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Centralized Carrier Collaboration Multihub Location Problem with Hub Processing Costs

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Abstract: This study proposes a Centralized Carrier Collaboration Multi-hub Location Problem (CCCMLP) with processing cost at hub for the small-to medium-sized LTL industry where a central entity (e.g., a third party logistics firm) seeks a set of hybrid collaborative consolidation transshipment hubs to help establish a collaborative hybrid hub-and-spoke network that minimized the total collaborative costs for the set of collaborating carriers in the system. A mathematical programming formulation was provided for the CCCMLP with hub processing cost and shown to be NP-hard. The model was solved using a two-phase tabu search heuristics. Computational runs were conducted to study the efficiency of the tabu search heuristic over CPLEX. As the expected cost reduction at the shipment level needed to incentivize collaboration decreases, likelihood of carriers entering into collaboration increases. If the carriers expect significant cost reductions to enter into a collaborative strategy, then the potential savings from the collaboration will decrease.

Key words: Collaborative logistics, freight transportation, less-than-truckload trucking, multi-hub location, hybrid hub-and-spoke

INTRODUCTION

Carrier collaboration in recent years has garnered much attention particularly from the perspective of the small- to medium-sized Less-Than-truck Load (LTL) carrier industry. This is because collaboration has the potential to improve operational efficiency (e.g., through increased capacity utilization) and reduced supply chain costs especially for small- to medium-sized LTL trucking industry which has endured increased costs that affect their ability to sustain profits.

In this study, we extend the recent work of Hernandez *et al*. (2012) by introducing processing cost at hub by transshipment volume and establish a framework for a centralized Carrier Collaboration Multi-hub Location Problem (CCCMLP) with processing cost at hub among a set of small- to medium-sized LTL carriers.

LITERATURE REVIEW

The carrier collaboration paradigm is an emerging trend that addresses dwindling profits and system inefficiencies. Earlier studies have addressed carrier collaboration from the perspective of the Truck Load (TL) (i.e., TL are characterized by fully loaded long-haul direct trips in contrast to LTL operations which are shorter in distance with frequent stops) carrier, liner shipping and rail industries. These works have primarily focused on optimization based methods and heuristics for shipper-shipper or shipper-carrier collaboration and cooperative game theory to reduce deadheading and allocate costs (Agarwal and Ergun, 2010; Dai and Chen, 2012; Ergun *et al*., 2007a, b; Goodwill, 2007; Houghtalen *et al*., 2011).

From the perspective of LTL carrier collaboration recently Bailey *et al*. (2011) developed two models for minimizing backhauls through freight collaboration for small- to medium-sized LTL carriers. In this work, freight agents attempt to minimize deadheading by making extra additional pick up and deliveries and sharing the revenue with their collaborators during their backhaul. (Hernandez *et al*., 2012) introduced and examined the viability of small-to medium-sized LTL carrier-carrier collaboration from a static and dynamic context for a single carrier and centralized planning perspective for multiple carriers, respectively.

MODEL OF THE CCCMLP WITH HUB PROCESSING COST

Problem description: The goal of the CCCMLP is to determine a set of consolidation transshipments hubs in a collaborative freight network comprising of geographically dispersed carriers and managed by a central entity like a third party logistics firm. The goal of the CCCMLP is thus to minimize the total collaborative system costs. The freight transport networks of the carriers may or may not overlap. The transshipment hubs

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will help in reducing the overall transportation costs through consolidation. Note that the carrier will have the option of transporting the goods directly to their destination if the collaborative routing strategy does not deliver significant benefits.

The CCCMLP differentiates itself from the model (Hernandez *et al*., 2012) in the following manner: (i) carrier will bear the fixed setup cost of the hubs and the hub processing cost of its shipment by volume; (ii) carrier will take both costs of routing and hub processing into consideration when making decisions on whether using collaborated hubs.

