Proceedings of the
4^{th} International Conference on Information Systems, Logistics and Supply Chain
CREATIVE LOGISTICS FOR AN UNCERTAIN WORLD
ILS 2012 – Quebec (Canada), August 26-29

Game theoretic contribution to horizontal cooperation in logistics

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Abstract : *Horizontal cooperation in logistics was proved globally advantageous, but we see only few realizations until now. The main obstacle to the successful implementation of horizontal cooperation is the absence of appropriate cooperation decision making model, consisting of the detailed cooperation process, the optimization model, and the stable-and-fair gain sharing mechanism. In this paper, we propose a practical cooperation decision making model for the realization of horizontal logistics cooperation scheme. This model is a decision process integrating an optimization tool and a game-theoretic approach to find a feasible allocation rule, and stable coalitions related to coalition structures issue. We propose a weighted allocation rule that takes bargaining power, contribution and core stability into account, and generalize it in games with coalition structure. Then we investigate related stability issue under two different cooperation patterns. At the end, we present a case study of France retail supply network, which verifies the cooperation model we proposed.*

Keywords : *Horizontal logistics cooperation, cooperation decision making model, cooperative game theory, weighted profit allocation, farsighted stability*

1 Introduction

Horizontal cooperation in logistics was proved efficient to reduce global cost and improve the performance level (Cruijssen et al., 2007; Pan et al., 2011). However, despite these advantages, horizontal cooperation is not considerably employed in logistics (Muir, 2010). One main obstacle in the implementation of horizontal cooperation is the absence of an appropriate cooperation decision making model. In this paper we use the cooperative-game-theoretic approaches to facilitate the decision making. The cooperative game theory investigates how players interact with each other in a cooperative relationship, and provides many approaches to fair profit allocation and stable coalition formation, which are important components in the cooperation model. Therefore, we use this approach to build a horizontal cooperation model, highlighting its complexity and possible drawbacks.

The contribution of this paper is as follows. At first, we propose a practical cooperation model, which is a detailed cooperation process consisting of several decision-making levels. Secondly, we introduce a practical profit allocation scheme that takes core stability, bargaining power and contribution into account. Finally, we model a supply-chains-pooling game with cooperation cost consideration as a cooperative game with *Coalition Structure* (CS), then investigate relative profit allocation and CS stability issues.

This paper is organized as follows. In Part 2, we present the questions raised by horizontal cooperation in logistics and propose a general cooperation model. In Part3, game-theoretic approaches are reviewed to establish a theoretic foundation of the essential part in the cooperation model: game-theory-based sharing mechanism. A specific cooperation model for supply chains pooling scheme is proposed in Part 4. Two most important questions: *profit allocation* and *stability* are identified. In Part 5, we investigate the profit allocation, and then propose a practical weighted-core-stable allocation rule and generalize it in games with CS. In Part 6, we examine the coalition stability under two cooperation patterns. A case study of French retail supply chains is presented in Part 7. Then in Part 8, we conclude the work.

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2 Questions raised by horizontal cooperation in logistics

2.1 Horizontal cooperation in logistics

A great emphasis was put on cooperation in supply chains, but mostly between suppliers and customers, a practice also known as *vertical cooperation*. Since few years another type of cooperation is studied and experienced within supply chains: *horizontal cooperation*. This form of cooperation takes place between companies operating at the same level of market and it requests them to share private information and resources in logistics. The aim is to improve the efficiency in logistics, for example reduce logistics cost (Cruijssen et al., 2007) or reduce environmental impact caused by transportation activities (Pan et al., 2011).

In this paper, we focus on transportation cost aspect. It's proved in the literatures that the horizontal cooperation in logistics can result in a 10% or higher percentage of cost reduction in transportation (Groothedde et al., 2005; Ergun et al., 2007; Pan et al., 2011). Considering the size of this market, it's a huge stake.

To study the transportation problem, we employ here the supply chains pooling concept that is a horizontal cooperation approach, which defines a common logistics system involving shippers of different supply chains to increase the supply chain efficiency. The supply chains pooling cooperation scheme is based on the optimization tool that is first developed in the dissertation of Pan (2010). The main idea of this optimization scheme is to strengthen the logistics cooperation in pooling among different companies, then to evaluate how can the logistics efficiency be enhanced to full extent in a pooled network.

The supply chains pooling is based on the pooling of logistics resources in a system illustrated here by a classic supply chain network for retail distribution, in the top part of figure 1. The pooled system described in the lower part of figure 1 shows, on the other hand, the grouping of flows. The advantage of this type of system was shown in Pan et al. (2011).

The cost optimization of the logistics network was studied as a transportation problem, formulated by a mixed linear integer optimization problem. For more details of implementation, readers who are interested can refer to Pan et al. (2011).

