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JOINT HUB NETWORK DEVELOPMENT

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Joint Hub Network Development

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This paper introduces a framework for joint hub network development. Building a joint physical hub for transshipment of goods is expensive and therefore involves considerable risks for the cooperating companies. In a practical setting, it is unlikely that an entire network will be built at once. Rather, the partners will have a more cautious attitude and build the hub facilities one-by-one. In the proposed framework, every time a new hub is introduced, partners will have the opportunity to decide whether or not they participate (and thus invest) in this network extension. The framework is also applicable in cooperative situations other than hub network development. In cases where multiple (infrastructural) investments have to be made by a consortium of logistics companies, the participants are likely to take advantage of a step-wise approach with gain sharing at intermediate steps. More specifically, the procedure can also benefit maintenance groups, warehouse sharing initiatives, and intermodal groups.

Keywords: Hub Networks; Horizontal Cooperation; Cooperative Game Theory

JEL codes: C61, C71

1. Introduction

This paper studies the cooperative development of hub networks. This means that companies combine forces to invest in constructing a physical network of hub facilities. If these companies are active on the same level of the supply chain, this constitutes a form of horizontal cooperation. Whereas horizontal cooperation is common and well studied within the maritime shipping and airline industry, the literature on horizontal cooperation in logistics and transport on the landside is scarce. In maritime shipping, conferences are a well-known concept. These are alliances of shipping companies that offer their services on a specific transport line against identical tariffs and service levels (van Eekhout, 2001). Conferences are mainly aimed at generating economies of scale through larger volumes shipped (Shepperd and Seidman, 2001). For a formal (game-theoretic) analysis of cooperation between members of liner shipping alliances, the reader is referred to Song and Panayides (2002). Alliances also play a prominent role in the airline industry. Some examples of major alliances are: Skyteam (9 airlines), Star Alliance (16 airlines), Qualifier (11 airlines), and OneWorld (8 airlines). Due to high operating costs, there are strong economic incentives for airlines to operate dense networks. Growth through mergers and acquisitions may expand their network, but the granting of international traffic rights is still largely confined to specific carriers substantially owned by a country. This has left horizontal strategic alliances between independent carriers as an effective compromise for international airliners to increase their market power (Fan, 2001). More information on airline alliances can be found in e.g. Park (1997) and Oum et al. (2000).

Horizontal cooperation in landside logistics has been studied by e.g. Erdmann (1999), Caputo and Mininno (1996), Bahrami (2003), Vos et al. (2003), and Hageback and Segerstedt (2004). The emphasis in these publications is on quantifying the potential cost savings through cooperation by means of simulation studies and a limited number of successful cases. Cruijssen et al. (2007a) conducted an empirical study to identify the opportunities and impediments for horizontal cooperation between logistics service providers (LSPs). It was revealed that LSPs considered the opportunity to cut costs the most important advantage of horizontal cooperation. Furthermore, according to the respondents the most severe impediments for cooperation are the problems associated with finding a reliable party capable of coordinating the cooperation in a manner acceptable to all participants and the construction of fair allocation mechanisms for the attained savings. These observations constitute an important incentive for the current research in which we propose horizontal cooperation by means of the development of a cooperative hub network that is able to significantly decrease logistics costs and also resolves the problems concerning leadership and gain sharing.

Since the construction and maintenance of physical distribution networks require substantial investments, a sufficiently high capacity utilization of these networks is crucial. Often it is not possible for individual shippers to attain the critical mass to justify such an investment. Therefore, horizontal cooperation between shippers that transport compatible products is an interesting option. Developing a well-performing distribution network is however already a difficult (operations research) problem in its own right. The fact that such networks create interdependencies between shippers with inherently different interests makes it even more complex.

This paper proposes a flexible framework that is able to analyse the problem of cooperative distribution hub network development using network design heuristics and methods from cooperative game theory. The objective is to improve the value

proposition to cooperating shippers, and to attain cooperation among the best possible combination of companies. The remainder of this paper is organized as follows. In the next section, a brief overview of related literature is provided. Section 3 discusses how this literature is extended in the current paper. Section 4 explains the solution method employed, which is elaborated upon in Section 5 by means of an illustrative example. Finally, Section 6 concludes.

2. Related literature

This section briefly examines literature relevant to cooperative distribution networks. Both its practical relevance and its theoretical richness have led academics to create a large body of literature on the topic. In its most basic form, the challenge is to design a physical network for directing flows of goods from production or assembly sites (i.e., the flows' origins) to warehouses of customers (i.e., the flows' destinations). A number of subproblems can be identified in which e.g. questions on the number, location, and size of the facilities, and the allocation of flows are answered (cf. Eskigun et al., 2005).

