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Agent-based simulation for horizontal cooperation in logistics and transportation: From the individual to the grand coalition

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ABSTRACT

Horizontal Cooperation is emerging as a way to increase competitiveness in logistics and transportation. Its implementation, however, may be hindered by conflicts and opportunist behavior among the members of the coalition. This paper develops an agent-based simulation model studying the evolution of a coalition over time taking into account various trust-related issues. Different degrees of cooperation, rules for enlarging the coalition with new members as well as a Shapley-based methodology for allocating savings are implemented. To calculate such savings, vehicle routing solution procedures are further integrated. This enables an extensive investigation of the effects of Horizontal Cooperation from both an economic and environmental perspective. Experimental results highlight that significant savings can be achieved with the degree of cooperation and trust-related issues indicating the highest importance.

1. Introduction

Cooperative strategies are inspiring new business models towards efficiency and sustainability. Interfirm agreements allow companies to access valuable information and technology or take advantage of economies of scale, whilst, at the same time, maintaining an independent legal personality. Such business agreements normally arise as a way to seek for efficiency by reducing cost [14], even though other objectives can be achieved such as carbon reduction [32], new product developments [50] or advances in research and development [39]. Involved companies may be related, either inside a supply chain (i.e., vertical cooperation), along the same level of the supply chain (i.e., horizontal cooperation - HC) or not. Vertical cooperation is well documented and it is highly related to supply chain management (SCM) [41].

Literature on HC, in contrast, is not as plentiful as literature on vertical cooperation, particularly within the field of logistics and transportation (L&T). Definitions of HC are provided in Bahinipati and Deshmukh [3], Cruijssen et al. [8], EC [10], Lambert et al. [23]. These can be summarized as any agreement, tacit or not, which involves more than one company without vertical relationship between them, i.e., no supplier-customer relationship, based on trust and mutual commitment to identify and exploit win-win situations with the goal of sharing benefits (or risks) that would be higher (or lower) than each company would obtain if they acted completely independently [36]. Within L&T, reducing transportation costs is both the most pursued and investigated goal in HC [14]. Nevertheless, many other benefits may be achieved as a result of an

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Table 1
Selected papers employing HC and its impacts on costs and CO_2 emissions.

Organizational level	Reference	Cost	CO_2
Operational	Sprenger and Mönch [43]	−25%	–
	Lin and Ng [27]	–	−20%
	Li [25]	−28%	–
	Pradenas et al. [34]	−30%	−30%
	Juan et al. [20]	−16%	−26%
Tactical	Soysal et al. [42]	−17%	−29%
	Muñoz-Villamizar et al. [30]	−25%	−25%
	Danloup et al. [9]	–	−26%
Strategic	Verdonck et al. [45]	−22%	–
	Vornhusen et al. [46]	−18%	–

integrated approach such as improving service quality [15,36], reducing environmental impact [e.g., 27,34], reducing risk [44] and protecting/enhancing market share [16].

Table 1 shows selected papers addressing HC that quantifies its impacts on either costs or CO2 emissions. Moreover, the organizational level in which cooperation takes place is identified. In this regard, operational cooperation is based on sharing vehicle capacities in order to improve load factors. That is the case of the works presented by Lin and Ng [27], Pradenas et al. [34], and Juan et al. [20] who presented a vehicle routing problem with backhauling as cooperative mechanism. On the other hand, in Li [25], cooperation is modeled as a multi-depot pickup and delivery problem, and Sprenger and Mönch [43] described a real experience in the German food industry with shared vehicles. Tactical cooperation further involves conjoint routes as described in Danloup et al. [9]. Muñoz-Villamizar et al. [30] focused on the last mile distribution with uncertainty and Soysal et al. [42] studied an inventory routing problem with multiple distribution centers. Finally, the strategic level mainly consists of sharing consolidation centers for the long run as proposed by Verdonck et al. [45] and Vornhusen et al. [46] in which a pickup and delivery problem is considered and a customer request exchange mechanism is implemented. A deeper analysis of the aforementioned works can be found in Serrano-Hernandez et al. [37].

A common characteristic of these works is their static perspective. They usually compare the setting in which companies operate independently with that of cooperating companies. Consequently, the development of a coalition over time as well as the evolution of the relational behavior has not been explicitly considered. Different degrees of cooperation have not been investigated and the dynamic allocation of benefits among members have been commonly ignored.

The successful implementation and operation of HC strategies over time, however, is complex. Due to their complex nature, HC practices offer a high potential for conflicts, i.e., situations where two or more parties are in disagreement [35,47]. To realize the benefits that HC provides, proper management of the coalition is required to avoid lack of coordination and opportunist behavior. Raue and Wieland [35] offer a survey on governance mechanisms to deal with cooperative and competitive relationships, identifying the most frequently used governance mechanisms: (i) operational governance through relational and formal rules as well as policies in order to work on a daily basis focus on enhancing trust and social identification; and (ii) contractual governance where legal parameters of the cooperation are fixed. In this regard, Adenso-Díaz et al. [1] concluded that the main factor affecting the cost synergy depends on the contractual conditions among companies. Difficulty to find a suitable partner is another common issue when dealing with HC [24]. On the one hand, profound knowledge of potential partners' assets (tangible and intangible) is required to evaluate the candidates; whilst, on the other hand, companies' interests must be met. Moreover, legal barriers are also determinants for HC. According to the European Union Antitrust Act [12], agreements and business practices which restrict competition (Article 101) are generally forbidden. However, many exemptions can be applied within the transportation sector such technical agreements and activities of small companies [11]. Additionally, the distribution of costs and profits among partners as well as trust levels between cooperating firms are other common points of conflict. Concerning the allocation of profits and costs, Guajardo and Rönnqvist [18] provided a survey on allocation methodologies. The authors provide more than 40 methodologies to share costs and profits inside a coalition, resulting in a huge variety of arbitrary ways to divide gains and losses. Of these, Shapley value is the most recurrent methodology as it holds desirable properties such as efficiency, symmetry, and the dummy axiom [38].

Consequently, while recent L&T literature has paid much attention to cooperation benefits, the conflicting nature of HC has been mostly omitted or treated from a theoretical viewpoint. In contrast, this paper contributes to the scientific literature by investigating the effects of trust-related issues when running a coalition over an extended time period. Starting from a base setting in which companies operate independently, a behaviorally driven logic is modeled and implemented within an agent-based simulation framework. Leadership, negotiation processes, coalition forming and evolution in both members and degree of integration are further considered to enable a complete view on HC agreements.

2. Methodology

This section details the methodology employed in this research. It consists of describing model assumptions and notation, the general framework and a detailed description of model components.