This optimization tool can help cooperators to find an optimal cooperation scheme, thus create a common gain that will be shared among them. However, the coalition construction and the profit sharing issues are not yet investigated in the studies related to logistics pooling. It is easy to see that appropriate gain sharing solution needs to be constructed at first place to give all cooperators incentive to take part in such cooperation. We investigate the cooperative game theory in the following sections for the construction of a gain sharing mechanism.

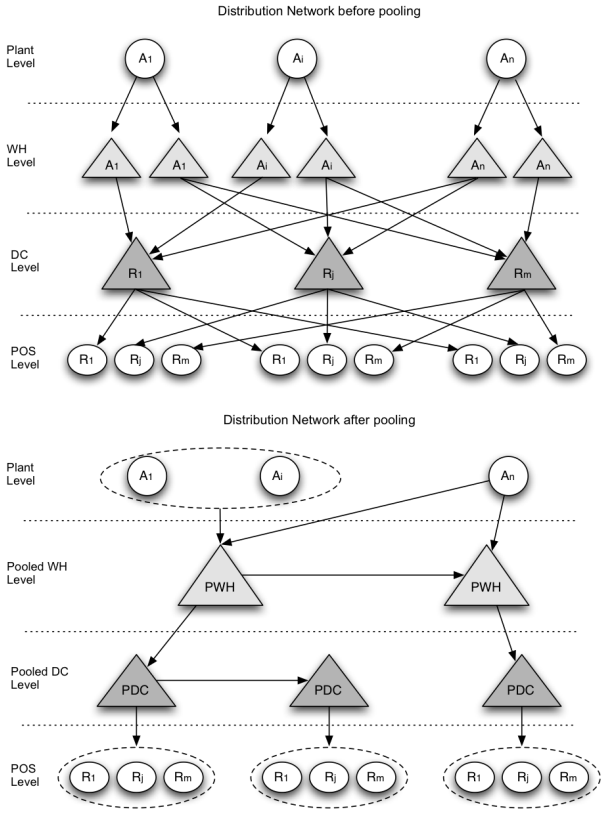


Figure 1: Illustration of the supply chains pooling (Ai: Supplier i; Rj: Retailer j;WH: Warehouse; DC: Distribution Center; POS: Point Of Sale)

2.2 A need for a general cooperation model

Despite its important advantages, horizontal cooperation is not yet considerably employed in logistics. A survey made in Flanders (Cruijssen et al., 2007) points out the difficulties for the implementation: find a reliable leader and construct a fair allocation of benefit. Therefore, to answer the requirement of a cooperation-aiding tool, we construct a cooperation model, which is a cooperation process, to facilitate the implementation of the horizontal logistics cooperation.

Here, we present a general model that can be applied in many fields to cooperation issues. This model is illustrated in figure 2.

At the beginning of the cooperation procedure, we have got a set of cooperation candidates who have incentive to cooperate with others. Then we evaluate the cooperation possibilities among all candidates to separate them into several "cooperation groups", for example groups of companies in different regions. Depending on the cooperation content, a consensus specifying related cooperation organization, co-

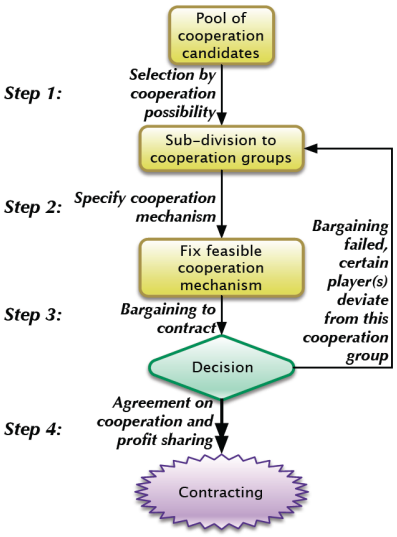


Figure 2: General cooperation model

ordination details and profit sharing scheme should be identified in the step 2 as the basis of cooperation. The step 2 is the most important one in this model, and the cooperation mechanism specified in this step should consist of an optimization model to find the optimal cooperation scheme and a gain sharing mechanism to propose fair sharing scheme. Based on the framework thus defined, there will always be some indefinite area left to bargaining. So in the step 3, cooperators try to establish an explicit contract by bargaining. In step 4, there are two possibilities: agreement being made, cooperation relationship contracted; or bargaining failed, someone in the cooperation group deviates, the others move back to step 2.

Thus there arise the vital question on gain sharing, the answer to which will complete this cooperation model. That is, what kind of gain sharing mechanism should be constructed to facilitate the implementation of the cooperation? In the business reality, gain sharing mechanisms based on identical unit delivery tariff and proportional allocation rules are widely applied (Cruijssen et al., 2007). However, the considerations of the cooperators' real contribution and their bargaining powers are missing in these practical sharing mechanisms, which is not fair and may result in the instability of the coalition thus formed. For the construction of a stable-and-fair sharing mechanism, we investigate the cooperative game theory in the rest of this paper.

