To link to this article : DOI : 10.1080/16258312.2014.11517359
URL : http://dx.doi.org/10.1080/16258312.2014.11517359

To cite this version : Battaia, Guillaume and Faure, Lucile and Marques, Guillaume and Guillaume, Romain and Montoya-Torres, Jairo Rafael *A Methodology to Anticipate the Activity Level of Collaborative Networks: The Case of Urban Consolidation Centers.* (2015) Supply Chain Forum: An International Journal, vol. 14 (n° 4). pp. 70-82. ISSN 1625-8312

A Methodology to Anticipate the Activity Level of Collaborative Networks: The Case of Urban Consolidation Centers

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Abstract—**This article presents a methodology relative to the assessment of a particular measure in city logistics: Urban Consolidation Centers (UCCs). We identify that this kind of collaborative network is, often, poorly evaluated and thus operates in a way that is neither sustainable nor efficient. By mobilizing several fields of knowledge, such as operational research, game theory, and transportation studies on real cases, we propose a solution to anticipate the activity level of a UCC and determine the condition under which it generates benefits for carriers. The aim is to provide a suitable aid to public decision makers in territorial management. The study concludes by an application of the method on the test case of the city of Saint-Etienne, France.**

Keywords: sustainable collaborative network, urban consolidation center, games theory, city logistics

City logistics is the last link of complex supply chains and involves numerous stakeholders: carriers, shopkeepers, e-customers, inhabitants, public administration, and so on. It is only a small part of the total traveled distance, nevertheless, it can represent up to 28% of the total transport cost (Roca-Riu & Estrada, 2012). Moreover, it has been estimated that urban freight transport is responsible for 16% to 50% of the pollution emissions generated by transport activities in cities (Albergel et al., 2006). On the top of that, public decision makers do not have, most of the time, the appropriate knowledge to adopt local policies to face these stakes (Dablanc, 2007). At the end, these issues often remain unsolved and most of the efforts are concentrated to address problems that are believed to have a more straightforward impact on populations, such as people transportation. In terms of the state of things that we have just depicted, it looks obvious that urban freight transportation should be taken into account in city planning (COST 321, 1998). By being better integrated into urban policies, city logistics may provide a way to enhance the attractiveness of the city by reducing congestion and sustaining the implementation of proximity retailing shops, for example (Taniguchi et al., 2013). That is why it is necessary to help public decision makers identify solutions that may relieve the traffic congestion in the city center and reduce the environmental impact of urban freight transport. Regarding the complexity of the urban logistics system and associated collaborations, we have to identify innovative and smart ways to support economic activities of city centers.

Many city logistics solutions have been depicted in the literature (Allen et al., 2007; Boudouin, 2006). It appears that most of the time these solutions were implemented without a preliminary study. The conclusions on the impact of city logistics measures are, in the end, the results of experimental studies. It thus makes it difficult to determine the characteristics that provide sustainable models to public decision makers who aim to implement innovative collaborative systems for urban freight transportation. Indeed, there is a need to establish models that enable ex ante assessment (Taniguchi et al., 2003). Russo and Comi (2011) have also identified the necessity of an ex ante approach and propose a classification of city logistics solutions in four groups: measures related to material infrastructure, measures related to equipment, measures related to intelligent transportation systems, and measures related to governance.

We chose to study a measure related to material infrastructure that introduces a particular node in the urban logistic system: an urban consolidation center (UCC). This type of measure is one of the most commonly considered solutions in European cities. However, several fundamental questions come up on such projects concerning, among other issues, their economic viability. There have been 114 projects of UCCs studied since the 1970s (Allen et al., 2012; Browne et al., 2005; Chwesiuk et al., 2010). Even if only 25 among the 75 reported the study made by Gonzales-Féliu et al. (2012) were still operational in 2011, collaboration seems to be one of the key solutions to address urban freight transportation issues (Gonzalez-Féliu & Salanova, 2012). The UCC appears to be a good candidate to provide solutions that achieve this goal.

Although, theoretically speaking, UCCs are very efficient, most of time, in practice, they produce the opposite of the expected results (Van Duin et al., 2008, 2012). This gap could probably be filled with an in-depth and sustainable ex ante evaluation of the impacts of a UCC. Our challenge is to answer the following questions: How is it possible to anticipate the activity level of a UCC? Which level of sustainability can be reached? We thus aim to determine the flows that the UCC will be able to manage. To do so, we chose to characterize the conditions under which local carriers should change the ways they perform city center deliveries by subcontracting their freight to the UCC. Our approach refers to a "make-or-buy" analysis, which means carriers asking themselves under which conditions are they interested in delivering by themselves or paying somebody else to do it.

To this goal, we propose to study some particular configurations of strategic games defined by this situation in which economic players (local carriers) have to choose between two decisions: whether or not to use the collaborative logistic network proposed in order to deliver to the city center. At this step, the target is not to predict optimal delivery routes in the city center. We are confronted with the decision problem consisting of evaluating the potential attraction of a collaborative network according to the local stakeholders' (mainly carriers') interests. As a consequence, we suggest using simulation (coupled with operational research in order to represent rational carrier behavior) to explore different demand scenarios and different logistic configurations. The demand is modeled by a number of delivery points that have to be visited by carriers. It describes solicitation scenarios of the logistics network.

In the next section, we present the background of UCCs, vehicle routing, and game theory. We then describe, in the following part, the proposed approach in terms of modeling and a simulation strategy. We then show some simulation results that were run on a test case agglomeration. Finally in the last section we draw some conclusions and perspectives.