The current paper illustrates the potential of existing network design techniques in a novel framework. For a general review on network redesign the reader is referred to Dullaert et al. (2007). This paper focuses on *hub distribution network development*. This is a specific kind of distribution network in which transshipment takes place at intermediate facilities (the hubs) between the origin and destination nodes. Such a system requires fewer transport links and the higher concentration of traffic on these links facilitates regular service with a smaller number of trucks (Campbell, 1996). Hub networks have become the standard in air transport, and are also becoming more prevalent in landside transport, e.g. in express parcel networks and for rail freight transport (see Jeong et al., 2007).

The design problem for hub distribution networks is well studied. Over time, a number of literature reviews have appeared (Campbell, 1994; Klincewicz, 1998; Bryan and O'Kelly, 1999). Taking into account the vast body of literature on hub networks, it is remarkable that there are only few publications on hub networks where cooperation is explicitly taken into account. Skorin-Kapov (2001) recognized that in order to reap the benefits of the economies of scale made possible by using hub distribution networks, modelling cooperation between users with possibly conflicting interests is essential. Cooperative game theory is used to tackle the problem of fairly allocating the total gain to the users. Furthermore, Matsubayashi et al. (2005) analysed the cost allocation problem in a large-scale hub-spoke network established by multiple agents. In their implementation, the network is treated as a public good, in the sense that users cannot prevent others from using the system. This is for example the case in telecommunication systems, but less likely in physical transport networks. The next section explains how the current paper is an extension to this literature on joint hub network design.

3. Step-wise hub network development

With hub network development, in addition to obtaining an efficient final solution, it is also important to take into account the development path towards this solution. To facilitate cooperation between shippers, a *step-wise* hub network development procedure is needed. Most previous research has focussed on constructing networks that are as close to the optimal solution as possible from a cost or service perspective.

Groothedde (2005) however indicates that having such a step-wise development path towards the final solution is vital if the benefits are to effectively materialize.

Unlike hub networks in e.g. telecommunications, physical hub networks require such large investments that having a sustainable development path towards the final network is an absolute precondition for cooperation. A step-wise approach is possible because participating in a cooperative hub network is not an all-or-nothing decision for shippers. Instead, they will initially only bring in those transport flows for which the highest savings can be attained. Because installing only a small number of hubs already requires a considerable capital investment, participants are likely to desire an evaluation period during which they can incorporate the changed network in their daily processes and ‘get used to’ the other partners. For the hub network to develop further, a trustworthy relationship between the partners has to be established. This will take some time, also because partners have to incorporate the new logistics structure in their operations. Therefore, in practical cases of joint hub network development, a step-wise approach can be more appropriate than a ‘big-bang’ approach where the complete final network is constructed at once. In the remainder of this paper, the intermediate solutions in which the hub network operates will be referred to as the *levels* of the hub network development process. These levels are illustrated in Figure 1¹.

Figure 1. Levels in hub network development

¹ Because in this paper, cooperation is assumed to only take place on inter-hub links (see further), a 1-hub scenario does not bring value, and therefore is not analysed.

In the setting of this paper, shippers engage in horizontal cooperation by jointly investing in a hub distribution network. Although aimed at horizontal cooperation between Logistics Service Providers, the empirical research by Cruijssen et al. (2007a) indicated that the outlook of cost reductions is the most important opportunity underlying horizontal cooperation. Furthermore, according to the respondents the most severe impediments are the problems associated with, firstly, finding a reliable party that can coordinate the cooperation in such a way that all participants are satisfied and secondly, the construction of fair allocation mechanisms for the attained savings.

Due to the fact that the final network is not constructed at once, it is not straightforward to construct a fair gain sharing mechanism. When applying a step-wise approach, it is essential that the network is stable, i.e. no shipper has an incentive to leave the cooperation, at all intermediate steps. In order to ensure stability fair gain sharing is an important ingredient of the procedure. Cooperative games are played iteratively at each level of the hub network development process, to share the benefits of cooperation. In this way, shippers can choose at every level whether or not they send additional flows through the newly extended network. The reasoning behind this is that in a practical setting, participating shippers are mostly multinational companies that potentially send many shipments through the hub network. At every level, shippers can choose whether or not to increase the number of shipments they send through the network. Hence, on any level of the hub network development process, some of a shipper's flows will be travelling via the hub network, while the others will remain with their individual direct routes. Such a step-wise approach to hub network development with gain sharing at each intermediate level does not yet exist in the literature. This approach is inspired by the method used in Cruijssen et al. (2005).

