.1.4 Cooperative versus non-cooperative games**

The book of von Neumann and Morgenstern (Von Neumann and Morgenstern 1944), states the basis of game theory, where an widespread analyses of both non-cooperative and cooperative situations are developed. In fact, the cooperative game and the non-cooperative game provide the most basic classification used in the game theory, according to the behavior logic of the plays.

Ascertaining what happens in a strategy combination when individuals make independent and strategic decisions is the purpose of non-cooperative game theory. A non-cooperative game is one in which players are unable to make enforceable contracts outside of those specifically modeled in the game and only think about their own profit. Hence, it is not defined as games in which players do not cooperate, but as games in which any cooperation must be self-enforcing.

On the contrary the cooperative game theory intends to identify a payoff set when various coalitions are tried out to improve participants' collective welfare. There are games where players can enforce contracts through outside parties. These cooperative games are in relation with a collective rationality, in which the players think about the profit of the group, and there is a binding agreement (such as contract or instance).

Finally the essential difference between cooperative and non-cooperative game can be state as follows: the participants in a non-cooperative game are individual players while they are groups of players in the cooperative games.

#### **2.3.2 Non-cooperative game**

In the remaining of this section, two well-known uncooperative games are presented: the classical "prisoner's dilemma" game and one of the oldest game theory models from the field of economy named the "Cournot competition".

### 2.3.2.1 Prisoner's dilemma

“Prisoner's dilemma” (Rapoport and Dale 1966) can be described as follows: Two members of a criminal gang are arrested and imprisoned. Each prisoner is in solitary confinement with no means of communicating with the other. The prosecutors lack sufficient evidence to convict the pair on the principal charge. They hope to get both sentenced to a year in prison on a lesser charge. Simultaneously, the prosecutors offer each prisoner a bargain. Each prisoner is given the opportunity either to: betray the other by testifying that the other committed the crime, or remain silent. Let us consider two players A and B, the offer is:

- If A and B each betray the other, each of them serves 2 years in prison
  - If A betrays B but B remains silent, A will be set free and B will serve 3 years in prison (and vice versa)
  - If A and B both remain silent, both of them will only serve 1 year in prison
- According to the above description, the payoff matrix can be represented as shown in Table 2-2. Based on the previous definition (section 2.3.1.2), it is obvious that “Prisoner's dilemma” is a normal-form game.

**Table 2-2 Prisoner's Dilemma**

|          |        |          |        |
|----------|--------|----------|--------|
|          |        | <b>B</b> |        |
|          |        | Betray   | Silent |
| <b>A</b> | Betray | -2,-2    | 0,-3   |
|          | Silent | -3,0     | -1,-1  |

Let us notice that “Betray” has the meaning of “cooperate” in the context of this game.

### 2.3.2.2 Cournot game

Cournot competition is another famous non-cooperative game. It is an economic model used to describe an industry structure in which companies compete on the amount of output they will produce, which they decide on independently of each other and at the same time. It has the following features:

1. There is more than one firm and all firms produce a same product;
2. Firms do not cooperate;
3. Each firm's output decision affects the good's price;
4. The number of firms is fixed;
5. The firms compete in quantities, and choose quantities simultaneously;

6. The firms are economically rational and act strategically, usually seeking to maximize profit given their competitors' decisions.

Each firm's own output decision will not have an effect on the decisions of its rivals. Price of goods is a commonly known decreasing function of total output. All firms know the total number of firms in the market, and take the output of the others as given. Each firm has a cost function. Normally the cost functions are treated as common knowledge. The cost functions may be the same or different among firms. The market price is set at a level such that demand equals the total quantity produced by all firms. Each firm takes the quantity set by its competitors, evaluates its residual demand, and then behaves as being in a monopolistic competition (Fang and Shou 2015), where some partners are always better off with other partners incentives.

We present hereunder a simple example of Cournot competition between two plants in a given market (i.e. plant 1 and plant2). Plant 1's amount of product output is denoted as  $q_1$ , and profit is  $u_1$ . Plant 2's amount of product output is denoted as  $q_2$ , and profit is  $u_2$ . The total quantity of products in the market is  $Q$ , and  $Q = q_1 + q_2$ . The price of the product in the market is  $P$ , and  $P$  can be expressed by the decreasing function of  $Q$ :  $P = P(Q) = 8 - Q$ . Both plants have the same marginal cost to produce this product, which are denoted respectively as  $c_1$  and  $c_2$ , and  $c_1 = c_2 = 2$ .

Consequently, profit functions  $u_1$  and  $u_2$  can be expressed as follows:

$$u_1(q_1) = q_1P(Q) - c_1q_1 = q_1[8 - (q_1 + q_2)] - 2q_1 = 6q_1 - q_1q_2 - q_1^2$$

$$u_2(q_2) = q_2P(Q) - c_2q_2 = q_2[8 - (q_1 + q_2)] - 2q_2 = 6q_2 - q_1q_2 - q_2^2$$

Each plant prefers to maximize their profit. To get the maximum, we have to get the derivative first, and make the derivative equal to 0, as following:

$$\begin{cases} 6 - q_2 - 2q_1 = 0 \\ 6 - q_1 - 2q_2 = 0 \end{cases}$$

The solution of  $q_1$  and  $q_2$  to get the maximum profit of each plant are denoted as  $q_1^*$  and  $q_2^*$ , and we can get the values of  $q_1^*$  and  $q_2^*$  from the above derivative functions:  $q_1^* = q_2^* = 2$ . Meanwhile, we can get the value of  $Q$ ,  $P$ ,  $u_1$  and  $u_2$ :  $Q = q_1 + q_2 = 2 + 2 = 4$ ,  $P = 8 - Q = 8 - 4 = 4$ ,  $u_1 = 6q_1 - q_1q_2 - q_1^2 = 4$ ,  $u_2 = 6q_2 - q_1q_2 - q_2^2 = 4$ . The amount of output products of plant 1 and plant 2 both are 2, thus the amount of product in the market is 4. The price of the products in the market is 4, and the profit of plant 1 and plant 2 both are equals to 4. In this particular example, the quantities competition results to equality between the two firms (same quantities).

In Cournot competition, two plants are equivalent and decide the quantity at the same time, thus Cournot competition is a static game,

As we have shown with these two elementary examples, non-cooperative games are based on a competition between the players. We consider that they are not fully adapted to the problems studied in this thesis. Let us recall that we focus on cooperation of partners inside the supply chain in two cases: heterogeneous cooperation (manufacturer and transport operators) and homogeneous cooperation (transport operators). Indeed in the modern production and distribution systems, the market competition reduces regularly the revenues and the potential reduction of the costs for fulfilling customers is more and more limited. Hence, increasing the level of competition between the partners does not seem the most interesting way to go. On the other hand, the global competitiveness could be increased if the partners (i.e. transport operators and manufacturers) cooperate in order to share their costs or their profits.

Consequently, in the next section, the cooperative game approaches are studied.

### **2.3.3 Cooperative game**

The previously introduced cooperative games are also called coalitional games. Notice that the participants in a cooperative game are coalitions which are groups of players. In the following section, we will try to answer to the two natural questions:

- What mechanism should be developed, so that players' decisions are identical to the globally-optimal solutions that maximize the coalition's payoff?
- How should the maximum coalition's payoff be fairly divided so that no players would have an incentive to leave the coalition?

#### **2.3.3.1 Definitions and types of coalition games**

As a preamble, let us start with two remarks:

- An important hypothesis considered in this section, which is also adopted in many cooperative approaches, is the "transferable utility assumption" stating that the payoffs of a coalition (i.e. group of players) can be redistributed to its members without any constraints i.e. there is a universal currency used to exchange between partners (Kevin Leyton-Brown and Shoham 2008).
- In this section, each coalition is assigned with a payoff. However one might also assign a cost instead of a payoff to each coalition, which would need a simple adaptation to the concepts presented below (i.e. reversal of certain inequalities).

Firstly, it is useful to offer the mathematic definition of cooperative game. A

cooperative game with transferable utility is a pair  $(N, v)$ , where:

- $N$  is a finite set of players, indexed by  $i$ ;
- $v: 2^N \mapsto R$  associates to each coalition  $S \subseteq N$  a real-valued payoff  $v(S)$  that the coalition's members can distribute among themselves. We assume that  $v(\emptyset) = 0$ .

Some definitions are now interesting to present, and are helpful for the coming analysis in the following chapters. In that aim, let us first recall the following vocabulary and notations:

- Let  $|S|$  be the number of members in coalitions set  $S$ .
- Let  $N \setminus \{i\}$  be the set  $N$  except element  $i$ .
- The “**grand coalition**” is the name given to the coalition of all elements in set  $N$ .

#### Super-additive game

A game  $G = (N, v)$  is super-additive if for all coalitions  $S, M \subset N$ , if  $S \cap M = \emptyset$ , then  $v(S \cup M) \geq v(S) + v(M)$ .

#### Convex game

A game  $G = (N, v)$  is convex if for all  $S, M \subset N$ ,  $v(S \cup M) \geq v(S) + v(M) - v(S \cap M)$ .

#### Additive game

A game  $G = (N, v)$  is additive (or inessential) if for all  $S, M \subset N$ , if  $S \cap M = \emptyset$ , then  $v(S \cup M) = v(S) + v(M)$ .

#### Constant-sum game

A game  $G = (N, v)$  is constant-sum if for all  $S \subset N$ ,  $v(S) + v(N \setminus S) = v(N)$ .

#### Simple game

A game  $G = (N, v)$  is simple if for all  $S \subset N$ ,  $v(S) \in \{0,1\}$ .

### 2.3.3.2 Solutions concepts for coalition game

As mentioned in (Kevin Leyton-Brown and Shoham 2008), one of the main questions in coalition games is the distribution of the payoff of the grand coalition among the players. One of the reasons is that in the context of super additive games which are the most studied ones, the grand coalition gives the highest payoff. Then, the question arises to know how this coalition must divide his payoff. Many solutions concepts have been proposed to solve this problem. In other words, solutions concepts can be viewed as a mean to identify certain subsets of outcomes (i.e. solutions).

Prior to the presentation of some solution concepts, we have to introduce some complementary terminology.

An **imputation** (labelled  $x$ ) is a vector of players' outcomes. Each element  $x_i$  of this vector denotes the share of the grand coalition's payoff that a player  $i \in N$  receives. From a negotiation perspective, the set of imputations can be seen as the set of feasible agreements between the players. Considering a coalition game  $(N, v)$ , the imputation is formally defined as follows:

- The **pre-imputation** set, labelled  $P$ , is defined as:  $\{x \in R^N \mid \sum_{i \in N} x_i = v(N)\}$ ;
- Based on set  $P$ , the **imputation** set, labelled  $X$ , is defined as:  $\{x \in P \mid \forall i \in N, x_i \geq v(i)\}$ .

This definition refers to the two following terminology frequently used in this domain:

- **Individual rationality** means that a player will not accept an outcome which is not at least equal to what he could obtain by acting alone as measured by his characteristic function value.
- **Group rationality** states that the total cooperative gain of the grand coalition is fully shared.

The set of imputation  $X$  is rarely unique, that is why other properties are needed to define the final issue of the game. A solution concept is a sharing mechanism based on a series of axioms which correspond to some interesting properties (e.g. fairness, stability, etc.). Many solutions concepts have been proposed in the literature such as the Shapley value, the nucleolus, the stable set, the kernel. Let us quote for instance (Ordeshook 1986, Osborne and Rubinstein 1994) which describe these solutions concepts.

The exhaustive study of all these solutions concepts is beyond the thesis objective. However, we noticed that the Shapley value has been successfully used in some planning cooperation problems such as for instance in the field of vehicles route planning (Krajewska, Kopfer et al. 2008). As far as we know there is a lack of studies using the Shapley value tackling the planning cooperation at a tactical level between transport operators as well as between manufacturers and transport operators. Due to these reasons, we have chosen to use the Shapley value principle which is presented in the next section.

### 2.3.3.3 Shapley value

In game theory, the Shapley value is a solution concept for cooperative game. To each cooperative game it assigns a unique distribution (among the players) of a total surplus generated by the coalition of all players. The Shapley value is characterized by a collection of desirable properties or axioms described below.

Shapley formalized, with 3 properties below, the “**fairness**” notion that we would expect a good solution concept to satisfy:

- **Symmetry:** Firstly let us define interchangeable agents “a” and “b” such as for all coalitions  $S$  and  $a \notin S, b \notin S$ , the following equality is verified:  $v(S \cup \{a\}) = v(S \cup \{b\})$ . If agents are interchangeable, they should receive the same payments (division of the grand coalition payoff)
- **Dummy players:** Firstly let us define a dummy player such as for all coalitions  $S$  and  $a \notin S$  the following equality is verified:  $v(S \cup \{a\}) - v(S) = v\{a\}$ . The dummy players should receive a payment exactly equals to the amount that they achieved alone (i.e. its individual payoff)
- **Additivity:** Considering two payoff functions  $v_1$  and  $v_2$  associated with two different games and the same set of players. If this game is redefined as a single game achieving a payoff of  $v_1(S) + v_2(S)$  for each coalition  $S$ , the payment of agent for each coalition should be the sum of the payments they would have achieved under the two different games.

The Shapley value is characterized by the three desirable properties or axioms described previously. An important result states that there exists one and only one imputation (i.e. unicity) satisfying these properties.

The definition of Shapley value is presented in the following. Considering a cooperative game  $(N, v)$ , the Shapley value of player  $i$  is given by

$$\phi_i(N, v) = \frac{1}{N!} \sum_{S \subseteq N \setminus \{i\}} |S|! (|N| - |S| - 1)! [v(S \cup \{i\}) - v(S)].$$

In the following, a numerical example is presented to show the calculation of the Shapley value. There are three partners, thus the grand coalition is  $N = \{1, 2, 3\}$ . The payoffs of each coalition are as following:

- $v(1) = v(2) = v(3) = v(2\&3) = 0$ ;
- $v(1\&2) = v(1\&3) = v(1\&2\&3) = 300$

A set of calculations is presented Table 2-3, which show the verification of super-additivity of the previous game according to the definition of the super-additive game in 2.3.3.1.

**Table 2-3 Super additivity**

| $S$ | $M$   | $v(S \cup M)$ | $v(S)$ | $v(M)$ | $v(S) + v(M)$ | $v(S \cup M) \geq v(S) + v(M)$ |
|-----|-------|---------------|--------|--------|---------------|--------------------------------|
| {1} | {2,3} | 300           | 0      | 0      | 0             | True                           |
| {2} | {1,3} | 300           | 0      | 300    | 300           | True                           |
| {3} | {1,2} | 300           | 0      | 300    | 300           | True                           |
| {1} | {3}   | 300           | 0      | 0      | 0             | True                           |
| {2} | {3}   | 0             | 0      | 0      | 0             | True                           |
| {1} | {2}   | 300           | 0      | 0      | 0             | True                           |

Considering the formula of Shapley value, the values  $\phi_i(v)(i=1, 2, 3)$  are expressed as:

$$\phi_1(v) = \frac{2}{6}(v(1) - v(\emptyset)) + \frac{1}{6}(v(1\&2) - v(2)) + \frac{1}{6}(v(1\&3) - v(3)) + \frac{2}{6}(v(1\&2\&3) - v(2\&3))$$

$$\phi_2(v) = \frac{2}{6}(v(2) - v(\emptyset)) + \frac{1}{6}(v(1\&2) - v(1)) + \frac{1}{6}(v(2\&3) - v(3)) + \frac{2}{6}(v(1\&2\&3) - v(1\&3))$$

$$\phi_3(v) = \frac{2}{6}(v(3) - v(\emptyset)) + \frac{1}{6}(v(1\&3) - v(1)) + \frac{1}{6}(v(2\&3) - v(2)) + \frac{2}{6}(v(1\&2\&3) - v(1\&2))$$

We work out the following results of  $\phi_1(v), \phi_2(v)$  and  $\phi_3(v)$ :

$$\phi_1(v) = 200, \phi_2(v) = 50, \phi_3(v) = 50.$$

The equation  $\phi_1(v) + \phi_2(v) + \phi_3(v) = v(1&2&3)$  can be clearly checked, which illustrates that the Shapley values are an allocation of the payoff of grand coalition.

#### 2.3.3.4 Core

The Shapley value defined a fair way of dividing the grand coalition's payment among its members. However, the Shapley value does not always belong to the core of the game which represents the set of un-dominated imputations. Indeed the core is in relation with the stability property: there is no coalition offering a better compromise to its members than the coalitions included in the core. Let us notice that the core can be empty or can encompass an important number of imputations.

So let us present the notion of core. A payoff vector  $x$  is in the core of a coalitional game  $(N, v)$  if and only if  $\forall S \subseteq N, \sum_{i \in S} x_i \geq v(S)$ .

Let us go back to the previous example of Shapley value (§ 2.3.3.3) and verify whether it is in the core, considering the following coalitions:

- coalition  $\emptyset$ : Obviously the formula  $\sum_{i \in S} x_i \geq v(S)$  is true;
- coalition  $\{1\}$ :  $x_1 \geq v(1)$  is true, since  $\phi_1(v) \geq v(1)$ , i.e.  $200 \geq 0$ ;
- Similarly,  $\phi_2(v) \geq v(2)$ ,  $\phi_3(v) \geq v(3)$ ,

Let us now observe that  $\phi_1(v) + \phi_2(v) = 200 + 50 = 250$ ,  $v(1&2) = 300$ , thus  $\phi_1(v) + \phi_2(v) < v(1&2)$ , i.e.  $x_1 + x_2 < v(1&2)$ . Therefore,  $\sum_{i \in S} x_i \geq v(S)$  is not true for  $\forall S \subseteq N$ . Consequently, the Shapley values are in not the core in this example.

Let us go back to observe the payoffs –  $v(1&2) = v(1&3) = v(1&2&3) = 300$ . Considering  $v(1&2) = v(1&2&3) = 300$ ,  $\{3\}$  does not give the added value to the coalition. The situation is same when we consider  $v(1&3)$  and  $v(1&2&3)$ . We can understand the meaning of the core in the following way: If a payoff vector of a coalition is in the core, each partner in this coalition is indispensable for the coalition to obtain the maximum collective gain.

The following theorems can give us more sense of core, and help us to know whether the core is nonempty in a specific game.

#### Theorem 1

In a simple game, the core is empty if there is no veto player (a player  $i$  is a veto player if  $v(N \setminus \{i\}) = 0$ ). If there are veto players, the core consists of all payoff vectors in which the non-veto players get 0.

### Theorem 2

Every convex game has a nonempty core.

### Theorem 3

In every convex game, the Shapley value is in the core.

The detail and the proof of Theorem 2 and Theorem 3 can be found in (Shapley 1971).

In this thesis we choose the Shapley value because it has the three following essential properties:

- **Fairness:** this property previously defined, is very important for any sharing problem (cost or profit). Any unfair solution has many chances to be rejected by the participants of the game.
- **Uniqueness:** the players appreciate to get a unique imputation, so that no other solutions are potentially better or overlooked. The Shapley value prevents the players to regret the chosen solution and prevent from any long bargaining and negotiation process.
- **Implementation:** the Shapley value is very easy to implement since it is obtained through a simple calculation formula. Contrary for instance to the nucleolus which requires solving many linear programs. Indeed Shapley value has been used in a very great number of applications of cooperative games in many fields of economics, management, and computers.

## **2.4 Conclusion**

Game theory is an important and useful theory which is widely used in many fields. Non-cooperative game and cooperative game are the mainly classification in game theory, which has been discussed in this section.

Non-cooperative games are based on a competition between the players, thus they are not fully adapted to the problems studied in this thesis. Among cooperative approaches, the Shapley value provides a good mechanism to distribute possible total gains between partners who search efficient and fair solutions in order to collaborate. Furthermore, the Shapley value has three essential properties – fairness, uniqueness and implementation. As far as we know, Shapley value has been successfully used in some planning cooperation problems, and there is a lack of studies using the Shapley value tackling the planning cooperation at a tactical level between transport operators

as well as between manufacturers and transport operators. Due to these reasons, the Shapley value principle is chosen in this thesis.

In the games implemented in the next chapter, manufacturer and transport operators are assimilated to players. These players can be organized in different groups (i.e. coalitions). The goal of the Shapley value is to find the best coalition sharing production and transportation costs or gains in a satisfying way for each partner. The implementation of game theory approaches for planning in distribution and in production/distribution is presented in the next chapter.

# Chapter 3

## Planning models and cooperation protocols

### 3.1 Introduction

The background of supply chain is presented in chapter 1. Supply chain planning and the game theory especially cooperative game theory are described in chapter 2. In this chapter, we propose an approach for solving cooperation planning problems inside supply chain. This approach is based on the cooperative game theory and more precisely the Shapley value principle. Two kinds of games are studied according to the character, homogeneous or heterogeneous of the partners involved in the cooperation. For homogeneous partners' game, we consider multiple transport operators cooperating in order to satisfy the delivery request of a manufacturer. In the heterogeneous partners' game, a manufacturer and multiple transport operators cooperate in order to satisfy the customer demand. These games are based on linear programming models which simulate the planning process of each partner. The cooperation between the various actors is modeled by a specific process (also called protocol) in which the execution of linear programming models allows to estimate costs or profits used to calculate the Shapley value representing a fair sharing among members of the supply chain.

### 3.2 Cooperation between homogeneous partners: multiple transport operators

The cooperation between homogeneous partners is introduced in this section. The partners participating in the cooperation are transport operators. In this section, the following points are concerned. First, multi-transport operators cooperation in the supply chain is introduced. Secondly, the transport planning model is proposed. Thirdly, the protocol of the game between multi-transport operators is depicted. At last, an example taking into account three transport operators is presented to explain the implementation of the cooperation. Notice that the distribution is called "transport" in order to indicate the transport operators as supply chain partners.

#### 3.2.1 Cooperation between multiple transport operators

The cooperation context is made up of one manufacturer requiring for delivery requests, the transport operators owning transport resources and the 4PL logistic provider acting as an intermediary partner facilitating the transportation resource sharing.

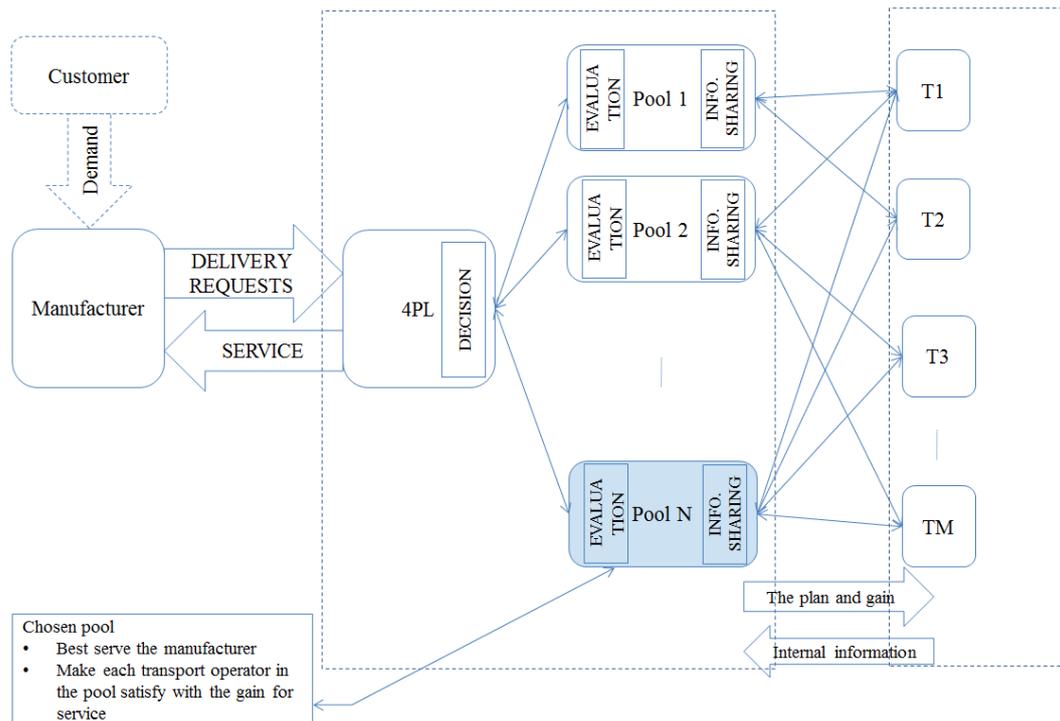
Let us remind that the fourth party logistics -- 4PL is a separate entity established as a

joint venture with the manufacturer and the transport operators (Norall 2013), and it acts as a single interface between them. All aspects of the supply chain are managed by the 4PL. 4PL can be defined as “*A supply chain integrator that assembles and manages the resources, capabilities, and technology of its own organization with those of complementary service providers to deliver a comprehensive supply chain solution*” (Mark Bedeman 2003).

Indeed, 4PL supports setting up pools containing transport operators, which serve the manufacturer together. Notice that if a transport operator serves the manufacturer itself, it can be thought it is a pool which has only one partner and the largest pool is the one which involves all the transport operators.

The general cooperation process requires that the manufacturer sends its delivery requests to 4PL, and all transport operators also send their internal information to the 4PL. Then, this logistic provider organizes a pool offering the delivery service to the manufacturer, and sends the plan to each transport operator in the pool and the corresponding prospective gain.

Figure 3-1 shows an overall view of the cooperation in the case of  $M$  transport operators. Notice that customers which are outside the scope of this are not explicitly represented. This figure shows that all information of the transport operators is known from the 4PL. This latter will evaluate and choose one of all these pools to serve the delivery requests of manufacturer as best as possible, i.e. optimizing the service quality or the profit of each partner. Notice that the service quality means that the products are picked up at the right time and right quantity. The manufacturer, as the customer of the 4PL, is the only one who receives the demand of the end customers, which is unknown by the 4PL. 4PL only have the information of delivery requests sent from the manufacturer. There are two rectangles with dotted line in Figure 3-1, the left rectangle shows the manager (4PL) and the pools which are proposed by 4PL, and all the actual partners in the game (transport operators) are included in the right one.



**Figure 3-1 Overall view of cooperation between 4PL logistic provider and transport operators**

The problem currently investigated in this work is based on the following assumptions which limit the complexity and define the context of the study.