BACKGROUND

Urban Consolidation Centers (UCCs)

Urban consolidation centers have been extensively described in the literature. The most popular definition is given by Browne (2005). Theoretically speaking it should provide a lot of benefits to reduce noise and pollution emission, limit congestion, and so on (Browne et al., 2011; Chwesiuk et al., 2010; Malhéné et al., 2012). The principle of consolidation itself seems to be a good opportunity to improve urban freight transportation (Verlinde et al., 2012). Nevertheless, the different experiments all around the world show that although the potential benefits of UCCs seem to be significant, it has not been always true in real life.

Actually, in many cases, it has been demonstrated that UCCs failed to achieve their goals (ADEME, 2005; Courivault, 2004; Delaître & De Barbeyrac, 2012; Van Rooijen & Quak, 2010). This might have been because they were not based on realistic estimates (Van Duin et al., 2010). Additionally, studies on benefits and losses related to UCCs were conducted most of the time after implementation, not enabling businesses to anticipate potential problems (Browne et al., 2011).

Some researchers tried to find success factors of UCCs by basing their studies on successful experiments. Among others, they identified raising receivers' awareness (not only carriers) of urban logistic potential nuisances, the chosen strategy to involve stakeholders in the project, or accompanying measures in terms of local policy (De Assis Correia et al., 2012; Malhéné et al., 2012; Van Rooijen & Quak, 2010).

Finally, it appears that UCCs need to better anticipate stakeholder behavior before choosing to set one up. We thus intended to elaborate on a model that determines the quantity of flow that a UCC is able to capture using the proposition offered by Marcucci and Danielis (2008).

We consider the UCC to be a part of an urban system that is composed of carriers and delivery points. It has been shown that the chosen strategy in the implementation of a UCC is extremely important to guarantee that carriers will adopt this new measure (De Assis Correia et al., 2012). That is why it is important to define correctly the position of a UCC within the whole system. In the literature (e.g., Allen et al., 2012; Browne et al., 2005; Patier

& Browne, 2010), we distinguish several attributes that describe UCCs. We assume that these attributes can be classified in two categories: those in relation to the location of the UCC and those in relation to the area serviced. In the former, we include the distance between the UCC and the city center and the distance between the UCC and other carriers. In the latter we consider the spatial coverage (the area serviced), the number of kilometers per vehicle, the number of routes, the travel time, the number of delivery points, the number of parcels per day, and the operating cost. This enables us to describe the behavior and interactions of such an urban logistic base.

In this article, we chose to study a reduced system including a UCC in order to investigate its impact on flows in the city. For this study, we take into account the two attributes describing the location of the UCC: distance between the UCC and the city center and distance between the UCC and other carriers; and attributes describing the area serviced: number of vehicle kilometers, number of vehicle routes, number of delivery points, and spatial coverage.

Vehicle routing

A crucial step in the decision-making process is thus to evaluate the total traveled distances inside the serviced area, with and without the UCC. This goal can be reached by solving the capacitated vehicle-routing problem (CVRP). This is a well-known combinatorial optimization problem that consists of finding the shortest routes that will make the delivery possible with each vehicle or truck being limited in its capacity. The complexity of this problem has been proven to grow exponentially regarding the number of delivery points considered. For this reason, in real cases involving a large number of delivery points, this problem is solved with rather approximate methods.

A large set of variations of this problem has also been addressed in the literature to match the constraints and specificities that can be encountered in real delivery situations. Among the most famous ones, is VRP with time windows, multiple depots, or heterogeneous fleets (see, among others, Cordeau et al., 2007; Golden et al., 2008; Toth & Vigo, 2002, for a review). However, the wide diversity of variations that should be taken into account for real delivery problems and especially those occurring in urban areas are, in themselves, modeling problems. Some authors have thus dedicated specific works to relevant variations of CVRP for urban logistics (see, e.g., Taniguchi et al., 2012, for a review of these methods). Implementation of a UCC in particular can be modeled by a class of problems known as multi-echelon VRP (Gonzalez-Féliu, 2012; Mancini, 2013). These problems take into account intermediate depots or satellites for the route generation.

An alternative to solving CVRP is to use an a priori estimate of the total traveled distance of rounds that would be a solution to the problem (Figliozzi, 2008; Langevin et al., 1996). The main advantage of this method is that the complete description of the route is not required. This approach was used by Davis and Figliozzi (2013) to propose a methodology to evaluate the competitiveness of electric trucks. However, the approximate formula is valid only from a statistical point of view. That means that CVRP instances have to involve a large enough set of points. Moreover the commonly used approximations include an essential parameter that depends on the network structure and needs an empiric calibration.

So, in this article, we chose to take advantage of the advances made in combinatorial optimization that led to the development of approximate methods that perform well on CVRP in a reasonable time. We thus use the well-known meta-heuristic greedy randomized adaptive search procedure (GRASP) (Resende & Ribeiro, 2003) to evaluate how the total traveled distance evolves under various logistical configurations that do or do not involve the UCC.

Game Theory

Many real-life situations, such as those encountered in supply chain management (SCM), present multi-actor confrontations and collaboration levels. In these contexts, the consequence of a decision for a given decision maker is a function of the following:

1. His or her own future decisions
2. The future (and uncertain) events that may occur
3. Decisions of other decision makers who may create indirect consequences for him or her (Cachon & Netessine, 2006)

Consequently, the optimal choice for a decision maker depends on those of others. Decisions makers are described as being in strategic interaction. This is consistent with a game theory context in which each decision maker may be seen as a player seeking to maximize his or her own profit. Potential consequences for each player are called *payoffs.*

A game can be *cooperative* or *non-cooperative* (Rasmusen, 1989). In the former, all players are linked with restrictive agreement(s). They are aware of the decisions of other players and have the possibility of planning and defining a common strategy before choosing. So, coalitions are allowed. In the latter, no coalition can be organized. It assumes that players do not communicate together and have no possibility of knowing the decision of other players.

