Generic Mechanisms for Coordinating Operations and Sharing Financial Benefits in Collaborative Logistics

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Abstract. Collaborative logistics is increasingly emerging as a new opportunity for cost reduction through internal and cross chains coordination. This paper presents different coordination mechanisms to support collaborative logistics. These mechanisms are differentiated by their planning function, their sharing approach and the information, decision and financial flows. Often, the logistics planning is run first, and secondly, the sharing is set on the basis of the plan. However, recently, new approaches have been proposed where both the logistics plan and the sharing are optimized simultaneously. Constraints on the financial flows also introduce specificities to the coordination mechanisms and these are described and discussed. Finally, the proposed coordination mechanisms are used to describe a series of research and applied projects in which collaborative logistics has been implemented.

Keywords: Coordination mechanism, Collaborative planning in logistics and transportation, Benefit sharing approach, Game Theory, Operations Research.

1 Introduction

In this paper, we propose five generic coordination mechanisms for logistics activities in a coalition. These mechanisms aim to help managers design their collaboration schemes. They define generic approaches to support how the collaborating units can share information, plan their activities jointly or sequentially, and share the financial benefit of the collaboration.

Logistics activities provide many opportunities for collaboration between companies. This collaboration aims to reduce the cost of executing the logistics activities, improve service, enhance capacities as well as protect the environment and mitigate climate change (Simchi-Levi et al., 1999). Collaboration occurs when two or more autonomous and self-interested *business units* form a *coalition* and exchange or share resources (including information) with the goal of making decisions or undertaking activities that will generate benefits that they cannot (or only partially) generate individually. Collaboration can occur among business units belonging to the same supply chain (i.e. vertical collaboration) or to different ones (horizontal collaboration), in competition or not. Information exchange to reduce the bullwhip effect is a typical example of vertical collaboration between business units located at different echelons in the same supply chain, while group purchasing organizations are a typical example of horizontal collaboration among buyers belonging to different business units. The level of collaboration can range from information exchange, joint planning, joint execution, to strategic alliance (e.g. co-evolution) (Frayret et al., 2003).

Frayret et al. (2004) propose a classification scheme of the various coordination mechanisms of manufacturing activities in a distributed manufacturing system. One class of coordination mechanism, designated as 'coordination by plan' (from March and Simon, 1958), involves the establishment of predefined plans to coordinate a priori interdependent activities under the responsibility of autonomous and self-interested business units.

This class is subdivided into three subclasses of mechanism: (i) 'direct supervision with plan', (ii) 'mediation with plan' and (iii) 'joint plan establishment'. The first two subclasses use a third party to perform the coordination. In subclass (i), the third party performs a centralized planning of all business units' activities and each business unit must follow the centralized plan. In subclass (ii), each business unit performs a first planning of their own activities and then the third party performs an integration of these individual plans into one coherent-centralized plan that each business unit must follow. Such integration involves modifications to the individual plans that are possible through the mediation between the third party and each business unit. In subclass (ii), the third party acts as a support (i.e. non-coercive) for the coordination rather than a supervisor (i.e. coercive) as in subclass (i). In the third subclass (iii), with mutual adjustments between them, the business units perform joint planning of their activities to agree on a centralized plan that each company will follow.

By addressing financial issues within these mechanisms, we can tailor some of them to coordinate interdependent (vertical collaboration) or similar (horizontal collaboration) logistics activities on which a coalition of business units aim to collaborate. These financial issues include a number of questions such as:

(a) How should the potential financial benefit of the coordination of the logistics activities among a set of collaborating business units be computed?

(b) How should the potential financial benefit be shared among the collaborating business units?

We address both questions (a) and (b) in the following Sections 2 and 3, respectively. The latter also describes the five generic coordination mechanisms proposed in this paper.