- The fourth party logistic (4PL) provider plays the role of manager of the transport operators. Notice that the economic model related to the 4PL is not taken into account in the scope of our study in order to limit the complexity of the problem.
- No inventory service is combined with the transportation service.
- Different customers require the service of a same set of transport operators and have to share the transportation capacity.
- A depot is a location where the trucks park when they are idle. A whole journey of a truck is made up of the following steps: departing from the depot, picking up the products from the manufacturer, delivering the products to the customers, afterwards returning to the depot for the purpose of next loading. The time required to execute this sequence of activities is called “round trip lead-time”. The time during which the truck carries a load from the manufacturer to the customers is more specifically considered and called “transportation lead-time”.
- To freight the numerous products from the manufacturer to the multiple customers, a group of identical trucks are utilized by the transport operators (homogeneous fleet of vehicles). Vehicle routing decisions are not taken into account

in this thesis, since each truck is dedicated to deliver a unique destination after departure.

- This thesis is focused on the tactical planning level, as a result, the truck is chosen as the unit to measure the transportation capacity, meaning that the number of used trucks has to be integer. The pickup quantities and the number of trucks occupied at each time period are the results of the decision making process, and full load for each truck is not a mandatory condition.
- Both a fix cost and a variable cost are regarded as components of transportation cost. The “destination related cost” is the fix part of the cost which can be assimilated to an operating cost per truck including any expense due to materials, computers, taxes and salary cost required for this treatment. As each truck is dedicated to a specific customer’s destination, we assume that this cost can be dependent on the travelled distance. The “product related cost” is the recurrent and variable part of the transportation cost, which is related to each unit of transported product. It is supposed that products will not be damaged during transport.
- It is assumed that a structural cost (i.e. administrative cost) is associated to the use of each transport operator. The structural cost may be assimilated to the required manpower cost to plan transportation activities and/or the administrative and infrastructures costs of each transport operator. This cost is added to others when the 4PL estimates the global transportation fees related to each transport operator.
- A common length of time horizon is used by the manufacturer and transport operators. The manufacturer and transport operators share their knowledge about products to deliver and customers to serve. For example, the manufacturer and the transport operator both know the quantities of requested products that have to be delivered by the manufacturer according to its own capacity.
- Hiring external transportation resources is enabled when the transport operators do not have enough capacity to serve its customers during the considered time horizon. When external transportation resources are available, the transport operator can require these resources to optimize its quality service.
- Some delivery quantities, requested by the manufacturer, can be discarded by the transport operators if they think that they have no enough capacity to fully serve the customers along the time horizon; this case happens when no extra capacity is available during the planning horizon. The transport operators do not pay the penalty due to the discarded quantities, since they do not have financial relationship with the customers. The value of the discarded quantities is thus the difference between the total delivery requests sent by manufacturer and total pickup quantities of the transport operator(s) in the whole time horizon.

### 3.2.2 Best Service Transportation model (BST-mT model)

Each transport operator aims to offer a best service quality to the manufacturer; thus, the model is done in accordance with this objective. A linear programming model will be built to simulate the planning process of each pool of transport operator(s). With regard to the variable number of transport operators and the goal of optimization to satisfy, this model is named the BST-mT model (Best Service Transportation model with Multiple Transport operators), meaning the model can be with  $m$  transport operator(s) and searches for finding solutions that serve the delivery requests of the manufacturer as closed as possible.

#### 3.2.2.1 Introduction of the BST-mT model

Let us recall that the model involves multiple transport operators, and depict the decision making process executed by the 4PL. The sets and indices of this model are displayed below:

##### Sets

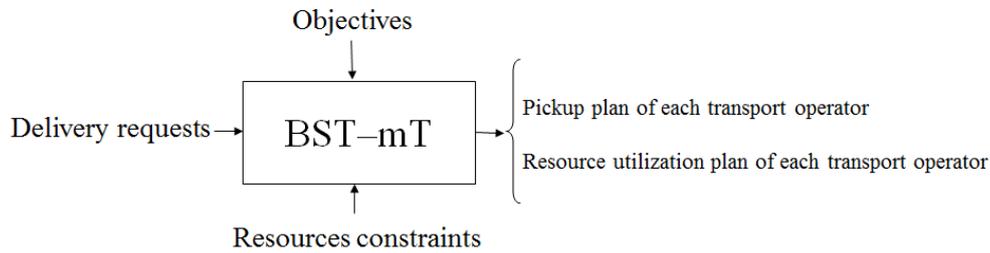
|     |   |                       |
|-----|---|-----------------------|
| $T$ | Set of periods composing the planning horizon | $T = \{1 \dots T_F\}$ |
| $P$ | Set of products                               | $P = \{1 \dots P_F\}$ |
| $J$ | Set of customers                              | $J = \{1 \dots J_F\}$ |
| $K$ | Set of transport operators                    | $K = \{1 \dots K_F\}$ |

##### Indices

|     |           |                              |
|-----|-----------|------------------------------|
| $t$ | $t \in T$ | Index of planning periods    |
| $p$ | $p \in P$ | Index of products            |
| $j$ | $j \in J$ | Index of customers           |
| $k$ | $k \in K$ | Index of transport operators |

Each transport operator receives the delivery requests from the manufacturer, and intends to serve them by taking into account the limitation of operations due to their resource capacities. Its objective aims to maximize the service quality and its own profit at the same time. The shipping of products in accordance with the delivery requests is operated by multiple transport operators, thus, their global resources will be taken into account in the model. The results provided by the model resolution concern the plan that each transport operator will execute to pick up the products from manufacturer – called “pickup plan” and a plan depicting the quantities of resources

(trucks) used by each operator to serve as best as possible the customer. This last plan is called “resources-utilization plan” (see Figure 3-2).



**Figure 3-2 Input and output of the BST-mT model**

- Resource utilization plan depicts the number of trucks either owned or extra resources used in each time period that composes the horizon.
- Pickup plan defines the quantities of products that must be shipped to each customer on each time period.

In this section, the customer of the 4PL is the manufacturer. Thus the delivery requests are the input of the model, and the target is to get the pickup plan to serve this delivery requests. It is assumed that some small deviations between the delivery requests and the pickup plan may be accepted when it provides benefits for the partners. Thus, a late pickup quantity in a single time period occurs when the accumulated delivery requests are more than the accumulated pickup quantities until this period. On the contrary, the early pickup quantity in a single time period happens when the accumulated pickup quantities are more than accumulated delivery requests until this period. The difference (absolute value) between the accumulated pickup quantities and the accumulated delivery requests until a single period (including this period) is then the value of late or early pickup quantity in this period. An example in Table 3-1 helps to understand the emerging of the early and late pickup quantities. In period 1, the delivery request of the manufacturer is 1000 units. However, the transport operator only can serve 800 units due to its capacity, thus 200 units of late pickup quantity are generated. In period 2, the deliver request is 1500 units, whereas 1800 units can be picked up by the transport operator, hence, there should be 300 units early pickup quantity. But due to the late pickup quantity of 200 units in the previous period – period 1, the early pickup quantity should be only 100 units. In period 3, the delivery request of the manufacturer is 1200 units. Nevertheless, the transport operator only serves 1100 units, since there are 100 units of early pickup quantity in the previous period –period 2.

**Table 3-1 Definition of early and late pickup quantities**

| Time period | Delivery request (unit) | Pickup quantity (unit) | Early pickup quantity (unit) | Late pickup quantity (unit) |
|-------------|-------------------------|------------------------|------------------------------|-----------------------------|
| 1           | 1000                    | 800                    | 0                            | 200                         |
| 2           | 1500                    | 1800                   | 100                          | 0                           |
| 3           | 1200                    | 1100                   | 0                            | 0                           |

The total late pickup quantity in the whole time horizon is the sum of late pickup quantities in every time period. The total early pickup quantity in the whole time horizon is the sum of early pickup quantities in every time period. The service quality is assessed by enumerating the total early and late pickup quantity of each product shipped to customer. The ‘best service’ aims at reducing the total early and late pickup quantities close from zero. The destination related cost, i.e. the fix transportation cost, the product related cost, i.e. the variable transport cost, and the structure cost for management paying to the 4PL are also taken into account for the total cost. The difference between revenue received from manufacturer and the total cost will be the profit of transport operator.

The parameters, variables, local resource constraints, and the objective function are represented in the following.

### 3.2.2.2 Parameters and variables

#### Parameters

The inputs of the mathematical model are parameters, such as manufacturer’s delivery requests sent from the manufacturer to the 4PL, the transportation lead time, the capacity of the transport operator and the financial information. The parameters used in this model are stated below:

$l_{p,j,t}$       *The delivery requests for product  $p$ , made for customer  $j$  during the period  $t$ , as sent by the manufacturer*

$v_p$       *Scalar representing the unitary weight of product  $p$*

$EC_{p,j}$       *Unitary penalty cost related to early pickup quantities of products  $p$  to customers  $j$  during period  $t$*

$BC_{p,j}$       *Unitary penalty cost related to late pickup quantities of products  $p$  to customers  $j$  during period  $t$*

$DT_j$       *Transportation lead-time when customer  $j$  is served*

|                    |  |
|--------------------|--|
| $D_j$              | <i>Round-trip lead-time when customer <math>j</math> is served</i>   |
| $FC_{j,k}$         | <i>Destination-related transportation cost when transport operator <math>k</math> uses its own resources to serve the customer <math>j</math></i>  |
| $FC\_extra_{j,k}$  | <i>Destination related transportation cost when transport operator <math>k</math> uses extra resources to serve the customer <math>j</math></i>  |
| $VC_{p,j}$         | <i>Product-related transportation cost associated to the pickup of one unit of product <math>p</math> to the customer <math>j</math>, via the use of trucks owned by transport operators</i>   |
| $VC\_extra_{p,j}$  | <i>product-related extra transportation cost associated to the pickup of one unit of product <math>p</math> to the customer <math>j</math>, via the use of extra trucks required by transport operators to increase their capacity</i> |
| $TP_{p,j}$         | <i>Transportation price per unit of product <math>p</math> to be picked up to the customer <math>j</math></i>  |
| $R_k$              | <i>Number of trucks owned by the transport operator <math>k</math></i>   |
| $cap_k$            | <i>Load capacity of any truck owned by the transport operator <math>k</math></i>   |
| $M\_extra_{j,k,t}$ | <i>Max number of external trucks available during the period <math>t</math> to be used by the transport operator <math>k</math> to serve the customer <math>j</math></i>   |
| $cap\_extra_k$     | <i>Load capacity of any extra truck hired by the transport operator <math>k</math></i>   |
| $M$                | <i>A large number</i>  |
| $SC$               | <i>The structural cost related to each transport operator</i>  |

### Variables

The values of variables depict plans obtained by execution of the mathematic model (Figure 3-2). The early and late pickup ( $te_{p,j,t}$  and  $tb_{p,j,t}$ ) quantities are variables useful to assess the service quality. Any variable depicting a quantity of products must be defined as an integer in the mathematic model.

|               |  |
|---------------|--|
| $q_{p,j,k,t}$ | <i>Pickup quantity of product <math>p</math> to be launched in transportation from manufacturer at time period <math>t</math> to customer <math>j</math> which use the owned trucks of transport operator <math>k</math></i> |
|---------------|--|

|                      |   |
|----------------------|---|
| $q\_extra_{p,j,k,t}$ | <i>Pickup quantity of product <math>p</math> to be launched in transportation from manufacturer at time period <math>t</math> to customer <math>j</math> by extra trucks of transport operator <math>k</math></i> |
| $tb_{p,j,t}$         | <i>Quantity of products <math>p</math> requested by customer <math>j</math> and picked up in late during the period <math>t</math></i>  |
| $te_{p,j,t}$         | <i>Quantity of products <math>p</math> requested by customer <math>j</math> and picked up in early during the period <math>t</math></i>   |
| $m_{j,k,t}$          | <i>Number of trucks of the transport operator <math>k</math> used during period <math>t</math> to serve the customer <math>j</math></i>   |
| $m\_extra_{j,k,t}$   | <i>Number of extra trucks required by the transport operator <math>k</math> and used during period <math>t</math> to serve the customer <math>j</math></i>  |
| $n_k$                | <i>Binary variable equal to 1 if the transport operator is used, 0 otherwise</i>  |

### 3.2.2.3 Constraints and objective function

#### Constraints

The problem is strongly constrained by the capacity of the transport operators, for instance the individual capacity of each transport operator or of the extra resource.

- Deviation from the delivery requests

$$\sum_k (q_{p,j,k,t} + q\_extra_{p,j,k,t}) - te_{p,j,t} + tb_{p,j,t} = l_{p,j,t} - te_{p,j,t-1} + tb_{p,j,t-1} \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BST.1})$$

The difference between the delivery requests sent by manufacturer ( $l_{p,j,t}$ ) and the total pickup quantities ( $\sum_k (q_{p,j,k,t} + q\_extra_{p,j,k,t})$ ) of every transport operators in each time period is expressed by this constraint. In each single time period, the total pickup quantities can be less or a little more than the delivery requests according to the limitation due to the transportation capacity.

- Delivery requests limitation

$$\sum_t \sum_k (q_{p,j,k,t} + q\_extra_{p,j,k,t}) \leq \sum_t l_{p,j,t} \quad \forall p \in P, \forall j \in J \quad (\text{BST.2})$$

For each product and for each customer, the accumulated pickup quantities ( $\sum_t q_{p,j,t}$ )

over the planning time horizon must be not higher than the corresponding accumulated quantities of demand ( $\sum_t d_{p,j,t}$ ).

- Transportation resource capacity

$$\sum_p v_p * q_{p,j,k,t} \leq m_{j,k,t} * cap_k \quad \forall j \in J, \forall k \in K, \forall t \in T \quad (\text{BST.3})$$

$$\sum_p v_p * q_{extra_{p,j,k,t}} \leq m_{extra_{j,k,t}} * cap_{extra_k} \quad \forall j \in J, \forall k \in K, \forall t \in T \quad (\text{BST.4})$$

$$\sum_j \sum_{i=1}^{D_j} m_{j,k,t-i+1} \leq R_k \quad \forall k \in K, \forall t \in T \quad (\text{BST.5})$$

$$m_{extra_{j,k,t}} \leq M_{extra_{j,k,t}} \quad \forall k \in K, \forall j \in J, \forall t \in T \quad (\text{BST.6})$$

These constraints guarantee that the transportation load respects the transportation capacity. Let us recall that transport operator owned trucks and external trucks are two kinds of resources, which can be used. The total number of transport operator owned trucks ( $R_k$ ) is limited. For each transport operator and for each customer at each time period, the total products load by transport operator owned trucks ( $\sum_p v_p * q_{p,j,k,t}$ ) should be less than the transportation capacity ( $m_{j,k,t} * cap_k$ ), as depicted by constraint BST.3. Constraint BST.4 is equivalent to BST.3 applied to the external trucks. Constraint BST.5 expresses that the total number of used trucks must not exceed the number of trucks owned by the transport operator k. The trucks are busy from the moment they leave the depot to the moment they go back to this depot, during a time interval equal to the round-trip lead-time  $D_j$ . Thus the calculation of occupied trucks at each time period has to consider the sum of the trucks over the round trip transport time ( $\sum_j \sum_{i=1}^{D_j} m_{j,k,t-i+1}$ ). The constraint (BST6) expresses that the number of used extra trucks must not exceed the max number of available extra resources. If no external resources are available during a given period, the extra transport capacity ( $M_{extra_{j,k,t}}$ ) can be equal to 0.

- The use of each transport operator

$$n_k \leq M * \sum_{j,t} (m_{j,k,t} + m_{extra_{j,k,t}}) \quad \forall k \in K \quad (\text{BST.8})$$

$$\sum_{j,t} (m_{j,k,t} + m_{extra_{j,k,t}}) \leq M * n_k \quad \forall k \in K \quad (\text{BST.9})$$

A binary variable  $n_k$  is used to indicate that a transport operator is used or not. A transport operator that utilizes owned or external trucks executes a transportation activity so that the value of  $n_k$  is then equal to 1. Otherwise,  $n_k = 0$ .

○ Non-negative constraint:

$$q_{p,j,k,t} \geq 0 \quad \forall k \in K, \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BST.10})$$

$$tb_{p,j,t} \geq 0 \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BST.11})$$

$$te_{p,j,t} \geq 0 \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BST.12})$$

$$m_{j,k,t} \geq 0 \quad \forall k \in K, \forall j \in J, \forall t \in T \quad (\text{BST.13})$$

$$m\_extra_{j,k,t} \geq 0 \quad \forall k \in K, \forall j \in J, \forall t \in T \quad (\text{BST.14})$$

These constraints ensure that all the variables in the model are positive or null.

▪ Objective function

The objective function of this model is presented by equation BST.15. Two objectives are taken into account in this function, the service quality and the profit obtained by the transport operator. The profit to maximize is the difference between the revenue received from customer and the total cost. The total cost is the sum of the penalty cost, the cost of using owned trucks which include the destination related cost (the fix transport cost per vehicle  $FC_{j,k}$ ) and the product related cost (the variable transport cost per product  $VC_{p,j}$ ), the cost of using external trucks, and the structural cost. The service quality is defined by the sum of all late and early pickup quantities along the planning horizon that must be minimized. The weights in the objective function --  $\alpha$  and  $\beta$  are used to indicate the preference between the different components of the function.

$$\max(\alpha * profit\_T - \beta * service\_T) \quad (\text{BST.15})$$

$$profit\_T = revenue\_T - cost\_T - penalty\_T - extra\_cost\_T - structural\_cost \quad (\text{BST.16})$$

$$service\_T = \sum_p \sum_j \sum_t (tb_{p,j,t} + te_{p,j,t}) \quad (\text{BST.17})$$

$$revenue\_T = \sum_p \sum_j \sum_t \sum_k q_{p,j,k,t} * TP_{p,j} \quad (\text{BST.18})$$

$$cost\_T = \sum_j \sum_k \sum_t FC_{j,k} * m_{j,k,t} + \sum_p \sum_j \sum_k \sum_t VC_{p,j} * q_{p,j,k,t} \quad (\text{BST.19})$$

$$penalty\_T = \sum_p \sum_j \sum_t BC_{p,j} * tb_{p,j,t} + \sum_p \sum_j \sum_t EC_{p,j} * te_{p,j,t} \quad (\text{BST.20})$$

$$extra\_cost\_T = \sum_j \sum_k FC_{extra_{j,k}} * \sum_t m_{extra_{j,k,t}} + \sum_p \sum_j \sum_k \sum_t VC\_extra_{p,j} * q\_extra_{p,j,k,t} \quad (\text{BST.21})$$

$$structure\_cost = SC * \sum_k n_k \quad (BST.22)$$

The BST-mT is a generic model which can encompass multiple transport operators. The case of a single transport operator without any sharing of resources with the others can easily be deduced from this model. According to the number of elements in set  $K$  ( $card /K/=K_F$ ), the transport operators' model is adapted. All the parameters and variables including the index  $k$  enable the model to be adapted to the size of a pool. In the next part, the game between multiple transport operators is introduced.

### 3.2.3 Protocol of the cooperation between multiple transport operators

An approach for implementing the cooperation between the transport operators is presented in this section. This approach is based on a cooperative game and more particularly on the Shapley value principle. The current approach is described in three steps: firstly the principle of the protocol is introduced; secondly the main steps of the planning cooperation approach are described; finally an additional step of this protocol is defined to depict how the limitation of the transportation capacity may induce the rejection of a part of the manufacturer's delivery requests by the transport operator.

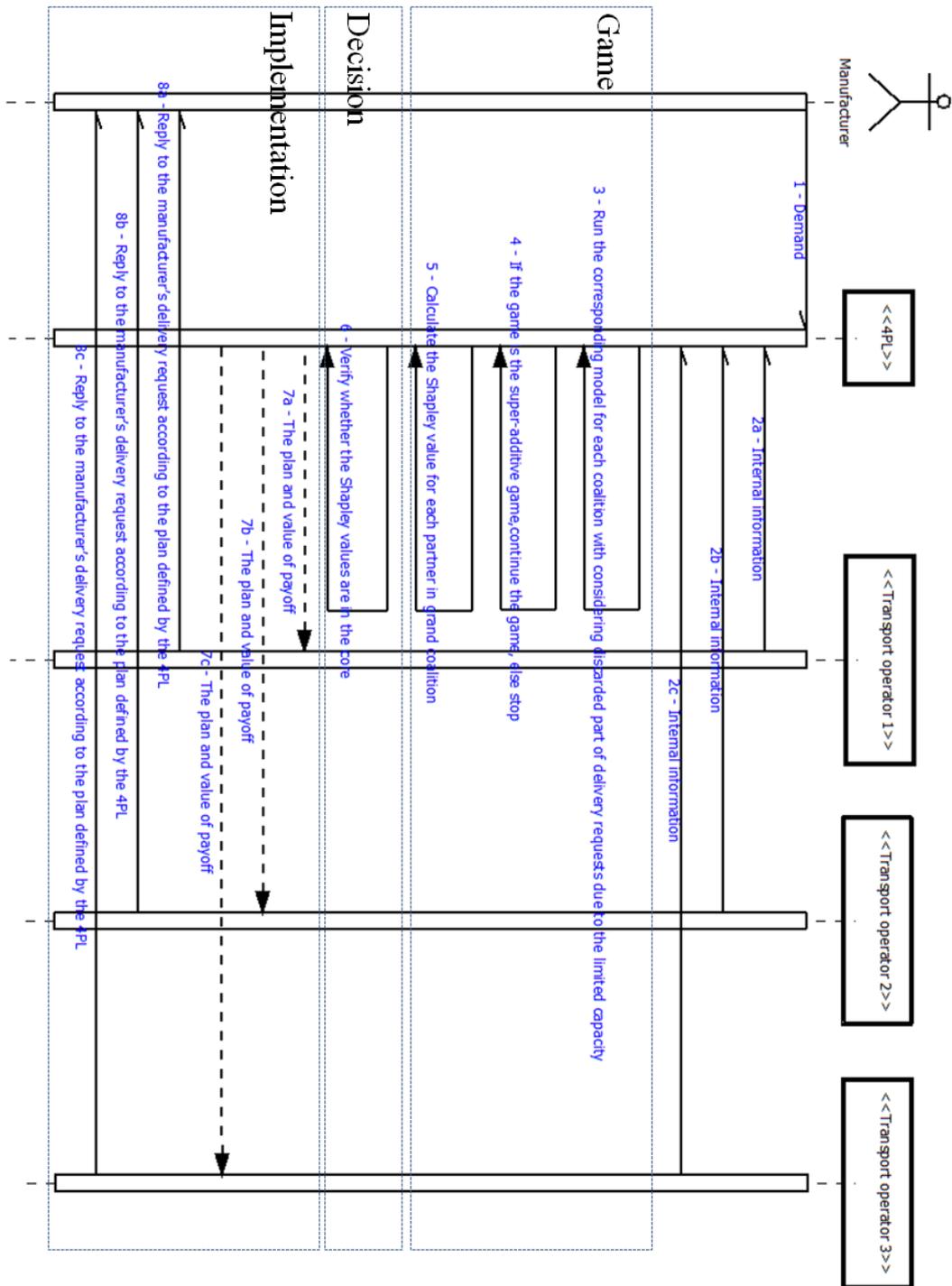
#### 3.2.3.1 Introduction of the cooperation protocol between multiple transport operators

As mentioned earlier, multiple partners cooperate in order to serve a set of customers. According to the cooperative game theory, the transport operators can be regarded as the partners of the game, and the pools which are mentioned in Figure 3-1 are assimilated to the game's coalitions. As mentioned in the working hypotheses (section 3.2.1) of this study, the 4PL economic model is not encompassed in our working context. Indeed let us consider a cooperation between multiple transport operators --  $T_1, T_2, \dots, T_M$ . Accordingly,  $N$  ( $N = 2^M$ ) coalitions are generated; for instance, coalition  $(T_1)$ , coalition  $(T_2)$ , coalition  $(T_1 \& T_2)$ , coalition  $(T_1 \& T_2 \& \dots \& T_M)$ , and coalition  $\emptyset$ . Let us remind that key definitions of cooperative game theory and Shapley value are given in section 2.3.3.

A UML sequence diagram with vertical timeline, including a 4PL, a manufacturer and limited to two only transport operators is displayed in Figure 3-3. The 4PL receives the delivery requests from the manufacturer and the transport operators' internal information. Then the 4PL runs the BST-mT model related to each possible coalition,

consequently, the Shapley value for each partner can be calculated. The 4PL sends the plan to the transport operators and inform them about the potential benefit in case of cooperation. According to the plan formulated by the 4PL, the transport operators serve the manufacturer to ship the products. Afterwards, the manufacturer pays the fees for the whole service to 4PL, and then 4PL carries out the payment to each partner. Indeed the cooperation protocol is made up of the three main following steps – game, decision and implementation, as mentioned in Figure 3-3:

- Game: using the information sent from the manufacturer and from every transport operators, the 4PL runs the BST-mT models (Num.3 in Figure 3-3). If the game is super-additive, 4PL will calculate Shapley value for each partner, else the game will stop (Num.4 and 5 in Figure 3-3).
- Decision: The 4PL verifies the game properties for the grand coalition (Num.6 in Figure 3-3). If the Shapley value is in the core, the cooperation is successful, and each partner will apply the plan of the grand coalition. The Shapley value is not always in the core, in this case, the cooperation is not the best solution. Thus, the cooperation stops.
- Implementation: The plans of partners in the grand coalition will be implemented in the real transport activity. As shown in Figure 3-3, the 4PL sends the plan and corresponding value of possible gain (payoff) to each transport operator (Num. 7). Each transport operator pickups the products at the manufacturer to answer to the delivery request according to the plans defined by the 4PL (See ‘reply’ Num. 8 in Figure 3-3). Notice that all the money transferring between the partners are not represented in this diagram.