Non-cooperative games can be described in two different ways:

- *Strategic form* game: a collection of strategies defining all possible actions of each player in all possible situations with associated profits (payoffs). The matrix of strategic form game is described in Table 1.
- *Extensive form* game: a tree describing how the game is played. It is a dynamic description of the game because it specifies the sequence of decisions made by the players. Each decision node represents a player who has to make a decision using the information available at this time. Payoffs associated with each scenario (a particular sequence of decisions and events) are represented by the leaves.

Because of the interactions among supply chain partners, SCM has become an important context in the development of game theory. These game-theoretical applications in SCM and other supply chain network equilibrium models (Nagurney et al., 2002; Zhang & Zhou, 2012) have been reviewed differently than game-theoretical techniques (Cachon & Netessine, 2006) or than those with SCM attributes (Cachon, 2003; Leng & Parlar, 2005). These reviews show that many models have been proposed to study the impacts of given SCM decision levers (inventory-related decisions, decisions in production and pricing, revenue sharing, quantity-flexibility contract, etc.).

Game theory literature enables different classical general game forms to be identified: Prisoners' Dilemma, Coordination Game, Battle of Sexes, Chicken Game, Stag Hunt Game, Hawk versus Doves, and so on. These forms are characterized by particular structures of player payoffs and have different equilibrium strategies, known as Nash equilibriums, associated with them.

In this article, the problem under study has several characteristics that enable identifying the type according to existing general forms. The particularities of the problem are as follows:

- The potential gain that one of the carriers can have participating in the collaborative network is not balanced with an equivalent loss of the other carrier. For this reason, the problem is a non-zero sum.
- The carriers have to be willing to take the risk of participating without knowing if the other will either. This is the definition of a non-cooperative game.
- There are no simultaneous decisions. Perfect information is assumed in the game.
- The gain (or loss) of each carrier is related to the location of its platform. So, in its general form, the problem is asymmetric.
- Each player knows all strategies and associated payoffs. The game is complete.
- Finally, the game is not repeated because it is played only once.

SOLUTION APPROACH

Global approach

As illustrated in Figure 1, our approach follows five main steps:

1. We first characterize the context by representing the city center as a graph $G = (N, E)$ defined by a set of nodes N and a set of edges E. Nodes represent the potential delivery points. Edges are the shortest path using the road network from one node to the other. At the moment, because points that need to be delivered have not been selected, routes are not defined yet.

2. Then, a subset of points among the potential delivery points is selected at random. This defines a demand scenario. This random selection can be based on some particular attributes affected by each point, such as the frequency of deliveries.
3. For each demand scenario, different logistical configurations are simulated. For each configuration a possible organization of the routes is generated. The various logistical schemes involve the following:
    a. The classical configuration scheme in which each carrier performs its own deliveries by itself
    b. The complete use of the collaborative logistics network in which all carriers achieve their deliveries by making use of the UCC
    c. A partial use of the collaborative network for which some carriers (but not all) deliver through the UCC
4. Each combination of demand scenario and logistical configurations is measured through a cost function, described in kilometers. Several replicates of the simulations are run until an average is obtained, assuming equal probability for each scenario. This results in the evaluation of the level of performance for the given configuration,
5. Finally, the game matrix is built. The initial state is the situation in which nobody uses UCC services. The aim is to know and quantify for each carrier how beneficial it might be to use the collaborative network offered by UCC services. We thus attempt to identify classes of game situations.

Model of the urban logistic system and notations

The object under study is a city center. Figure 2 represents one configuration of the city center as it will be used in this article. The model is, however, more general and this is a schematic representation that has been simplified for a better comprehension of the system and its different parameters.

As shown in Figure 2, two kinds of zones are defined in our modeling approach:

1. An external zone where local carrier platforms (H_1 and H_2 in Figure 2) and the UCC are located
2. The city center where roads network and potential delivery points are modeled by using a graph $G = (N, E)$ where N is a set of nodes that include delivery points and access points to the city center and E is a set of valuated edges that link the nodes of the graph. The values are the distances from one node to the other following the road network. They are preliminarily computed by solving the shortest path problem on the whole set of roads using the Dijkstra's algorithm.

This subdivision of the spatial domain enables defining the position of each element relative to each other. We will now introduce the different parameters of the model.

We first define the position of the platform operated by a carrier i. In order to do this, we assume that each carrier enters and leaves the city center through a preferential and unique access point. This access point enables linking the two levels of description that we use, that is, the external zone and the city center. It is then possible to localize carriers with respect to the city center and to the UCC. Parameter k_i corresponds to the length of the shortest path between carrier i's platform and its access point to reach the city center. Parameter l_i is the length of the shortest path between carrier i's platform and the UCC. In the particular case depicted in Figure 2, we chose to represent two carriers: carrier 1 and carrier 2, which are located at a distance k_1 (respectively, k_2) from the city center access point and at a distance l_1 (resp., l_2) from the UCC.

Afterward, the UCC also needs to be located with respect to the city center. This is achieved by introducing the parameter (δ), which represents the distance from the UCC to its access point to the city center. This particular access point is, in a general assumption, different from carriers' own access points.