2 How to compute the potential benefit of the coordination

In several case studies involving collaboration in logistics, question (a) is addressed with optimization problems, and Operations Research (OR) methods are used to solve them, see e.g. Cruijssen et al. (2005), Forsberg et al. (2005), Palander and Väätäinen (2005), le Blanc et al. (2007), Cruijssen et al. (2007), Ergun et al (2007), Krajewska et al. (2007), Agarwal and Ergun (2008a,b), Lehoux et al. (2008), Özener and Ergun

(2008), Lehoux et al. (2009), Marier et al. (2009) and Frisk et al. (2010). The solution of one optimization problem corresponds to the predefined plan on which is based the coordination mechanisms within the class ‘coordination by plan’. The financial benefit for an optimization problem with a minimization objective generally refers to a savings, whereas with a maximization objective, the benefit refers to a profit. In logistics, most optimization problems have a minimization objective. Thus for the potential financial benefit of the collaboration, we will refer to a savings except when we mention it as a profit. In many of the previously mentioned case studies, the savings are defined according to hypothesis 1: the savings are the difference between the sum of the cost of each stand-alone solution (i.e. logistics activities planning of each business unit alone) and the cost of the common solution (i.e. logistics activities planning of all business units together).

In the literature, there exist many optimization problems and OR methods for the planning of the logistics activities for one business unit (i.e. stand-alone solution). Modifications to such problems and OR methods could be required in a context of collaboration in which the planning of the logistics activities is for several autonomous and self-interested business units (i.e. common solution). For example, Forsberg et al. (2005) report, in their case study of raw material exchange between two companies, some additional constraints to their allocation model according to a different exchange scenario (e.g. a limit on the total volume that could be exchanged between the companies). By adding constraints to the common optimization problem, such modifications usually reduce the potential savings of the collaboration. In a case study of raw material exchange on a monthly basis between three companies, Lehoux et al. (2009) report that each company must remain the main supplier (specified minimum percentage, for example, 50%) for its own mills and raw material exchange must be pair-wise equal (i.e. a company must supply each collaborator with the equivalent volume received from this collaborator). These two modifications (or constraints in the optimization problem) decrease by 1-2% the potential savings of each month, which are in the range of 5-20%. Moreover, as we will explain in subsections 3.3 and 3.4, such modifications could also be directly linked to question (b).

Modifications to the individual optimization problem of some companies can also be required. With the previously mentioned hypothesis 1, the solution value of the individual optimization problem of one specific company represents its expected stand-alone cost. Consequently, to obtain a realistic value, the individual optimization problem should be representative of the stand-alone logistics or transportation approach of each company. For instance, if a low volume shipping company A uses only less-than-truckload (LTL) carriers, while a high volume shipping company B uses only full-truckload (FT) carriers, the individual optimization problem of each company must be adapted to fit such different cost functions. Otherwise, if in the individual optimization problem of both companies, allow the use of LTL carriers only, the stand-alone cost of company B will be overestimated since with high shipping volume, the use of FT carriers is cheaper than the use of LTL carriers.

3 How to share the potential benefit of the coordination

When question (b) is addressed in the previously mentioned case studies involving collaboration in logistics, different sharing approaches are employed. Furthermore, they can be grouped into five generic coordination mechanisms (CM), as illustrated in Figure 1. In other words, these five generic coordination mechanisms result of a categorization exercise based on several sharing approaches discussed in the literature and used in various cases studies involving collaborative logistics. Each mechanism includes at least two collaborating business units (only two business units are illustrated to keep Figure 1 simple) having logistics activities (e.g. transportation) to be coordinated by a plan and their own resources (e.g. carriers) available to achieve the plan. Even though collaborating business units may share different resources such as warehouses, this possibility is not illustrated to keep Figure 1 simple. Also, designated as a 'Planning function', the latter represents the step in the mechanism where the predefined plan is established according to the sharing approach of the generic mechanism. Such a planning function could be performed by a third party (as in the previously mentioned subclasses (i) and (ii)) or with a joint planning process between the collaborating units (as in subclass (iii)). Finally, the information, decision and financial flows in each mechanism are illustrated (the flows numbering respects the chronological sequence of the mechanism). The following subsections describe each proposed coordination mechanism.