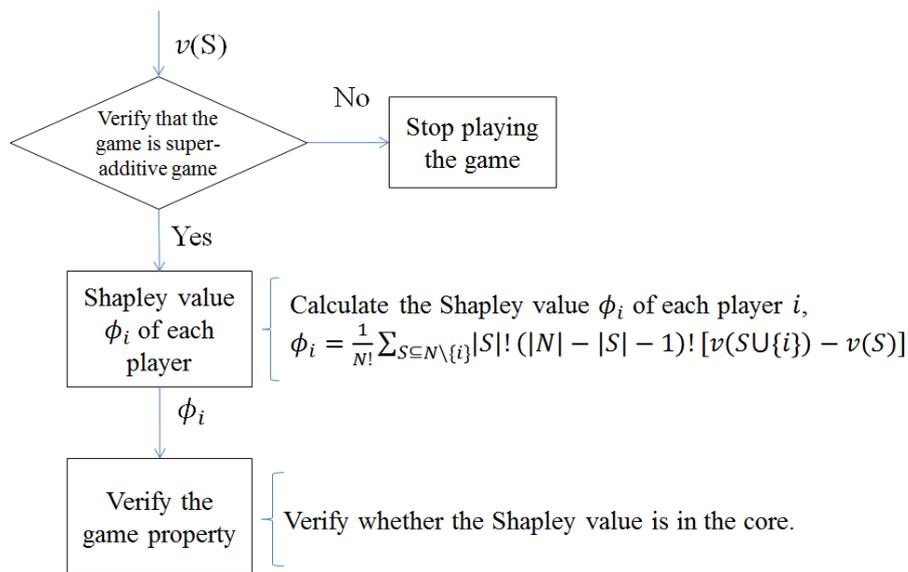


**Figure 3-3 Cooperation protocol (three transport operators): a UML sequence diagram**

After this introduction, we present below the details and the main steps of our approach.

### 3.2.3.2 Main steps of the planning cooperation approach

According to the above paragraph, a specific cooperation procedure is detailed in Figure 3-4, which corresponds to the ‘Game’ and “Decision” steps in the Figure 3-3. It is necessary to introduce the notion of  $\phi_i$  here, which represents the Shapley value of player  $i$  ( $\phi_i$  is a simplified notation for  $\phi_i(N, v)$ ). The Shapley value is calculated based on payoff -  $v(S)$  of each coalition (Kevin Leyton-Brown and Shoham 2008). It is worth to mention that the payoffs are issued from the results of the model simulation.



**Figure 3-4 The main steps of the cooperative approach based on the Shapley value**

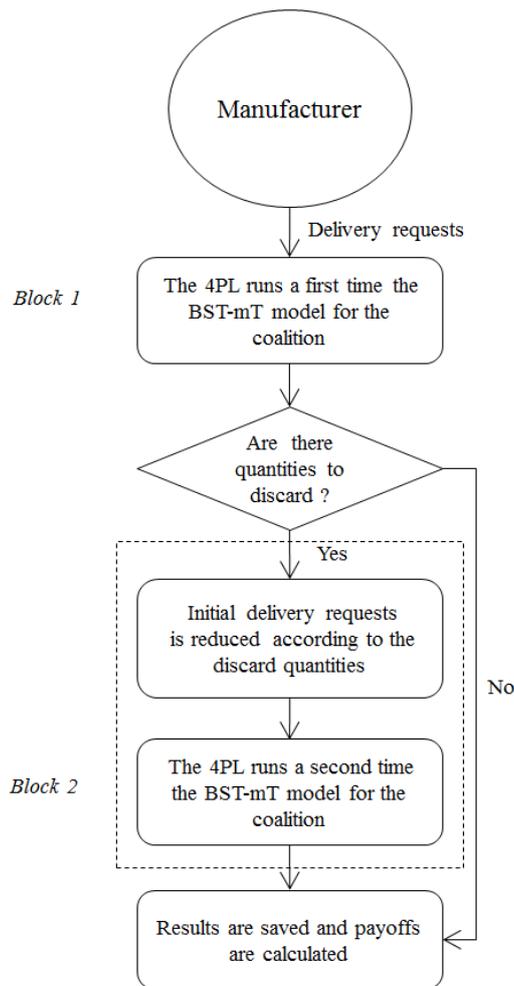
The property of super-additive game, which is a property assumed for the cooperative games, is verified before the calculating of the Shapley value to decide if the game can be continued or not. It is such as “go/ no go” decision making. When the Shapley values of each partner are obtained, the property verifying if the Shapley values are in the core must be verified. The checking of this property is useful to estimate if the grand coalition is stable and if this coalition can be considered as the best way to cooperate. Otherwise, cooperation between the partners of the game is considered as less efficient than independent work.

If the game is successful, the plan of the grand coalition will be implemented in the real transport activity (“Implementation” step).

### **3.2.3.3 Discarded delivery requests in case of limitation of transportation capacities**

In this section we present an additional treatment related to situations where the capacity of the transport operators is not enough to serve the entire delivery requests of the manufacturer. This additional processing of the cooperative treatment takes place in the “game” stage in Figure 3-3. It helps to obtain the reasonable payoff; it means that when the transport operators’ capacity is not enough to serve all the delivery requests, they could accept only a part of the delivery requests to avoid unnecessary penalty cost. Correspondingly, the total cost will decrease. Thus, some parts of delivery requests are considered as rejected and these quantities are called “discarded quantities”. Hence, only part of the whole delivery requests is served in this case. According to the hypothesis of section 3.2.1, these discarded quantities, do not generate penalty to be paid by the transport operators’ coalition.

In order to simulate that transport operators can refuse to serve some parts of the manufacturer’s delivery requests during the time horizon, when the transport operators’ capacity is strongly limited, the following mechanism is implemented (Figure 3-5). If the transport operators have enough capacity to serve the whole delivery requests, the payoff is directly obtained (Figure 3-5, block 1). If the transport operators must refuse some quantities that cannot be served during the whole time horizon, the initial delivery requests will be reduced by the quantity of products that are considered as not yet delivered in the last period (Figure 3-5, block 2). Indeed, considering that delivery requests of products expressed for the first periods of the time horizon must be primarily served – no enough time to find solution with no disruption, it is assumed that the discarded quantities concern delivery requests on the last periods, so as to keep time flexibility to serve the delivery requests when transportation is limited, even if it is late.



**Figure 3-5 The information flow of the limitation of the manufacturer's delivery requests**

A first running of the BST-mT model judges whether there are quantities to discard, if it is the case, it allows to estimate the discarded quantities in order to reduce the initial delivery requests and this model will be applied one more time (second running) based on reduced delivery requests to assess the impact of this refusal. Then the payoff will be determined in relation with the results of the second running of the BST-mT model.

An example is presented in the following to illustrate the process in Figure 3-5. Table 3-2 shows a part of results given by the first execution of the BST-mT model. The accumulated late quantity in the last period is '900'; this quantity will not be served and must be discarded. This quantity is then deduced from the delivery request concerning the last period so that The new delivery request in the period 4 will be ' $6000-900=5100$ '. The reduced delivery requests are shown in Table 3-3.

**Table 3-2 The result of a coalition in the first running of the BST-mT model**

| Product | Customer | Time period | Delivery request | Pickup quantity | Late quantity |
|---------|----------|-------------|------------------|-----------------|---------------|
| 1       | 1        | 1           | 6500             | 4700            | 1800          |
| 1       | 1        | 2           | 4500             | 6300            | 0             |
| 1       | 1        | 3           | 5500             | 5000            | 500           |
| 1       | 1        | 4           | 6000             | 5600            | 900           |

**Table 3-3 The result of a coalition in the second running of the BST-mT model**

| Product | Customer | Time period | Delivery request | Pickup quantity | Late quantity |
|---------|----------|-------------|------------------|-----------------|---------------|
| 1       | 1        | 1           | 6500             | 4700            | 1800          |
| 1       | 1        | 2           | 4500             | 6300            | 0             |
| 1       | 1        | 3           | 5500             | 5000            | 500           |
| 1       | 1        | 4           | 5100             | 5600            | 0             |

### 3.2.4 Example of the cooperation between three transport operators

Three transport operators are adopted for taking an example. To get a specific effect of the method, a numerical example will be represented to illustrate the cooperation approach. Several parts of the cooperation are presented in the following, as main input parameters, cooperation process including game, decision and implementation, and limitation of the manufacturer's delivery requests.

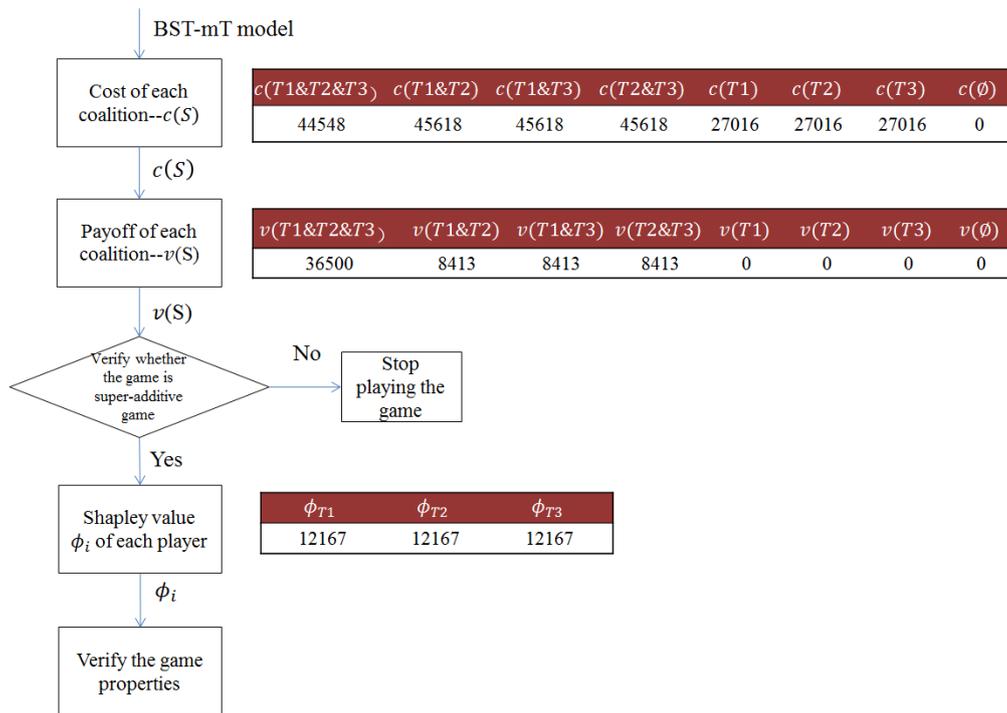
#### 3.2.4.1 Cooperation process

The game procedure described in Figure 3-4 is implemented to illustrate the previous description. Values of input parameters are not presented here, as there are considered as useless. The numerical values given in the following tables are used to help understandings of the cooperation process, but do not lead to any interpretation of results. Nevertheless, the current example is based on values defined in details in part 4.2. Let us introduce first, the total cost  $c(S)$  represents all the cost of the coalition  $S$ ; it is defined as follows:  $c(S) = cost_T + penalty_T + extra\_cost_T + structural\_cost$  with the following elements  $cost_T$ ,  $penalty_T$ ,  $extra\_cost_T$  and  $structural\_cost$  resulting from BST\_mT model.

Notice that the transport planning of each transport operators is also generated by BST\_mT. The BST-mT model is run for each coalition  $S$ . Let us recall that this model is a generic model that can be applied for all coalitions. For example, one partner

coalition only includes one transport operator. The total cost of each coalition is obtained by adding the different components of the cost ( $cost_T$ ,  $penalty_T$ ,  $extra\_cost_T$ ,  $structure\_cost$ ) after running the corresponding model.

The cost and cost saving of each coalition by running the related BST-mT, and the Shapley value for each partner are calculated and displayed in Figure 3-6. There are eight coalitions, coalition ( $T_1$ ), coalition ( $T_2$ ), coalition ( $T_3$ ), coalition ( $T_1 \& T_2$ ), coalition ( $T_1 \& T_3$ ), coalition ( $T_2 \& T_3$ ), coalition ( $T_1 \& T_2 \& T_3$ ) and  $\emptyset$ . The total cost of each coalition could be obtained by running the models related to each coalition.



**Figure 3-6 The results of the numerical example for each step of the cooperative process**

Each partner  $T_i$  gets the same cost saving as shown in Figure 3-6. That means that the cost of each partner is not  $c(T_i)$  ( $i = 1,2,3$ ) yet, but  $c(T_i) - \phi(T_i)$ . Thus, in this example the cost is reduced to  $\frac{c(T_i) - \phi(T_i)}{c(T_i)} = \frac{27016 - 12167}{27016} = 55\%$  of its initial value.

Three transport operators serve the manufacturer, thus, the 4PL gets structural cost from these three transport operators. And the plans of  $T_1 \& T_2 \& T_3$  model – grand coalition are applied by each partner.

Game

Using the information send by the manufacturer and the three transport operators, the 4PL runs the BST-mT for each coalition. Consequently, the value of  $c(S)$  could be

obtained for each coalition, and then the payoff of each coalition  $v(S)$  may be deduced. For example,  $c(T1\&T3) = 45618$ , and through equation (CS.1),  $v(T1\&T3) = c(T1) + c(T3) - c(T1\&T3) = 8413$ , in Figure 3-6. It should be verified whether the game is the super-additive game before calculating the Shapley value. The grand coalition is  $\{T1, T2, T3\}$ , consequently  $N = \{T1, T2, T3\}$  in the definition of super-additive game.

We present below, the calculation to verify whether a game from the previous example is super-additive or not. Table 3-4 shows the calculated values that explain how to check the property of super-additivity of the game.

**Table 3-4 Super additivity**

| $S$  | $M$      | $v(S \cup M)$ | $v(S)$ | $v(M)$ | $v(S) + v(M)$ | $v(S \cup M) \geq v(S) + v(M)$ |
|------|----------|---------------|--------|--------|---------------|--------------------------------|
| {T1} | {T2, T3} | 36500         | 0      | 8413   | 8413          | True                           |
| {T2} | {T1, T3} | 36500         | 0      | 8413   | 8413          | True                           |
| {T3} | {T1, T2} | 36500         | 0      | 8413   | 8413          | True                           |
| {T1} | {T3}     | 8413          | 0      | 0      | 0             | True                           |
| {T2} | {T3}     | 8413          | 0      | 0      | 0             | True                           |
| {T1} | {T2}     | 8413          | 0      | 0      | 0             | True                           |

Thus, for all  $S, M \subset N$ , if  $S \cap M = \emptyset$ , then  $v(S \cup M) \geq v(S) + v(M)$  is true, consequently the game in this example is a super-additive game.

Shapley values for each partner in the grand coalitions are then calculated,  $\phi_{T1}$ ,  $\phi_{T2}$ , and  $\phi_{T3}$  and given in Figure 3-6.

Decision

The 4PL judges the game properties for the grand coalition. In this example, Shapley value  $\phi_i$  is the payoff vector  $x_i$  in the definition of core in this context.

For  $\emptyset$ , obviously the formula  $\sum_{i \in S} x_i \geq v(S)$  is true.

For {T1},  $x_{T1} \geq v(T1)$  is true, since  $\phi_{T1} \geq v(T1)$  in Figure 3-6.

Similarly,  $\phi_{T2} \geq v(T2)$ ,  $\phi_{T3} \geq v(T3)$ ,  $\phi_{T1} + \phi_{T2} \geq v(T1\&T2)$ ,  $\phi_{T1} + \phi_{T3} \geq v(T1\&T3)$ ,  $\phi_{T2} + \phi_{T3} \geq v(T2\&T3)$ , and  $\phi_{T1} + \phi_{T2} + \phi_{T3} \geq v(T1\&T2\&T3)$ , thus,  $\sum_{i \in S} x_i \geq v(S)$  is true for  $\forall S \subseteq N$ . Consequently, these Shapley values are in the

core, and the cooperation is effective. As a result, each partner will apply the plan of the grand coalition.

### Implementation

The plan of the grand coalition will be implemented in the real activity. The value of cost saving is the Shapley value of each transport operator.

#### **3.2.4.2 Discarded delivery requests in case of limitation of transportation capacities**

Let us complete this presentation with a focus on how to define the discarded delivery requests when the transportation capacity is strongly limited. When the discarded quantities appeared in the results of the first running of the BST-mT model (see Figure 3-5), how the coalition refuses this part of delivery requests? Table 3-5 shows a part of the resulting plan of a coalition related to the previous example. Accordingly the coalition refuses to serve the quantity remained on the last period and considers this quantity as discarded (data highlighted in Table 3-5).

**Table 3-5 Results of the first simulation**

| Product | Customer | Time period | Delivery request | Pickup quantity | Late quantity |
|---------|----------|-------------|------------------|-----------------|---------------|
| 1       | 1        | 1           | 0                | 0               | 0             |
| 1       | 1        | 2           | 6500             | 4700            | 1800          |
| 1       | 1        | 3           | 7500             | 4400            | 4900          |
| 1       | 1        | 4           | 8500             | 12700           | 700           |
| 1       | 1        | 5           | 6500             | 4100            | 3100          |
| 1       | 1        | 6           | 8500             | 11600           | 0             |
| 1       | 1        | 7           | 8950             | 4760            | 4190          |
| 1       | 1        | 8           | 10000            | 3800            | 10390         |
| 1       | 1        | 9           | 8500             | 10600           | 8290          |
| 1       | 1        | 10          | 0                | 0               | 8290          |

The quantity in the last time bucket of the Table 3-5 ('8290') is rejected, and a portion of demand quantity in period 11 is canceled as shown in Table 3-6. The delivery requests in the beginning periods of the time horizon is preferentially shipped, thus discarding the delivery requests from the last period can give the transport operators more time to arrange the work.

**Table 3-6 The new delivery requests for the second simulation**

| Product | Customer | Time period | New delivery request | Pickup quantity | Late quantity |
|---------|----------|-------------|----------------------|-----------------|---------------|
| 1       | 1        | 1           | 0                    | 0               | 0             |
| 1       | 1        | 2           | 6500                 | 4700            | 1800          |
| 1       | 1        | 3           | 7500                 | 4400            | 4900          |
| 1       | 1        | 4           | 8500                 | 12700           | 700           |
| 1       | 1        | 5           | 6500                 | 4100            | 3100          |
| 1       | 1        | 6           | 8500                 | 11600           | 0             |
| 1       | 1        | 7           | 8950                 | 4760            | 4190          |
| 1       | 1        | 8           | 10000                | 3800            | 10390         |
| 1       | 1        | 9           | 210                  | 10600           | 0             |
| 1       | 1        | 10          | 0                    | 0               | 0             |

### **3.3 Cooperation between heterogeneous partners: one manufacturer and many transport operators**

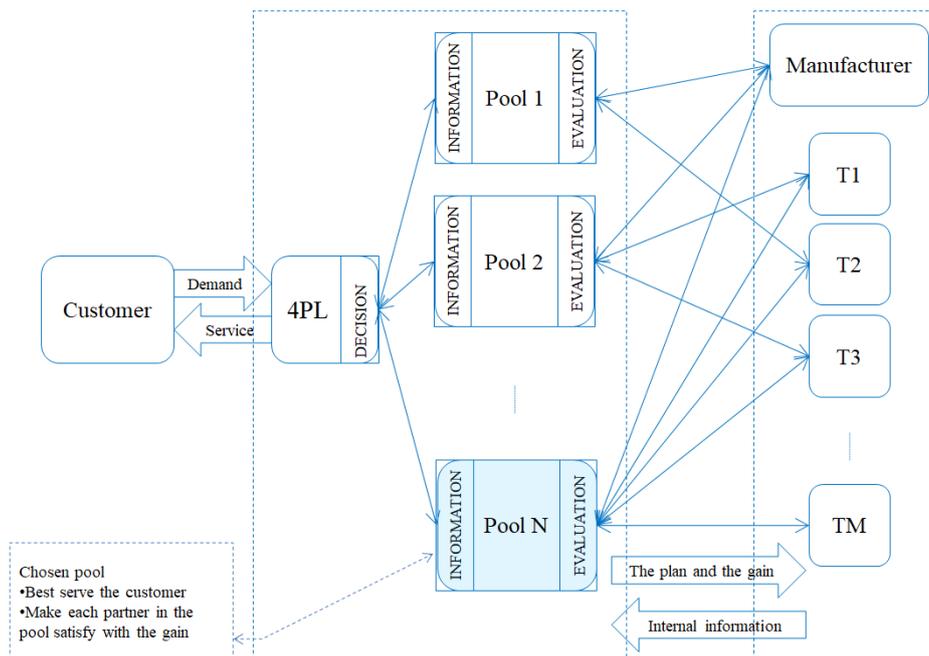
The cooperation between heterogeneous partners is presented in this section. A manufacturer and multiple transport operators are the partners of the game. The following points are presented in this section: First, the different roles of the partners inside the supply chain are introduced. Second, the manufacturer and the hybrid (manufacturer and multiple operators) planning models are proposed. Third, protocol of the game between a manufacturer and multi-transport operators is established. Finally, an example which includes a manufacturer and two transport operators is presented.

#### **3.3.1 The partners of the supply chain and their roles**

By continuing the work carried out in the specific context of one manufacturer and one transport operator presented in (Wang, Deschamps et al. 2016), the cooperation context of this thesis is made up of the customers' request for products, the manufacturer with its own production resources and many transport operators with transport resource. The 4PL receives the demand from the customers, and considers all the resources of the manufacturer and the transport operators to intend to serve the customers. Planning decisions are made by the 4PL according to information sent by the transport operators and the manufacturer, as represented Figure 3-7.

The main difference of this section compare to section 3.2 is that the manufacturer is working in cooperation with the transportation to serve the customers. Furthermore, the discarded quantities have also to be taken into account in this section, which generate discarded penalty. The justification of this penalty is issued from compensation required by the customers to the manufacturer due to the missing quantities of demand.

The 4PL intends to define the pool of partners that offers the best service to the customers. Figure 3-7 shows an overall view of the cooperation in the case of one manufacturer and  $m$  transport operators (labelled T1 up to TM). The 4PL chooses one of all these pools to offer the delivery of the products according to a given objective such as for instance, the search for best service for the customers, or maximum profit acquired by each partner in the pool. The 4PL gets the plan of the demand from the customer and serves it according to the capacity of the pool. Then the 4PL sends the plan and the expected gain to the manufacturer and the transport operators in the selected pool. Meanwhile, 4PL takes some charges from the transport operators as the fees of management. As the manager of the pool, the 4PL aims to satisfy each partner with the best possible gain.



**Figure 3-7 Overall view of cooperation between one manufacturer and many transport operators**

All the hypotheses in the cooperation between multiple transport operators are still active in this section. Simultaneously, the hypotheses about the manufacturer are presented below:

- Different products are made by the manufacturer to satisfy the demands of different customers.
- The inventory of raw materials required by the manufacturer to produce finish products is supposed to be infinite, and the transport only is concerned by the move of finish products. Thus, the replenishment decisions of raw materials are not considered in the scope of this problem.
- The production and finished products inventory capacities are limited.
- The manufacturer knows the products' demand of all customers in the whole planning horizon.
- Due to the capacity limitation of the manufacturer and/or the transport operators, the customer demand cannot be fulfilled every time. Consequently, the customers are forced to accept that the delivered quantities of products can be less than the initial ordered quantity and hence some part of their demand is not satisfied; let us recall that these quantities are called discarded delivery quantities. The value of the discarded delivery quantities is the difference between the total customer demand and total delivery quantities of the manufacturer or the pool in the whole time horizon. The insufficient supply leads to a certain penalty cost paid by the manufacturer to the customers.
- A small deviation of the quantity of delivered products from the initial ordered quantity is accepted by the customers. The deviation generates the penalty costs paid to the customers. The notions of late delivery quantity and early quantity are earlier defined in this chapter. The possibility to deliver quantities in early is limited for the manufacturer, since we consider that the stock space at the customer is restricted and any product prematurely received in this stock leads the customer to have more cost.
- The transportation prices and the delivery lead time related to the different customers are known by the manufacturer.
- The manufacturer needs to be aware about the transportation capacity of each operator. This detailed information is not communicated by the transport operator due to reasons of data confidentiality. The manufacturer has then to assess this capacity for correctly dimensioning its delivery plan and choose to underestimate it in order to limit the risks.

BST-mT model in section 3.2.2 describes the activities of the transport operators. In the next section, the production planning model is set up to represent the activities of the manufacturer who has to cooperate with the transport operators within the pool. A hybridized model (i.e. manufacturer and transport operator) is then proposed to describe the activities of the pool including manufacturer and the transport operators.

### 3.3.2 Production and hybridized planning models

The impact of manufacturer in the planning model is taken into account in this section. The manufacturer prefers to get maximum profit, and the model is in agreement with this purpose. In this case, the best profit production model is built for the manufacturer, for short BPP model.

The hybridized model is set up to encompass the activities of the manufacturer and the transport operators in cooperation with the purpose to get maximum profits. With regard to different number of transport operators and the best profit objective, the model is named the BPP&mT model, meaning the model can deal with m (1, 2, 3, etc.) transport operator(s).

#### 3.3.2.1 Best profit production model (BPP model)

Let us give some general information about BPP models, corresponding to the following hypotheses:

The manufacturer receives the customers' demands, and takes into account the constraints of local resources capacities while searching to maximize its profit. The BPP model is thus run to generate the production plan, delivery plan and inventory plan, as shown in Figure 3-8.

The parameters, variables, local resource constraints, and the objective function are represented in the following sections.