3 Game theory literature review

As to Hart et al. (1997), the game theory is divided into two main approaches: the non-cooperative and the cooperative game theory. The cooperative game theory can be applied to the case where players can achieve more benefit by cooperating than staying alone. The gain sharing issue is intensively investigated in the cooperative game theory, therefore we adopt cooperative-game-theoretic approaches in constructing the sharing mechanism. Nagarajan and Sosic (2008) divided cooperative game approaches into multivalued-mapping approaches and single-valued-mapping approaches. Multivalued-mapping approaches, such as *core* and *coalition structure core* (CS core), give a set of value allocations that conform some general properties of feasible solution, usually serves as stability criterions; and single-valued-mapping approaches, such as *Shapley value* and *compromise value*, try to identify specific allocation by a set of axioms, usually serves as allocation rules.

Shapley (1953b) introduced his famous *Shapley value* (SV), which is a representative allocation rule that conforms five axioms: *individual fairness, efficiency, symmetry, additivity*, and *null player*. *Symmetry* axiom means that all players in the game are treated equally. But in business reality, companies possess different bargaining power, which comes from company size, market share or some other aspects, so it will be more realistic, weighted allocation rules that take this into account. Monderer and Samet (2002) construct a explicit theoretical framework for variations on SV, and the *weighted Shapley value* (WSV) introduced by Shapley (1953b,a) alongside the standard SV is re-examined in this framework. In WSV, the *symmetry* axiom is relaxed by considering players' different weights, which can be regarded as bargaining powers in the cooperative game investigated here. This allocation rule is axiomatized by Kalai and Samet (1987). Monderer et al. (1992) prove the monotonicity of the WSV in convex game, but this does not hold in non-convex game. The monotonicity mentioned here means that when a player's weight is increased, while keeping the other players' weights unchanged, the player's payoff in the given game increases. Haeringer (2006) propose another way to introduce players' weights in the SV, which is named *modified weighted Shapley value* (MWSV) and is monotonic with respect to player weights. The main drawback of this work is that it may allocate negative payoffs, thus non-stable in cooperative games. Dai and Chen (2011) investigated a carrier cooperation problem. They proposed several profit allocation mechanism that combine core solution concept with SV, proportional allocation and contribution-based allocation. Inspired by this, we propose a *contribution-and-power weighted value*, which take player bargaining power, SV and core stability into consideration. This allocation rule is detailed in Part 5.

The Multivalued-mapping concepts, according to their non-uniqueness, often serve as the stability criterion. For example, the *core* and the *CS core* may be the best-known stability concepts. They address the stability of the grand coalition and an arbitrary CS respectively. The *core*, firstly introduced by Gillies (1959) contains all stable allocations,

which guarantee that there is no coalition can benefit by jointly deviating from the grand coalition. Its main drawback is that, it may be an empty set. Aumann and Dreze (1974) generalize the core solution concept to games with CS, i.e. the *CS core*. Similarly, given a CS, the CS core contains all allocations that can guarantee no incentive to deviate from this CS. Aumann and Dreze (1974) prove that a necessary condition for a game with CS have a non-empty CS core is that the CS formed is the optimal one. "Optimal" means this CS can generate highest global profit.

These solution concepts are criticized to be myopic, since they take into account only one-step deviation. Suppose a coalition structure denoted CS, and there is a coalition Z who can be better off by deviating from CS. For a myopic view of stability, CS is not stable. However, we should consider further deviations. Any deviation would trigger a sequence of deviations, which may end with an outcome where the initial deviators, members of Z, receive lower payoffs than in CS. In such case, if members of Z were farsighted enough, they would prefer to not deviate in the first place. Thus CS, non-stable in the myopic view, may prove to be stable in farsighted sense.

A solution concept that examine the coalition stability by farsighted is *largest consistent set* (LCS), introduced by Chwe (1994). It is criticized to be too "inclusive", so Xue (1998) and Mauleon and Vannetelbosch (2004) proposed refinement of LCS in their works. Konishi and Ray (2003) proposed a dynamic approach to CS stability, the *equilibrium process of coalition formation* (EPCF). This approach can verify the stability of CS core elements by farsighted arguments, while in the other hand, can support some farsighted stable CS, which is not in the CS core, as stable outcomes.

We have briefly reviewed the game theoretic approaches applied for fair allocation and stability evaluation. In Part 4, we will introduce a cooperation model to investigate the implementation issues in logistics cooperations.

