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Profit allocation problems for fourth party logistics supply chain coalition based on game theory approach

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Abstract

Aim/purpose – The paper analyses how game theory can be exploited to provide the implementation of profit allocations among the members of the fourth party logistics supply chain coalition system.
Design/methodology/approach – The study compares four allocation rules from cooperative game theory in order to explore fair and reasonable sharing of revenue among the partners in the venture.
Findings – As a result, more practical situations can be modelled and more supply chain efficiency can be obtained throughout the several steps carried out by decision makers. Our computational analysis establishes that the proposed methods are computationally efficient and can be implemented to solve real-life problems.
Research implications/limitations – Our business process simulation of the 4PL supply chain coalition including a simulation of the profit allocation concept allowed us to develop a broad understanding of the management process of the 4PL supply chain coalition approach.
Originality/value/contribution – A comparison of the different methods based on game theory provided an opportunity for reaching the prefect collaboration. These views enrich our understanding of the 4PL supply chain coalition and help us to implement an innovative development for the sector.

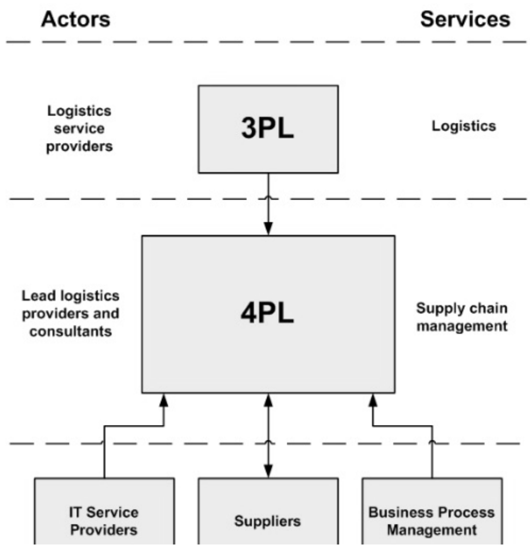
Keywords: logistics collaboration, fourth-party logistics, game theory, profit allocation.
JEL Classification: C71, J51, L91.

1. Introduction

In order to meet the unique and special needs of the market in the global environment, many companies have made the decision to outsource certain business functions, and the main operation to be outsourced is usually logistics (Li, 2007; Li, Su, & Chen, 2011; Li & Warfield, 2011). As a result, nearly 75% of the Fortune 500 firms have used logistics providers, known as third party logistics (3PL) (Trebilcock, 2002). 3PL may be defined as employing an external supplier for transportation, warehousing, distribution, and financial services (Marasco, 2008). But most of the users of 3PL have indicated that they are only provided with a transportation and warehousing service (Büyüközkan, Feyzioğlu, & Ersoy, 2009), on the other hand, companies which provide such services have claimed that they do not have the opportunity to develop new ideas (Rushton, Croucher, & Baker, 2014).

One consequence of this has been the concept of fourth party logistics (4PL) that was put forward by the consulting group Accenture Inc. The functionality of 4PL defines itself as a connection between the client and the multiple logistics provider. 4PL may be considered as a supply chain solution which combines the capability of management consulting, information technology and 3PL service providers (Büyüközkan et al., 2009), as shown in Figure 1.

Figure 1. The fourth party logistics supply chain coalition



Source : Author's own work.

Ever since the idea was conceived, it has gradually been proven that 4PL is an effective mode to integrate the resources of a supply chain (Yao, 2010). As a result, 4PL provides benefits in various areas

1) handling process and cooperation management while taking the dynamics of the networks into account (Nissen & Bothe, 2002);
2) generating a logistical concept of information about services that a single actor cannot provide (Nissen & Bothe, 2002);
3) the 4PL provider maintains primary accountability and quality within the arrangement (Bhatnagar & Viswanathan, 2000);
4) 4PL impact on the entire supply chain by increasing revenue, lowering costs, reducing working capital (Stefansson, 2006);
5) provision of consulting competencies and strategies with regard to outsourcing, business process optimization, and modification of the network actors (Nissen & Bothe, 2002).