4. Solution framework

This section explains the step-wise approach in three steps. First, two basic necessary network design routines that serve as building blocks for the procedure are discussed in general terms. Then, Section 4.2 summarises the cooperative game underlying the hub network development procedure. Finally, the integrated solution approach is explained.

4.1. *Network design routines*

The procedure requires two basic components: the 'add-hub' and 'add-flows' routines. For the purpose of this paper it suffices to provide a high-level description of their main functionality. A detailed discussion of possible implementations of these building block heuristics can be found in Groothedde (2005).

Add-hub chooses the best location for a hub that is to be newly introduced in an existing hub network configuration. It is assumed here that hubs are fully interconnected. Every time a hub is added, a check is run to monitor whether there are nodes that were connected to a more distant hub than the newly added hub. In those cases, these nodes are re-linked to the new hub.

The other routine, add-flows, adds flows to a given hub network configuration. A 'flow' is defined as a shipment of a fixed size, belonging to one of the cooperators, that travels from a known origin to a known destination. If a flow is added, this means that instead of travelling directly from origin to destination, this flow now goes from its

origin to the closest hub, then via an inter-hub link to the hub that is located closest to its destination, and finally from this hub to the destination.

4.2. The underlying cooperative games

A fair allocation of the generated synergy savings is critical to any horizontal cooperation. Mistrust about the fairness of the applied allocation rule for the savings has already caused many horizontal cooperation initiatives among shippers to marginalize or disintegrate. This particularly holds true for capital-intensive projects such as the construction of hub networks for physical distribution.

To ensure a fair gain sharing mechanism, the marginal contributions of each shipper to the total gain have to be accurately quantified. Therefore, solution procedures from cooperative game theory are used. Some basic notions of cooperative game theory that are used in the current procedure are briefly discussed here.

Let N be a finite set of players (here: shippers) and denote by 2^N the collection of all subsets of N . Elements of 2^N are called *coalitions*. N itself is called the *grand coalition*. The maximal joint cost savings that a coalition S can generate is called the *value* of coalition S . The characteristic function $v: 2^N \rightarrow \Re$ describes the values of all coalitions S .

In the case of step-wise hub network development, coalitional values are calculated based on the current level of the network development process (level j). Every time a new hub is introduced to reach the next level of the development process, a new game is calculated. The game for level j is denoted by (N, v_j) . Coalitional values $v_j(S)$ resemble the cost savings that can be attained with respect to the initial situation where there are no hubs, by a coalition S on level j of the development process. They are calculated as follows:

$$v_j(S) = \sum_{i \in S} C_0(i) - C_j(S) \quad (1)$$

Here, $v_j(S)$ is the value of coalition S on level j of the network development, $C_0(i)$ are the costs that shipper i incurs in the original situation where there is no hub network and all flows travel directly from origin to destination, and finally $C_j(S)$ are the costs that coalition S incurs for the execution of all their flows at level j of the network development process. These costs also include the fixed costs for establishing hubs.

The Shapley value (Shapley, 1953), represented by Φ , is used to evaluate the game (N, v_j) at level j and to allocate the value of the grand coalition at this stage:

$$\Phi_i(N, v_j) = \sum_{S \subset N: i \notin S} \frac{|S|!(|N|-1-|S|)!}{|N|!} [v_j(S \cup \{i\}) - v_j(S)] \in \Re^N, \text{ for all } i \in N. \quad (2)$$

The Shapley value is a widely used game theoretic solution concept, based on an appropriately weighted average of marginal contributions taking into account the size of coalitions.

Global Solution approach

All necessary ingredients are now available to describe the solution approach for developing a cooperative hub network. Figure 2 gives a global description of the procedure, which consists of a number of iterative steps.

Figure 2. High-level solution procedure

The procedure initialises by constructing a network configuration consisting of two hubs. This is because in the current setting it is assumed that horizontal cooperation by joint transport only takes place on inter-hub links. It is also possible to perform joint route planning on the links between hubs and origin or destination nodes (cf. Cruijssen et al., 2007b). This would however require a much higher intensity of cooperation, which introduces additional risks and coordination costs. Here the choice is made to restrict cooperation to the inter-hub links. Because of this choice, no benefits can be gained by introducing only a single hub. Therefore, the first configuration that is tested incorporates two hubs. The locations of these hubs are chosen by the add-hub heuristic. Below, only those steps of the procedure that need further explanation are commented on. These are indicated by the numbers in Figure 2.