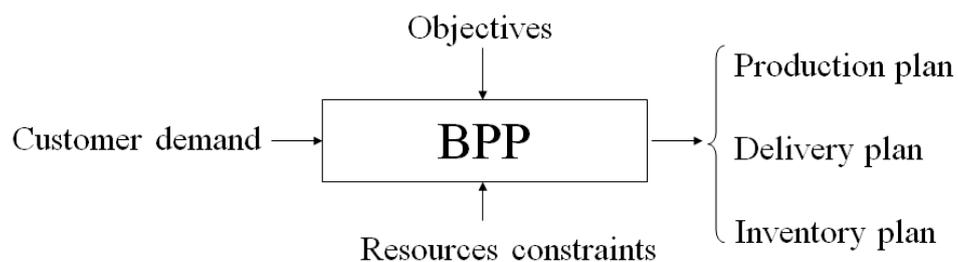


Figure 3-8 Input and output of the BPP model

##### 3.3.2.1.1 Parameters and variables

- Parameters

The input of the mathematic model is represented by parameters. The parameters are the customer demand, the production lead time, the capacity of the manufacturer and the financial information. The parameters used in this model are stated in the following.

|                 |  |
|-----------------|--|
| $d_{p,j,t}$     | <i>Customer demand for product p, made for customer j during the period t</i>        |
| $DP_p$          | <i>Production lead time for producing product p</i>                                  |
| $DT_j$          | <i>Transportation lead-time when customer j is served</i>                            |
| $Pcap_p$        | <i>Production capacity for product p in each period</i>                              |
| $Icap_p$        | <i>Inventory capacity for product p in each period</i>                               |
| $u_p$           | <i>Quantity of required resource for producing one unit of product p</i>             |
| $v_p$           | <i>Scalar representing the unitary weight of product p</i>                           |
| $CS_p$          | <i>Unitary inventory cost of product p</i>   |
| $CP_p$          | <i>Unitary production cost of product p</i>  |
| $CR_{p,j}$      | <i>Unitary late delivery penalty cost of product p requested by customer j</i>       |
| $CE_{p,j}$      | <i>Unitary early delivery penalty cost of product p requested by customer j</i>      |
| $E_{max_{p,j}}$ | <i>Maximum allowed early supplied quantity of product p to customer j per period</i> |
| $SP_{p,j}$      | <i>Selling price of one unit product p to customer j</i>                             |
| $TP_{p,j}$      | <i>Transportation price per unit of product p to be picked up to the customer j</i>  |
| $D_j$           | <i>Round-trip lead-time when customer j is served</i>                                |
| $R$             | <i>Number of trucks operated by the transport operator</i>                           |
| $cap$           | <i>Load capacity of a truck</i>  |
| $ T $           | <i>Number of valid time period</i>   |

- Variables

These variables correspond to the output flows of the mathematic model which are depicted in Figure 3-8: the production plan, the delivery plan (including the early and late delivery quantities showing deviation with the demand), and the inventory plan. The quantities of products are defined as integer variables in the mathematic model.

|             |   |
|-------------|---|
| $i_{p,j,t}$ | <i>Inventory quantity of products p requested by customer j in period t</i>                           |
| $f_{p,j,t}$ | <i>Production quantity of products p requested by customer j in period t</i>                          |
| $l_{p,j,t}$ | <i>The delivery quantities of manufacturer for product p, made for customer j during the period t</i> |

$b_{p,j,t}$  Late delivery quantities of products  $p$  requested by customer  $j$  in period  $t$

$e_{p,j,t}$  Early delivery quantities of products  $p$  requested by customer  $j$  in period  $t$

### 3.3.2.1.2 Constraints and objective function

#### Constraints

The decision variables in the model are constrained by resources, such as for instance the production capacity, inventory capacity and the estimation for transportation's capacity.

#### Stock balance

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

The inventory of finished products ( $i_{p,j,t}$ ) is controlled with this constraint. The number of finished products vary at each time period, i.e. the inventory increases by the quantity of ( $f_{p,j,t-DP_p}$ ), and decreases by the quantity of ( $l_{p,j,t}$ ).

- Deviation from customer demand

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

The difference between the demand ( $d_{p,j,t+DT_j}$ ) sent by the customer and the delivery quantity  $l_{p,j,t}$  in each time period is expressed by this constraint. The transportation lead-time  $DT_j$  must be considered, i.e., the customer demand in time period  $t + DT_j$  is delivered by the manufacturer in time period  $t$ . In each single time period, the delivery quantity can be a little less ( $b_{p,j,t}$ ) or more ( $e_{p,j,t}$ ) than the demand according to the limit of the production capacity and the estimated transportation capacity. The gap between the demand and delivery quantities in the current period ( $b_{p,j,t}$  and  $e_{p,j,t}$ ) and the previous period ( $b_{p,j,t-1}$  and  $e_{p,j,t-1}$ ) is controlled in this equation.

- Early supply limitation

$$e_{p,j,t} \leq Emax_{p,j} \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP.3})$$

The early supplied quantities ( $e_{p,j,t}$ ) to customers are limited by this constraint. The customer provides the manufacturer a certain flexibility ( $Emax_{p,j}$ ) to deliver early products.

- Delivery limitation

$$\sum_t l_{p,j,t} \leq \sum_t d_{p,j,t} \quad \forall p \in P, \forall j \in J \quad (\text{BPP.4})$$

For each product and for each customer, the accumulated delivery quantities ( $\sum_t l_{p,j,t}$ ) in the whole planning time horizon must be less than the corresponding accumulated quantities of customer demand ( $\sum_t d_{p,j,t}$ ).

- Production limitation

$$\sum_t f_{p,j,t} \leq \sum_t l_{p,j,t} \quad \forall p \in P, \forall j \in J \quad (\text{BPP.5})$$

The accumulated production quantities ( $\sum_t f_{p,j,t}$ ) in the whole planning time horizon must not overcome the corresponding accumulated quantities of delivery quantities ( $\sum_t l_{p,j,t}$ ) for each product and for each customer.

- Production resource capacity

$$\sum_j \sum_{k=1}^{DP_p} u_p * f_{p,j,t-k+1} \leq Pcap_p \quad \forall p \in P, \forall t \in T \quad (\text{BPP.6})$$

The production loads ( $\sum_j \sum_{k=1}^{DP_p} u_p * f_{p,j,t-k+1}$ ) must be in accordance with the production resource capacity ( $Pcap_p$ ), as expressed by this constraint.

- Inventory capacity

$$\sum_j v_p * i_{p,j,t} \leq Icap_p \quad \forall p \in P, \forall t \in T \quad (\text{BPP.7})$$

Inventory capacity is considered in this constraint. The space occupied by finish products in the stock ( $\sum_j v_p * i_{p,j,t}$ ) must not topped the total space of stock ( $Icap_p$ ) of each product for each time period in the planning horizon.

- Limitation of the estimated transportation's capacity

$$\sum_t \sum_j \sum_p l_{p,j,t} * v_p \leq \frac{|R|}{\frac{\sum_j D_j}{|J|}} * cap * |T| * percentage \quad (\text{BPP.8})$$

When the manufacturer is considered alone (i.e. as an independent partner from the others), it does not know the exact capacity of the transportation, thus it has to estimate it. Using limited information sent by the transport operators, the manufacturer estimates the transportation capacity to adapt its production activity. The  $|R|$  trucks of the transport operators are considered as serving the delivery quantities required by the manufacturer. The round-trip lead-time of each customer is  $D_j$ , thus the average value of all customers is  $\frac{\sum_j D_j}{|J|}$ . Each truck is thus considered as

busy during  $\frac{\sum_j D_j}{|J|}$  days before reloading. Based on this hypothesis, the average number of idle trucks per day (time period) is estimated to  $\frac{|R|}{\frac{\sum_j D_j}{|J|}}$ . The load weight capacity of each truck is ‘*cap*’. This estimation is multiplied by a ‘percentage’ for a conservative estimation, which is a kind of estimation lower than the real transportation capacity. It can ensure the transport operators have enough capacity to serve the whole delivery requests, meanwhile, the whole delivery requests of manufacturer can be served by the transport operators. The customer demand is sent in ‘ $|T|$ ’ discrete time periods. The manufacturer arranges its plans according to this capacity, and takes into account the limit capacity of transport operator as formula (BPP.8).

○ Non-negative constraint:

$$i_{p,j,t} \geq 0 \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP.9})$$

$$f_{p,j,t} \geq 0 \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP.10})$$

$$l_{p,j,t} \geq 0 \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP.11})$$

$$b_{p,j,t} \geq 0 \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP.12})$$

$$e_{p,j,t} \geq 0 \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP.13})$$

These constraints ensure all the variables in the model are positive.

▪ Objective function

The objective of this model (BPP.14) is the maximization of the total profit.

The profit of the manufacturer is the difference between revenue received from customer and the total cost. The total cost consists in the production cost (*fcost*), the inventory cost (*icost*), the penalty cost (*penalty*), and the transportation cost (*tcost*). The production cost is the cost made the products, including the raw material fees, the fees of machine running and the corresponding manpower fees etc. The inventory cost is the cost due to the stock of the finish products. The penalty cost consists of three parts, which are respectively caused by late delivery quantities, early delivery quantities and discarded delivery quantities. The discarded penalty is an optional penalty, which is only activated if there is second run of model according to the protocol in section 3.3.3.3. The discarded delivery quantity of product *p* requested by customer *j* is the difference between the total customer demand ( $\sum_t d_{p,j,t}$ ) and total delivery quantities ( $\sum_t l_{p,j,t}$ ) of the manufacturer in the whole time horizon. The value of the discarded quantity in the results of the model is the late delivery quantity in the

last time period ( $b_{p,j,T_F}$ ). The transportation cost is the fee paid to the transport operator(s) for the transport service.

$$\text{Max (profit)} \quad (\text{BPP.14})$$

$$\text{Profit} = \text{revenue} - \text{fcost} - \text{icost} - \text{penalty} - \text{tcost} \quad (\text{BPP.15})$$

$$\text{revenue} = \sum_p \sum_j \sum_t SP_{p,j} * l_{p,j,t} \quad (\text{BPP.16})$$

$$\text{fcost} = \sum_p \sum_j \sum_t CP_p * f_{p,j,t} \quad (\text{BPP.17})$$

$$\text{icost} = \sum_p \sum_j \sum_t CS_p * i_{p,j,t} \quad (\text{BPP.18})$$

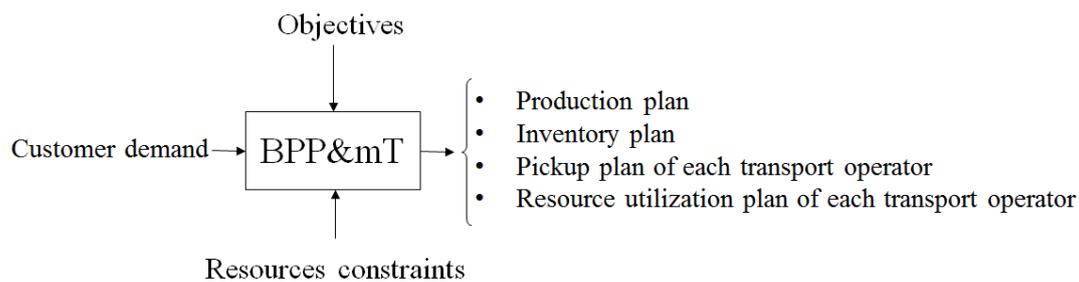
$$\text{penalty} = \sum_p \sum_j \sum_t CR_{p,j} * b_{p,j,t} + \sum_p \sum_j \sum_t CE_{p,j} * e_{p,j,t} (+ \sum_p \sum_j DC_{p,j} * b_{p,j,T_F}) \quad (\text{BPP.19})$$

$$\text{tcost} = \sum_p \sum_j \sum_t TP_j * l_{p,j,t} \quad (\text{BPP.20})$$

### 3.3.2.2 Best profit hybridized model of one manufacturer and many transport operators (BPP&mT model)

BPP&mT model has the same hypotheses as both models: BST-mT and BPP model.

The production and transportation, i.e., manufacturer and transport operators receive the customer demand. They consider their resource constraints, and aim to maximize their profit. As a result, a production plan and an inventory plan are generated for the manufacturer, a resource utilization plan is also generated for each transport operator, and the pickup plans are generated for both manufacturer and transport operators, as represented in Fig 9.



**Figure 3-9 Input and output of the BPP&mT model**

The parameters, variables, local resource constraints, and the objective function of BPP&mT model are displayed in the following.

#### 3.3.2.2.1 Parameters and variables

- Parameters

The parameters of BPP&mT model, include the information related to the manufacturer and also to the transport operators as defined below.

|                    |  |
|--------------------|--|
| $d_{p,j,t}$        | <i>Customer demand for product p, made for customer j during the period t</i>  |
| $DP_p$             | <i>Production lead time for producing product p</i>  |
| $DT_j$             | <i>Transportation lead-time when customer j is served</i>  |
| $Pcap_p$           | <i>Production capacity for product p in each period</i>  |
| $Icap_p$           | <i>Inventory capacity for product p in each period</i>   |
| $u_p$              | <i>Quantity of required resource for producing one unit of product p</i>   |
| $v_p$              | <i>Scalar representing the unitary weight of product p</i>   |
| $CS_p$             | <i>Unitary inventory cost of product p per period</i>  |
| $CP_p$             | <i>Unitary production cost of product p</i>  |
| $CR_{p,j}$         | <i>Unitary late supplied cost of product p for customer j per period</i>   |
| $CE_{p,j}$         | <i>Unitary early supplied cost of product for customer j p per period</i>  |
| $E_{max_{p,j}}$    | <i>Maximum allowed early delivered quantity of product p to customer j per period</i>  |
| $SP_{p,j}$         | <i>Selling price of one unit product p requested by customer j</i>   |
| $D_j$              | <i>Round-trip lead-time when customer j is served</i>  |
| $FC_{j,k}$         | <i>Destination-related transportation cost when transport operator k uses its own resources to serve the customer j</i>  |
| $FC\_extra_{j,k}$  | <i>Destination related transportation cost when transport operator k uses extra resources to serve the customer</i>  |
| $VC_{p,j}$         | <i>Product-related transportation cost associated to the pickup of one unit of product p to the customer j, via the use of trucks owned by transport operators</i>   |
| $VC\_extra_{p,j}$  | <i>product-related extra transportation cost associated to the pickup of one unit of product p to the customer j, via the use of extra trucks required by transport operators to increase their capacity</i> |
| $R_k$              | <i>Number of trucks owned by the transport operator k</i>  |
| $cap_k$            | <i>Load capacity of any truck owned by the transport operator k</i>  |
| $M\_extra_{j,k,t}$ | <i>Max number of external trucks available during the period t to be used by the transport operator k to serve the customer j</i>  |

$cap\_extra_k$  Load capacity of any extra truck hired by the transport operator  $k$

$M$  A large number

$SC$  The structure cost related to each transport operator

▪ Variables

The output of the BPP&mT model correspond to the following variables: production plan, inventory plan, pickup plan and resource utilization plan of each transport operator. The decision variables of this model also include the early and late quantities which are the deviation from the customer demand.

$i_{p,j,t}$  Inventory quantity of products  $p$  requested by customer  $j$  in period  $t$

$f_{p,j,t}$  Production quantity of products  $p$  requested by customer  $j$  in period  $t$

$b_{p,j,t}$  Quantity of products  $p$  requested by customer  $j$  and delivered in late during the period  $t$

$e_{p,j,t}$  Quantity of products  $p$  requested by customer  $j$  and delivered in early during the period  $t$

$q_{p,j,k,t}$  Pickup quantity of product  $p$  to be launched in transportation from manufacturer at time period  $t$  to customer  $j$  which use the owned trucks of transport operator  $k$

$q\_extra_{p,j,k,t}$  Pickup quantity of product  $p$  to be launched in transportation from manufacturer at time period  $t$  to customer  $j$  by extra trucks of transport operator  $k$

$m_{j,k,t}$  Number of trucks of the transport operator  $k$  used during period  $t$  to serve the customer  $j$

$m\_extra_{j,k,t}$  Number of extra trucks required by the transport operator  $k$  and used during period  $t$  to serve the customer  $j$

$n_k$  Binary variable equal to 1 if the transport operator  $k$  is used, 0 else

### 3.3.2.2.2 Constraints and objective function

#### Constraints

The production and transportation resources restrict the possible values of decision variables in the BPP&mT model. Consequently, the following constraints express these restrictions. Notice that these constraints combine the constraints of BST-mT model and BPP model.

$$i_{p,j,t} = i_{p,j,t-1} + f_{p,j,t-DP_p} - \sum_k (q_{p,j,k,t} + q\_extra_{p,j,k,t}) \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP\&mT.1})$$

$$\sum_k (q_{p,j,k,t} + q\_extra_{p,j,k,t}) - e_{p,j,t} + b_{p,j,t} = d_{p,j,t+DT_j} - e_{p,j,t-1} + b_{p,j,t-1} \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP\&mT.2})$$

$$e_{p,j,t} \leq Emax_{p,j} \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP\&mT.3})$$

$$\sum_t \sum_k (q_{p,j,k,t} + q\_extra_{p,j,k,t}) \leq \sum_t d_{p,j,t} \quad \forall p \in P, \forall j \in J \quad (\text{BPP\&mT.4})$$

$$\sum_j \sum_{k=1}^{DP_p} u_p * f_{p,j,t-k+1} \leq Pcap_p \quad \forall p \in P, \forall t \in T \quad (\text{BPP\&mT.5})$$

$$\sum_j v_p * i_{p,j,t} \leq Icap_p \quad \forall p \in P, \forall t \in T \quad (\text{BPP\&mT.6})$$

$$\sum_p v_p * q_{p,j,k,t} \leq m_{j,k,t} * cap_k \quad \forall j \in J, \forall k \in K, \forall t \in T \quad (\text{BPP\&mT.7})$$

$$\sum_p v_p * q\_extra_{p,j,k,t} \leq m\_extra_{j,k,t} * cap\_extra_k \quad \forall j \in J, \forall k \in K, \forall t \in T \quad (\text{BPP\&mT.8})$$

$$\sum_j \sum_i^{D_j} m_{j,k,t-i+1} \leq R_k \quad \forall k \in K, \forall t \in T \quad (\text{BPP\&mT.9})$$

$$m\_extra_{j,k,t} \leq M\_extra_{j,k,t} \quad \forall k \in K, \forall j \in J, \forall t \in T \quad (\text{BPP\&mT.10})$$

$$\sum_t f_{p,j,t} \leq \sum_t \sum_k (q_{p,j,k,t} + q\_extra_{p,j,k,t}) \quad \forall p \in P, \forall j \in J \quad (\text{BPP\&mT.11})$$

$$n_k \leq M * \sum_{j,t} (m_{j,k,t} + m\_extra_{j,k,t}) \quad \forall k \in K \quad (\text{BPP\&mT.12})$$

$$\sum_{j,t} (m_{j,k,t} + m\_extra_{j,k,t}) \leq M * n_k \quad \forall k \in K \quad (\text{BPP\&mT.13})$$

Non-negative constraint:

$$q_{p,j,k,t} \geq 0 \quad \forall k \in K, \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP\&mT.14})$$

$$q\_k\_extra_{p,j,k,t} \geq 0 \quad \forall k \in K, \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP\&mT.15})$$

$$tb_{p,j,t} \geq 0 \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP\&mT.16})$$

$$te_{p,j,t} \geq 0 \quad \forall p \in P, \forall j \in J, \forall t \in T \quad (\text{BPP\&mT.17})$$

$$m_{j,k,t} \geq 0 \quad \forall k \in K, \forall j \in J, \forall t \in T \quad (\text{BPP\&mT.18})$$

These constraints insure that all the variables in the model are positive.

### Objective function

Likewise BPP model, the objective of BPP&mT model (BPP&mT.19) also aims to maximize the total profit. The main difference is the costs of transport operators which are considered in this model instead of the transportation price in the BPP model

$$\text{Max (profit)} \quad (\text{BPP\&mT.19})$$

$$\begin{aligned} \text{Profit} = & \text{revenue} - \text{fcost} - \text{icost} - \text{penalty} \\ & - \text{tcost} - \text{extra tcost} - \text{structural cost} \end{aligned} \quad (\text{BPP\&mT.20})$$

$$\text{revenue} = \sum_p \sum_j \sum_t SP_{p,j} * q_{p,j,t} \quad (\text{BPP\&mT.21})$$

$$\text{fcost} = \sum_p \sum_j \sum_t CP_p * f_{p,j,t} \quad (\text{BPP\&mT.22})$$

$$\text{icost} = \sum_p \sum_j \sum_t CS_p * i_{p,j,t} \quad (\text{BPP\&mT.23})$$

$$\text{penalty} = \sum_p \sum_j \sum_t CR_{p,j} * b_{p,j,t} + \sum_p \sum_j \sum_t CE_{p,j} * e_{p,j,t} \quad (\text{BPP\&mT.24})$$

$$\text{tcost} = \sum_j \sum_k \sum_t FC_{j,k} * m_{j,k,t} + \sum_p \sum_j \sum_k \sum_t VC_{p,j} * q_{k,p,j,k,t} \quad (\text{BPP\&mT.25})$$

$$\begin{aligned} \text{extra tcost} = & \sum_j \sum_k FC\_extra_{j,k} * \sum_t m\_extra_{j,k,t} \\ & + \sum_p \sum_j \sum_k \sum_t VC\_extra_{p,j} * q_{k\_extra_{p,j,k,t}} \end{aligned} \quad (\text{BPP\&mT.26})$$

$$\text{structure cost} = SC * \sum_k n_k \quad (\text{BPP\&mT.27})$$

### **3.3.3 Protocol of the cooperation**

The implementation of the cooperation between one manufacturer and the transport operators is presented in this section. This approach of the cooperation is based on the Shapley value principle as in the previous section related to homogeneous partners.

#### **3.3.3.1 Introduction of the cooperation protocol between one manufacturer and many transport operators**

In this paragraph, multiple heterogeneous partners are taken into account. The manufacturer and transport operators are considered as the partners of the game, and each pool which has been mentioned in Figure 3-7 corresponds to a coalition in the game.

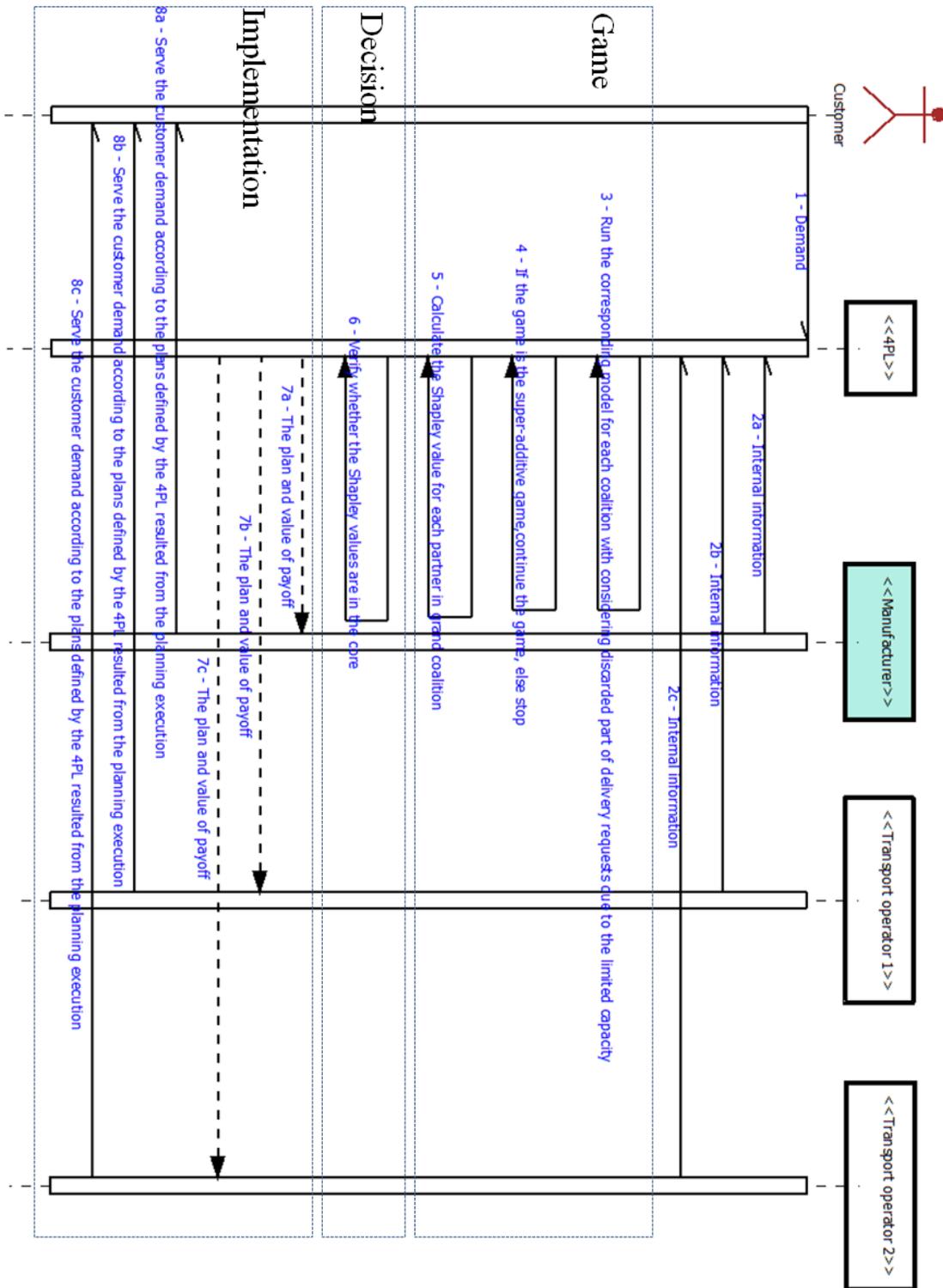
A game between a manufacturer and multiple transport operators – P and T<sub>1</sub>, T<sub>2</sub>, ..., T<sub>M</sub> is presented. Let us recall that M is the number of transport operators. Consequently, N (N = 2<sup>M+1</sup>) coalitions are generated; for instance, coalition (M),

coalition ( $T_1$ ), coalition ( $T_2$ ), coalition ( $M \& T_1$ ), coalition ( $M \& T_2$ ), coalition ( $T_1 \& T_2$ ), coalition ( $M \& T_1 \& T_2 \& \dots \& T_M$ ), and coalition  $\emptyset$ .

A UML sequence diagram with vertical timeline made up of a customer, a 4PL, a manufacturer and transport operators is presented in Figure 3-10.

The 4PL receives the demand from the customer and also receives internal information of the manufacturer and the transport operators. Then 4PL runs the corresponding model for each possible coalition. Consequently, the Shapley value for each partner is obtained and the 4PL sends the plan and the payoff value to each partner. According to the plan formulated by the 4PL, the manufacturer manufactures the products and prepares the delivery, and the transport operators ship the products to the customers. Afterwards, the customer pays the fees for the whole service to 4PL, and then 4PL carries out the payment to each partner. Indeed the cooperation protocol is made up of the following steps displayed in Figure 3-10: game, decision and implementation:

- Game: the demand of customer and internal information of the manufacturer and every transport operators are utilized. The 4PL runs the corresponding model for each possible coalition to obtain the payoff, as represented in Figure 3-10 (Num. 3). For example, 4PL runs BPP model for the one partner coalition P, and runs P&T1&T2 model for coalition P&T1&T2 to get the results of the model. If the game is the super-additive, the 4PL calculates Shapley values for each partner in the grand coalition, else the game stops (Num. 4 and 5 in Figure 3-10).
- Decision: The game properties are checked by 4PL (Num. 6 in Figure 3-10) in the same way as in section 3.2.3.1.
- Implementation: The plans of the partners in the grand coalition will be implemented in the real activity. As displayed in Figure 3-10, the 4PL sends the plan and corresponding payoffs (profits) to the manufacturer and all transport operators (Num. 7); the latter serve the customer demand according to the plans defined by the 4PL resulted from the planning execution (Num. 8).