On this basis, 4PL has become a dominant development direction of the logistics industry both in practice and in theory (Hertz & Alfredsson, 2003; Marino, 2002). However, to attain the expected benefits from the 4PL applications, there is an important problem that should be settled in the fourth party logistics supply chain coalition which is: How to reasonably and practically allocate the profits among every enterprise to ensure the establishment of a coalition? That is an underlying research question. Precisely before companies agree to participate in a horizontal cooperation scheme a profit allocation method must be available. This type of problem arises in many real world scenarios (Cruijssen, Cools, & Dullaert, 2007; Frisk, Göthe-Lundgren, Jörnsten, & Rönnqvist, 2010). This issue is the main goal of this paper.

In order to solve this operational issue, the purposes of this paper is to analyse how game theory can be exploited to provide the implementation of profit allocations among the members of the fourth party logistics supply chain coalition system. The aim of the research is to compare four allocation rules from cooperative game theory in order to explore fair and reasonable sharing of revenue among the partners in the venture. The data are based on Xu (2013) and involve four enterprises (labelled $X_1 - X_4$) in the fourth party logistics supply chain coalition.

This study makes several contributions to the existing knowledge base in the following ways. First, an overview of existing horizontal logistics alliances is presented. Second, a sharing mechanism for the 4PL supply chain coalition is discussed. This sharing mechanism takes into account collaborator contribution and coalition stability. As a result, more practical situations can be modelled and more supply chain efficiency can be obtained throughout the several steps carried out by decision makers. Finally, our computational analysis establishes that the proposed methods are computationally efficient and can be implemented to solve real-life problems. Following these observations, the contribution of the paper is thus the applicability of the allocation mechanism in a 4PL supply chain coalition environment, this requires a change of focus.

The remainder of the paper is organized as follows. A research problem is described in Section 2. In Section 3, the allocation methods are introduced. Then numerical examples are presented in Section 4. In Section 5, a summary and conclusion are presented to discuss the contribution of the paper and suggestions for future research.

2. Literature review

In recent times, a great emphasis in supply chain management has been placed not only on cost efficiency, but also on CO_2 emissions and other emission reductions (Kellner & Otto, 2012; Mehmann & Teuteberg, 2016). To be able to respond to this development, companies collaborate with other companies operating at the same level of the supply chain. This is called horizontal collaboration. In current horizontal logistics collaboration, the evaluation of benefits is mainly conducted using operational research models (e.g. Beaudoin, LeBel, & Frayret, 2006; Clifton, Iyer, Cho, Jiang, Kantarcıoğlu, & Vaidya, 2008; Ergun, Kuyzu, & Sayelsbergh, 2007; Frisk et al., 2010). There have been publications in the literature reporting on horizontal cooperation within specific contexts, such as forest (Frisk et al., 2010) and grocery distribution (Caputo & Mininno, 1996).

There has been an increasing volume of research in applying cooperative game theory to problems related to supply chain profit allocation (Table 1). Krajewska, Kopfer, Laporte, Ropke, & Zaccour (2008) study the profit sharing problem among carriers, the proposed mechanism is based on the Shapley value. Frisk et al. (2010) investigate a cooperation forest transportation planning problem and study classical cost savings allocation solution concepts, namely the Shapley value and the Nucleolus. Sherali & Lunday (2011) use the Shapley value approach to examine the problem of apportioning a railcar fleet to car manufacturers within a pooling agreement for shipping automobiles. These papers in general deal with the problem of profit allocation based on game theory. However, to the best of our knowledge as yet, there is no literature on profit allocation for 4PL that considers a comparison of different cooperative game solution concepts, which is very important for the improvement of supply chain competitiveness. Therefore, a reasonable profit allocation approach for 4PL based on cooperative game theory should be designed.