Step 1

The total costs $C_j(N)$ of the network configuration at each level consist of three components:

- The transport costs of the flows that do not use the hub network (the direct shipments from origins to destinations)
- The transport costs of the flows that travel via the hub network (origin-hub, hub-hub, hub-destination)
- The fixed costs of the established hubs (including handling, interest, overhead etc.)

Step 2

In Step 2 the cooperative game is calculated. For this game it is important to note that the individual shippers might have multiple flows passing through the hub network. This constitutes an important difference with existing literature on joint network development, where players are usually single flows or nodes. Based on all coalitional values following from formula (1), the Shapley values are calculated using formula (2).

Step 3 and Step 4

Consequently, the current level of the hub network development process is checked for what is called *Shapley monotonicity*. The basic idea behind the step-wise approach is to consistently check whether each shipper is willing to ‘take the next step’. If this is not the case, the development of the network will stop. Therefore, in Step 3 a ‘reconsideration loop’ is initiated for each new level of network development (see Figure 2). In this loop, it is checked whether each shipper has a higher payoff than he had on the previous level. If the Shapley value that is allocated to shipper i indeed corresponds to higher savings than were attained at any previous level (i.e., shipper i benefits from the newly added hub), then this shipper’s flows that were added on the current level are retained. In fact, to compensate for risks and switching costs, it can even be expected that shippers will require a certain minimum level of savings before engaging in an extended hub network. These thresholds can easily be incorporated in the proposed procedure.

If on the other hand shipper i is worse off at a level j than in the earlier level $j-1$, he withdraws the added flows in Step 4. This means that these particular flows will travel directly from origin to destination again. Note however that the flows of shipper i that were added at previous levels are retained in the hub network.

Subsequently, the Shapley allocation of Step 2 is repeated based on the coalitional values that are updated according to the withdrawal of the flows of shipper i . This updating is necessary because the resignation of shipper i reduces the total volume transported through the network, which may influence the costs of the remaining shippers. In a sense, the process is therefore a ‘correction’ of the add-flows heuristic. Furthermore, in cases where more than one shipper loses, the flows of the shipper that has the highest percentual loss are withdrawn. The flows of the other losing shippers are (temporarily) retained.

Only when after these iterative steps the add-hub routine is applied again, the flows that have entered the hub network in the last iteration and constituted cost reductions are really committed. Before this point, flows were only tentatively included and possibly excluded again in the reconsideration loop when benefits turned out to be absent or insufficient.

5. An illustrative example

This section provides a hypothetical example for joint hub network development (see Figure 3). It should be noted that the only goal of this example is to illustrate the procedure, not to evaluate the concept's cost savings potential in practice. For example, practical considerations such as volume-dependent transport tariffs are not incorporated.

Consider three shippers (white, grey and black) that each have two flows travelling from disjunctive origins to disjunctive destinations. For each shipper, these two flows are depicted as either a square or a circle. Note that in the tables in this section, the white shipper is referred to as 'w', the grey shipper as 'g', and the black shipper as 'b'. For the purpose of illustration, but without loss of generality, it is assumed that all flows travel from left to right (see Figure 3). Furthermore, the demand size of each shipment is displayed underlined next to both the origin and destination nodes. The flows are transported in trucks with a capacity of 25 units and there are no further restrictions in terms of product compatibility, time windows, etc. The transport costs that the shippers incur are proportional to the Euclidean distances. However, it is assumed that inter-hub links have a 10% costs discount per unit of distance as compared to the other links as a result of the larger economies of scale. The transport costs are displayed on the links. In the current setting, shippers are only charged for one-way transport: the trucks are free at the destination node. It is however straightforward to adjust the procedure to support routes in which trucks must return to their origin. Furthermore, establishing a hub facility costs 1. This is the share of the costs incurred during the hub's complete lifetime that is allocated to the period under consideration. By doing so, it becomes possible to make a fair trade-off between the non-recurrent costs of establishing a hub and the recurrent benefits of sending flows through the hub network. Finally, it is assumed that hubs are always located at origin or destination nodes of flows.

Because there is no hub structure in Step 0, there is no cooperation and no savings can be shared among the shippers. This starting situation is displayed in Figure 3 and Table 1. Figure 3 contains the real Euclidean distances between the given origin-destination combinations. Note that the Euclidean distances between the other pairs are also needed to apply all the steps of the method. Below, these distances are reported when needed.