**Figure 3-10 Cooperation protocol (a manufacturer and two transport operators): a UML sequence diagram**

The main steps of the planning cooperation approach are the same as the ones presented in section 3.2.3.2 and Figure 3-4.

### 3.3.3.2 Discarded customer demand and the corresponding penalty

In the same way as in the cooperation between homogeneous partners, the discarded quantities can exist in the case of the cooperation between heterogeneous partners. It is worth to remind that the difference between these two kinds of cooperation. In the cooperation between heterogeneous partners, the partners are not only transport operator(s) but they also encompass one manufacturer. Contrary to the cooperation between homogeneous partners where there are only transport operator(s). The discarded quantities of the pure transport operator(s) coalitions in this section are exactly the same as those described in section 3.2.3.3. For the coalitions with the manufacturer, pure manufacturer coalition and mix coalitions (the manufacturer and the transport operators), the method to deal with the discarded quantities are almost same as in section 3.2.3.3, regarding the definition of these values and regarding the way to refuse some quantities in the customer demand. However, the target of the service is the customer here, thus the coalitions (including the manufacturer) must pay the penalties to the customers due to the discarded quantities (labelled discarded penalty. This payment is not necessary for pure transport operators' coalitions. The calculation process of the payoff for the pure manufacturer coalition and mix coalitions are presented in Figure 3-11. Notice that the penalty due to the discarded quantities of the customer demand is taken into account in the payoff.

If the block 2 is carried out, the value of discarded penalty is calculated, and the profit is updated to get the payoff.

The unitary discarded delivery penalty cost of product  $p$  requested by customer  $j$  --  $DC_{p,j}$  is defined for calculating the discarded penalty, corresponding to the hypotheses mentioned in section 3.3.1.

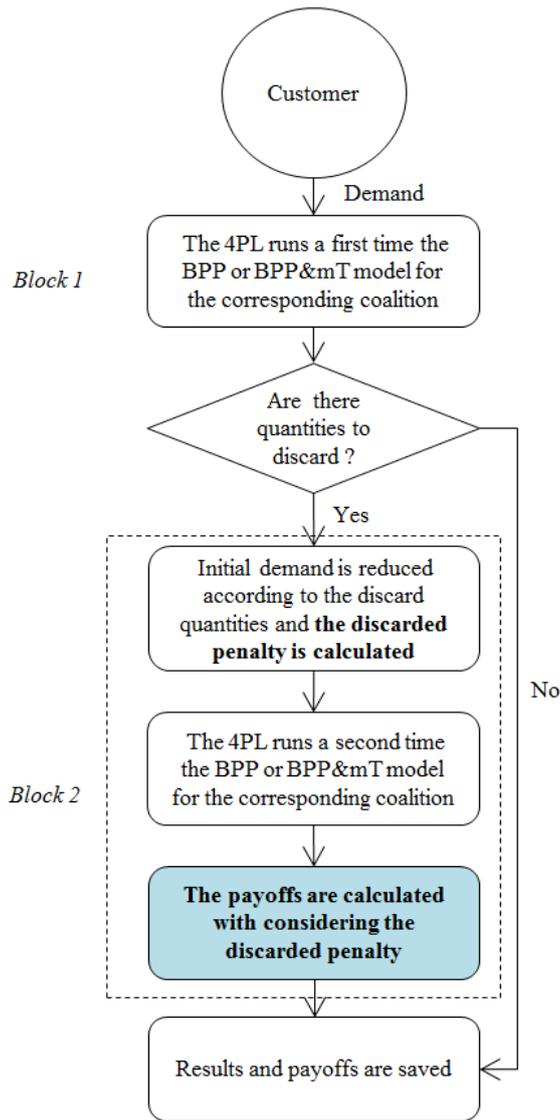
$$\text{discarded penalty} = \sum_p \sum_j DC_{p,j} * b_{p,j,T_F} \quad (\text{SC.1})$$

The profit from the simulated model (BPP model or BPP&mT model) is noted as  $profit_1$ , and the updated profit taking into account the discarded penalties is noted as  $profit_2$ .

$$profit_2 = profit_1 - \text{discarded penalty} \quad (\text{SC.2})$$

$$v(S) = profit_2 \quad (\text{SC.3})$$

If the block 2 is not carried out, i.e. there is not discarded quantity; the payoff is the profit from the simulated model.



**Figure 3-11 The process of obtaining payoff for the coalition included the manufacturer**

### **3.3.4 Example of the cooperation between one manufacturer and two transport operators**

To illustrate the method, a numerical example with one manufacturer (P) and two transport operators (T1, T2) is represented in the following. For the coalitions with the manufacturer, such as coalition P, P&T1, P&T2, and P&T1&T2, the corresponding models are given in the previous section of this chapter. For coalition T1, T2, and T1&T2, the models are presented in section 3.2.2.

As for section 3.2.4.1, values of input parameters are not presented here but can be found in section 4.2. The game procedure of Figure 3-4 is then implemented. The payoff -- profit, and the Shapley value for each partner are displayed in Figure 3-12.

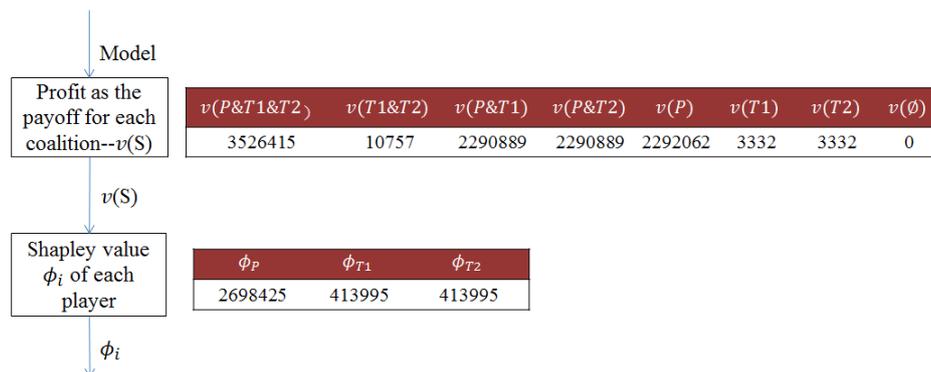
Notice that in this case the profit seems more adapted because of the heterogeneity of the partners, which leads to difficulties for using cost saving.

Table 3-7 shows the model used in each coalition. The profit of each coalition is obtained as a result of the models execution.

**Table 3-7 The coalitions and the corresponding models**

| Coalition | Applied model |
|-----------|---------------|
| P         | BPP           |
| T1        | BST-1T        |
| T2        | BST-1T        |
| T1&T2     | BST-2T        |
| P&T1      | P&1T          |
| P&T2      | P&1T          |
| P&T1&T2   | P&2T          |

When the manufacturer is in a one partner coalition, there are three pure transport operator coalitions--T1, T2 or T1&T2 among all possible coalitions. The load capacity of these coalitions (T1, T2 or T1&T2) in the whole time horizon is used to estimate the profits of this coalition. For avoiding important exceeds of inventory quantity, the minimum load capacity between coalition T1, coalition T2 and coalition T1&T2 is chosen for estimating the manufacturer's profit.



**Figure 3-12 The results of the numerical example**

According to the definition of the core, the Shapley values ( $\phi_P, \phi_{T1}, \phi_{T2}$ ) in this example are in the core, and the demonstration is in the following.

In this example, Shapley value  $\phi_i$  is the payoff vector  $x_i$  in the definition of core.

For  $\emptyset$ , obviously the formula  $\sum_{i \in S} x_i \geq v(S)$  is true.

For  $\{P\}$ ,  $x_P \geq v(P)$  is true, since  $\phi_P \geq v(P)$  in Figure 3-12.

Similarly,  $\phi_{T1} \geq v(T1)$ ,  $\phi_{T2} \geq v(T2)$ ,  $\phi_P + \phi_{T1} \geq v(P\&T1)$ ,  $\phi_P + \phi_{T2} \geq v(P\&T2)$ ,  $\phi_{T1} + \phi_{T2} \geq v(T1\&T2)$ , and  $\phi_P + \phi_{T1} + \phi_{T2} \geq v(P\&T1\&T2)$ , thus,  $\sum_{i \in S} x_i \geq v(S)$  is true for  $\forall S \subseteq N$ .

### 3.4 Conclusion

In this chapter, we described the implementation of cooperative games to solve the planning problems involving different partners of the supply chain at the transport level. The concept of pool of partners emphasizes the notion of the cooperation and corresponds to the notion of coalition in game theory.

Two types of games are proposed according to the partners are homogeneous or heterogeneous. The cooperation between homogeneous partners includes multiple transport operators. The cooperation between heterogeneous partners consists of one manufacturer and multiple transport operators. To achieve the purpose of cooperation planning, a set of models has been implemented: BST-mT model is built for the homogeneous partners – transport operators. BPP model and BPP&mT model are established, and BST-mT model is also used for the cooperation between heterogeneous partners.

Then, the cooperation protocol is described in three steps, which are game, decision and implementation. When the payoffs are obtained, it is necessary to decide whether the game is super-additive. If the game is the super-additive game, the game will continue and the Shapley values are calculated, else the game will stop. The property of the game (whether the Shapley values are in the core) is verified in the last step of the game. At the end, the plan of the grand coalition will be implemented in the real activity.

The principle of discarding part customer demand is applied in the cooperation between heterogeneous partners, and discarding part delivery quantities is applied in the cooperation between homogeneous partners. It helps to obtain a reasonable payoff, since the discarded quantities are rejected.

In the next chapter, some experiments are carried out utilizing the models and protocols in this chapter. The results will be presented to validate our method.

# Chapter 4

## Experimental results and analysis

### 4.1 Introduction

The planning models of the production and transportation<sup>1</sup> activities as well as cooperation protocols have been described in chapter 3. In this chapter the value and interest of the cooperative approaches are evaluated. Consequently, numerical experiments will be designed and implemented to evaluate the performance of the cooperation solution based on game theory. The cooperation decisions are influenced by the values of parameters – transport operators’ capacity, manufacturer’s capacity, transport cost etc., since the combination of parameters in the models defined in chapter 3 can impact on the responses of the system. Accordingly, the main parameters which can affect the cooperation decisions and SC performances will be identified for the experiments design at the beginning of section 4.3 and 4.4. In the first experimentation, three transport operators are considered as cooperative partners. In this case, the transport capacity and the transport cost are considered as input parameters of the design of experiments. In the second experimentation one manufacturer and two transport operators are considered in cooperation between heterogeneous partners. In this context, section 4.2 will introduce the generation of instances for production and transport planning problem, which involves the complete input parameters. In section 4.3 and 4.4, the cooperation cases stated in chapter 3 will be examined. Three transport operators are chosen as the players to verify the effect of cooperation between homogeneous partners in 4.3, and one manufacturer and two transport operators are selected for the cooperation between heterogeneous partners in 4.4.

### 4.2 Generation of instances for production and transport planning problem

The current description intends to present the data set used to lead the experiments. The main concern is to propose consistent values based on realistic reasoning, failing to obtain and work with real data. The Table 4-1 reminds the main notations of

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<sup>1</sup> Notice that the entity “distribution” of a SC is called “transport” in this chapter.

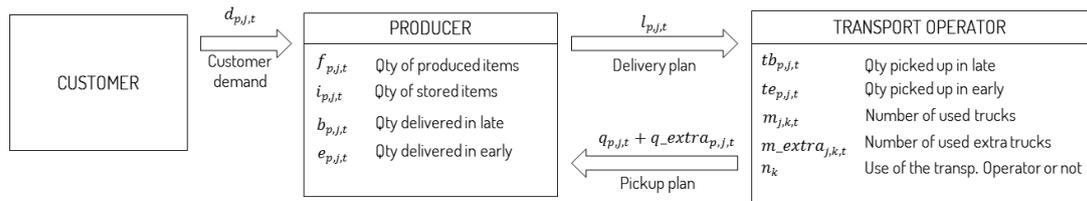
parameters used to propose a linear programming model in Chapter 3, and terms used in this part to define their meaning.

**Table 4-1 Parameters**

| PRODUCER    |                      | TRANSPORT OPERATOR |   |
|-------------|----------------------|--------------------|---|
| $CE_{p,j}$  | Early Cost Penalty   | $CP_p$             | Production cost                               |
| $CR_{p,j}$  | Late Cost Penalty    | $CS_p$             | Inventory cost                                |
| $Pcap_p$    | Production capacity  | $SP_{p,j}$         | Product selling price                         |
| $Icap_p$    | Inventory capacity   | $DP_p$             | Production lead time                          |
| $u_p$       | Qty of required res. |                    |   |
| CUSTOMER    |                      |                    |   |
| $d_{p,j,t}$ | Customer demand      |                    |   |
|             |                      | $EC_{p,j}$         | Early Cost Penalty                            |
|             |                      | $BC_{p,j}$         | Late Cost Penalty                             |
|             |                      | $R_k$              | Number of trucks                              |
|             |                      | $cap_k$            | Truck capacity                                |
|             |                      | $v_p$              | Product weight                                |
|             |                      | $DT_j$             | Transp. leadtime                              |
|             |                      | $D_j$              | Roundtrip duration                            |
|             |                      | $FC_{j,k}$         | Transp. fixed cost                            |
|             |                      | $VC_{p,j}$         | Transp. variable cost                         |
|             |                      | $TP_{p,j}$         | Transp. price                                 |
|             |                      | $SC$               | Structural cost                               |
|             |                      | $FC\_extra_{j,k}$  | Transp. fixed cost related to extra trucks    |
|             |                      | $VC\_extra_{p,j}$  | Transp. variable cost related to extra trucks |
|             |                      | $M\_extra_{j,k,t}$ | Number of extra trucks                        |
|             |                      | $cap\_extra_k$     | Extra truck capacity                          |

The Table 4-2 also presents the variables, their usage context and their meaning.

**Table 4-2 Variables**



#### 4.2.1 General characteristics

Before describing the main data used to experiment the model, we define the situation and the main characteristics of Customers, Products and Vehicle. The detailed description of each studied experimental situation will be presented in the remainder of this chapter.

##### Customer's characteristics

To ensure reasonable variety of situations in the experimental problem we intend to solve, we consider two customers with specific locations and products demand. Some parameters in relation with the activity of customers (demand, location, costs and prices...) are given throughout this presentation of the experimental data set.

##### Product characteristics

We consider two families of product. The unit weigh of each type of product is chosen in an arbitrary manner, presented in Table 4-3. The weight will be the product

characteristic that will be used to verify the balance between the load to deliver and the capacity of a truck.

**Table 4-3 The weights of each product**

|                     |             |        |
|---------------------|-------------|--------|
| Weight of product 1 | 0,0050 tons | 5 kg   |
| Weight of product 2 | 0,0015 tons | 1,5 kg |

### Vehicle characteristics

Long-haul transport of freight is only provided by heavy trucks. Since 1989, the total load of a heavy truck is considered as equal to 40 tons (Table 4-4). We retain this value to define the truck capacity in our experimentations.

**Table 4-4 The truck capacity**

|                |         |           |
|----------------|---------|-----------|
| Truck capacity | 40 tons | 40 000 kg |
|----------------|---------|-----------|

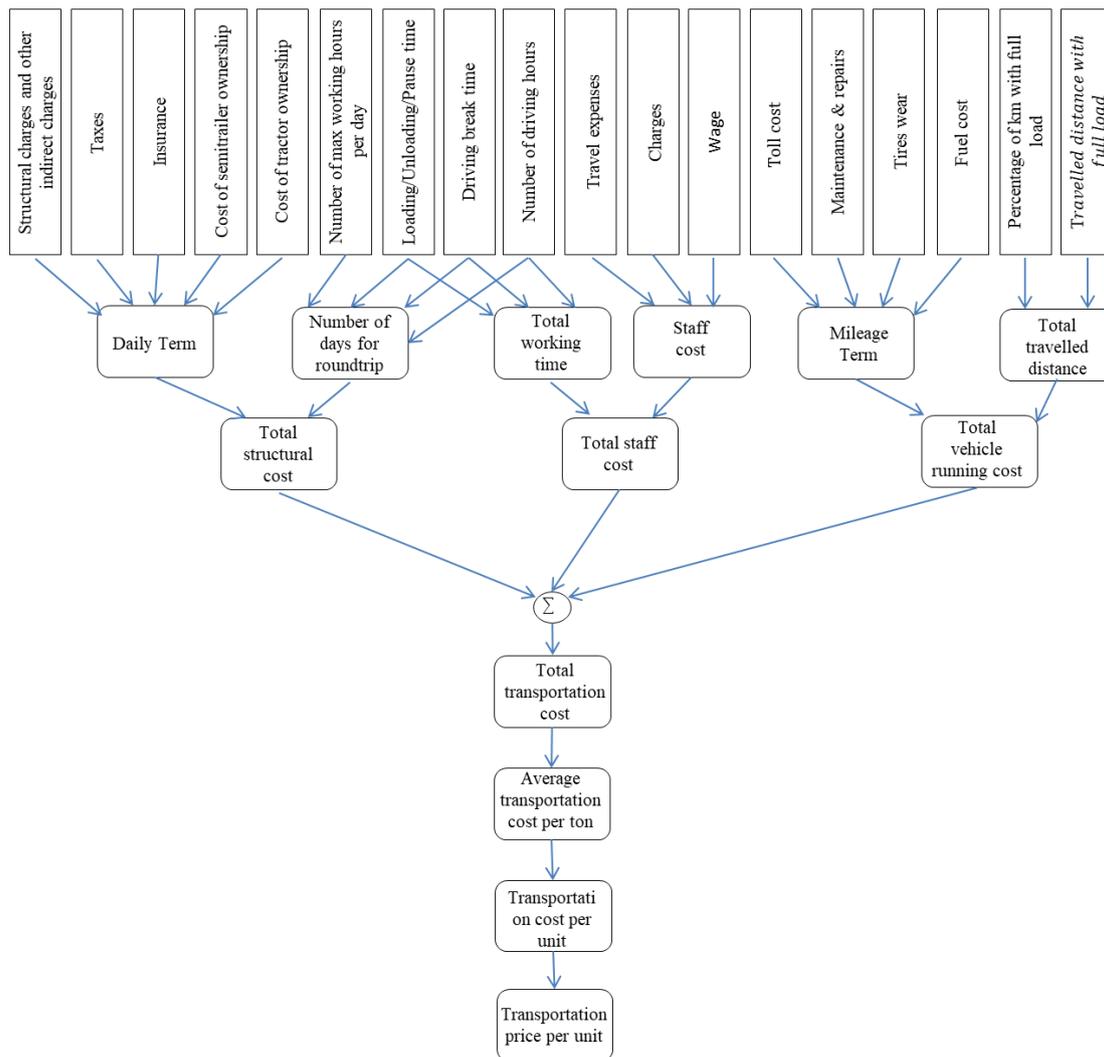
## **4.2.2 Transportation features**

The main concern in defining a realistic data set was to rightly estimate the cost for transportation. To attain this objective, we base our reasoning on the following points:

- Overall transportation costs can be divided in two portions: a fixed portion in relation with administrative costs induced by the treatment of the customers' service request, a variable portion which directly depends on the travel executed by the vehicle.
- Calculation of the variable portion of the transportation cost is deduced from information provided by the French Road National Committee (CNR) under the responsibility of the French Labor Department.
- If necessary, each transport operator has recourse to subcontractors to provide a best service.

### **4.2.2.1 Variable portion of the transportation cost**

An overview of variable transportation cost is presented, in Figure 4-1. This map shows the reasoning to get the value of variable transportation cost, starting from the input parameters (i.e. fixed data) and to achieve the final transportation price per unit.



**Figure 4-1 A general view of variable transportation cost**

First, broad parameters representing the key transportation costs must be defined. Three main costs are identified: staff cost / hour, Mileage term and daily term; and their values may be calculated in accordance with the following principles. The costs induced by the wages and the associated charges, as well as the daily travel expenses allow the estimation of the “staff cost / hour”, in accordance with the following expression:

$$\text{Staff cost / hour} = \text{wages / hour} + \text{charges / hour} + \text{travel expenses / hour} \quad (4.1)$$

Table 4-5 describes the values used to estimate this parameter.

**Table 4-5 Staff related cost**

|  |         |
|--|---------|
| Wages and other remuneration elements / hour | 13,13 € |
| Wage charges and other remunerations / hour  | 4,11 €  |
| Travel expenses (daily average) / hour       | 1,80 €  |
| Staff cost /hour                             | 19,04 € |

The parameter named “Mileage term” consists in estimating any cost in relation with the vehicle operation. The Mileage term is determined as follows:

$$\text{Mileage term} = \text{kilometer fee charge (excluding toll)} + \text{Toll cost / km} \quad (4.2)$$

With:

$$\text{Kilometer fee charge} = \text{fuel cost / km} + \text{tyre wear / km} + \text{Maintenance \& repairs / km} \quad (4.3)$$

Estimated values for fuel cost, tyre wear and maintenance-repairs are deduced from data issued from the CNR analysis. Table 4-6 summarizes the values used to assess the parameter “Mileage term”.

**Table 4-6 Mileage term and the values used to estimate it**

|   |         |
|---|---------|
| Diesel / km                                   | 0,322 € |
| Tyres / km                                    | 0,044 € |
| Maintenance and repairs / km                  | 0,087 € |
| Kilometre fee charge (excluding tolls) / hour | 0,453 € |
| Tolls / km                                    | 0,087 € |
| Mileage term                                  | 0,540 € |

The last parameter we need to determine concerns the estimation of costs induced by the vehicle and trailer ownership and any charge in relation with them (insurance, taxes) combined with structural charges and others indirect charges. The considered values are defined in Table 4-7.

**Table 4-7 Structural charges and others indirect charges**

|   |         |
|---|---------|
| Cost of tractor ownership / day                     | 45,41 € |
| Cost of semitrailer ownership / day                 | 12,21 € |
| Insurance / day                                     | 12,48 € |
| Taxes / day   | 2,24 €  |
| Total per operating day                             | 72,34 € |
| Structural charges and other indirect charges / day | 83,35 € |

The “daily term” is the sum of all these costs, shown in Table 4-8.

**Table 4-8 Daily term**

|            |          |
|------------|----------|
| Daily term | 155,69 € |
|------------|----------|

In our dataset, we assume that orders are sent by two customers, respectively separated from the shipper by a distance of 548 and 974 km. Considering that a truck do not move with a load during the full route from its departure of the depot to its return to this same location, we define the percentage of kilometers travelled with load by 65% for customer 1 and 70% for customer 2. According to traffic conditions, we assume that the mean speed of trucks that deliver customer 1 (resp. customer 2) is equal to 62 km/h (resp. 68 km/h). This information is shown in Table 4-9.

**Table 4-9 Vehicles' information**

| VEHICLE (CUSTOMER 2)              |        |      | VEHICLE (CUSTOMER 1)              |        |      |
|-----------------------------------|--------|------|-----------------------------------|--------|------|
| Mean speed                        | 68,00  | km/h | Mean speed                        | 62,00  | km/h |
| Travelled distance with full load | 974,00 | km   | Travelled distance with full load | 548,00 | km   |
| Capacity of vehicle : truck       | 40,00  | tons | Capacity of vehicle : truck       | 40,00  | tons |
| percentage of km with full load   | 70,00  | %    | percentage of km with full load   | 65,00  | %    |

The first step consists in defining the duration of the transport operation. Two different times are considered:

- The transportation lead time (Equation 4.4) that specifies the time spent to travel from the shipper to the final customer,

$$\text{Transportation leadtime} = \frac{\text{Travelled distance} / \text{mean speed}}{\text{Number of working hours per day}} \quad (\text{days}) \quad (4.4)$$

- The number of days needed to make a roundtrip, i.e. to leave the depot, serve the shipper and the final customer and come back to the depot. Handling time concerns the time spent to load, unload, and to pause when the truck is at a client site. Driving break time is a legal and mandatory break after a certain number of driving hours. The roundtrip duration is shown in Equation 4.5.

$$\text{Roundtrip duration} = \frac{\text{handling times} + \text{total driving breaktime} + \text{Total number of driving hours}}{\text{Number of max working hours per day}} \quad (\text{days}) \quad (4.5)$$

with:

$$\text{Total driving break time} = (\text{Number of driving hours} / 4,5) * \text{Driving Break time} \quad (\text{hours}) \quad (4.6)$$

Indeed, the French legislation required drivers to stop their truck three-quarters of an hour after half and four hours of continual driving.

All this values shall be rounded up to the nearest integer. The Estimation of round trip time to each customer is shown in Table 4-10.