3.1 Coordination mechanism 1 (CM 1)

In this mechanism, the planning function solves the optimization problem in order to achieve maximum savings and then, the benefit sharing is addressed with a financial flow between the business units. Such a financial flow is based on a predefined incentive rule such as pricing agreements or quantity discount. A detailed review of these incentives can be found in Cachon (2003). Lehoux et al. (2009) present a case study using coordination mechanism 1. The case study involves bilateral collaboration between a paper producer and a wholesaler. To establish the collaborative approach providing the greatest savings for the coalition as well as for both companies, the paper producer must share part of its transportation savings (i.e. incentive rule) with the wholesaler.

3.2 Coordination mechanism 2 (CM 2)

In this mechanism, the planning function solves the optimization problem in order to achieve maximum savings and then, the benefit sharing is addressed with a sharing principle based on an economic model (i.e. cost allocation method) such as the Shapley value, the nucleolus and the separable and non-separable costs. Such economic models, generally based on cooperative game theory, effect an allocation of the total cost of the common-solution among the companies. These fractions paid by each company are then used to pay each resource. A survey on these models can be found in Tijs and Driessen (1986) and in Young (1985, 1994). Case studies using coordination mechanism 2 include e.g. Frisk et al. (2010) and Audy et al. (2009) for collaboration in transportation activities.