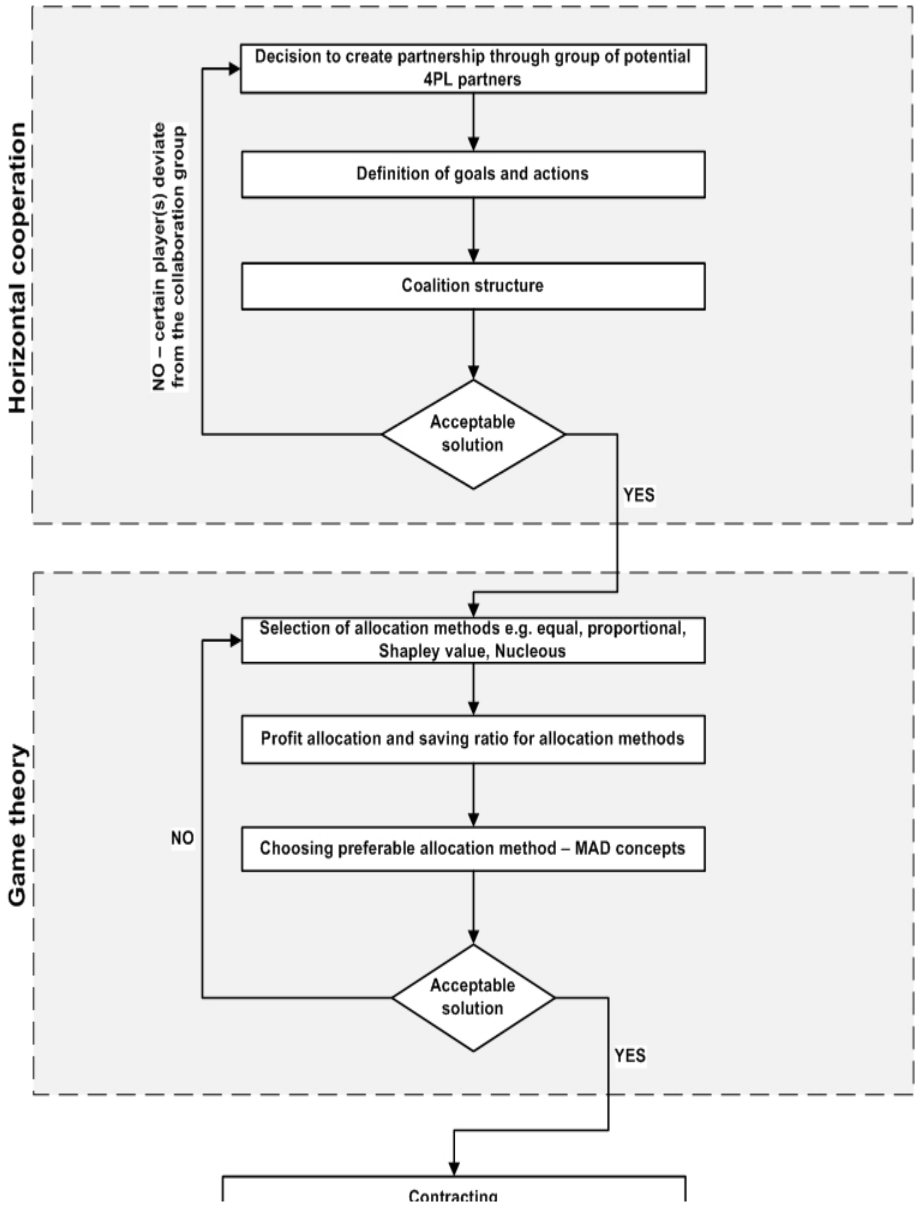
Table 1. Overview of the most important contributions to logistics collaboration

Problem	Solution	References
A cost allocation problem arising from hub-spoke network systems and cooperative game is studied. Numerical experiments are presented with real telecommunication traffic data in order to illustrate the usefulness of the analytical findings	Cooperative game and core allocation	Matsubayashi, Umezawa, Masuda, & Nishino (2005)
The profit margins resulting from horizontal cooperation among freight carriers are analyzed. Numerical results for real-life and virtual scenarios are presented	Shapley value	Krajewska et al. (2008)
A new procedure for Logistics Service Provider (LSP) was introduced. The solution minimizes the LSP's financial risks, while making sure that it offers very competitive tariffs to each potential customer	Operational research and game theoretical insights	Cruijssen, Born, Fleuren, & Hamers (2010)
The article discusses the allocation of the cost of collaborative distribution and sharing the profits among 3PL enterprises	Nash barging solution	Zhuang, Wang, Huang, & Tian (2010)
A carrier collaboration problem in pickup and delivery service becomes apparent. The profit allocation among carriers is addressed under a centralized collaboration framework	Shapley value and proportional allocation concept	Dai & Chen (2012)
An estimation of the cost savings and a cost savings allocation among shippers in a full-truck-load problem	Mathematical programming model and game theory	Lozano, Moreno, Adenso-Díaz, & Algaba (2013)
How to allocate profit rationally and practically among the member enterprises is the problem discussed in the paper	Weighted Shapley value	Xu (2013)
This paper establishes a model to minimize the total cost of the multiple centers joint distribution network when each distribution center is assigned to serve a series of distribution units. The computational results, suggest that the optimal sequential coalition of distribution centers can be achieved according to Strictly Monotonic Path	Shapley value	Wang, Ma, Xu, Wang, Wang, & Liu, (2015)