The next step is to define notations that describe the different strategies that carriers can choose. In this study, we considered that each carrier i has two possible choices regarding UCC supply service:

- Whether to join the UCC and thus to transfer its whole shipment there. The notation in the payoffs matrix will be $\mathrm{UCC_i}$.
- Whether to perform all the deliveries on its own account, which means without using the UCC. The notation will be $\overline{\mathrm{UCC_i}}$.

A partial transfer of the carrier shipment to the UCC is not considered in this study. When $\mathrm{UCC_i}$ is chosen, it is assumed that the carrier mutualizes the delivery to the UCC (for example, a big truck can be used to deliver the items instead of having two smaller trucks). We denote $\mathrm{Nb_{mut}^{i\rightarrow ucc}}$ to be the number of trucks needed to deliver the UCC from the i carrier's platform.

A given number of delivery points (denoted Nb_{Pt}^{i}) in the city center area that are randomly selected is affected by each carrier. The random procedure is such that a given point may be selected for both carriers.

This set of delivery points is then split up to build several routes. The set of routes and the number of routes that carrier i (resp., UCC) has to perform are denoted $\mathrm{R_i}$(resp., $\mathrm{R_{ucc}}$) and $\mathrm{Nb_r^i}$ (resp., $\mathrm{Nb_r^{UCC}}$). Finally, the route m made by the carrier i is noted r_m^i and r_m^{UCC} when it is made by the UCC. All routes performed by the carriers (resp., UCC) are characterized by a total traveled distance denoted $Km_{r_m^i}$ (resp., $Km_{r_m^{UCC}}$).

Model of the carrier behavior (vehicle routing)

Once given a set of points to be visited by each carrier and/or UCC, the distances that have to be traveled need to be evaluated. For a simulation purpose, that means to find a procedure that will mimic the way carriers behave when they have to organize their routes to perform deliveries. It is thus particularly relevant to use a meta-heuristic that is based on a compilation of strategies one can have to find a good solution to the problem. Meta-heuristics will then provide a solution close to the optimum. That is in close agreement to what a carrier would do regarding the fact that, because of the numerous uncertainties related, among others, to traffic conditions, the optimal solution is, most of the time, difficult to predict.

The procedure (GRASP) (Resende & Ribeiro, 2003) that was used is a multi-start meta-heuristic algorithm. It proceeds by the repetition of two successive steps. The first step consists of the construction of a feasible solution. This solution is built by using a rather simple strategy (greedy) that enables the construction step to give a quick solution that is already somewhat organized. It also involves a certain degree of randomness so that further iterations will be able to produce new solutions. The next step performs a local search in order to improve the current solution resulting from the constructive phase. Basic operations such as inverting two nodes of the routes or reversing route segments are used. After several iterations of these two successive steps, the best solution is kept. The total traveled distance in this case is evaluated to give an estimate of the performance of the logistic configuration that is investigated. The overall procedure is fast enough to enable multiple simulations to be performed in a reasonable time period.

Evaluation of the catchment area

To estimate the flow caught by the UCC we study the game where the set of players is the set of carriers and the set of decisions by each player is whether or not to join the UCC (respectively denoted UCC_i and $\overline{UCC_i}$). Players are supposed to behave in order to minimize their costs. In our modeling approach, we assume, for the sake of simplicity, that, for a given carrier, the cost per delivery point is equal to its total traveled distance. Indeed, based on interviews with carriers, we observed that even if the price range is given per delivery point, it is generally calculated by estimating the kilometers traveled per position. To stick to our spatial representation of the city, we separate this cost into two parts. A first part depends on distances that have to be traveled outside the city center. It is proportional to the k_i parameter, which is the distance to access the city center and the number of rounds that the carrier has to perform. The other part depends on distances traveled inside the city center that are the result of the previously described optimization procedure.

When a carrier trusts the UCC to perform its delivery, costs are primarily split into two kinds. A first kind of cost corresponds to the part of the delivery that is performed on its own, which is the routing of its freight to the UCC. In a similar manner to what we previously did, this cost, related to trips performed outside the city center, is assumed to be proportional to the distance between the carrier's platform and the UCC (parameter l_i) and to the number of trips ($Nb_r^{i\text{-}UCC}$). The second kind of cost is attributed to the price that the carrier has to pay to use UCC services. This price is assumed to cover the costs that the UCC has to bear to achieve all deliveries. They are evaluated in the same way for individual carriers. That means that we distinguish the cost related to distances traveled outside the city center (proportional, in this case, to the parameter δ and the number of routes performed) from distances traveled inside that are the result of the organization of the routes. However, because having more points to deliver enables better organization, this price will vary depending on how many carriers join the UCC. Costs related to various scenarios are summarized in Table 2.

From the whole set of demand scenarios, simulations are run and give access to the expected costs f_i^X where *X* is related to a logistical configuration that underlies a particular set of decisions made by carriers. These configurations can be $\overline{UCC}$, UCC_{alone} if the carrier joins the UCC alone, or $UCC_{tog.}$ if both carriers join it. Indeed we assume that, if a given carrier decides not to join the UCC, its costs will not be affected by the decision of the other. We are therefore in a particular form where (with the notation of Table 1) $c_1 = d_1$ and $b_2 = d_2$. With the notation already introduced, the strategic form of the game is given in Table 3. As in real life, the initial state is $\overline{UCC_1}$ / $\overline{UCC_2}$. We are seeking equilibrium for carrier strategies. The target is to identify situations in which the initial state is not the best solution for at least one of the carriers. Two cases are worth being investigated. The first one corresponds to the case when a carrier reduces its cost by joining the UCC, whatever the other one does. This is the most favorable case for UCC implementation. It has to be mentioned that, because carriers may be located at different distances away from the city center, if one of them is in this situation, it is not necessarily the case for the other. The second interesting case that might be more likely to happen is when a carrier has interest in joining the UCC only if the other carrier does so as well. This particular case reveals the necessity of setting up a consultation with stakeholders because UCC success will emerge only from cooperation between carriers.