4 A practical logistics cooperation model

4.1 Cooperation model for supply chains pooling

We redefined following model in figure 3 for the implementation of supply chains pooling, which is of more explicit details on each decision level. In this cooperation model, a *cooperation coordinator*, working as organizer and communication hub, will play a crucial role. It is also a side payment implementer, which can ensure the profit allocation. The most important and complicated step is the step 2, where the optimization tool and related game theoretic approaches are applied to establish a consensus as the base

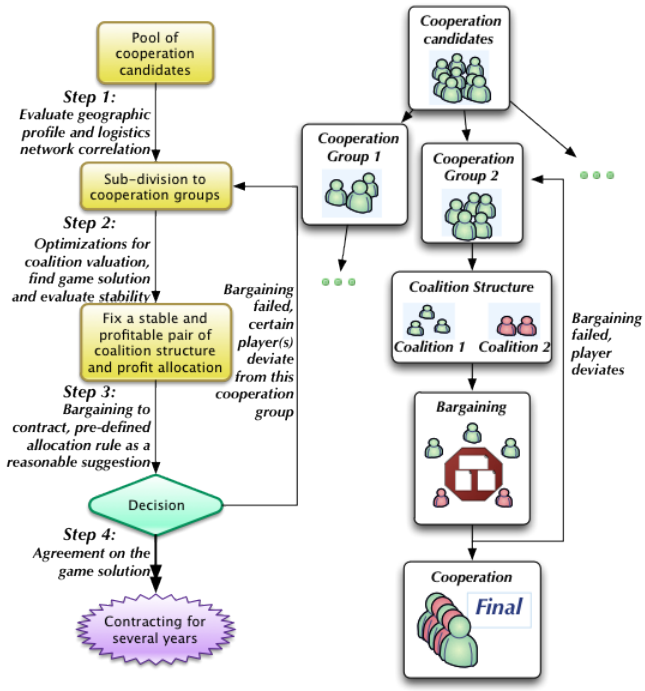


Figure 3: A specific cooperation model for supply chains pooling

of further bargaining. We use optimization tool to evaluate possible profit that can be generated by all possible coalitions, then use game theoretic approaches to find a solution for corresponding pooling game. In the game theoretic aspect, we mainly focus on weighted profit allocation schemes and CS stability. We also make some suggestion on the application of farsighted stability concepts.

4.2 Scheme of logistics cooperation game investigation

To apply this cooperation model to supply chains pooling game, at first we need to identify different problems that may be encountered. The game $G = (N, v)$ is said to be *super-additive* if the characteristic function v satisfies equation (1)(Shapley, 1971).

$$v(S) + v(T) \leq v(S \cup T),\ \forall S, T \subset N \text{ and } S \cap T = \emptyset \quad (1)$$

It signifies that the two separate coalitions can create at least as much value if they form one large coalition.

Consider two supply-chains-pooling cooperation patterns: the limited cooperation and the long-term, in-depth cooperation. In modeling these two cooperation relationships as cooperative games, we note that there is no need to invest heavily for specific warehouses, standardized container and trucks, and dedicated information system in the limited cooperation, such as the potential-lane cooperation introduced by Institute of Grocery Distribution (2007), or a compromised version of supply chains pooling that is suitable

for small and median sized enterprises, where efficiency promoting is constrained by limited investment. In such kind of cooperations, the cooperation cost is negligible and it can be modeled as a super-additive game, since if any two coalitions of players S and T cooperate to optimize their pooling scheme, at worst, while there is no further pooling possibility between S and T, it will still guarantee $v(S) + v(T) = v(S \cup T)$, which satisfy super-additivity.

And in the long-term, in-depth cooperation, related investment is necessary for the efficiency of the cooperative network and the payment to the coordinator. That means, for participating in the cooperation, one should first pay the cooperation cost. As cooperation cost increases to a certain level, the game become non-superadditive, which means that, in this situation, some players may gain less than the cooperation cost they paid if they take part in cooperation. Such a game is no longer super-additive, so the players either cooperate in separated coalitions (the most profitable coalitions will form separately), or stay alone (for the players who cannot generate more profit than cooperation cost). We present an investigation scheme in figure 4.

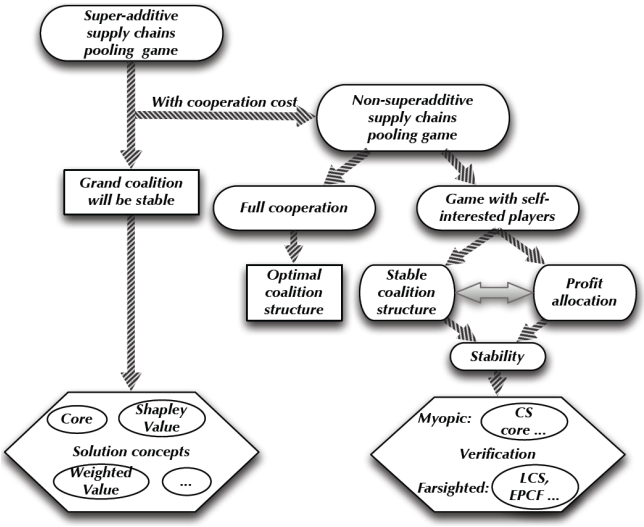


Figure 4: Scheme of logistics cooperation game investigation

As figure 4 shows, there are two substantial questions lie in the cooperative game theory: *profit allocation* and *coalition (CS) stability*. These two questions will be investigated in following two sections.