3. Research methods and procedure

After specifying the domain in which this paper is situated, the description of the problem is presented. The main problems that impede collaboration are a fair way of dividing the profits, this issue is singled out by both academics (Cruijssen et al., 2007) and by practitioners. Thus, the profit allocation mechanisms among the member enterprises have been developed in the paper, more specifically cooperative game theory is presented as the solution to the problem. Moreover, considering the problem of the fourth party logistics supply chain coalition game (Xu, 2013) and the collaboration life cycle (Simatupang & Sridharan, 2002), the general structure of the collaboration-relationship process is proposed. For a better understanding of the process, the different process phases are presented in Figure 2.

Figure 2. Model of the study



Source : Author's own work.

At the start of the process, there is a group of players with a strong incentive to collaborate. The first step of the process is the definition of goals and actions in the coalition. Based on a summary of the first step, the 4PL coalition is ready to start. At this point, in practice, once a near optimal coalition is proposed, some players may still take part in the negotiation through a bargaining process. Consequently, there are two possibilities: an agreement is achieved or bargaining fails and some players resign from the coalition, while the others move back to the beginning of the process. Next, in the second phase, the game theory approach is proposed to find the most preferable allocation methods. As a result of applying the MAD concept, the decision-making process is concluded and the best possible contract is designed. In Section 4 we examine the second phase of the 4PL supply chain coalition approach according to the research methods provided.

This section presents the existing profit (cost) allocation methods from cooperative game theory. The two major problems in cooperative game theory are: coalition formation and profit (cost) distribution gained through cooperation. Every player wants to gain their maximum profit in the coalition, therefore, a satisfactory scheme of allocating profits among the participants becomes very important (Jia & Yokoyama, 2003). In this paper, the concepts of Shapley value (Shapley, 1953), nucleolus (Schmeidler, 1969), and equal and proportional allocations are introduced and the above problem is considered as a cooperative game.

A *cooperative game* with transferable utility (TU game) is a pair N, v where $N = \{1,2, \dots, n\}$ is a player set, and $v: 2^n \rightarrow R$ is a function such that $v(\emptyset) = 0$ is called the *characteristic function* of the game. A subset $S \subset N$ is called a coalition, N is called the *grand coalition*. The number of all subsets of N excluding the null set is equal $2^n - 1$. A game (N, v) is superadditive if

$$v(S) + v(T) \leq v(S \cup T \text{ for all } S \text{ and } T \subset N \text{ such that } S \cap T = \emptyset.$$

In a superadditivity game, it is always beneficial for two disjointed coalitions to cooperate and form a grand coalition. A game (N, v) is *convex* if

$$v(S \cup \{i\}) - v(S) \leq v(T \cup \{i\}) - v(T) \text{ for all } i \in N, S \subset T \subset N \backslash \{i\}.$$

An allocation function is denoted by $x_i(v)$ that is used to assign a payoff x_i to player $i \in N$. The *core* of the game (N, v) is defined

$$Core(N, v) = \{x \in R^n : \sum_{i \in N} x_i = v(N) \; and \; \sum_{i \in N} x_i \geq v(S) \text{ for all } S \subset N\}.$$

A core divides the total payoff of the grand coalition among all the players, and the sum of the payoffs to the players of each coalition S is no less than the payoff of the coalition S. The *equal allocation* rule is introduced first. This gives an equal portion to each player and is defined by the equation

$$\varphi_i(v) = \frac{v(N)}{n}, i = 1,2,\dots,n.$$

Another way of sharing savings is to distribute them in proportion to the initial contributions of each partner. This is expressed as

$$\varphi_i(v) = \frac{C(i)}{\sum_{j\in N} C(j)} v(N).$$

The *Shapley value* (Shapley, 1953) is defined by the formula

$$\varphi_i(v) = \sum_{S\subset N\setminus\{i\}} \frac{|S|!(n-|S|-1)!}{n!} (v(S\cup\{i\}) - v(S)), \text{ for all } i \in S.$$

The last commonly used solutions concept is *Nucleolus*, defined by (Schmeidler, 1969) and is expressed as

$minimize\ \varepsilon$

$$\text{s.t. } \sum_{i\in S} x_i - v(S) \leq \varepsilon, \text{ for every } S \subset N, S \neq \emptyset$$

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

There are other interesting methods, such as the τ −value (Tijs & Driessen,1986) or minimax core (Drechsel & Kimms, 2011). However, these methods want be used in the paper.