EXPERIMENTS

In order to illustrate the implementation of the proposed approach, experiments were carried out using real data from the city of Saint-Étienne, France. It is a medium-size city with a population, inside the city, of approximately 17,5000 , expanding to over 40,0000 in the metropolitan area (2010).

Characterization of the case

The study takes into account a system composed by two local carriers: H_1 and H_2. Consequently, we evaluated the four different logistic configurations from a graph linking the 200 nodes, corresponding to the potential demand points, and 40,000 (200×200) edges that represent the path from one node to the other.

We consider that each carrier organizes two routes ($Nb_r^i = 2$), each having 40 delivery points ($Nb_{Pt}^i = 80$). This choice corresponds to a relatively high number of delivery points compare to the average number of routes actually performed in the city. However, it still lies within an acceptable range of values. This assumption would indeed represent routes for which the size of the goods to deliver is rather small. These routes are likely to be rather uncomfortable and/or unattractive for the carrier. Thus, subcontracting a third party that would be more efficient for these deliveries may be an option to consider.

We also assume that, if two trucks are necessary to deliver to the 80 points, one larger truck is enough to deliver the whole freight from the carrier's platform to the UCC. That means $Nb_{mut}^{i \rightarrow UCC} = 1$ for each carrier H_i. Indeed, the difficulty accessing and traveling inside the city center often forces carriers to use small trucks to perform their deliveries. When a carrier chooses to collaborate with the UCC, it is supposed to circumvent traveling inside the city center. It thus has the possibility of mutualizing its own freight by using a bigger truck that is more efficient in terms of cost.

Finally, we assume that when a carrier decides to give some freight to the UCC, its whole freight will be given to it, that is, 80 delivery points. This hypothesis is justified by the fact that the activity of the carrier may not be limited to the delivery of the city center and may involve suburbs and/or other cities. Here, we give a special focus on rounds made inside the city center for which the question is whether to go on performing routes on its own account or subcontract a third party. That is why the hypothesis of a complete transfer of the freight that is to be delivered inside a specific area is suitable. So, when one carrier entrusts its routing to the UCC's service, then $Nb_{Pt}^{UCC} = 80$. When both carriers subcontract their routing to the UCC, then $Nb_{Pt}^{UCC} = 160$, even if a single delivery position is visited by both carriers. Thus, the UCC will benefit from a possible redundancy of delivery points and can propose services with attractive prices.

To get results that are as realistic as possible, we simulated ten different replicates of customer locations. For each replicate, delivery points were randomly selected for each carrier within a list of 200 possible location points on the network. This enables us to obtain averaged parameters more representative of reality than a single random distribution. Moreover, it characterizes correctly the fact that carriers do not always use the same routes in the city center. At a decision level, we are not able to anticipate precisely what the exact location of the delivery points will be. However, we can perform an estimation of the general activity.

Costs comparisons using the results obtained from the simulations enable us to predict precisely the type of game carriers are involved in (see Faure et al., 2013, for details). Indeed, it shows that if a carrier decides to collaborate with the UCC then, from this point of view, there is no interest in stopping its collaboration if the other one also joins the UCC.

That comes from the fact that freight consolidation enables the UCC to propose more attractive prices. If a carrier has made a first step to join the UCC because it was reducing its costs then the involvement of another carrier in the collaborative network will thus generate some new benefits. We are thus able to conclude that this situation corresponds to equilibrium in pure strategy. This result enables us to confirm the good behavior of our model. Indeed it is a well-known fact that UCCs should benefit from a larger set of demands because their purpose is precisely to consolidate freight.

We now focus on how parameters k_i, l_i, and δ can be used to elect an area of possible locations for the UCC that will benefit both carriers.

Results and Discussion

As already mentioned, the decision for a carrier to join the UCC or not is based on cost comparisons and may not be the same depending if the other one joins it or not, too. To illustrate this, we have used our cost functions to identify, for a given carrier, the domain of values for the parameters k_i, l_i, and δ for which the option to join the UCC is a more cost-effective solution. This was done in both cases when the carrier joins the UCC alone (Figure 3) or when both join it together (Figure 4). Inside the tetrahedron (truncated in Figure 4) is the domain of values where joining the UCC lowers the cost of the given carrier. A set of k_i, l_i, and δ parameter values that would lie inside this domain implies that the carrier should be interested in subcontracting its freight to the UCC. The gray shaded face corresponds to the values of the parameters generating equal cost for both options.

If a particular location of a carrier's platform is set, this implies that the value of the parameter k_i is fixed. The favorable domain for the other two parameters corresponds now to a slice of the tetrahedron, which is a triangular-shaped domain. Comparing the same value of parameter k_i, the resulting domains when a carrier joins the UCC alone and when both do so (Figure 5) clearly show that the latter option gives a wider set of choices to locate the UCC (which means higher admissible l_i and δ).