5 Profit allocation according to different bargaining powers

5.1 Preliminaries on cooperative game theory and weighted allocation rules

A cooperative game can be denoted by $G = (N, v)$, where N is the set of all players and v is the characteristic function which is the difference between the logistics cost before cooperation and that after cooperation, *i.e.*, $v(S) = A(S) - M(S)$. Coalition S is a subset of N. For each $S \subseteq N$, we have $v(S)$ which gives the common profit created by S. An allocation x is a vector with elements x_i that indicate the corresponding payoff of each player. A payoff vector satisfies *efficiency* if $\sum_{i \in N} x_i = v(N)$. For a coalition, we have $x(S) = \sum_{i \in S} x_i$. Further, an allocation x is called an *imputation* if x satisfies $x_i \geq v(i)$, $\forall\, i \in N$ and *efficiency*. The set of all imputations of a game $G = (N, v)$ is denoted by $I(N, v)$.

The core of game $G = (N, v)$, introduced by Gillies (1959), is defined by equation 2.

$$Core(N,v) = \{x | \sum_{x_i \in I(N,v)} x_i = v(N)\, and \\ x(S) \geq v(S), \forall S \subseteq N, x \in I(N,v)\} \quad (2)$$

A cooperative game with coalitional structure can be denoted by $G = (N, v, P)$, where CS P is a partition of N into coalitions, *i.e.*, $P = \{S_1, S_2, ..., S_k\}$ where for all $l \in \{1, 2, ..., k\}$,we have $S_l \subseteq N, \bigcup_{l=1}^{k} S_l = N$, and $(i \neq j) \rightarrow S_i \cap S_j = \emptyset$. Note that we also take {N} as a special CS. The core of $G = (N, v, P)$, introduced by Aumann and Dreze (1974), is defined by equation 3.

$$CS\,core(N,v,P) = \{x | \sum_{i \in S_l} x_i = v(S_l),\ \forall\, S_l \in P, \\ and\, x(S) \geq v(S),\ \forall\, (S \subseteq N, x \in I(N,v))\} \quad (3)$$

A best-known weighted value allocation rule may be the *weighted Shapley value* (WSV). In this allocation rule, Shapley proposes to model players' bargaining power through weights. All games can be decomposed as a linear combination of unanimity games: $v = \sum_{S \subseteq N} a_S u_S$, where a_S is the coefficient of unanimity game u_S. The SV is an equal allocation of unanimity games' value to players, *i.e.*, $SV_i(v) = \sum_{S \ni i} \frac{a_S}{|S|}$; while the WSV is a weighted allocation according to the weights w assigned to players, *i.e.*, $WSV_i(v, w) = \sum_{S \ni i} \frac{a_S w_i}{\sum_{j \in S} w_j}$.

However, as Owen (1968) has shown, the weights in the construction of WSV cannot be interpreted as a measure of power, but players' delay to reach the grand coalition, which means it is not sure that as one player's weight increases while keeping other players weights unchanged, if his payoff will increase. Haeringer (2006) proposed a new weighted scheme for the SV, which generate different sets of bargaining weights to divide the worth of unanimity games, depending on whether the unanimity game coefficient is positive or negative. The main drawback of this allocation rule is that it may allocate negative payoffs. Considering the supply chains pooling game investigated in this paper, we proposed a new allocation rule in following section.

5.2 A practical allocation rule with both contribution and bargaining power consideration

We suppose that a fair profit allocation rule in the supply chains pooling game should take following factors into consideration: *contribution* to the common profit, *bargaining power* and *stability*. Since the SV is the weighted average marginal contribution of player, so it can be regarded as the measure of players' contribution to the common profit. Bargaining power should be modeled into the construction of such a fair allocation rule by weight, so that with the player's weight increasing while that of the others unchanged, his payoff increases. And at last, the allocation rule integrates stability consideration alongside its construction. Thus, we propose a practical weighted allocation rule, named *contribution-and-power weighted value* (CPWV), computed by following linear programming (LP) (equations (4a)–(4c)).

$$MIN: \theta$$

$$s.t.: \frac{x_i}{s_i w_i} - \frac{x_j}{s_j w_j} \leq \theta, \forall\, i, j \in N \tag{4a}$$

$$\sum_{i \in S} x_i \geq v(S), \forall S \subset N \tag{4b}$$

$$\sum_{i \in N} x_i = v(N). \tag{4c}$$

The s_i in this LP is the SV of player i. w_i is the factor denotes the bargaining power of player i, for example, i's total weight/volume of goods transported in this cooperative logistics system, i's annual revenue, etc. Since in the step 1 in the cooperation model, only non-dummy players will be selected into cooperation groups, and the bargaining power factors are positive, which imply $s_i > 0$ and $w_i > 0$. This LP can identify a payoff vector x that minimize the maximum difference between any two players' payoff rates $\frac{x_i}{s_i w_i}$.