Figure 3. Illustrative example: Level 0

S	$\{w\}$	$\{g\}$	$\{b\}$	$\{w,g\}$	$\{w,b\}$	$\{g,b\}$	$\{w,g,b\}$
Hub costs	0	0	0	0	0	0	0
Transport costs	11.4	12.3	10.2	23.7	21.6	22.5	33.9
$C_0(S)$	11.4	12.3	10.2	23.7	21.6	22.5	33.9
$v_0(S)$	0	0	0	0	0	0	0
$\Phi(N, v_0)$	0	0	0				

Table 1. Coalitional values and allocations on level 0

The first iteration of the procedure (to reach level 1) is then entered and a hub structure is actually installed. The add-hub routine chooses both ‘circle locations’ of the black shipper as the most appropriate hub locations. This is illustrated in Figure 4 by the circles around these nodes, which have furthermore changed into triangles to represent hubs. The link connecting both hubs is in bold. Note that the 10% cost reduction on the interhub link (see above) makes that the costs on this link decrease from 4.1 to 3.7. The add-flows routine determines that in addition the circle locations of the white and grey shippers will now enter the hub network. Note that in the new configuration the circle locations’ demands of 10, 8 and 7 exactly fit into one truck, so that the hub link needs to be crossed only once to serve all three added flows. This results in a significant cost reduction for these flows.

Based on the costs incurred in the new configuration, coalitional values are calculated. These values are given in Table 2, together with the Shapley values. It turns out that the black shipper receives the highest savings (21.6%), because his two

locations are beneficial for the other two shippers and coincide with the hub locations. Note that the fixed costs for establishing the hubs are evenly spread over its users. This is a direct consequence of the additivity property of the Shapley value. When the game is split up into two subgames, one for the hub costs and one for the transport costs, it is readily verified (see the first row of Table 2) that in the hub costs subgame all coalitional values are equal and the costs will be evenly shared.

Table 2 shows that all cooperators receive a cost reduction for their participating flows. This means that none of the flows will be withdrawn from the hub network via the reconsideration loop. Now, a new iteration of the procedure can be started to reach the next level of network development.

Figure 4. Illustrative example: Level 1

S	$\{w\}$	$\{g\}$	$\{b\}$	$\{w,g\}$	$\{w,b\}$	$\{g,b\}$	$\{w,g,b\}$
Hub costs	2	2	2	2	2	2	2
Transport costs	12.6	12.1	9.8	21.0	18.7	18.2	27.1
$C_1(S)$	14.6	14.1	11.8	23.0	20.7	20.2	29.1
$C_0(S)$	11.4	12.3	10.2	23.7	21.6	22.5	33.9
$v_1(S)$	-3.2	-1.8	-1.6	0.7	0.9	2.3	4.8
$\Phi(N, v_1)$	0.6	2.0	2.2				
Allocation hub costs	0.67	0.67	0.67				
Allocation transport costs	10.13	9.63	7.33				
Costs after allocation	10.8	10.3	8.0				
Costs previous level	11.4	12.3	10.2				
Savings w.r.t. previous level	5.3%	16.3%	21.6%				

Table 2. Coalitional values and allocations on level 1

In the second iteration, add-hub chooses the grey square origin node as the new hub location (see Figure 5). The add-flows routine now adds all remaining flows to the cooperative hub network.

Note that since there are now multiple inter-hub links in the network, some elementary routing problems need to be solved to calculate the coalitional values. For example, for the coalition consisting of only the white shipper ($S = \{w\}$), the best choice is to combine the two flows at one of the left-hand side hubs and then cross the link to the hub at the right-hand side together. This route is feasible, because the corresponding shipments amount to 22 (10+12). This amount still fits into one truck so that the inter-hub link has to be crossed only once to transport both shipments. This is however not possible for any of the 2-shipper coalitions, nor for the grand coalition. For these coalitions, it is best to respectively combine the square and circle shipments into separate groups that travel from left to right via the two inter-hub links. For coalition $S = \{w, b\}$ and the grand coalition, a long hub-link even needs to be crossed three times.