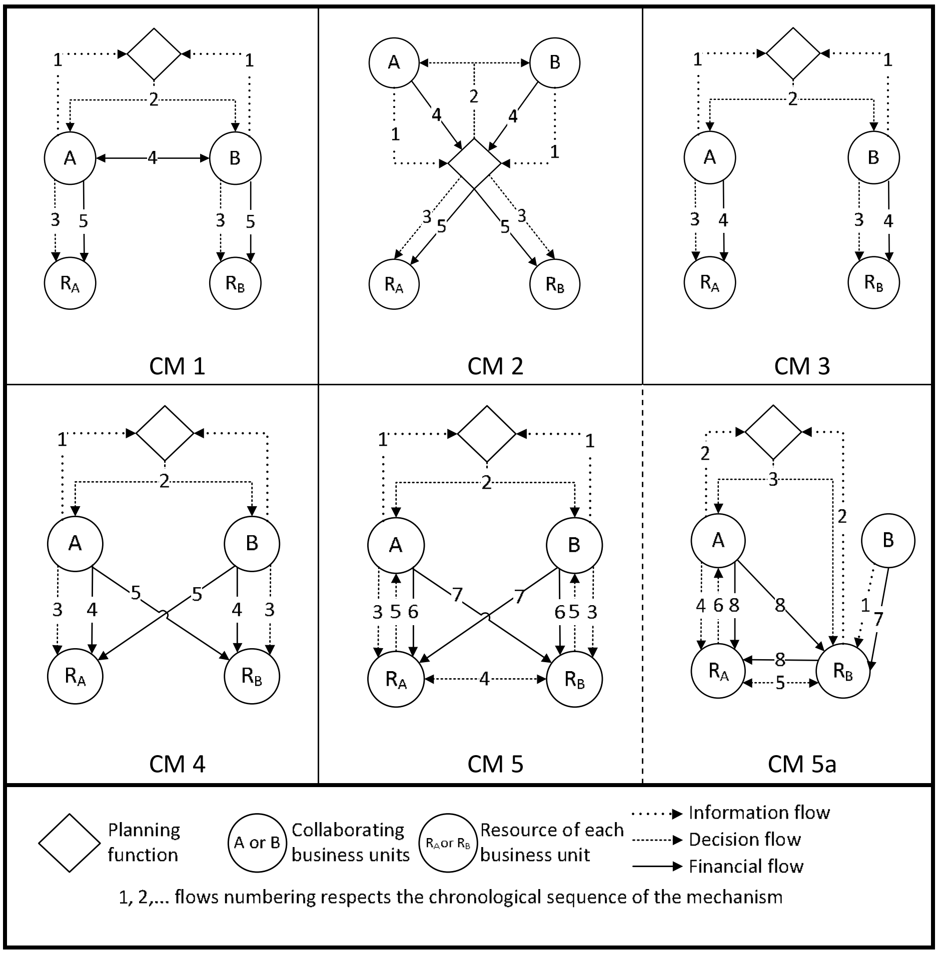

Fig. 1. Generic coordination mechanisms for the logistics activities

3.3 Coordination mechanism 3 (CM 3)

In this mechanism, the planning function solves the optimization problem in order to achieve maximum savings, with respect to an additional constraint related to the benefit sharing. The optimization problem decides that certain activities belonging to a business unit are accomplished by its own resource and others are accomplished by the resource of the second business unit. Such decisions lead to the generation of two plans, one for each company. Since there is no financial flow between the business units or between the business unit and the resource belonging to the other business unit, the cost of the plan of each business unit must be, at the least, less than the cost of their stand-alone plan. Such a condition (or a more restrictive one) related to benefit sharing could be expressed by a constraint in the optimization problem.

In their case study involving three companies performing raw material pair-wise exchange, Lehoux et al. (2009) report the use of this mechanism. These companies previously agree with the sharing principle behind the Equal Profit Method (from Frisk et al., 2010), an economic model that aims to find a stable allocation such that the maximum difference in relative savings between all pairs of two collaborating companies is minimized. Thus, to come up with three plans resulting in a benefit sharing that the companies could agree on, a new constraint has been added to the optimization problem. The new constraint states that each pair of companies must have the same relative savings.

3.4 Coordination mechanism 4 (CM 4)

In this mechanism, the planning function simultaneously addresses the resolution of the optimization problem and the benefit sharing. For each activity, the optimization problem fixes a cost to be paid for its completion by a specific resource. The fixing of the cost takes into account the cost incurred by the resource to realize the activity and the revenue associated to the activity. For all their activities, each company pays this cost to their resource or to that of the other company, according to which resource has been chosen in the plan. Thus, the benefit sharing is addressed with the financial flow between each company and the resource of the other company. In Agarwal and Ergun (2008a), coordination mechanism 4 is used by sea container carriers sharing the loading capacity of their ships to deliver their respective customers' shipments. Other collaborative logistics case studies or examples using coordination mechanism 4 include e.g. Agarwal and Ergun (2008b) and Agarwal et al. (2009).

3.5 Coordination mechanism 5 (CM 5)

In this mechanism, the planning function partially solves the optimization problem (or a relaxation (i.e. more simplified version) of the optimization problem) and provides its partial plan to each business unit. Firstly, each business unit assigns its activities to its own resource, but also provides the partial plan. Such a partial plan includes a list of potential collaboration opportunities, if any, for each activity. That means that such opportunities may appear within the activities assigned to one resource, but also between activities assigned to different resources. Given these latter potential collaboration opportunities, it is then up to the two resources to decide together to collaborate or not, and if they collaborate, to decide together which resource will carry out the activities (i.e. flow 4). Since the resources are paid only for each activity they accomplish (i.e. flows 6 and 7), the decisions they made in flow 4 fix the benefit sharing.

Mechanism 5 is based on a generalization of the mechanism used in the case study in Eriksson and Rönnqvist (2003), which is illustrated in CM 5a. In this case study, the potential collaboration opportunities are back-hauling tours existing among the transportation activities of two forest companies. Moreover, this collaboration is realized through the carrier (i.e. the resource) of the second company (i.e. business unit).

4 Conclusion

This paper proposes five generic coordination mechanisms for logistics activities in a coalition. These mechanisms are differentiated by their planning function, their sharing approach and the information, decision and financial flows. Some mechanisms perform their logistics planning first and then their sharing on the basis of the complete (mechanisms 1 and 2) or the partial (mechanism 5) plan while others perform both simultaneously (mechanisms 3 and 4). Proposed recently in the literature, these latter mechanisms guarantee that a logistics plan satisfying the sharing conditions of the coalition will be obtained.

To our knowledge this is the first attempt to characterize generic coordination mechanism building on the integration of the planning function, the information sharing as well as financial benefit sharing.

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