From the LP of CPWV, we can easily prove that CPWV of a game with non-empty core satisfies following axioms:

Symmetry. If two players i and j that $w_i = w_j$ can be interchanged without changing any $v(S)$, then $x_i(v, CPWV) = x_j(v, CPWV)$.

Efficiency. $\sum_{i \in N} x_i = v(N)$.

Individual rationality. $x_i \geq v(i)$, $\forall\, i \in N$.

Collective rationality. $\sum_{i \in S} x_i \geq v(S)$, $\forall S \subset N$.

Weak monotone. As player i's weight increases while the other players' weight unchanged, i's payoff does not decrease.

5.3 Generalization of CPWV in games with CS

We generalize CPWV in games with CS (CS CPWV) by integrating the SV in games with CS (CS SV) introduced by Aumann and Dreze (1974) and the CS core solution concept. The CPWV with CS is identified by following LP (equations (5a)–(5c)).

$$MIN: \theta$$

$$s.t.: \frac{x_i}{s_i' w_i} - \frac{x_j}{s_j' w_j} \leq \theta, \forall\, i, j \in S_k, \forall\, S_k \in P \tag{5a}$$

$$\sum_{i \in S} x_i \geq v(S), \forall S \subset N \tag{5b}$$

$$\sum_{i \in S_k} x_i = v(S_k). \forall\, S_k \in P \tag{5c}$$

In this LP, $s_i^{'}$ is the CS SV of player i CPWV with respect to a given CS P, and S_k is a coalition in the CS P. To implement this allocation rule, at the beginning of step 2, an appropriate CS should be fixed, then the coalition S_k that $v(S_k) = 0$ should be excluded from this cooperation group to make sure that $s_i^{'} > 0$, $\forall\, i \in N$.

Similarly, we can prove that CS CPWV of a game in coalitional form with non-empty CS core satisfies *symmetry*, *efficiency*, *individual rationality*, *collective rationality*, and *weak monotone* axioms.

In Part 5, we proposed a practical allocation rule that takes into account bargaining power, contribution and core stability. In next section, we will discuss related stability issues based on the cooperation model and supply chains pooling background.

6 Stable coalition formation in supply chains pooling game

6.1 Equilibrium process of coalition formation

Konishi and Ray (2003) introduces a dynamic approach to the stability of CS, named *equilibrium process of coalition formation* (EPCF). Denote the set of all possible CS by $\overline{CS}$, the *process of coalition formation* (PCF) is a transition probability $p : \overline{CS} \times \overline{CS} \rightarrow [0, 1]$ (so that $\sum_{CS_k \in \overline{CS}} p(CS_i, CS_k) = 1, \forall\, CS_i \in \overline{CS}$). Based on a fixed allocation rule, a PCF p induces a value function $v_i(CS_k, p)$, which is used to evaluate farsighted players' CS preference. A PCF is *equilibrium* if transition probability and players' preference are consistent in this PCF. EPCF can be interpreted in the following way. A PCF induces value function $v_i(CS_k, p)$ based on the given allocation rule, while the value function, interpreted as players' farsighted estimation of total payoff throughout the PCF,

make players have incentives to move to profitable CS according to their preference, no matter if such moves are consistent or not with the PCF. An EPCF is such an equilibrium: EPCF p^* can induce a value function that can in turn ensure this EPCF.

Denote by $\mathcal{P}$ the set of all PCFs, they construct a set mapping $\phi : \mathcal{P} \to \mathcal{P}$, and prove by Kakutani fixed point theorem that a fixed point $p^* \in \phi(p^*)$ exists and is an EPCF. In such an EPCF, if there exists absorbing state (or CS) CS_i that $p(CS_i, CS_i) = 1$, which means that no farsighted players have incentive to deviate, we can confirm that CS_i is a stable CS.