In this case, on the one hand, the surface area corresponding to the scenario when the carrier joins alone is very difficult to satisfy. Indeed, for any possible set of values of l_i and δ lying inside the favorable domain, the UCC location is constrained to be in a very narrow region close to the carrier's platform itself and to the UCC access point to the city center. On the other hand, the size of this domain is considerably larger when both carriers use the UCC services. Note also that, on this figure (Figure 5), $l_i$and δ axes do not have the same scale. It appears that, thanks to the possibility of using bigger trucks to deliver to the UCC, it is more beneficial to enlarge l_i (distance between a carrier's platform and the UCC) and keep δ (distance from the UCC to its access point to the city center) as small as possible.

Depending on the UCC location, the situation may correspond to a classic problem of the Stag Hunt Game or, at least, show some important similarities with it. In this type of game, each player (carrier) may have no interest in playing alone because it would result in an increase of its own initial cost. However, if both carriers decide to join the collaborative network, then their respective costs will decrease compared to the initial state. Because this game is non-cooperative, it means that carriers have to be willing to take a risk to participate without knowing if the other one will either. In this particular situation, it makes sense to consider the possibility to set up a temporary subsidy. Indeed, the subsidy may be used to propose prices at the same level as they would be if both carriers were involved. This is likely to reduce a possible, but justified, unwillingness of carriers to decide, on their own, to join the UCC. Once both carriers have joined the UCC, which should be the case if the price set by the UCC is attractive, it is possible to stop the subsidy without changing the price.

Finally, to further this analysis by giving geographical results, we have considered two specific carriers and reported their locations on a map. Doing so, we have fixed the k_i parameters for both carriers. Considering road network distances, it is then possible to represent the sets of points not located further away than a given distance l_i from carrier *i*'s platform and the set of points not located further away than a distance δ from the UCC access point to the city center. These are pseudo-circular areas delimited by an iso-distance contour. Points located in the intersection of the three pseudo-circles (l_1, l_2, and δ constant) are the set of locations where the implementation of the UCC is favorable for both carriers. These results are presented on a map (Figure 6) where two existing local carriers ($k_1 = 1.485\ km$ and $k_2 = 7.42\ km$) were selected and represented by a star. We have considered that carrier 1 enters from a west point in the city center and carrier 2 from an east point. The three access points, for both carriers and the UCC, are represented with open squares. Parameters l_i and δ are chosen, in this case because they lie in a favorable domain for both carriers if they join the UCC together. One of them is represented with white circles and the other with black ones. The gray circles correspond to the possible locations for the UCC, which meets the all the stated requirements. The white area represents the city center and the small black dots in it are the possible delivery points.

It thus appears that the willingness to join a collaborative structure is strongly influenced by the distance of the carrier's platform from the city center. Even if this result is far from being trivial, it can be understood through the following remarks. When a carrier operates from a platform located far away from the city center it might reveal that its activity is not limited to the city center but rather involves a wider area to deliver. In that case, we can guess that the routes performed in the city center are not its main source of income. As we already stated, performing routes in the city center is a rather complicated task that does not often provide large benefits for carriers. For such a carrier, subcontracting its freight to the city center at attractive price is a way to enhance a secondary part of its activity. Other reasons, such as high prices for land or for building, may also explain the fact that a carrier chooses to operate from a platform that is not close to the city center. In our model, the proximity to the city center may be defined by the ratio of the costs inside and outside the city center such as they are before choosing to join the UCC or not. The higher the costs outside the city center, the more likely they are to be reduced when joining the UCC by mutualizing the freight to it in a single truck. If the third party costs remain acceptable compared to their own account costs inside the city center, subcontracting may indeed be a cost-effective strategy.

In the case when the carrier is located close to the city center, there is no clear assumption to make on the specificity of the carrier activity. Delivering to the city center can either represent a large or small part of its business. Moreover, the cost related to the distances traveled outside the city center to deliver to this area can eventually represent a negligible part of the overall cost. In that case there will not be significant benefit from mutualizing its own freight into a single truck to reach the UCC. What we observe from our results is that such a carrier is more likely to wait until the prices are low enough to join the UCC. This carrier may not be a pioneer in using the UCC service. However, its contribution to it, afterward, may favor the stability of the UCC.

CONCLUSIONS AND PERSPECTIVES

In this study, we presented a method that gives the structure of what would be an ex ante decision support system. It can be used by stakeholders to help them in a beforehand phase in which the purpose would be to identify possible UCC locations that are economically relevant. We ended up with a graphical representation of the set of admissible locations using a geographical information system (GIS). This aims at providing the decision markers with adequate information. Indeed, decision makers do not necessarily have in-depth knowledge of city logistics but they are, most of the time, familiar with the spatial structure of the city and may be sensitive to the graphical information a GIS can provide.

We elaborated a methodology that identifies favorable situations for carriers to collaborate with a UCC. In that case, they may conceive of urban logistics schemes rather in terms of services. Although a case study does not necessarily enable generalization, we confirmed that efficient collaborative logistics networks are, within our assumptions, achievable. The illustrative case presented here was chosen because of its simplicity on the one side and, on the other side, its ability to reflect a situation in which the carriers may have very different expectations according to their respective locations. Similar results were obtained with different locations both for carrier platforms and for the UCC. According to a given cost function, we enlightened the existence of an area where the UCC can be implanted in a sustainable way.

The results depicted might not seem so trivial. Indeed, the carrier that is the most likely to get involved in the UCC appears to be the one that operates from the platform located the furthest away from it. That may seem counterintuitive: most of the time, UCC locations are chosen as close as possible to the industrial areas where most of the carriers own their platforms.