Figure 5. Illustrative example: Level 2

S	{w}	{g}	{b}	{w,g}	{w,b}	{g,b}	{w,g,b}
Hub costs	3	3	3	3	3	3	3
Transport costs	10.5	10.1	9.6	17.0	20.2	16.1	24.8
$C_2(S)$	13.5	13.1	12.6	20.0	23.2	19.1	27.8
$C_0(S)$	11.4	12.3	10.2	23.7	21.6	22.5	33.9
$v_2(S)$	-2.1	-0.8	-2.4	3.7	-1.6	3.4	6.1
$\Phi(N, v_2)$	1.08	4.23	0.78				
Allocation hub costs	1	1	1				
Allocation transport costs	9.32	7.07	8.42				
Costs after allocation	10.32	8.07	9.42				
Costs previous level	10.8	10.3	8.0				
Savings w.r.t. previous level	4.4%	21.7%	-17.8%				

Table 3. Coalitional values and allocations in level 2

The bottom row of Table 3 shows that on level 2, the black shipper loses compared to level 1. This means that in the reconsideration loop of the procedure, this shipper will withdraw the flow that he added to reach level 2. This situation is illustrated in Figure 6. The black ‘square-flow’ does not use the grey hub anymore, but chooses direct transport again. This illustrates how the reconsideration loop corrects the add-flows routine based on fair gain sharing between the participating shippers: although adding the black square flow might be beneficial from a total costs perspective, the

black shipper does not gain and is not willing to lose money to the benefit of the other shippers.

As explained above, the black shipper again incurs the costs he incurred at level 1 (8.0) and does not bring additional value to any of the coalitions (see Table 4). Note that since the black player has committed his circle flow in level 1, he still incurs his share of the fixed costs for the two hubs established on level 1 (see Table 2), but is in fact inactive on level 2.

Figure 6. Illustrative example: Level 2 (reconsidered)

S	{w}	{g}	{b}	{w,g}	{w,b}	{g,b}	{w,g,b}
Hub costs	2.33	2.33	0.67	2.33	3	3	3
Transport costs	10.5	10.1	7.33	17.0	17.83	17.43	24.33
$C_2(S)$	12.83	12.43	8.0	19.33	20.83	20.43	27.33
$C_0(S)$	11.4	12.3	-	23.7	-	-	-
$v_2(S)$	-1.43	-0.13	-	4.37	-	-	-
$\Phi(N, v_2)$	1.54	2.84	-				
Allocation hub costs	1.17	1.17	-				
Allocation transport costs	8.69	8.29	-				
Costs after allocation	9.86	9.46	8.0				
Costs previous level	10.8	10.3	8.0				
Savings w.r.t. previous level	8.7%	8.2%	0.0%				

Table 4. Coalitional values and allocations in level 2 (reconsidered)

After the withdrawal of the black shipper, it turns out that the white and grey shipper still benefit from the extra hub (8.7%, and 8.2% with respect to level 1).

Therefore, the reconsideration loop of level 2 is terminated here without any further flow withdrawals. It is a straightforward exercise to check that adding another hub would not be sustainable, because in the reconsideration loop of level 3, all flows will be withdrawn and the procedure will stop. The final network therefore is the one depicted in Figure 6.

This finishes the discussion of the framework for developing cooperative hub distribution networks.

6. Concluding remarks

This paper focuses on shippers that cooperate by setting up a joint hub network for the transport of goods. The construction of such networks is a well-studied optimisation problem in the operations research literature. However, besides the final solution, the development path towards this solution is also of importance. Building a physical hub for the transshipment of goods is expensive and therefore involves considerable risks for the cooperating companies. In a practical setting, it is unlikely that the entire network corresponding to the final solution of the optimisation problem will be built at once. Rather, the partners will have a more cautious attitude and build the hub facilities one-by-one. Every time a new hub is introduced, partners will have the opportunity to decide whether or not they participate (and thus invest) in this network extension.

Compared to the ‘big bang’ approach that prevails in literature, the step-wise procedure developed in this paper will generally result in an inferior final solution in the sense that possibly fewer flows will travel via the hub network, overall costs will be higher and less hubs will be constructed. However, in a real-life setting this should not be considered a valid drawback. The investments in physical transport hub networks are that large that they cannot be made without a sustainable development path towards the final network. Nevertheless, comparing the performance of the step-wise and big-bang approaches is an interesting direction for further research.

It is important to note that the framework introduced in this paper is also applicable in situations other than hub networks. In many cases where multiple (infrastructural) investments have to be made by a consortium of (logistics) companies, the participants are likely to take advantage of a step-wise approach with gain sharing at intermediate levels. More specifically, in logistics the procedure can also benefit maintenance groups, warehouse sharing initiatives and intermodal groups.

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