**Table 4-10 Estimation of round trip time to each customer**

| ESTIMATION OF ROUNDRIP TIME (CUSTOMER 1)         |        |        | ESTIMATION OF ROUNDRIP TIME (CUSTOMER 2)         |          |        |
|--|--------|--------|--|----------|--------|
| Total travelled distance                         | 843,08 | km     | Total travelled distance                         | 1 391,43 | km     |
| Number of driving hours                          | 13,60  | hours  | Number of driving hours                          | 20,46    | hours  |
| Loading / unloading / Pause time                 | 2,00   | hours  | Loading / unloading / Pause time                 | 2,00     | hours  |
| Driving breaktime                                | 0,75   | hours  | Driving breaktime                                | 0,75     | hours  |
| Number of max working hours / day (driver)       | 9,00   | hours  | Number of max working hours / day (driver)       | 9,00     | hours  |
| Total working time (driver) during the roundtrip | 17,85  | hours  | Total working time (driver) during the roundtrip | 26,21    | hours  |
| Transportation lead time                         | 1,00   | day(s) | Transportation lead time                         | 2,00     | day(s) |
| Number of days for roundtrip                     | 2,00   | day(s) | Number of days for roundtrip                     | 3,00     | day(s) |

The total travelled distance is equal to

$$\text{Total travelled distance} = \frac{\text{travelled distance with full load} * 100}{\text{percentage of km with full load}} \quad (4.7)$$

The number of driving hours is deduced from

$$\text{Number of driving hours} = \frac{\text{total travelled distance}}{\text{mean speed}} \quad (4.8)$$

Based on these values, we can calculate the transportation price / ton. The first step consists in defining the total cost induced by the travelled distance, the number of working hours and the structural charges in relation with the transportation service offered to each customer. The different costs are estimated in relation with the following expressions:

$$\text{Total vehicle running cost} = \text{mileage term} * \text{total travelled distance} \quad (4.9)$$

$$\text{Total personnel cost} = \text{staff cost / hour} * \text{total working time} \quad (4.10)$$

$$\text{Total structural charge} = \text{daily term / day} * \text{number of days for roundtrip} \quad (4.11)$$

The calculated values are (Table 4-11):

**Table 4-11 Estimation of total transportation cost for each customer**

| ESTIMATION OF COSTS (CUSTOMER 1)       |                       | ESTIMATION OF COSTS (CUSTOMER 2)       |                       |
|--|-----------------------|--|-----------------------|
| Total vehicle running cost (distance)  | 451,05 euros          | Total vehicle running cost (distance)  | 744,41 euros          |
| Total personnel cost (working hours)   | 339,83 euros          | Total personnel cost (working hours)   | 499,08 euros          |
| Total structural charge (working days) | 311,38 euros          | Total structural charge (working days) | 467,07 euros          |
| <b>Total COST</b>                      | <b>1 102,25</b> euros | <b>Total COST</b>                      | <b>1 710,56</b> euros |

The next step leads to assess the average cost / ton as described in the next table. We assume for this calculation that the truck fill rates are respectively 83% and 94% for customer 1 and 2. The average cost / ton is calculated as follow and defined in the Table 4-12:

$$\text{Average cost / ton} = \text{Total Cost} / (\text{fill rate} * \text{vehicle capacity}) \quad (4.12)$$

**Table 4-12 Average transportation cost per ton for each customer**

| CUSTOMER 1                |                    | CUSTOMER 2                |                    |
|---------------------------|--------------------|---------------------------|--------------------|
| Fill rate                 | 83,00 %            | Fill rate                 | 94,00 %            |
| Load                      | 33,20 tons         | Load                      | 37,60 tons         |
| <b>Average Cost / ton</b> | <b>33,20</b> euros | <b>Average Cost / ton</b> | <b>45,49</b> euros |

We deduce the transportation cost / unit (€) in relation with the concerned product and the target client (Table 4-13).

$$\text{transportation cost / unit} = \text{average cost / ton} * \text{weight} \quad (4.13)$$

**Table 4-13 Transportation cost per unit product for each customer**

|  | CUSTOMER 1 | CUSTOMER 2 |
|--|------------|------------|
| Transportation cost / unit - PRODUCT 1 | 0,166      | 0,227      |
| Transportation cost / unit - PRODUCT 2 | 0,050      | 0,068      |

The transportation prices / product unit (Table 4-14) are then deduced from these transportation cost / unit, according to the respective marge in relation with each customer.

$$\text{transportation price / unit} = \text{transportation cost / unit} * (1 + \text{benefit margin}) \quad (4.14)$$

**Table 4-14 Transportation price per unit product for each customer**

|   | CUSTOMER 1 | CUSTOMER 2 |
|---|------------|------------|
| Transportation price / unit - PRODUCT 1 | 0,235      | 0,320      |
| Transportation price / unit - PRODUCT 2 | 0,070      | 0,096      |

#### 4.2.2.2 Fixed portion of the transportation cost and structural cost

The fixed portion of the transportation cost is in relation with the administrative treatment of any customer request service. It includes any expense due to materials, computers, taxes and salary cost required for this treatment. This cost is defined for each vehicle and supposed dependent on the customers. Table 4-15 provides the values considered in the current experimentation.

**Table 4-15 Fix transportation costs and structural cost**

|            | Fixed transportation cost (€ / Truck) | Structural cost (€) |
|------------|---------------------------------------|---------------------|
| CUSTOMER 1 | 120                                   | 50                  |
| CUSTOMER 2 | 150                                   |                     |

When a transport operator is selected to provide a service, there is corresponding administrative fee (Structural Cost, i.e. SC) that has to be taken into account in the evaluation of the whole transportation costs. (See the value of SC in Table 4-15)

#### 4.2.2.3 Subcontracting

Sometimes, the considered transport operators may not have enough capacity to serve the overall demand of customers. We then suppose that each transport operator can work with other service providers to extend their service offers; in this case, the recourse to subcontracting leads to increase the transportation cost initially defined in paragraphs 4.2.2.1 and 4.2.2.2. We assume that the transportation costs induced by subcontracting (called extra cost) are 50% higher than the initial cost. Table 4-16 shows the values of extra costs in detail.

**Table 4-16 Extra transportation costs for each customer**

|  | CUSTOMER 1 | CUSTOMER 2 |            | Fixed transportation cost (€ / Truck) |
|--|------------|------------|------------|---------------------------------------|
| Transportation cost / unit - PRODUCT 1 | 0,249      | 0,341      | CUSTOMER 1 | 180                                   |
| Transportation cost / unit - PRODUCT 2 | 0,075      | 0,102      | CUSTOMER 2 | 225                                   |

(a) Fixed portion of the extra transportation cost

(b) Variable portion of the extra transportation cost

#### 4.2.2.4 Late and early deliveries

The transport operators have a limited capacity to serve its customers. If the demand is too high, they can't deliver all the orders at the right time, and can decide to serve them in advance or with late. In this case, the transport operator has to pay financial penalties to the manufacturer as described in Table 4-17.

**Table 4-17 Early and late delivery penalty cost of each product for each customer**

|   | CUSTOMER 1 | CUSTOMER 2 |  | CUSTOMER 1 | CUSTOMER 2 |
|---|------------|------------|--|------------|------------|
| Early Delivery Penalty cost - PRODUCT 1 | 0,024      | 0,032      | Late Delivery Penalty Cost - PRODUCT 1 | 0,047      | 0,064      |
| Early Delivery Penalty cost - PRODUCT 2 | 0,007      | 0,010      | Late Delivery Penalty Cost - PRODUCT 2 | 0,014      | 0,019      |

The early delivery penalty cost is deduced from the transportation price / unit (10% of the value) and the late delivery penalty cost is two times more expensive than the first cost.

#### 4.2.2.5 Discarded quantities

Let us remind that if the capacity or the transport operators are stronger limited, some quantities ordered by the customers cannot be delivered along the considered time horizon. As described in chapter 3, we assume that any quantity that cannot be served during this horizon is discarded, based on the assumption that a transport operator will not accept new delivery request for customers' demand if it has no enough capacity to make an efficient delivery.

Consequently, the transport operator has no penalty to pay in case of refusal, but this situation will induce the payment of penalties from the manufacturer to the customers (later described).

#### 4.2.3 Production features

The data set concerning the production is quite arbitrary to define. Many parameters must be valuated while trying to preserve some logical links between values. We intend here to describe the reasoning we used to define all these values.

##### 4.2.3.1 Production cost

The first step concerns the estimation of the purchasing prices for raw materials. We arbitrary define these prices as shown in Table 4-18. We assume that the percentage of production added value is respectively equal to 55% (70%) for the product 1 (product 2).

**Table 4-18 Production costs**

|  | Product 1 | Product 2 |       |
|--|-----------|-----------|-------|
| Raw materials purchasing price / product | 16,97     | 11,53     | euros |
| Added value percentage                   | 55%       | 70%       | %     |
| Production cost (without storage cost)   | 26,30     | 19,60     | euros |

The second step consists in assessing the cost induced by storage. We define the average stock per day for each product type as equal to 15 994 units of product 1 and 30 850 units of product 2 (these values have been defined in relation with the customers demand (as presented shortly after) extrapolated over 30 days, shown in Table 4-19).

**Table 4-19 Average stock per day**

|                         | Product 1 | Product 2 |       |
|-------------------------|-----------|-----------|-------|
| Average inventory / day | 15 994,00 | 30 850,00 | units |

We have calculated the stock value per day (Table 4-20) as the result of the expression:

$$\text{Stock value / day} = \text{Average inventory / day} * \text{Purchasing price} \quad (4.15)$$

**Table 4-20 The stock values per day**

|                   | Product 1  | Product 2  |       |
|-------------------|------------|------------|-------|
| Stock Value / Day | 271 418,18 | 355 700,50 | euros |

The average inventory cost per day and per product can be deduced as follows: we respectively define the stock possession rate equal to 12 and 15% for product 1 and 2. The Average Inventory Cost per day (Table 4-19) and per product (Table 4-22) may be then estimated:

$$\text{Average Inventory Cost / day} = \text{Stock Value / day} * (1 + \text{possession rate}) \quad (4.16)$$

**Table 4-21 Average inventory costs**

|                              | Product 1 | Product 2 |       |
|------------------------------|-----------|-----------|-------|
| Average Inventory Cost / Day | 32 570,18 | 53 355,08 | euros |

$$\text{Average Inventory Cost/day/product} = \frac{\text{Average Inventory Cost per day}}{\text{Average inventory per day}} \quad (4.17)$$

**Table 4-22 Average inventory costs per product**

|  | Product 1 | Product 2 |       |
|--|-----------|-----------|-------|
| Average Inventory Cost / Day / Product | 2,04      | 1,73      | euros |

Step three – We consider that we need to order twice during the considered period to keep the stock at its nominal level. The Replenishment Cost / order is considered as equal to 330€. The Replenishment Ordering Cost / product (Table 4-23) is deduced:

$$\text{Ordering Cost / product} = \frac{(\text{Replenishment cost per order} * \text{number of orders})}{\text{Average inventory per day}} \quad (4.18)$$

**Table 4-23 The Replenishment Ordering Cost per product**

|   | Product 1 | Product 2 |       |
|---|-----------|-----------|-------|
| Replenishment cost / order                | 330,00    | 330,00    | euros |
| Number or orders / considered time period | 2,00      | 2,00      | times |
| Monthly Replenishment Ordering Cost       | 660,00    | 660,00    | euros |
| Replenishment Ordering Cost per Product   | 0,04      | 0,02      | euros |

The total production cost / product (Table 4-24) is:

$$\text{Total production cost/product} = \text{Production cost} + \frac{\text{Average Inventory Cost} / \text{day} / \text{product} + \text{Ordering Cost} / \text{product}}{\text{Average inventory per day}} \quad (4.19)$$

**Table 4-24 Total production cost**

|                       | Product 1 | Product 2 |       |
|-----------------------|-----------|-----------|-------|
| Total production cost | 28,38     | 21,35     | euros |

#### 4.2.3.2 Selling price

The selling price is directly deduced from the total production cost in relation the financial margin the manufacturer wants to have. Considering that the financial margin depends on the negotiation made with each customer, the Table 4-25 defines these selling prices for each product.

**Table 4-25 The selling prices**

|            | Product 1 |         | Product 2 |         |
|------------|-----------|---------|-----------|---------|
|            | Marge (%) | Price   | Marge (%) | Price   |
| Customer 1 | 11,00     | 31,50 € | 11,00     | 23,70 € |
| Customer 2 | 21,00     | 34,34 € | 21,00     | 25,84 € |

#### 4.2.3.3 Customers demand

The customers' demand is arbitrary defined to meet some expected characteristics. We assume that:

- The demand of products 1 is relatively balanced between the two customers. The number of products 2 requested by the customer 2 is a little more important than for the customer 1, shown in Table 4-26.

**Table 4-26 Customers' demand**

| DEMAND OF CUSTOMER 2 |           |              |           |              |                    | DEMAND OF CUSTOMER 1 |           |              |           |              |                    |
|----------------------|-----------|--------------|-----------|--------------|--------------------|----------------------|-----------|--------------|-----------|--------------|--------------------|
| Period               | PRODUCT 1 |              | PRODUCT 2 |              | Total weight (ton) | Period               | PRODUCT 1 |              | PRODUCT 2 |              | Total weight (ton) |
|                      | Quantity  | Weight (ton) | Quantity  | Weight (ton) |                    |                      | Quantity  | Weight (ton) | Quantity  | Weight (ton) |                    |
| 1                    | -         | -            | -         | -            | -                  | 1                    | -         | -            | -         | -            | -                  |
| 2                    | -         | -            | -         | -            | -                  | 2                    | -         | -            | -         | -            | -                  |
| 3                    | 7 500     | 37,50        | 20 000    | 30,00        | 67,50              | 3                    | 6 500     | 32,50        | 11 000    | 16,50        | 49,00              |
| 4                    | 6 500     | 32,50        | 21 000    | 31,50        | 64,00              | 4                    | 7 500     | 37,50        | 12 000    | 18,00        | 55,50              |
| 5                    | 8 500     | 42,50        | 17 000    | 25,50        | 68,00              | 5                    | 8 500     | 42,50        | 11 000    | 16,50        | 59,00              |
| 6                    | 10 000    | 50,00        | 20 000    | 30,00        | 80,00              | 6                    | 6 500     | 32,50        | 13 000    | 19,50        | 52,00              |
| 7                    | 8 500     | 42,50        | 15 000    | 22,50        | 65,00              | 7                    | 8 500     | 42,50        | 13 000    | 19,50        | 62,00              |
| 8                    | 6 000     | 30,00        | 12 000    | 18,00        | 48,00              | 8                    | 8 950     | 44,75        | 10 800    | 16,20        | 60,95              |
| 9                    | 7 500     | 37,50        | 20 000    | 30,00        | 67,50              | 9                    | 10 000    | 50,00        | 14 000    | 21,00        | 71,00              |
| 10                   | 8 500     | 42,50        | 19 000    | 28,50        | 71,00              | 10                   | 8 500     | 42,50        | 18 000    | 27,00        | 69,50              |
| TOTAL                | 63 000    | 315,00       | 144 000   | 216,00       | 460                | TOTAL                | 64 950    | 324,75       | 102 800   | 154,20       | 409                |

- o Considering the respective weights of 5 kg / 1.5 kg for one product 1/product 2, and the capacity of a truck limited to 40 tons, the weight of the total load to deliver per day must not exceed a cumulated capacity of two trucks. For instance, the load induced by the orders of customer 1 on period 7 is equal to 62 tons, so that  $\frac{62}{40} = 1,55 \approx 2$  trucks are needed to deliver all the ordered products (Table 4-27).

**Table 4-27 Max number of trucks used per period**

| CUSTOMER 1         |                  |  |   |   |   |   |   |        |                      |
|--------------------|------------------|--|---|---|---|---|---|--------|----------------------|
| Total weight (ton) | Number of trucks | Use of trucks depending on the duration of roundtrip |   |   |   |   |   | Period | Total of used trucks |
|                    |                  | 1  | 2 | 3 | 4 | 5 | 6 |        |                      |
| -                  | -                |  |   |   |   |   |   | 1      | -                    |
| -                  | -                | 2  |   |   |   |   |   | 2      | 2,00                 |
| 49,00              | 2,00             | 2  | 2 |   |   |   |   | 3      | 4,00                 |
| 55,50              | 2,00             | 2  | 2 |   |   |   |   | 4      | 4,00                 |
| 59,00              | 2,00             |  | 2 | 2 |   |   |   | 5      | 4,00                 |
| 52,00              | 2,00             |  |   | 2 | 2 |   |   | 6      | 4,00                 |
| 62,00              | 2,00             |  |   |   | 2 | 2 |   | 7      | 4,00                 |
| 60,95              | 2,00             |  |   |   |   | 2 | 2 | 8      | 4,00                 |
| 71,00              | 2,00             |  |   |   |   |   | 2 | 2      | 4,00                 |
| 69,50              | 2,00             |  |   |   |   |   |   | 2      | 2,00                 |
| 409                |                  |  |   |   |   |   |   |        |                      |

| CUSTOMER 1         |                  |  |   |   |   |   |   |        |                      |
|--------------------|------------------|--|---|---|---|---|---|--------|----------------------|
| Total weight (ton) | Number of trucks | Use of trucks depending on the duration of roundtrip |   |   |   |   |   | Period | Total of used trucks |
|                    |                  | 1  | 2 | 3 | 4 | 5 | 6 |        |                      |
| -                  | -                | 2  |   |   |   |   |   | 1      | 2,00                 |
| -                  | -                | 2  | 2 |   |   |   |   | 2      | 4,00                 |
| 67,50              | 2,00             | 2  | 2 | 2 |   |   |   | 3      | 6,00                 |
| 64,00              | 2,00             |  | 2 | 2 | 2 |   |   | 4      | 6,00                 |
| 68,00              | 2,00             |  |   | 2 | 2 | 2 |   | 5      | 6,00                 |
| 80,00              | 2,00             |  |   |   | 2 | 2 | 2 | 6      | 6,00                 |
| 65,00              | 2,00             |  |   |   |   | 2 | 2 | 2      | 6,00                 |
| 48,00              | 2,00             |  |   |   |   |   | 2 | 2      | 6,00                 |
| 67,50              | 2,00             |  |   |   |   |   |   | 2      | 4,00                 |
| 71,00              | 2,00             |  |   |   |   |   |   |        | 2,00                 |
| 460                |                  |  |   |   |   |   |   |        |                      |

|                                   |       |
|-----------------------------------|-------|
| MAXIMUM OF TRUCKS NEEDED PER DAY* | 10,00 |
|-----------------------------------|-------|

\* in case of no late deliveries...

- o According to the number of days for roundtrip depends on the distance between the shipper and the customers, the number of trucks used per period may be defined in

Table 4-28, so that the max number of trucks used to serve all the customers for all the products must not exceed 10 trucks. Therefore, ten trucks are required to deliver the entire load during from period ‘3’ to period ‘8’.

- As the roundtrip lead time is known, no demand of customer 1 is expressed on the two first periods. Otherwise, the manufacturer still does not have enough time to produce the right quantity to serve this customer at the right time ; indeed, if a quantity of products must be delivered at period ‘1’ and the roundtrip / production spends respectively two / one day(s) , the production should have started at period ‘-1’ (which corresponds to a past moment).

- By the same reasoning, no demand of customer 2 is expressed on the two first periods. Nevertheless, the roundtrip lead time is equal to 3 days, so that products quantity required for a delivery for period 2 must be still produced at the beginning of the horizon. That’s why the initial inventories levels at the manufacturer are respectively defined as equal to 7500 and 20 000 units for products 1 and 2.

#### **4.2.3.4 Production lead time, production capacity and operating time**

The current problem concerns tactical decision making, so the production lead time is defined on an aggregated basis. The time bucket used to discretize the time scale is the day. Even if the production lead time requires less than one day, we assume that the production lead time is equal to one period, i.e. one day.

Concerning the production capacity, the daily working time is equal to 8 hours, as defined by law. The production capacity is expressed in seconds to be compatible with the expression of a production throughput with high speed. The production capacity is:

$$Production\ capacity\ per\ day = Number\ of\ working\ hours/day * 3600\ sec \quad (4.20)$$

The operating time / product are evaluated in relation with the quantities to produce per day. We need to define the time values corresponding to the minimum, mean and maximum number of products that can be finished for a day. The total demand / product are first calculated - min / mean / max values – and the operating times / product (Table 4-28) are deduced from these values, as follows:

$$Operating\ Time\ per\ product = Production\ capacity\ per\ day / Total\ Demand \quad (4.21)$$

**Table 4-28 The operating time / product**

| DEMAND OF PRODUCT 1 |          |              |          |              |                  |                    |
|---------------------|----------|--------------|----------|--------------|------------------|--------------------|
|                     |          | CUSTOMER 1   |          | CUSTOMER 2   |                  |                    |
| Period              | Quantity | Weight (ton) | Quantity | Weight (ton) | Total Quantities | Total weight (ton) |
| 1                   | -        | -            | -        | -            | -                | -                  |
| 2                   | -        | -            | -        | -            | -                | -                  |
| 3                   | 6 500    | 32,50        | 7 500    | 37,50        | 14 000           | 70,00              |
| 4                   | 7 500    | 37,50        | 6 500    | 32,50        | 14 000           | 70,00              |
| 5                   | 8 500    | 42,50        | 8 500    | 42,50        | 17 000           | 85,00              |
| 6                   | 6 500    | 32,50        | 10 000   | 50,00        | 16 500           | 82,50              |
| 7                   | 8 500    | 42,50        | 8 500    | 42,50        | 17 000           | 85,00              |
| 8                   | 8 950    | 44,75        | 6 000    | 30,00        | 14 950           | 74,75              |
| 9                   | 10 000   | 50,00        | 7 500    | 37,50        | 17 500           | 87,50              |
| 10                  | 8 500    | 42,50        | 8 500    | 42,50        | 17 000           | 85,00              |
| TOTAL               | 64 950   | 324,75       | 63 000   | 315,00       | 127 950,00       |                    |

| DEMAND OF PRODUCT 2 |          |              |          |              |                  |                    |
|---------------------|----------|--------------|----------|--------------|------------------|--------------------|
|                     |          | CUSTOMER 1   |          | CUSTOMER 2   |                  |                    |
| Period              | Quantity | Weight (ton) | Quantity | Weight (ton) | Total Quantities | Total weight (ton) |
| 1                   | -        | -            | -        | -            | -                | -                  |
| 2                   | -        | -            | -        | -            | -                | -                  |
| 3                   | 11 000   | 16,50        | 20 000   | 30,00        | 31 000           | 46,50              |
| 4                   | 12 000   | 18,00        | 21 000   | 31,50        | 33 000           | 49,50              |
| 5                   | 11 000   | 16,50        | 17 000   | 25,50        | 28 000           | 42,00              |
| 6                   | 13 000   | 19,50        | 20 000   | 30,00        | 33 000           | 49,50              |
| 7                   | 13 000   | 19,50        | 15 000   | 22,50        | 28 000           | 42,00              |
| 8                   | 10 800   | 16,20        | 12 000   | 18,00        | 22 800           | 34,20              |
| 9                   | 14 000   | 21,00        | 20 000   | 30,00        | 34 000           | 51,00              |
| 10                  | 18 000   | 27,00        | 19 000   | 28,50        | 37 000           | 55,50              |
| TOTAL               | 102 800  | 154,20       | 144 000  | 216,00       | 246 800,00       |                    |

| Demand     |        |       | Operating time/ product 1 |       |         |
|------------|--------|-------|---------------------------|-------|---------|
| Min value  | 14 000 | units | Min value                 | 1,650 | seconds |
| Mean value | 15 994 | units | Mean value                | 1,801 | units   |
| Max value  | 17 500 | units | Max value                 | 2,057 | units   |

| Total demand |        |       | Operating time/ product 2 |       |       |
|--------------|--------|-------|---------------------------|-------|-------|
| Min value    | 22 800 | units | Min value                 | 0,780 | units |
| Mean value   | 30 850 | units | Mean value                | 0,934 | units |
| Max value    | 37 000 | units | Max value                 | 1,263 | units |

By using the three possible values (min, max, mean) for defining the operating time / product, we can define a variety of production situations. The mean value corresponds to a situation in which we have enough time to serve all the demand on the horizon, even if for certain periods, the quantity to produce can be less than the requested quantity. The use of the max value means that the production system has not enough capacity to serve all the demand along the entire horizon, but also during each period, while the min value leads to have enough capacity to satisfy all the demand of customers on any period

However, in some situations of the experiments carried out in the following of this chapter, an extra value of operating time between “Max” and “Mean” is needed. Indeed the following intermediary value has been considered “(Max+Mean)/2” in order to take into account the case when production does not have enough capacity in some time periods whereas the global capacity is enough. This intermediary value is displayed in Table 4-29.

**Table 4-29 Intermediary unitary producing time**

|           | (Max +Mean) / 2 |
|-----------|-----------------|
| Product 1 | 2,07 s          |
| Product 2 | 1,90 s          |

#### 4.2.3.5 Inventory capacity

The inventory capacity (Table 4-30) is arbitrary defined for each product.

**Table 4-30 Inventory capacity**

|           | Inventory capacity |       |
|-----------|--------------------|-------|
| Product 1 | 71 830,00          | units |
| Product 2 | 42 894,00          | units |

#### 4.2.3.6 Late and early delivery costs

If the transport operators decide to discard some quantities ordered by customers for a delivery requested by the manufacturer, due to a stronger limited transportation capacity, manufacturer cannot satisfy all the customers' demand during the considered time horizon. In this situation, he has to pay some penalties to customers to compensate the delays. These penalties are calculated on the basis of a percentage of the selling price, as shown in Table 4-31.

**Table 4-31 Late and early delivery costs**

| Unit Late Supply Penalty Cost |           |         |           |         | Unit Early Supply Penalty Cost |           |         |           |         |
|-------------------------------|-----------|---------|-----------|---------|--------------------------------|-----------|---------|-----------|---------|
|                               | Product 1 |         | Product 2 |         |                                | Product 1 |         | Product 2 |         |
|                               | %         | Cost    | %         | Cost    |                                | %         | Cost    | %         | Cost    |
| Customer 1                    | 10,00     | 3,150 € | 5,00      | 1,185 € | Customer 1                     | 5,00      | 1,575 € | 2,00      | 0,474 € |
| Customer 2                    | 15,00     | 5,151 € | 10,00     | 2,584 € | Customer 2                     | 3,00      | 1,030 € | 3,00      | 0,775 € |

#### 4.2.3.7 Discarded penalty cost

If the production cannot fulfill the customer demand due to the insufficient capacity of itself and/or transportation, some quantities ordered by the customers cannot be delivered along the considered time horizon as mentioned 4.2.2.5. The manufacturer has to pay corresponding penalties to the customer induced by the discarded quantities. We define the discarded penalty cost as 20% of the selling price. The unit discarded penalty cost of each product for each customer is presented in Table 4-32.

**Table 4-32 Unit discarded penalty**

|            | Product 1 | Product 2 |
|------------|-----------|-----------|
| Customer 1 | 6,300 €   | 4,740 €   |
| Customer 2 | 6,868 €   | 5,168 €   |

### 4.3 Cooperation between three transport operators

Three transport operators with similar characteristics are chosen as partners of the game to evaluate the cooperation within a set of homogeneous partners. The experimentation is based on the values of parameters presented in 4.2; different

scenarios corresponding to different values for input parameters are implemented to analyze the response of the models and the protocol proposed in section 3.2.