Several refinements of the model are achievable. First, the definition of the cost could be stated in terms of time spent rather than distances traveled. Indeed, if the distance per parcel is a good and easy way to calculate an indicator of the cost, the time spent may be slightly more meaningful for stakeholders in general and for carriers in particular. Nevertheless, the methodology would remain the same even if another cost function were used. The global trends depicted in this article would also remain the same.

Accounting for time constraints, and especially time windows, in the simulation could give a more precise estimation of the costs. These are indeed important constraints that often apply to the rounds performed in urban goods delivery. These issues have been treated in the field of operational research and it appears that they may modify significantly the structure of the problem and its solution. Time regulation is very important for public decision makers and it should be investigated how a given measure will meet or not the expected results without being too restrictive. Route construction would need to be adapted to take into account this new feature of the problem. It might be interesting then to observe how the results we obtained would be affected by these new parameters.

Another field of investigation may concern the evaluation of pollution emissions in the model. The full sustainability can be achieved only if it has been validated by a proper environmental assessment of city logistics measures including the externalities (such as traffic) that it generates. Extending our analysis in such a way would help DMs to make environmentally friendly decisions.

Finally, it could also be relevant to investigate scenarios with more than two carriers and to refine our evaluation of their needs. The involvement of a whole set of carriers could lead to complex situations in which various strategies may occur. Game theory still provides, in that case, an efficient basis on which to investigate the conditions under which the collaborative system may successfully involve at least part of the carriers.

Our work is an attempt to provide new means dedicated to anticipate the relevance of new measures for urban freight management, such as UCCs, from a logistics point of view. We elaborated a global approach and investigated some keys factors of the UCC sustainability related to its location. We showed that a way to achieve this goal combines a set of tools that belongs to different fields, such as operational research, game theory, GIS, and transportation economics applied to real cases.

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FIGURES

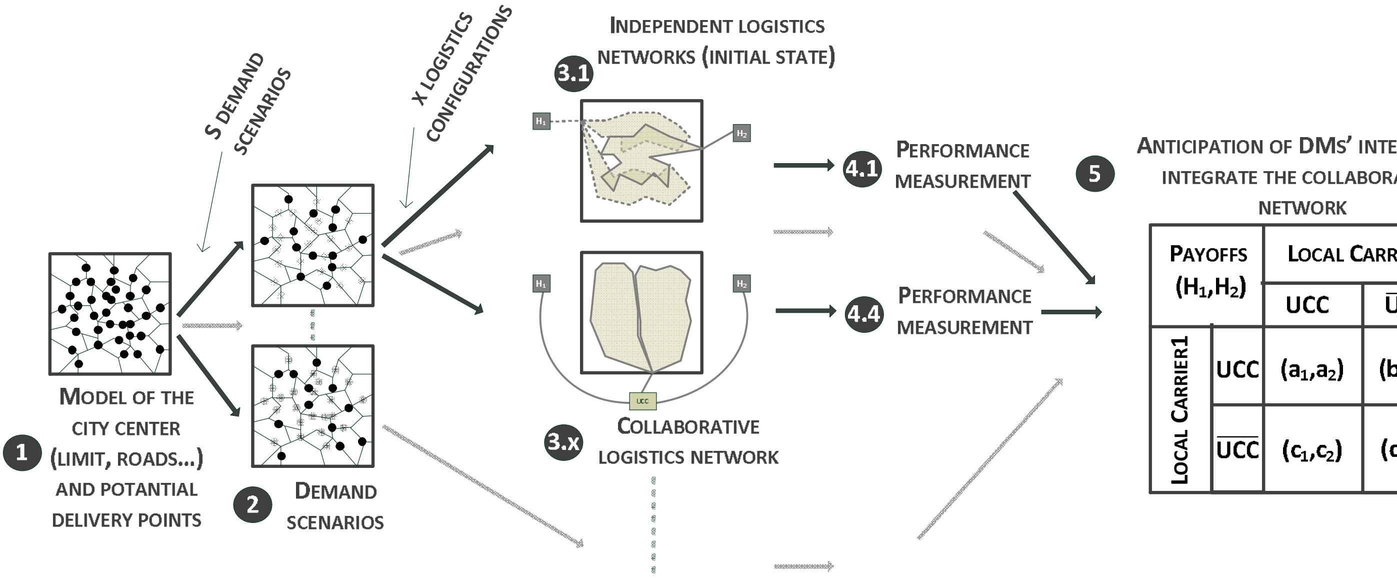

Figure 1: Global approach

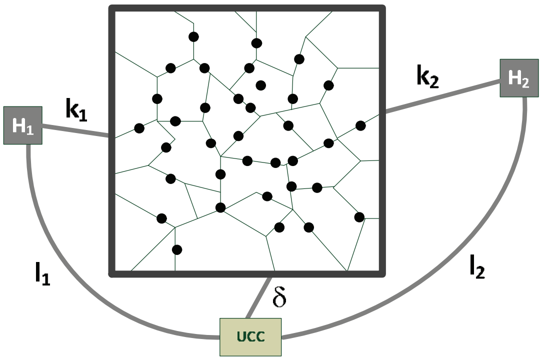

Figure 2: Model of the urban logistics system

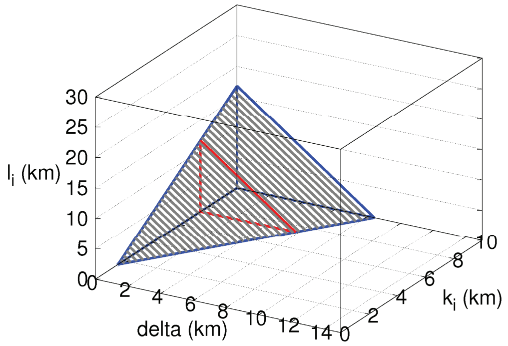

Figure 3: Favorable domain for the parameters of the model: case when one carrier uses the UCC