4. Research findings and discussion

The numerical example is designed to illustrate the potential of collaboration. It considers a fourth party logistics chain coalition which has two manufactures and two suppliers (labelled $X_1 - X_4$). All of the relevant information is summarized in Table 2, the profit and cost data are based on the existing test instances in Xu (2013).

Note that, the Profit is zero when companies fail to cooperate, and the Synergy increases as the size of the coalition grows. When players are willing to create a grand coalition – the Synergy measure is as high as 29.7% in the case of $\{X_1, X_2, X_3, X_4\}$ coalition. For this reason, by acting together the companies in 4PL can reduce their costs significantly. Moreover, in general, the Synergy value of the coalition depends on the participants partners. For example, in the case of two partners, from the point of view of X_1 company, collaboration with X_3 company is the most profitable (21% Synergy). In addition, the Profit function is monotonic, and superadditive. These two properties mean that it is always profitable for two groups of players to work together. However, it is not convex since we have

$$Profit(\{X_1, X_2, X_3\}) = 2770.60$$
$$< Profit(\{X_1, X_3\}) + Profit(\{X_1, X_2\}) - Profit(\{X_1\})$$
$$= 1{,}768.30 + 1{,}216.70 = 2{,}985$$

Indeed, contrary to the superadditivity property, in many practical logistics issues (as is the case with our example), complexity is too exigent (Lozano et al., 2013). All papers should begin with an introduction.

Table 2. The 4PL cost and synergy for each of possible coalitions

Coalition S	Profit	Cost	Synergy
$\{X_1\}$	0.00	5,603.70	0.00%
$\{X_2\}$	0.00	4,156.90	0.00%
$\{X_3\}$	0.00	4,598.40	0.00%
$\{X_4\}$	0.00	5,406.90	0.00%
$\{X_1, X_2\}$	1,216.70	8,543.90	14.2%
$\{X_1, X_3\}$	1,768.30	8,433.80	21.0%
$\{X_1, X_4\}$	1,174.00	9,836.60	11.9%
$\{X_2, X_3\}$	975.30	7,780.00	12.5%
$\{X_2, X_4\}$	629.70	8,934.10	7.0%
$\{X_3, X_4\}$	1,516.90	8,488.40	17.9%
$\{X_1, X_2, X_3\}$	2,770.60	11,588.40	23.9%
$\{X_1, X_2, X_4\}$	2,772.90	12,394.60	22.4%
$\{X_1, X_3, X_4\}$	3,123.60	12,485.40	25.0%
$\{X_2, X_3, X_4\}$	2,881.10	11,281.10	25.5%
$\{X_1, X_2, X_3, X_4\}$	4,527.50	15,238.40	29.7%

Source: Author's own calculations.

Table 3 and Figure 3 summarize the computations of the proposed allocation methods: equal allocation, proportional allocation, Shapley value and Nucleolus. For each allocation concept, Profit allocation is calculated according to the definitions and formulas discussed in Section 3. From Table 3, proof is proved that each player can earn a greater profit after cooperation than that obtained before cooperation. The cost saving ranges from 21% to 28%. To sum up, we can see that individual X_1 gains the maximum Profit according to Proportional allocation while individual X_3 gains the maximum Saving ratio according to the Shapley value. While, the lowest Profit and Saving ratio are gained according to Nucleolus.