According to the principle of cooperation we propose, the 4PL receives the delivery request from the manufacture, who plays the role of an intermediary partner and assigns the delivery tasks to three transport operator, labelled  $T_1, T_2, T_3$  which are not equivalent each other's. The performance of the grand coalition is concerned in these experiments indicating whether the cooperation is interesting for each partner or not. Model BST-mT is used in these experiments. For each set of collaborative transport operators (also called coalition " $S_m$ "), the corresponding BST-mT is applied. For instance, BST-2T is applied for the two transport operators' coalition.

### 4.3.1 Experimentations

In these experiments, most of the values of input parameters presented in section 4.2 are constant. However, some parameters are chosen to vary in each experiment in order to show the influence of these parameters on the performance of the grand coalition in different situations. Two main parameters are considered to vary: the capacity and the transport cost of each transport operator.

Concerning the capacity of each transport operator, we focus on two points, i.e. the possibility of requiring and using extra resources or not, and the number of vehicles locally owned by each transport operator. The number of available extra resources is defined by parameter  $M\_extra_{j,k,t}$ . Note that only two situations are studied in this case: (i) a given transport operator can use an infinite number of extra resources during every time period (represented in our experimentation by  $M\_extra_{j,k,t} = 100$ ) or (ii) the transport operator has no possibility to use extra capacity ( $M\_extra_{j,k,t} = 0$ ). The number of vehicles owned by the transport operator  $k$  is expressed by the value of parameter  $R_k$ . Let us remind that  $R_k = 10$  is the lowest value for which the transport operator  $k$  can fulfill the whole delivery request by itself without extra resources, as it is explained in section 4.2.3.3. For the variation of  $R_k$ , four values are chosen: 2, 3, 4 and 6. These values respectively indicate the different levels of insufficient individual transport capacity to fulfill the whole delivery request without extra resources. For example,  $R_k = 2$  represents a strong insufficient capacity of the transport operator  $k$ , and  $R_k = 6$  means a moderate lack of capacity.

Regarding the transport cost, we propose to consider it can vary from one transport operator to another, and this variation is described by a *cost ratio*. This cost ratio expresses a proportional relation between the fix transport costs ( $FC_{j,k}$ ) of two transport operators. There are three transport operators in these experiments, and we

set the cost of transport operator  $T_1$  ( $FC_{j,1}$ ) as the standard values; two cost ratios can be thus defined  $\frac{FC_{j,2}}{FC_{j,1}}$  and  $\frac{FC_{j,3}}{FC_{j,1}}$  and two values are defined for each cost ratio as shown in Table 4-33. For instance,  $\frac{FC_{j,2}}{FC_{j,1}} = 0.9$  means the fix transport cost of transport operator 2 is 90% of transport operator 1.

Notice that when extra resources can be used, the transport cost induced by the use of extra vehicles is one and a half times higher than in the case of using vehicles owned by the transport operator; thus,  $FC\_extra_{j,k} = 1.5 * FC_{j,k}$ ,  $\forall j \in J, \forall k \in K$ .

The Table 4-33 summarizes the different values of the fixed transport cost depending on the studied scenarios. In Table 4-33, the white cells can be deduced from the grey cells, i.e.  $FC\_extra_{j,k}$  can be deduced from  $FC_{j,k}$ , according to the cost ratio.

**Table 4-33 Fixed transport cost of each transport operator**

|                   |     | $\frac{FC_{j,2}}{FC_{j,1}} = 1$ and $\frac{FC_{j,3}}{FC_{j,1}} = 1$ |                        | $\frac{FC_{j,2}}{FC_{j,1}} = 0.9$ and $\frac{FC_{j,3}}{FC_{j,1}} = 0.8$ |                        |
|-------------------|-----|---|------------------------|---|------------------------|
| Fixed costs       |     | Customer 1 ( $j = 1$ )  | Customer 2 ( $j = 2$ ) | Customer 1 ( $j = 1$ )  | Customer 2 ( $j = 2$ ) |
| $FC_{j,k}$        | k=1 | 120 €   | 150 €                  | 120 €   | 150 €                  |
|                   | k=2 | 120 €   | 150 €                  | 108 €   | 135 €                  |
|                   | k=3 | 120 €   | 150 €                  | 96 €  | 120 €                  |
| $FC\_extra_{j,k}$ | k=1 | 180 €   | 225 €                  | 180 €   | 225 €                  |
|                   | k=2 | 180 €   | 225 €                  | 162 €   | 202 €                  |
|                   | k=3 | 180 €   | 225 €                  | 144 €   | 180 €                  |

The experiments array is shown in Table 4-34.

**Table 4-34 Experiments array of the cooperation between three transport operators**

| Num. | Capacity           |       |       |       | Cost ratio                  |                             |
|------|--------------------|-------|-------|-------|-----------------------------|-----------------------------|
|      | $M\_extra_{j,k,t}$ | $R_1$ | $R_2$ | $R_3$ | $\frac{FC_{j,2}}{FC_{j,1}}$ | $\frac{FC_{j,3}}{FC_{j,1}}$ |
| 1    | No (0)             | 4     | 4     | 4     | 1.0                         | 1.0                         |
| 2    | Yes(100)           | 3     | 3     | 3     | 1.0                         | 1.0                         |
| 3    | No (0)             | 3     | 4     | 2     | 1.0                         | 1.0                         |
| 4    | No (0)             | 4     | 4     | 2     | 1.0                         | 1.0                         |
| 5    | No (0)             | 4     | 4     | 4     | 0.9                         | 0.8                         |
| 6    | Yes(100)           | 3     | 3     | 3     | 0.9                         | 0.8                         |
| 7    | No (0)             | 3     | 4     | 2     | 0.9                         | 0.8                         |
| 8    | No (0)             | 4     | 4     | 2     | 0.9                         | 0.8                         |
| 9    | No (0)             | 6     | 4     | 2     | 0.9                         | 0.8                         |

Balanced situations ( $\frac{FC_{j,2}}{FC_{j,1}} = \frac{FC_{j,3}}{FC_{j,1}}$ ) and also unbalanced situations ( $\frac{FC_{j,2}}{FC_{j,1}} \neq \frac{FC_{j,3}}{FC_{j,1}}$ ) are considered for the experiments array. Notice that this is an ad hoc experiments array which is neither a complete experiments array including all possible experimentations nor deduced from a design of experiments study.

Now that the values of all input parameters are known, the results of the experiments using these values for input parameters are presented in the next section.

### 4.3.2 Results and analysis

According to the main steps of the cooperative approach described in section 3.2.3.2 obtaining the payoffs is the start of the process. In the experiments, the cost saving is considered as the payoff of each coalition, since the benefit of cooperation is easier to observe in this way. Indeed the saving expresses the economy on cost when the partners decide to cooperate within a coalition. The cost saving of each coalition  $S$  can be calculated as the difference between the sum of individual costs and the cost of the entire coalition, i.e.  $v(S) = \sum_{i \in S} c(\{i\}) - c(S)$ . Element  $c(S)$  represents the entire cost of the coalition  $S$ , which is stated as  $c(S) = cost_T + penalty_T + extra\_cost_T + structural\_cost$ . Let us remind that the results  $cost_T$ ,  $penalty_T$ ,  $extra\_cost_T$  and  $structural\_cost$  are parts of the objective function of the corresponding BST\_mT planning model; indeed, they are obtained through the corresponding BST\_mT model execution applied to the perimeter of a coalition  $S$  including  $m$  partners.

Table 4-35 shows the total cost of each coalition corresponding to the experiments array in Table 4-34. Considering a game with three players (transport operators), there are eight possible coalitions:  $(T_1)$ ,  $(T_2)$ ,  $(T_3)$ ,  $(T_1 \& T_2)$ ,  $(T_1 \& T_3)$ ,  $(T_2 \& T_3)$ ,  $(T_1 \& T_2 \& T_3)$  and  $\emptyset$ . The total cost of each coalition is obtained by running the models representing the planning process of each coalition. In Table 4-35, the black results mean that the transport(s) coalition can fulfill all the delivery request, and the red results mean that some delivery request are discarded due to the limitation of transportation capacities, as defined in section 3.2.3.3.

Let us also notice the following implementation context of our experimentations:

- In the objective function of BST\_mT model -  $max(\alpha * profit_T - \beta * service_T)$ , the following couple of possible values is chosen:  $\alpha = 0.01$ , and  $\beta = 1$ . Indeed, various executions of the model have shown that values of ‘ $profit_T$ ’ and ‘ $service_T$ ’ have different orders of magnitudes with a scale ratio equal to 100. The

chosen values aims at balancing the preferences of the two parts of the objective function.

- GLPK software is chosen as our experimental tool for implementing our models, since it is dedicated for the linear programming, easy to operate, and free for user. (GLPK)
- The maximum operation time is set to 30 minutes for all coalitions in order to limit the computation duration.

**Table 4-35 Total cost of each coalition**

| Num. | Total cost  |          |          |          |       |       |       |                  |
|------|-------------|----------|----------|----------|-------|-------|-------|------------------|
|      | c(T1&T2&T3) | c(T1&T2) | c(T1&T3) | c(T2&T3) | c(T1) | c(T2) | c(T3) | c( $\emptyset$ ) |
| 1    | 44548       | 45618    | 45618    | 45618    | 27016 | 27016 | 27016 | 0                |
| 2    | 45381       | 49992    | 49992    | 49992    | 57276 | 57276 | 57276 | 0                |
| 3    | 44519       | 45000    | 34635    | 40922    | 22596 | 27016 | 17014 | 0                |
| 4    | 44548       | 45618    | 40922    | 40922    | 27016 | 27016 | 17014 | 0                |
| 5    | 44017       | 45414    | 45210    | 45048    | 27016 | 26830 | 26644 | 0                |
| 6    | 44946       | 50115    | 49776    | 49562    | 57276 | 56703 | 56130 | 0                |
| 7    | 44126       | 44796    | 34419    | 40532    | 22596 | 26830 | 16816 | 0                |
| 8    | 44149       | 45414    | 40706    | 40532    | 27016 | 26830 | 16816 | 0                |
| 9    | 44179       | 44288    | 45402    | 40532    | 40872 | 26830 | 16816 | 0                |

In order to understand the cost of each coalition, the discarded delivery quantity of each coalition is shown in Table 4-36.

**Table 4-36 Discarded quantities of each coalition**

| Num. | Discarded quantity |       |       |       |        |       |        |
|------|--------------------|-------|-------|-------|--------|-------|--------|
|      | T1&T2&T3           | T1&T2 | T1&T3 | T2&T3 | T1     | T2    | T3     |
| 1    | 0                  | 290   | 290   | 290   | 89991  | 89991 | 89991  |
| 2    | 0                  | 0     | 0     | 0     | 0      | 0     | 0      |
| 3    | 0                  | 12990 | 60490 | 36990 | 117724 | 89991 | 196719 |
| 4    | 0                  | 290   | 36990 | 36990 | 89991  | 89991 | 196719 |
| 5    | 0                  | 290   | 290   | 290   | 89991  | 89991 | 89991  |
| 6    | 0                  | 0     | 0     | 0     | 0      | 0     | 0      |
| 7    | 0                  | 12990 | 60490 | 36990 | 117724 | 89991 | 196719 |
| 8    | 0                  | 290   | 36990 | 36990 | 89991  | 89991 | 196719 |
| 9    | 0                  | 0     | 290   | 36990 | 36990  | 89991 | 196719 |

For experiment number 2 and 6, the discarded quantity of each coalition is 0, since the extra transport resource is available for each coalition to fulfill the delivery request. In the grand coalition corresponding to these two experiments, the capacity is enough to respond the delivery request, thus the delivery request is satisfied. In experiment number 3, 196719 units of product are discarded in coalition T3, which is larger than in coalition T1 and coalition T2, since there are only two trucks in coalition T3, and three trucks in coalition T1, four trucks in coalition T2. Logically when the extra transport resource is not available and the owned transport resource is not enough to fulfill the delivery request, the discarded quantities will be less in the situation where more owned trucks are available.

For a more precise observation on the results, the delivery quantity by each partner in each coalition is presented in Table 4-37. The total quantity of all delivery requests including all kinds of product for each customer is 374750, and this quantity is the targeted delivery quantity (i.e. not necessarily reached) for all the partners in a coalition. Let us compare an aspect of the results in experiment number 1 and 5 -- each partner's delivery quantities in coalition T1&T2&T3. Each partner (T1, T2, and T3) owns 4 trucks without extra transport resource in these two experiments, but the transport cost ratio is different. In experiment number 1,  $\frac{FC_{j,2}}{FC_{j,1}} = 1$ ,  $\frac{FC_{j,3}}{FC_{j,1}} = 1$ , thus the delivery request is assigned randomly (by GLPK) in coalition T1&T2&T3. In experiment number 5,  $\frac{FC_{j,2}}{FC_{j,1}} = 0.9$ ,  $\frac{FC_{j,3}}{FC_{j,1}} = 0.8$ , T3 has the cheapest transport cost, so that T2's cost is more expensive than T3, and T1 has the most expensive transport cost. Let us remind that the objective function is profit oriented ( $max(\alpha * profit_T - \beta * service_T)$ ), so that T3 is used prior in the grand coalition to satisfy the delivery request. When T3's capacity is not enough, T2 is also used to answer the request. If T3 and T2 together do not have enough capacity to serve the delivery request, T1 can be only used in this situation. Let us notice that in Table 4-37, there are some blanks, since the corresponding partner is not in the particular coalition. For example, partner T2 is not in the coalition T1&T3, thus for coalition T1&T3, the delivery quantity of T2 is not available.

**Table 4-37 Delivery quantity by each partner in each coalition**

| Num. | Coalition | Delivery quantity |        |        |        |        |        |        |
|------|-----------|-------------------|--------|--------|--------|--------|--------|--------|
|      |           | T1&T2&T3          | T1&T2  | T1&T3  | T2&T3  | T1     | T2     | T3     |
| 1    | T1        | 140300            | 185400 | 185400 |        | 284759 |        |        |
|      | T2        | 121000            | 189060 |        | 185400 |        | 284759 |        |
|      | T3        | 113450            |        | 189060 | 189060 |        |        | 284759 |
|      | Total     | 374750            | 374460 | 374460 | 374460 | 284759 | 284759 | 284759 |
| 2    | T1        | 140469            | 163606 | 163606 |        | 374750 |        |        |
|      | T2        | 109750            | 211144 |        | 163606 |        | 374750 |        |
|      | T3        | 124531            |        | 211144 | 211144 |        |        | 374750 |
|      | Total     | 374750            | 374750 | 374750 | 374750 | 374750 | 374750 | 374750 |
| 3    | T1        | 124134            | 177300 | 187322 |        | 257026 |        |        |
|      | T2        | 168866            | 184460 |        | 199466 |        | 284759 |        |
|      | T3        | 81750             |        | 126938 | 138294 |        |        | 178031 |
|      | Total     | 374750            | 361760 | 314260 | 337760 | 257026 | 284759 | 178031 |
| 4    | T1        | 131200            | 185400 | 199466 |        | 284759 |        |        |
|      | T2        | 157850            | 189060 |        | 199466 |        | 284759 |        |
|      | T3        | 85700             |        | 138294 | 138294 |        |        | 178031 |
|      | Total     | 374750            | 374460 | 337760 | 337760 | 284759 | 284759 | 178031 |
| 5    | T1        | 75500             | 173900 | 163400 |        | 284759 |        |        |
|      | T2        | 123400            | 200560 |        | 179700 |        | 284759 |        |
|      | T3        | 175850            |        | 211060 | 194760 |        |        | 284759 |
|      | Total     | 374750            | 374460 | 374460 | 374460 | 284759 | 284759 | 284759 |
| 6    | T1        | 109600            | 211921 | 182093 |        | 374750 |        |        |
|      | T2        | 129750            | 162829 |        | 192281 |        | 374750 |        |
|      | T3        | 135400            |        | 192657 | 182469 |        |        | 374750 |
|      | Total     | 374750            | 374750 | 374750 | 374750 | 374750 | 374750 | 374750 |
| 7    | T1        | 91250             | 154800 | 183838 |        | 257026 |        |        |
|      | T2        | 159200            | 206960 |        | 212000 |        | 284759 |        |
|      | T3        | 124300            |        | 130422 | 125760 |        |        | 178031 |
|      | Total     | 374750            | 361760 | 314260 | 337760 | 257026 | 284759 | 178031 |
| 8    | T1        | 113300            | 173900 | 228600 |        | 284759 |        |        |
|      | T2        | 165450            | 200560 |        | 212000 |        | 284759 |        |
|      | T3        | 96000             |        | 109160 | 125760 |        |        | 178031 |
|      | Total     | 374750            | 374460 | 337760 | 337760 | 284759 | 284759 | 178031 |
| 9    | T1        | 111500            | 185000 | 256500 |        | 337760 |        |        |
|      | T2        | 156500            | 189750 |        | 212000 |        | 284759 |        |
|      | T3        | 106750            |        | 117960 | 125760 |        |        | 178031 |
|      | Total     | 374750            | 374750 | 374460 | 337760 | 337760 | 284759 | 178031 |

The payoffs – cost savings can now be calculated respectively. For instance, the payoff of the grand coalition is  $v(T1\&T2\&T3) = c(T1) + c(T2) + c(T3) - c(T1\&T2\&T3)$ , and the payoff of the coalition made up of only one transport operator is  $v(T1) = c(T1) - c(T1) = 0$ , which shows there is no saving in this particular case (independency case).

Table 4-38 shows the payoff of each coalition in each game of the experiments array of Table 4-34. This payoff represents the saving obtained by taking part to a coalition.

**Table 4-38 The payoff -- cost saving of each coalition**

| Num. | Payoff -- cost saving             |                         |                         |                         |         |         |         |                |
|------|-----------------------------------|-------------------------|-------------------------|-------------------------|---------|---------|---------|----------------|
|      | $v(T1\&T2\&T3)$                   | $v(T1\&T2)$             | $v(T1\&T3)$             | $v(T2\&T3)$             | $v(T1)$ | $v(T2)$ | $v(T3)$ | $v(\emptyset)$ |
|      | $c(T1)+c(T2)+c(T3)-c(T1\&T2\&T3)$ | $c(T1)+c(T2)-c(T1\&T2)$ | $c(T1)+c(T3)-c(T1\&T3)$ | $c(T2)+c(T3)-c(T2\&T3)$ | 0       | 0       | 0       | 0              |
| 1    | 36500                             | 8414                    | 8414                    | 8414                    | 0       | 0       | 0       | 0              |
| 2    | 126449                            | 64561                   | 64561                   | 64561                   | 0       | 0       | 0       | 0              |
| 3    | 22107                             | 4612                    | 4975                    | 3108                    | 0       | 0       | 0       | 0              |
| 4    | 26498                             | 8414                    | 3108                    | 3108                    | 0       | 0       | 0       | 0              |
| 5    | 36473                             | 8432                    | 8450                    | 8425                    | 0       | 0       | 0       | 0              |
| 6    | 125164                            | 63865                   | 63631                   | 63272                   | 0       | 0       | 0       | 0              |
| 7    | 22116                             | 4630                    | 4993                    | 3113                    | 0       | 0       | 0       | 0              |
| 8    | 26513                             | 8432                    | 3126                    | 3114                    | 0       | 0       | 0       | 0              |
| 9    | 40339                             | 23414                   | 12286                   | 3114                    | 0       | 0       | 0       | 0              |

In this step, the property of super-additive game must be verified for each game (number 1, 2, ..., 9) to decide whether these games are valid, as it has been defined in the protocol in section 3.2.3.2. If the game is successful, the plan of the grand coalition  $\{T1, T2, T3\}$  will be implemented in the real transport activity, which is generated by BST\_3T model for coalition  $\{T1, T2, T3\}$ .

All the games in these experiments array are super additive, thus, these games are successful. Notice that this conclusion is based on the definition of super-additive game which is recalled in section 3.2.3.2. Following the main steps of the planning cooperation approach, the Shapley value must be calculated in this step. According to the definition of Shapley value in section 3.2.3.1, Shapley values of each game in the experiments array are presented in Table 4-39.

The meaning of Shapley value in Table 4-39 represents the cost saving of each partner when they share the total cost of the grand coalition.

**Table 4-39 Shapley value of each game**

| Number | Shapley value |             |             |
|--------|---------------|-------------|-------------|
|        | $\phi_{T1}$   | $\phi_{T2}$ | $\phi_{T3}$ |
| 1      | 12167         | 12167       | 12167       |
| 2      | 42150         | 42150       | 42150       |
| 3      | 7931          | 6997        | 7179        |
| 4      | 9717          | 9717        | 7064        |
| 5      | 12163         | 12151       | 12160       |
| 6      | 41880         | 41700       | 41584       |
| 7      | 7938          | 6998        | 7180        |
| 8      | 9726          | 9720        | 7067        |
| 9      | 18358         | 13772       | 8208        |

The property whether the Shapley values are in the core have to be checked to evaluate if the grand coalition is stable and can be considered as the best way to cooperate. According to definition of core in section 3.2.3.2, the judgement whether the Shapley values are in the core for each game in the experiments array in Table 4-34 can be obtained. The Shapley values ( $\phi_{T1}, \phi_{T2}, \phi_{T3}$ ) shown in Table 4-39 are in the core for each game (1-9). Hence the grand coalition is stable, and cooperating with the grand coalition is the best way to work and save cost.

Let us verify it for experiment 1 as follows. In experiment 1, the payoff vector  $x_i$  as mentioned in the definition of core (2.3.3.4) is substituted by the Shapley value  $\phi_i$  for calculation.

For  $\emptyset$ , obviously the formula  $\sum_{i \in S} x_i \geq v(S)$  is true.

For  $\{T1\}$ ,  $x_{T1} \geq v(T1)$  is true, since  $12167 \geq 0$ , that is  $\phi_{T1} \geq v(T1)$ .

Similarly,  $\phi_{T2} \geq v(T2)$  ,  $\phi_{T3} \geq v(T3)$  ,  $\phi_{T1} + \phi_{T2} = 12167 + 12167 \geq v(T1\&T2) = 8414$  ,  $\phi_{T1} + \phi_{T3} = 12167 + 12167 \geq v(T1\&T3) = 8414$  ,  $\phi_{T2} + \phi_{T3} = 12167 + 12167 \geq v(T2\&T3) = 8414$  , and  $\phi_{T1} + \phi_{T2} + \phi_{T3} = 12167 + 12167 + 12167 \geq v(T1\&T2\&T3) = 36500$  , thus,  $\sum_{i \in S} x_i \geq v(S)$  is true for  $\forall S \subseteq N$ . Consequently, these Shapley values are in the core.

As it was mentioned before, the payoffs used to calculate the Shapley values are the cost savings. Consequently, the Shapley value is the cost saving of each partner in the grand coalition. The final cost (  $fc(T1), fc(T2), fc(T3)$  ) of each partner in the grand coalition can be obtained through difference between the individual cost (  $(c(T1), c(T2), c(T3))$  ) and the Shapley value ( $\phi_{T1}, \phi_{T2}, \phi_{T3}$ ), i.e.  $fc(Ti) =$

$c(T_i) - \phi_{T_i}$  ( $i = 1, 2, 3$ ). The final cost of each partner in each game of Table 4-34 is presented in Table 4-40. Let us observe that the gap between  $fc(T_i)$  and  $c(T_i)$ . The summation of the final costs in each game is shown in the last column of Table 4-40, which is totally equal to the cost of the grand coalition --  $c(T1\&T2\&T3)$ . This consistency can illustrate the effect of partners working in the grand coalition.

**Table 4-40 Final cost of each partner in the grand coalition**

| Number | $fc(T1)$ | $c(T1)$ | $fc(T2)$ | $c(T2)$ | $fc(T3)$ | $c(T3)$ | Total $fc$ |
|--------|----------|---------|----------|---------|----------|---------|------------|
| 1      | 14849    | 27016   | 14849    | 27016   | 14849    | 27016   | 44548      |
| 2      | 15127    | 57276   | 15127    | 57276   | 15127    | 57276   | 45381      |
| 3      | 14665    | 22596   | 20019    | 27016   | 9835     | 17014   | 44519      |
| 4      | 17299    | 27016   | 17299    | 27016   | 9950     | 17014   | 44548      |
| 5      | 14853    | 27016   | 14679    | 26830   | 14484    | 26644   | 44017      |
| 6      | 15396    | 57276   | 15003    | 56703   | 14547    | 56130   | 44946      |
| 7      | 14658    | 22596   | 19832    | 26830   | 9636     | 16816   | 44126      |
| 8      | 17290    | 27016   | 17110    | 26830   | 9749     | 16816   | 44149      |
| 9      | 22514    | 40872   | 13058    | 26830   | 8608     | 16816   | 44179      |

In the above experiments, all the games are the super-additive game, thus all these games can be proceeded. The Shapley values are checked to verify they are in the core. Consequently, the plan of the grand coalition  $\{T1, T2, T3\}$  will be implemented in the real transport activity, which is generated by BST\_3T model for coalition  $\{T1, T2, T3\}$ . The total cost (column “Total  $fc$ ”) in Table 4-40 is exactly equal to column “ $c(T1\&T2\&T3)$ ” in Table 4-35, which shows that the final cost of each partner is an allocation (i.e. imputation) of the cost of grand coalition. Comparing  $fc(T_i)$  ( $i = 1, 2, 3$ ) with  $c(T_i)$  ( $i = 1, 2, 3$ ) in Table 4-40, we can see that  $fc(T_i) < c(T_i)$  ( $i = 1, 2, 3$ ) in each experiment, which represents the benefit to cooperate in the grand coalition. Notice that the number of discarded quantities is not the same in all the coalitions for a given experience (Table 4-36) due to the discarded mechanism.

#### 4.4 Cooperation between one manufacturer and two transport operators

To study the cooperation within a set of heterogeneous partners, one manufacturer and two transport operators are chosen as partners of the game to carry out experiments. The values of the input parameters defined in section 4.2 are applied in this section. The purpose of the experiments is analyzing the response of the protocols described in section 3.3.3. The models proposed in 3.2.2 and 3.3.2 are implemented.