6.2 Coalition stability in the limited-cooperation pooling game

In a limited-cooperation pooling game, since there is negligible cooperation cost, so the game is super-additive and the grand coalition can achieve the highest global profit. However, whether the core of a super-additive supply chains pooling game is non-empty is still uncertain, even though according to real-world case study experiences that by cooperating in the grand coalition players can get much higher payoffs than in any sub-coalition, we estimate this game would have non-empty core in most cases. But there is another tactical consideration in this specific cooperation modality that can serve as argument for players' grand-coalition preference, which is the possibility to increase freight frequency arising from the cooperation among a large quantity of players. We evaluate only the transportation cost reduction in the optimization model, based on periodical flow of goods. The cooperators will realize that besides the transportation cost reduction, an increased freight frequency is also an obvious advantage of the supply chains pooling, which may reduce the storage cost and the leading time of deliveries. So it may be more preferable to stay in a cooperation relationship among as many cooperators as possible, rather than to deviate. So the grand coalition can still be stable even the core is empty.

When the core of a supply chains pooling game is empty, we need to consider another profit allocation rule. Béal et al. (2008) proved that, for any super-additive game, its SV is a stable imputation either in the core or in the farsighted stable sets, so SV in this case can be a reasonable suggestion for players' further bargaining in step 3.

6.3 CS stability in the long-term pooling game

In this section, we investigate the long-term pooling game under two different assumptions: full-cooperative and self-interested players. In a full-cooperative game, the players have no incentive to deviate from a CS that optimizes the performance of the whole cooperation group. Under full cooperation assumption, the optimal CS will be implemented, and the profit allocation will base on the optimal CS. Rahwan and Jennings (2008) developed an improved dynamic programming algorithm to find an optimal CS.

When the pooling game has a non-empty CS core, the CS CPWV can be applied to propose a stable allocation. When the CS core is empty, some other allocation rules, *e.g.*, CS SV and CS nucleolus, can be referred to as a base of further bargaining.

In reality, usually the full cooperation assumption cannot be fulfilled. Players try to maximize their own profit, rather than global performance. It is in this situation the CS stability will be investigated.

Firstly, we consider a supply chains pooling game with a non-empty CS core. From the myopic point of view, CS core is a credible stability judgment. It is the set of all imputations that no player can benefit by deviation. Aumann and Dreze (1974) showed that a necessary condition for non-emptiness of the CS core is that the CS formed is the optimal CS. Since the CS CPWV contains in its definition the CS-core stability, we can conclude that, for a game with non-empty CS core, the CS CPWV is a stable allocation rule. We can also confirm the farsighted stability of CS core elements by EPCF approaches. A PCF is *deterministic* if $p(CS_i, CS_j) \in \{0, 1\}, \forall CS_i, CS_j \in \overline{CS}$. Let x_i^{CS} denote i's payoff in CS, a *strong core state* is a CS such that there is no coalition S with $x_i^S \geq x_i^{CS}, \forall i \in S$ and for at least one player, $x_i^S > x_i^{CS}$. Konishi and Ray (2003) prove that, if CS^* is a strong core state of a characteristic function, then with discounter factors big enough, there exist a deterministic EPCF with CS^* as its unique absorbing state. Assume that there is a CS core element x^{CS} that is not a strong core state. This induces that there is a S such that $x_i'^S \geq x_i^{CS}, \forall i \in S \, and \, x_{i^*}'^S > x_{i^*}^{CS}$. $\sum_{i \in S} x_i'^S > \sum_{i \in S} x_i^{CS}$ follows, which induces $v(S) > \sum_{i \in S} x_i^{CS}$, which is contradictory to CS core element property. So CS CPWV, as CS core element, is also farsighted stable.

Secondly, we consider a pooling game with empty CS core. In that case, fix a specific allocation rule agreed by all players, the related EPCF could support non-core element as stable state. But to find this EPCF, specific algorithm for computing fixed point in this model should be developed. Another solution is also to use the optimal CS and arbitrary allocation rule, *e.g.*, CS SV, as the base of further bargaining.

7 Horizontal logistics cooperation: case study

7.1 Presentation of the supply chains pooling game

The case study in this work is conducted with real flows data provided by *Club Déméter* (the association of major logistics players in France, www.club-demeter.fr). This support enables us to conduct studies on the basis of a real database of French retail supply chains.

From the database provided by partners, we chose four neighboring suppliers who delivery to the distribution centers of a common retailer. Since the supply chains pooling is the cooperation among suppliers and retailer, so we can easily imagine that the supplier in this case will claim part of the profit obtained by pooling. Therefore, the grand coalition N should be defined as $N = s_1, s_2, s_3, s_4, r$, where s_1, s_2, s_3, s_4 are four suppliers and r is the retailer in this case study. The related flows of these 5 players, as listed in table 1, are determined from weekly records over a 33 - week horizon. The flows can be seen as the

Table 1: Flow of 4 suppliers and 1 retailer

Suppliers	Flow (Pallet)	Total flow (r)
1	77	909
2	714	
3	55	
4	63	

measure of their scales of operation and the pooling opportunity they provided, thus we use the related flows as the weights in the pooling game. We define the coalitions that contain at least 2 suppliers and 1 retailer the *valid coalition*, since only in such coalition the cooperation relationship lies. All non-valid coalitions can be regarded as singleton status. The characteristic function v is defined as $v(S) = B(S) - M(S) - CC(S)$, where $B(S)$ is the transportation cost of coalition S before pooling, $M(S)$ is transportation cost after pooling and $CC(S)$ is the cooperation cost of coalition S.