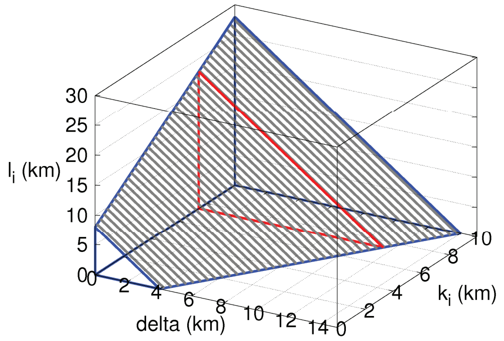

Figure 4: Favorable domain for the parameters of the model: case when both carriers use the UCC

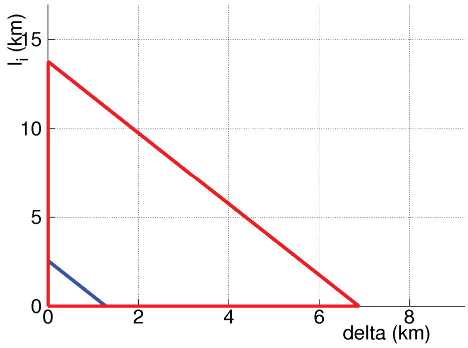

Figure 5: Comparison for a given carrier of the favorable domains for the parameters of the model to locate the UCC (k_i is fixed): small triangle shows the carrier joins the UCC alone; large triangle shows when both join

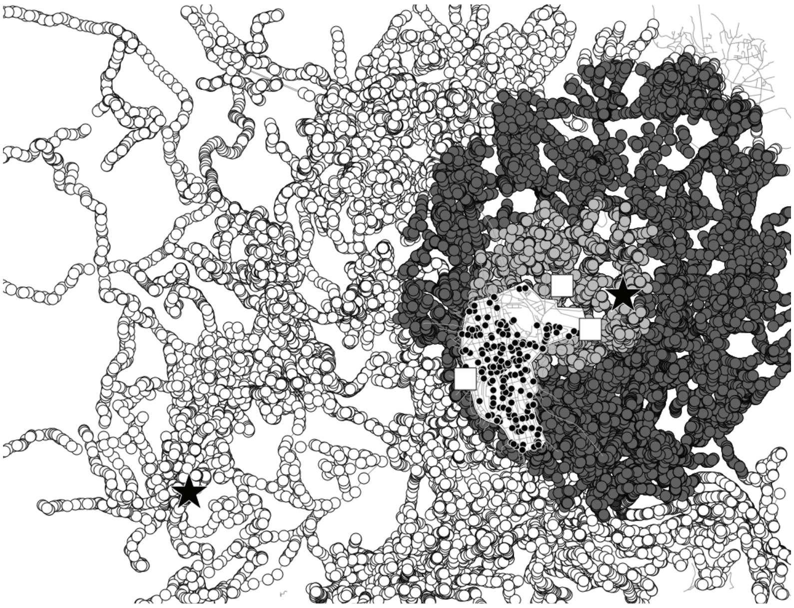

Figure 6: Illustration of the profit area on the road map. Local carrier platforms are represented with black stars, access points to the city center by open squares. White areas represent the city center and small black dots are the possible delivery points. Gray circles are the set of locations for the UCC that are favorable for both carriers. White and dark circles define the regions constrained by the distance from the carrier's platform to the UCC. See text for details.

TABLES

Payoffs: (Player 1, Player 2)		Player 2	
		Decision L	Decision R
Player 1	Decision U	(a_1, a_2)	(b_1, b_2)
	Decision D	(c_1, c_2)	(d_1, d_2)

Table 1: Normal-form game

	Own Account Costs		Third Party Cost	
	Inside city center	Outside city center	Inside city center	Outside city center
$\overline{UCC_i}$	CVRP approximate solution	Proportional to k_i and Nb_r^i	-	-
UCC_i	-	Proportional to l_i and Nb_{mut}^{i-UCC}	CVRP approximate solution (reduced as more carriers join the UCC)	Proportional to δ and Nb_r^{UCC}

Table 2: Various scenario costs

		$i = 2$	
		UCC_2	$\overline{UCC_2}$
$i = 1$	UCC_1	$f_1^{UCC_{tog.}}; f_2^{UCC_{tog.}}$	$f_1^{UCC_{alone}}; f_2^{\overline{UCC}}$
	$\overline{UCC_1}$	$f_1^{\overline{UCC}}; f_2^{UCC_{alone}}$	$f_1^{\overline{UCC}}; f_2^{\overline{UCC}}$

Table 3: Normal form of the UCC game

ACKNOWLEDGMENTS

The work of Jairo R. Montoya-Torres was supported by Universidad de La Sabana under Research Grant EICEA-86-2014. Part of the work of Guillaume Battaïa was supported by the ECLUSE project, which aims to study the future evolutions in city logistics for the urban agglomeration of Saint-Etienne, France. This project is part of the Interdisciplinary Research Programme 'City and Environment' (PIRVE). Reviewers are warmly thanked for their valuable comments that enabled the quality of the article to be improved.

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