According with the principle of cooperation presented in 3.3, the 4PL receives the

customer demand, who acts as an intermediary partner. The 4PL assigns the production task to the manufacturer ( $P$ ) and the delivery task to two transport operators ( $T_1, T_2$ ). The aim of our approach is to decide whether the cooperation is interesting for each partner or not, i.e. whether the grand coalition can bring an additional benefit to each partner. Models BPP, BST-mT and BPP&mT are used in the following experiments. For production, BPP is applied; for “pure” transportation coalition ( $T_1, T_2, T_1&T_2$ ), BST-mT is applied; for mix coalition ( $P&T_1, P&T_2, P&T_1&T_2$ ), BPP&mT is applied. For instance, BPP&2T is applied for the grand coalition (one manufacturer and two transport operators).

#### 4.4.1 Experimentation

As in section 4.3.1, an ad hoc experiments array is defined to evaluate our cooperative approach. In this experimentation, the production time and the owned transport capacity are chosen to vary. Indeed three input parameters are selected to build the experiments array (Table 4-41):

- $u$ : the production time for producing one unit product;
- $R1$ : number of owned trucks for transport operator 1, representing the capacity of transport operator 1;
- $R2$ : number of owned trucks for transport operator 2, representing the capacity of transport operator 2.

**Table 4-41 Experiments array of the cooperation between manufacturer and transport operators**

| Num | $u$          | $R1$ | $R2$ |
|-----|--------------|------|------|
| 1   | Mean         | 6    | 7    |
| 2   | Mean         | 6    | 5    |
| 3   | Mean         | 4    | 7    |
| 4   | Mean         | 4    | 5    |
| 5   | (Max+Mean)/2 | 6    | 7    |
| 6   | (Max+Mean)/2 | 6    | 5    |
| 7   | (Max+Mean)/2 | 4    | 7    |
| 8   | (Max+Mean)/2 | 4    | 5    |

This experiment array corresponds to two situations, which occur in the cooperation relation between the transport operators and the manufacturer.

Let us use the following notation to characterize these situations:  $C_{T_i}$  represents the capacity in terms of maximum number of products that each transport operator  $k = 1, 2$  can carry on the whole horizon;  $d_{p,j,t}$  represents the customers' demand which is defined in section 3.3.2. The two situations are as follows:

1.  $C_{T_k} < \sum_p \sum_j \sum_t d_{p,j,t}, \forall i \in \{1, 2\}$ , and  $\sum_k C_{T_k} \geq \sum_p \sum_j \sum_t d_{p,j,t}$

(Experiment number 1, 2, 3, 5, 6, 7 );

In this situation, any single transport operator cannot satisfy the customers' demand in the whole time horizon, but the global capacity of all the transport operators is enough to serve the customers' demand in the whole time horizon.

2.  $\sum_k C_{T_k} < \sum_p \sum_j \sum_t d_{p,j,t}$ ,

(Experiment number 4 and 8 ).

In this situation, the global capacity of all the transport operators cannot satisfy the customers' demand in the whole time horizon.

#### 4.4.2 Results and analysis

In this section, two different cases are considered: in the first one, all the transport operators can use unlimited extra transport resources; in the second situation, none of the transport operators can use extra resource. In both cases, the profit of each coalition is chosen as the payoff, since "profit" can synthesize the information of revenue and cost. Moreover some experiments considering "cost saving" as the payoff were done, but some games are not super-additive and the payoff of some coalitions are negative.

##### 4.4.2.1 Experimental case 1– transport operators with unlimited extra transport resource

In this section, all the transport operators can utilize unlimited extra transport resources.

Table 4-42 shows the experimental results -- profit of Table 4-41. In Table 4-42, the black cells represent the results without discarded quantities, the red cells represent the results with discarded quantities, and the green cells represent the delivery quantities.

**Table 4-42 The payoff -- profit of each coalition**

| Num. | Payoff -- Profit |            |           |           |         |         |         |                |
|------|------------------|------------|-----------|-----------|---------|---------|---------|----------------|
|      | $v(P&T1&T2)$     | $v(T1&T2)$ | $v(P&T1)$ | $v(P&T2)$ | $v(P)$  | $v(T1)$ | $v(T2)$ | $v(\emptyset)$ |
| 1    | 2039272          | 11889      | 2033940   | 2035900   | 2027383 | 6557    | 8517    | 0              |
|      | 374750           | 374750     | 374750    | 374750    | 374750  | 374750  | 374750  | 0              |
| 2    | 2039272          | 11889      | 2033940   | 2031764   | 2027383 | 6557    | 4381    | 0              |
|      | 374750           | 374750     | 374750    | 374750    | 374750  | 374750  | 374750  | 0              |
| 3    | 2039272          | 11889      | 2029275   | 2035900   | 2027383 | 1892    | 8517    | 0              |
|      | 374750           | 374750     | 374750    | 374750    | 374750  | 374750  | 374750  | 0              |
| 4    | 2038545          | 11015      | 2029275   | 2031764   | 2027383 | 1892    | 4381    | 0              |
|      | 374750           | 374750     | 374750    | 374750    | 374750  | 374750  | 374750  | 0              |
| 5    | 1746005          | 11596      | 1741282   | 1743268   | 1734409 | 6873    | 8859    | 0              |
|      | 356580           | 356580     | 356580    | 356580    | 356580  | 356580  | 356580  | 0              |
| 6    | 1746005          | 11596      | 1741282   | 1739041   | 1734409 | 6873    | 4632    | 0              |
|      | 356580           | 356580     | 356580    | 356580    | 356580  | 356580  | 356580  | 0              |
| 7    | 1746005          | 11596      | 1736551   | 1743268   | 1734409 | 2142    | 8859    | 0              |
|      | 356580           | 356580     | 356580    | 356580    | 356580  | 356580  | 356580  | 0              |
| 8    | 1745683          | 11274      | 1736551   | 1739041   | 1734409 | 2142    | 4632    | 0              |
|      | 356580           | 356580     | 356580    | 356580    | 356580  | 356580  | 356580  | 0              |

This table shows some discarded quantities in the coalition  $P&T1&T2$ ,  $P&T1$ ,  $P&T2$  and  $P$  in experiment 5, 6, 7, 8, because in these experiments the production time is set to “(Max+Mean)/2” which represents an insufficient production capacity. It also shows that the profit of grand coalition in experiment 1-4 is larger than in experiment 5-8, due to the delivery quantities (Table 4-42), which can be equal or less than the customers’ demand.

Notice that the comparison of  $v(T1)$  in experiment 1 and experiment 5 shows a larger value of profit  $v(T1)$  in experiment 5 (“6873”) than in experiment 1 (“6557”). It is contrary to the delivery quantities -- the delivery quantities in experiment 1 (“374750”) are larger than in experiment 5 (“356580”). In both experiment 1 and 5, T1 has 6 owned trucks and extra resource. However, 10 trucks are needed to deliver products with the quantity “374750”, thus extra resource should be used. Consequently, the more delivery quantities, the more extra resource is needed, and as the cost of extra resource is more expensive than the owned trucks, the value  $v(T1)$  in experiment 5 is higher than experiment 1 (“6557”).

In this step, it has to be decide whether each game (experiment number 1, 2, ..., 8) can be continued and if the property of super-additive game need to be checked, as defined in the protocol in section 3.3.3.2. If the game succeeds to go on, the plan of

the grand coalition  $\{P, T1, T2\}$  will be applied in the real producing and transport activity, which is generated by BPP&2T model for coalition  $\{P, T1, T2\}$ .

The games of experiments 2, 3, 4, 6, 7, 8 are super additive (Table 4-45), thus, these games are valid. The games of experiments 1, 5 are not super additive. For instance, a set of calculations is given Table 4-43, which show the verification of non-super-additivity of the game in experiment 1 according to the definition of the super-additive game in 2.3.3.1. In Table 4-43,  $v(S \cup M) \geq v(S) + v(M)$  are not always true, thus the game in experiment 1 is not super-additive.

**Table 4-43 The verification of non-super-additivity of the game in experiment 1**

| $S$      | $M$          | $v(S \cup M)$ | $v(S)$  | $v(M)$  | $v(S) + v(M)$ | $v(S \cup M) \geq v(S) + v(M)$ |
|----------|--------------|---------------|---------|---------|---------------|--------------------------------|
| $\{P\}$  | $\{T1, T2\}$ | 2039272       | 2027383 | 11889   | 2039272       | True                           |
| $\{T1\}$ | $\{P, T2\}$  | 2039272       | 6557    | 2035900 | 2042457       | False                          |
| $\{T2\}$ | $\{P, T1\}$  | 2039272       | 8517    | 2033940 | 2042457       | False                          |
| $\{P\}$  | $\{T1\}$     | 2033940       | 2027383 | 6557    | 2033940       | True                           |
| $\{P\}$  | $\{T2\}$     | 2035900       | 2027383 | 8517    | 2035900       | True                           |
| $\{T1\}$ | $\{T2\}$     | 11889         | 6557    | 8517    | 15074         | False                          |

In experiment number 1, transport operator 1 has 6 owned trucks, and transport operator 2 has 7 owned trucks i.e. 13 in total. However 10 trucks are enough to deliver all the quantities of the customers' demand as mentioned in section 4.2.3.4, thus 13 trucks are too much for delivery. Meanwhile, for the single transport operator, 6 or 7 trucks are not extremely insufficient for delivering, so that a kind of compensation can be brought by extra resource. Consequently, the transport operator is willing to work independently by using extra resource. Therefore, the game in experiment number 1 is not super-additive.

The Shapley value has to be calculated in this step to follow the main steps of the planning cooperation approach in 3.3.3.2. According to the definition of Shapley value in section 2.3.3.3, Shapley values are presented in Table 4-44.

**Table 4-44 Shapley values of each game**

| Number | Shapley value |             |             |
|--------|---------------|-------------|-------------|
|        | $\phi_P$      | $\phi_{T1}$ | $\phi_{T2}$ |
| 2      | 2027383       | 7032        | 4856        |
| 3      | 2027383       | 2632        | 9257        |
| 4      | 2027432       | 4312        | 6801        |
| 6      | 1734409       | 6918        | 4677        |
| 7      | 1734409       | 2439        | 9157        |
| 8      | 1734409       | 4392        | 6882        |

After Shapley values for each partner are obtained, it has to be checked whether these values are in the core as mentioned the protocol of 3.3.3.1. If the Shapley values are in the core, the grand coalition is a stable and more interesting cooperation.

According to the definition of core in section 2.3.3.4, this property is checked in Table 4-41 with unlimited extra resources. The Shapley values ( $\phi_P$ ,  $\phi_{T1}$ ,  $\phi_{T2}$ ) of experiment 2, 3, 4, 6, 7, 8 in Table 4-44 are in the core. Therefore, the grand coalition is steady for these games. However, according our cooperation principle based on Shapley value, in experiments 1 and 5, the partners have an interest in working independently since these experiments are neither super-additive, nor in the core (Table 4-45).

**Table 4-45 The properties of the games**

| Num. | Super-additive game | Shapley value in the core |
|------|---------------------|---------------------------|
| 1    | No                  | No                        |
| 2    | Yes                 | Yes                       |
| 3    | Yes                 | Yes                       |
| 4    | Yes                 | Yes                       |
| 5    | No                  | No                        |
| 6    | Yes                 | Yes                       |
| 7    | Yes                 | Yes                       |
| 8    | Yes                 | Yes                       |

By inspecting the input data of these experiments, it has to be noticed that coalition made up by T1 and T2 has 13 (6+7) trucks in total in experiments 1 and 5. Since 10 trucks are enough to serve all the customers' demand, we think the insufficient capacity of single transport operator is remarkable when the number of a transport operator's trucks is equal or less than half (10/2). In experiments 1 and 5, the insufficient capacity of single transport operator is not remarkable, and the total transport capacity is much more than the need, thus the cooperation is not interesting for number 1 and 5.

For all other experiments, their total transport capacity is either a little more (number 2, 3, 6, 7) than the requirement or less (number 4, 8). In these experiments, the capacity level is significantly insufficient for at least one single transport operator in the grand coalition, thus explaining with this cooperation can be consider as advantageous.

Table 4-46 shows the difference between the profit of each partner in the grand coalition and the profit in the independent case in experiments number 2, 3, 4, 6, 7, 8. This table also shows the relative increase of profit. As  $\phi_i \geq v(i), i = P, T1, T2$ , the profit values of the partner are greater or at least equal to the non-cooperative situation.

**Table 4-46 The comparison of profits**

| Number | $\phi_P - v(P)$ | $\phi_{T1} - v(T1)$ | $\phi_{T2} - v(T2)$ | $\frac{\phi_P - v(P)}{v(P)}$ | $\frac{\phi_{T1} - v(T1)}{v(T1)}$ | $\frac{\phi_{T2} - v(T2)}{v(T2)}$ |
|--------|-----------------|---------------------|---------------------|------------------------------|-----------------------------------|-----------------------------------|
| 2      | 0               | 475                 | 475                 | 0                            | 7.2%                              | 10.8%                             |
| 3      | 0               | 740                 | 740                 | 0                            | 39.1%                             | 8.7%                              |
| 4      | 49              | 2420                | 2420                | ~0                           | 127.9%                            | 55.2%                             |
| 6      | 0               | 45                  | 45                  | 0                            | 0.7%                              | 1.0%                              |
| 7      | 0               | 297                 | 297                 | 0                            | 13.9%                             | 3.4%                              |
| 8      | 0               | 2250                | 2250                | 0                            | 105.1%                            | 48.6%                             |

The following conclusion can be drawn from Table 4-46: the cooperation is more interesting for the transport operators than the manufacturer; however, concerning the manufacturer a small benefit of the cooperation is observed (i.e. only in experiment number 4). We have to remind the experimental context of this experiment: the production's capacity is just enough to serve all the customers' demand, and the two transport operators do not have enough capacity to serve the delivery request together. Consequently it appears that the more the transport operators' capacity is insufficient, the more interesting the cooperation is.

#### 4.4.2.2 Experimental case 2– all the transport operators without extra resource

In this section, all the transport operators do not have available extra transport resources, thus, the corresponding parameter --  $M\_extra_{j,k,t}$  is set to 0.

Table 4-47 presents the profit and serving quantity of each coalition for each game of the experimental array in Table 4-41. Notice that in the pure production coalition (coalition containing no transport operator), the served quantity is the quantity of products manufactured whereas in the pure transportation coalition (containing none manufacturer), the served quantity is the quantity of products delivered; in the mix coalition (including production and transportation), the served quantity is quantity of products manufactured and products delivered. Let us also remind that the profit is chosen as the payoff for the following game. In Table 4-47, the black words represent the profit without discarded quantities; the red words represent the profit with

discarded quantities (referring to 3.3.3.2), and the green words show the serving quantities.

**Table 4-47 The payoff -- profit and serving quantity of each coalition**

| Num. |          | v(P&T1&T2) | v(T1&T2) | v(P&T1) | v(P&T2) | v(P)    | v(T1)  | v(T2)  | v( $\emptyset$ ) |
|------|----------|------------|----------|---------|---------|---------|--------|--------|------------------|
| 1    | Profit   | 3683084    | 7401     | 2487750 | 3106794 | 2237369 | 4904   | 6661   | 0                |
|      | Quantity | 374750     | 273240   | 338260  | 362260  | 273240  | 273240 | 273240 | 0                |
| 2    | Profit   | 3683084    | 6247     | 2487750 | 2010993 | 1846670 | 5438   | 3070   | 0                |
|      | Quantity | 374750     | 245662   | 338260  | 308760  | 245662  | 245662 | 245662 | 0                |
| 3    | Profit   | 3683084    | 5076     | 1733787 | 3106794 | 1322030 | 1838   | 4815   | 0                |
|      | Quantity | 374750     | 206520   | 290260  | 362260  | 206520  | 206520 | 206520 | 0                |
| 4    | Profit   | 3627602    | 5076     | 1733787 | 2010993 | 1322030 | 1838   | 3791   | 0                |
|      | Quantity | 374750     | 206520   | 290260  | 308760  | 206520  | 206520 | 206520 | 0                |
| 5    | Profit   | 3301179    | 7188     | 2321537 | 2947415 | 2089688 | 5647   | 6837   | 0                |
|      | Quantity | 356676     | 265344   | 326315  | 352720  | 265344  | 265344 | 265344 | 0                |
| 6    | Profit   | 3301179    | 6311     | 2321537 | 1796990 | 1741695 | 5150   | 3458   | 0                |
|      | Quantity | 356676     | 239810   | 326315  | 296815  | 239810  | 239810 | 239810 | 0                |
| 7    | Profit   | 3301179    | 5057     | 1448150 | 2947415 | 1232227 | 2071   | 5098   | 0                |
|      | Quantity | 356676     | 197231   | 272815  | 352720  | 197231  | 197231 | 197231 | 0                |
| 8    | Profit   | 3298155    | 5057     | 1448150 | 1796990 | 1232227 | 2071   | 3857   | 0                |
|      | Quantity | 356676     | 197231   | 272815  | 296815  | 197231  | 197231 | 197231 | 0                |

As shown in Table 4-47, the results prove that the games are not super-additive.

**Table 4-48 Super additivity**

| S         | M              | $v(S \cup M)$ | $v(S)$  | $v(M)$  | $v(S) + v(M)$ | $v(S \cup M) \geq v(S) + v(M)$ |
|-----------|----------------|---------------|---------|---------|---------------|--------------------------------|
| {P}       | { $T_1, T_2$ } | 3683084       | 2237369 | 7401    | 2244770       | True                           |
| { $T_1$ } | {P, $T_2$ }    | 3683084       | 4904    | 3106794 | 3111698       | True                           |
| { $T_2$ } | {P, $T_1$ }    | 3683084       | 6661    | 2487750 | 2494411       | True                           |
| {P}       | { $T_2$ }      | 3106794       | 2237369 | 6661    | 2244030       | True                           |
| { $T_1$ } | { $T_2$ }      | 7401          | 4904    | 6661    | 11565         | False                          |
| {P}       | { $T_1$ }      | 2487750       | 2237369 | 4904    | 2242273       | True                           |

A set of calculations is presented below in Table 4-48 to show an example (experiment Num. 1) of super-additivity verification, according to the definition of the super-additive game mentioned in section 2.3.3.1. Since  $v(T_1 \& T_2) < v(T_1) +$

$v(T_2)$ , we can therefore deduce that experiment Num. 1 is not a super-additive game. The verification of super-additivity of other experiments can be done in the same way.

Let us also remark that due to the limitation of the estimated transportation's capacity (BPP.8) the available capacity of some transport coalitions is strongly reduced compared to its real capacity. That is why in table 4-47, the quantities of (T1 &T2) can be equal to the quantity of (T1) and also equal to the quantity of (T2) in all the experiments. In these results, there is obviously an excessive reduction in capacity which should be reduced in future experimentations.

According to the protocol in 3.3.3.1, if the game is not super-additive, the process will stop. Why they all are not super-additive game? At the beginning of the process, the production discards some customer demand according to the minimum transport operator's capacity, thus single transport operator can serve the rest quantity for new delivery request. Consequently, it is not interesting to cooperate in this situation.

#### **4.5 Conclusion**

In this chapter, all the input parameters needed for the experiments and the validation of our cooperative approach are generated. The cooperation sharing mechanism proposed in chapter 3 is evaluated. Numerical experiments are designed for cooperation both between homogeneous partners and heterogeneous partners. For the cooperation between homogeneous partners, three transport operators are selected as the partners; for the cooperation between heterogeneous partners, one manufacturer and two transport operators are chosen.

In the cooperation between three transport operators, the cost saving is considered as the payoff. Our results show that all the games are the super-additive, and their Shapley values are in the core, so that the grand coalition is stable and can be considered as the best way to cooperate. Consequently, the plan of the grand coalition can be implemented in the real transport activity. The cost saving shows the benefit to cooperate in the grand coalition.

In the cooperation between one manufacturer and two transport operators, the payoff is defined as a profit, and two cases of experiments are considered. When the transport operators have unlimited extra transport resource to use, the properties of the games depends on the input data such as the owned trucks by two transport operator's. When the capacity of single transport operator is extremely insufficient and the global capacity is not enough or just enough to serve all the customers' demand, the game will be super-additive game and its Shapley values are in the core. In this situation the cooperation is more interesting for the transport operators than the manufacturer,

since the manufacturer's profit does not increase, however transport operator's profit can be improved significantly. Hence, the cooperation is interesting and profitable overall. When all the transport operators do not have available extra resource, none of the games are super-additive. Consequently, the process of cooperation stops since these games are not valid. Hence, it is not interesting to cooperate in this situation.

## General conclusion

This thesis proposes to study the problem of the decision making at a tactical decisional level, for coordinating planning activities (i.e. production and/or transportation) as a cooperative game, and proposes cooperation protocols in the context of homogeneous and heterogeneous partners.

### Scientific contributions of our work

The main contribution of this thesis is the implementation of cooperative games to solve the planning problems involving different partners of the supply chain at the tactical level. Two types of problems are studied according to the nature of partners;

- The cooperation between homogeneous partners concerns multiple transport operators offering identical delivery services to a set of customers. The expected gain in this cooperation is the sharing of operating costs, in order to respect as best as possible the demand of customers, and to minimize the total costs.
- The cooperation between heterogeneous partners focuses on the relationship between one manufacturer and multiple transport operators. In this context, the gap of scales between the revenues of manufacturer and the revenues of the transport operators is known to be important (i.e. smaller benefits for the transport operator). Indeed, the expected gain of the cooperation is more relevant in terms of profit, due to the heterogeneity of the concerned partners.

The first step of the implementation focuses on the development of mathematical models to simulate the planning process of each partner. Two kinds of models have been developed, based on Linear Programming (LP):

- A generic BST-mT model dedicated to support the transportation planning function with up to  $m$  transport partners. This model allows to consider a homogeneous set of partners, when these latter have the same input parameters, or can simulate the planning process of a heterogeneous set of partners. As mentioned in the name of the model (BST – Best Service Transportation), the objective of the planning is to propose a plan as close as possible to the delivery plan requested by the manufacturer.

- A BPP model (Best Profit Production model) modeling the behavior of the manufacturer's planning -- its producing and delivery activities. BPP means "Best Profit Production", so the optimization aims to maximize the financial gain for the manufacturer.
- A BPP&mT model which integrates production and transportation features and constraints in a same model. This model corresponds to the joined planning process between partners with a heterogeneous nature (production and transport). In the current work, the only situation studied concerns one manufacturer and up to m transport operators.

The second step of the implementation concerns the development of the cooperation protocol. We have decided to base our approach on Game Theory (GT) because some properties and principles of calculation seemed to be interesting to apply to the cooperation process: the concept of pool of partners corresponds to the notion of coalition from the game theory domain, the principle of gain sharing based on Shapley values is considered as interesting to implement the cooperation. The proposed cooperation protocol is then structured in three steps:

- Game: planning models modeling the planning process of any coalition of the game are used to estimate the expected gain (profit or cost saving) in each situation. After considering all the possible coalitions, the Shapley value is calculated and the property of *super-additivity* is verified. It is recalled that this property checks if a partner within a coalition has more gain (or same gain) than as an independent partner.
- Decision: An important property has to be verified at this step: if the Shapley values are in the core, it means that the more stable situation in terms of gain is represented by the grand coalition (i.e. with all partners). This coalition is considered as the best possible cooperative situation, and cooperation is successful. In the other case, the grand coalition is not the best solution and the cooperation fails.
- Implementation: Plans resulting from the planning process concerning the grand coalition are implemented for the different partners.

It is recalled that in the proposed cooperation protocol, a specific behavior was added to depict the situation where the capacity of the transport operators are strongly insufficient compared to the delivery quantities ordered by the customers. Indeed we assume that all quantities which cannot be served by transport operators during the planning horizon can be discarded, which is based on the assumption that a transport

operator will not accept new delivery request for customers' demand if it has no enough capacity to make an efficient delivery.

Based on a simulation platform coupling GLPK solver and excel input and output files, numerical experiments are designed and implemented for the two types of problems. Experimentations related to the set of homogeneous partners show that all situations lead to a successful cooperation for the grand coalition. All the games verify the super additivity property and the Shapley values are in the core. Consequently, the plan of the grand coalition can be implemented in the real transport activity and the cost saving shows the benefit of the cooperation. Considering a set of heterogeneous partners, experimentations lead to more complex results. If extra transportation resources are enabled (i.e. for instance when some of the activities can be outsourced), the properties of the games depend on the input data, such as the capacity of each transport operator represented by the number of owned trucks. If the capacity of a single transport operator is strongly insufficient and if the transport operators globally need to outsource a part of their activities (i.e. the global capacity is not enough or just enough to serve all the customers' demand), the cooperation is successful but it is more interesting for the transport operators than the manufacturer. Nevertheless, this latter do not lose money. In case of transport operators which cannot use outsourcing, none of the games are super-additive. Consequently, the process of cooperation stops since these games are not valid.

### Limitations and perspectives

Various limitations of this work can be pointed out, showing the scope for further investigation.

In considering the cooperation protocol as successful, we only assume that the grand coalition (i.e. group of players) can be the best. However, among the activities between multi partners, even if the grand coalition is not interesting, small coalitions may represent interesting situations in which the cooperation of only a part of the full set of partners is sufficient to guarantee an economical gain, while extending the cooperation to the full set can lead to increase the whole operating costs.

In the cooperation between the heterogeneous partners, at the beginning of the process, the production discards some customer demand according to the minimum transport operator's capacity to avoid superabundant stocks. In this way overmuch stock due to the insufficient capacity of the transportation can be avoided. When the transport operators have unlimited extra transport resource, this limitation (i.e. discarded

demands) has no practical effect, since production entity always believes that the transportation can fulfill its delivery request. But when transport operators do not have any extra transport resource, this limitation has an important role for the production to decide the discarded quantities of the customers' demand. In this situation, the transport operator does not have motivation to cooperate with other transport operator(s), since it can accomplish the delivery task alone.

The studied cooperative situation includes a specific partner called 4PL, which is not explicitly considered in the game whereas the services it provides - integration and management of partners - can have associated operating costs. The previous remark leads to another perspective, considering situations where different 4PLs are available to provide a service with different costs. These partners increase the diversity of partners and lead to more complex games, in which some of them can be in cooperation and some others in competition. The study of this situation and its modeling with Game Theory can lead to consider different forms of games and need to develop new protocols.

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