7.2 Case study

At first, we investigate a limited-cooperation pooling game, where $CC(S) = 0$ for all coalitions. The coalition profits of all valid coalitions, optimal coalition and the CPWV allocation (when $w = \{77, 714, 55, 63, 909\}$) is listed in the table 2. Four suppliers and the retailers are denoted by 1, 2, 3, 4 and r in this table. The CPWV allocates global profits to players according to their contributions and bargaining weights, while in the same time satisfies the core stability. Therefore it is a reasonable suggestion for further

Table 2: The limited-cooperation pooling game solution

Valid coalition	{1,2,r}	{1,3,r}	{1,4,r}	{2,3,r}	{2,4,r}	{3,4,r}
Profit	530	0	0	3929	1854	994
Valid coalition	{1,2,3,r}	{1,2,4,r}	{1,3,4,r}	{2,3,4,r}	{1,2,3,4,r}	Stable coalition
Profit	4459	2384	994	5783	6313	{1,2,3,4,r}
Player	1	2	3	4	r	Sum of allocation
CPWV allocation	25	2425	140	81	3642	6313

bargaining.

Secondly, we present how does cooperation cost make a difference in the long-term pooling game based on the limited-cooperation pooling game investigated. We define the cooperation cost as a linear function $CC(S)$ of the *valid-coalition* scale $|S|$:

$$CC(S) = \begin{cases} 0, & \text{if } |S| \leq 2 \, or \, r \notin S \\ cc \cdot |S|. & \text{if } |S| \geq 3 \, and \, r \in S \end{cases} \quad (6)$$

This cost function represents the investment required for all participants. In the equation 6, cc is a constant representing the linear cost rate. When $cc = 0$ €, it is the same as the limited-cooperation pooling game. As cc increases, coalitions' profits decrease. When cc exceeds someone's marginal contribution to the grand coalition, it will be out of the grand coalition, keeping singleton or form another coalition with others, where their marginal contribution to this coalition can support the cooperation cost. And at the end, when cc increases to a level that makes none of the players in the cooperation group feel it's profitable to cooperate, the optimal CS will be singletons. In this 4-supplyer-and-single-retailer game, when $cc > 530$ €, the grand coalition is no more stable, and when $cc > 1446$ €, players tend to singletons. We present the CS profits, optimal CS and the CPWV allocation (based on the same weight vector) when $cc = 600$ €in table 3. The allocation computed

Table 3: Long-term pooling game solution

CS	{1,2,3,4,r}	1,{2,3,4,r}	2,{1,3,4,r}	3,{1,2,4,r}	Optimal CS
Profit	3313	3383	-1406	-16	
CS	4,{1,2,3,r}	1,2,{3,4,r}	1,3,{2,4,r}	1,4,{2,3,r}	
Profit	2059	-806	54	2129	
CS	2,3,{1,4,r}	2,4,{1,3,r}	3,4,{1,2,r}	1,2,3,4,r	1,{2,3,4,r}
Profit	-1800	-1800	-1270	0	
Player	2	3	4	r	Sum of allocation
CPWV allocation	1468	64	16	1835	3383

is CS core stable.

Note that, in this case study, we have adopted arbitrarily the weight vector and the cooperation cost function. It is just for giving an example, to show how this cooperation model works. By adopting other weight vectors and other cooperation cost functions, results that may fit better the reality can be found, but the essential will always be the same.

8 Conclusion

In this paper, we proposed a practical cooperation decision making model, which can be implemented step by step for horizontal logistics cooperation. This model is constructed by following components: a decision process as the outline, optimization model as cooperation potential evaluation tool, game-theoretic approaches as gain sharing mechanism, and management details as coordinator of all above components.

A practical weighted allocation scheme, the *contribution-and-power weighted value*, is proposed and generalized in game with CS. We investigated the related coalition (CS) stability under different cooperation patterns. By a case study of French retail supply network, we justified its fairness and stability.

The proposed decision process highlights the complexity of this process and proposes solutions to identify possibly-overcome obstacles to cooperation partners. This methodology gives guide lines to coordinator and let also margin for bargaining. The game theory is used as a framework to help partners to reach an agreement.

The main drawback of this cooperation model is the lack of flexibility. The requirement of mid-term commitment may make players hesitate to cooperate. And in examining pooling game with cooperation cost, when the CS core is empty, some other allocation rules and farsighted stability concepts will be needed for providing reasonable suggestions for further bargaining.

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