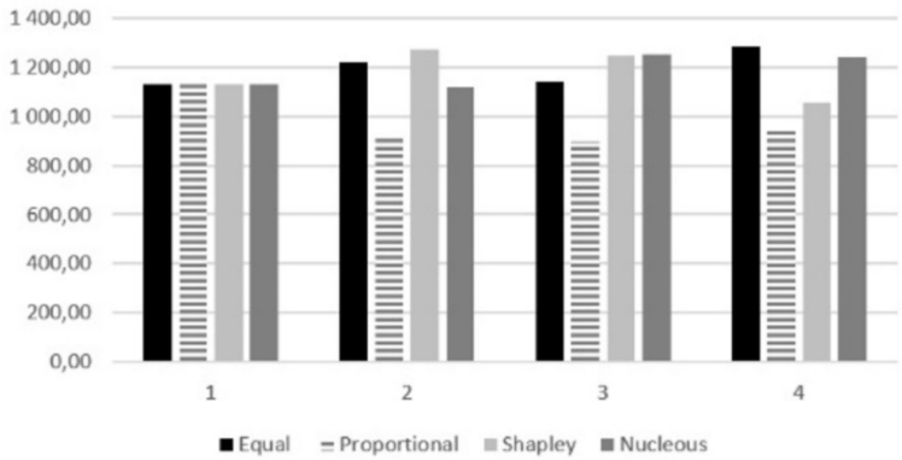
The core is an important set solution for the cooperatives game. Figure 4 shows the core the 4-players coalition as computed by TUGlab (http://www.tuglabweb.co.nr). The core is nonempty which means that a grand coalition will form. Note that, as this illustration shows, only the profit allocated to players $\{X_1, X_2, X_3, X_4\}$ are shown. The gain allocated to X_4 could be calculated from the efficiency condition. Within an allocation in the core of a game, no players can get more without lowering the payoff of another agent.

Table 3. Results for test instances

Enterprises	Equal allocation		Proportional allocation		Shapley value		Nucleolus	
	Profit allocation	Saving ratio	Profit allocation	Saving ratio	Profit allocation	Saving ratio	Profit allocation	Saving ratio
$\{X_1\}$	1,131.9	20%	1,283.6	23%	1,220.3	22%	1,137.8	20%
$\{X_2\}$	1,131.9	27%	952.2	23%	916.6	22%	895.3	22%
$\{X_3\}$	1,131.9	25%	1,053.3	23%	1,273.3	28%	1,246.1	27%
$\{X_4\}$	1,131.9	21%	1,238.5	23%	1,117.4	21%	1,248.3	23%
Sum	4,527.6		4,527.6		4,527.6		4,527.6	

Source: Author's own calculations.

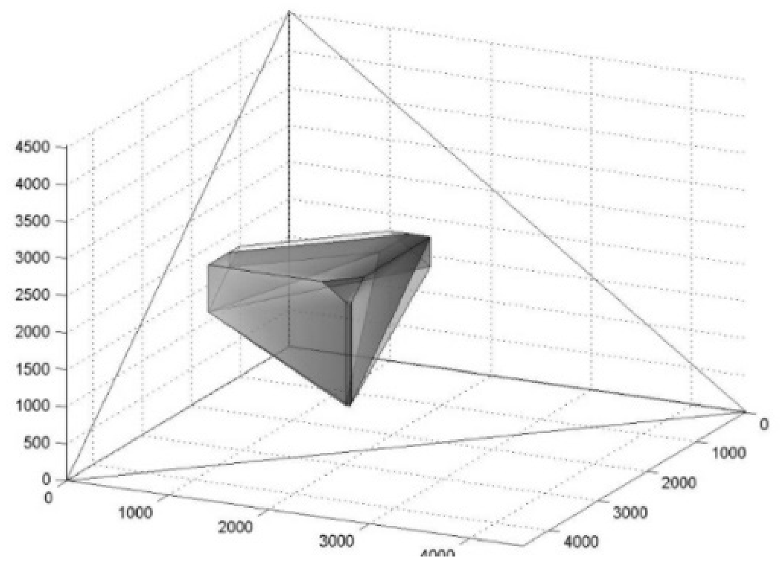
Figure 3. Allocation of cooperation profits for 4-players



Source: Author's own calculations.

Given a cost saving allocation $\bar{x} = (x_1, x_2, \dots, x_n)$ it may be defined as the *satisfaction* $F_S(Cost, x)$ of a coalition S as the excess of the sum of their allocated cost savings shares if the companies create a grand coalition over the total cost savings if coalition S acts independently (Lozano et al., 2013). Table 4 shows the resulting satisfaction value as a percentage of the corresponding coalition cost. It can be seen that as a coalition grows, the satisfaction of the coalitions tends to decrease.

Figure 4. Core for the 4-players coalition



Source: Author's own calculation

Table 4. Coalition satisfaction for equal allocation, proportional allocation, Shapley value, Nucleolus

Coalition S	Equal allocation	Proportional allocation	Shapley value	Nucleolus
$\{X_1\}$	20.2%	22.9%	21.8%	20.3%
$\{X_2\}$	27.2%	22.9%	22.0%	21.5%
$\{X_3\}$	24.6%	22.9%	27.7%	27.1%
$\{X_4\}$	20.9%	22.9%	20.7%	23.1%
$\{X_1, X_2\}$	12.3%	11.9%	10.8%	9.6%
$\{X_1, X_3\}$	5.9%	6.7%	8.6%	7.3%
$\{X_1, X_4\}$	11.1%	13.7%	11.8%	12.3%
$\{X_2, X_3\}$	16.6%	13.2%	15.6%	15.0%
$\{X_2, X_4\}$	18.3%	17.5%	15.7%	16.9%
$\{X_3, X_4\}$	8.8%	9.1%	10.3%	11.5%
$\{X_1, X_2, X_3\}$	5.4%	4.5%	5.5%	4.4%
$\{X_1, X_2, X_4\}$	5.0%	5.7%	3.9%	4.1%
$\{X_1, X_3, X_4\}$	2.2%	3.6%	3.9%	4.1%
$\{X_2, X_3, X_4\}$	4.6%	3.2%	3.8%	4.5%

Source: Author's own calculations

However, there is an agreement in the literature that no single cost allocation method works best in all situations. In order to inform and guide decision makers in the final step, which involves choosing one preferable allocation method, Table 5 summarizes the dissimilarity between the four cost saving allocation methods by using the Mean Absolute Deviation (MAD).

$$MAD(\bar{x}, \overline{x'}) = \frac{|N|}{Profit(N)} \cdot \sum_k |x_k - x'_k|,$$

where $\bar{x}$ and $\overline{x'}$ are any pair of solutions computed for each allocation rule solved. The MAD describes the average distance between allocation values in a distribution and the mean of the distribution. Note that the pair of methods that give the more distance solution are the Shapley value and proportional while equal and proportional allocation are those that are closest.

Table 5. Similarity between solution concepts, measured by MAD

	Equal allocation	Proportional allocation	Shapley value	Nucleous
Equal allocation	–	2.2	2.5	2.4
Proportional allocation	–	–	2.6	2.8
Shapley value	–	–	–	4.3
Nucleous	–	–	–	–

Source: Author's own calculations.

5. Conclusions

In this paper, a model to solve the cost allocation problem of fourth party coalitions is studied. Four types of allocation rules from cooperative game theory, namely equal and proportional allocation, Shapley value and Nucleolus, are analyzed and compared. Thus, the computational results indicate that it is appropriate to represent and solve real case instances in order to evaluate the performance of practical 4PL collaboration mechanisms.

In this study, it is proposed that the procedure for profit allocation among the member enterprises is rational, practical and easy to implement. First, the profits and costs for all subcoalitions are presented. All companies in the chain are willing to cooperate since this results in reduced costs and consequently, in increased profits. Then, four potential solutions are proposed. Our business process simulation of the 4PL supply chain coalition including a simulation of the profit allocation concept based on data from Xu (2013) allowed us to develop a broad understanding of the management process of the 4PL supply chain coalition approach. The major contribution of this paper was to provide a profit allocation scheme for the 4PL supply chain coalition that indicates how to distribute the savings achieved through the application of a 4PL profit sharing scheme among involved firms. Additionally and lastly, a comparison of the different methods based on game theory provided an opportunity for reaching the prefect collaboration. These views enrich our understanding of the 4PL supply chain coalition and help us to implement an innovative development for the sector. To the best of our knowledge, no previous work has investigated such a problem. Hence, there are a number of topics for further research.

As our present model deals with only four partners, future extensions could include using more than n-companies, where $n \geq 4$. This would be a complex task as a large number of subcoalitions $(2^n - 1)$ are possible. Another interesting extension to this base model might be an analysis of the weight of the importance of each firm by the analytic hierarchy process. A common situation between retailers and suppliers is that some of them have different negotiating positions according to their size, their know-how or market position. Therefore this factor should be considered during 4PL modelling and solving management process. In the end, real-world cases could be provided, which would enrich the business processes simulation. These issues will be studied in our future research.

In addition to the results, limitations have also been revealed which may indicate the need for further research in this field. In the paper the core was not empty. This implies that some additional property should be considered. Another limitation with regard to the experiment is that there still not have real enterprises be set yet as a result of Fourth Part Logistics Coalition. In a future study, we should give also more attention to the implementation of a graphical tool in order to design the cooperation based on profit allocation problem.

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