Notation: This section describes the mathematical formulation of CCCMLP. Let W.1.J.N denote the set of carriers, the set of origin nodes where the shipment enter the collaborative network, the set of destination nodes where the shipment leave the collaborative network and the set of nodes, respectively. A shipment from collaborative carrier $q\epsilon Q$ either enters the collaborative network through an origin facility $i\epsilon i\subseteq N$ and travels via collaborative transshipment hubs $1.m\in N$ and exits through a destination facility $j\in J\subseteq N$ or is routed directly from origin facility $i\in I\subseteq N$ to destination facility $j\in I\subseteq N$ without consolidation. Note that the origin and destination facility can represent a supplier or DC/warehousing, or retailer.

Let d_{ijq} denote the demand to be transported from origin facility $i\in I\subseteq N$ to destination facility $j\in J\subseteq N$ by carrier $q\in Q$. Let S_{ijlm} be the collaborative transportation costs associated with a unit of demand for carrier $q\in Q$ to travel between origin facility $i\in l$ to destination facility $j\in J$ when transported via hybrid collaborative transshipment facilities at node $l\in N$ and $m\in N$. A revenue oriented cost structure is followed (Houghtalen *et al*., 2011). Note that:

$$\text{Sijlm} = \varsigma_{il} + \delta\varsigma_{lm} + \varsigma_{mj} \tag{1}$$

In equation 1, ς_{il}, ς_{lm}, ς_{mj} represents the cost of transporting a unit of demand from origin facility $i\epsilon l$ to collaborative transshipment facility $i\epsilon N$, collaborative transshipment facility $i\epsilon N$ to collaborative transshipment facility $i\epsilon N$ and collaborative transshipment facility $m\epsilon N$ to destination facility $m\epsilon N$, respectively. In the above equation, δ represents the collaborative discount parameter (falls between 0 and 1) between consolidation collaborative transshipment facilities $1.m\epsilon N$ and is composed of transfer rates per shipment and line haul costs (Houghtalen *et al*., 2011).

Let φ_{lq} denote the fixed cost to the carrier $q\epsilon Q$ for using the collaborative consolidation hub at location $l\epsilon N$, R_{lq} denote the unit processing cost to the carrier $q\epsilon Q$ for using the collaborative consolidation hub at location $l\epsilon N$.

The maximum number of collaborative consolidation facilities to be established is p. Let w_{ijq} represent the cost of moving a unit demand from origin facility $j\epsilon J$ to a destination facility $q\epsilon Q$ directly for carrier γ. In the problem variant studied in this study, a shipment enters a collaborative network only if there is significant savings obtained through consolidation. The parameter γ captures the cost reduction expected at a shipment level for the carrier to consider consolidation worthwhile. There are three decision variables. The decision variable Y_{ijlmq} takes the value 1 if a shipment originating from origin $i\epsilon l$ headed to destination $j\epsilon J$ by collaborative carrier $q\epsilon Q$ travels via consolidation hubs at node $l\epsilon N$ and $m\epsilon N$ and 0 otherwise. This binary variable captures if a shipment is routed through a consolidation hub. The problem formulation uses one more binary decision variable which captures if a shipment is routed directly to the destination. The decision variable V_{ijq} takes the value 1 if a shipment from origin $i\epsilon l$ headed to destination $j\epsilon J$ by carrier $q\epsilon Q$ is shipped directly and 0 otherwise. The decision variable X_l takes the value 1 if the facility at node $l\epsilon N$ is used by any carrier to consolidate and 0 otherwise.

Problem formulation:

$$\begin{aligned}\text{Min}\sum_{i\in l}\sum_{j\in J}\sum_{l\in N}\sum_{m\in N}\sum_{q\in Q}\varsigma_{ijlm}d_{ijq}Y_{ijlmq}+\sum_{i\in l}\sum_{j\in J}\sum_{q\in Q}W_{ijq}d_{ijq}V_{ijq}+\\ \sum_{l\in N}\sum_{q\in Q}\varphi lqX_l+\sum_{l\in N}\sum_{q\in Q}F_{lq}R_{lq}\end{aligned} \tag{2}$$

$$\sum_{l\in N}X_l\ 1\rho \tag{3}$$

$$\sum_{l\in N}\sum_{m\in N}Y_{ijlmq}+V_{ijq}=1,\ li\in I,J\in,q\in Q \tag{4}$$

$$li\in I,j\in J,l\in N,q\in Q \tag{5}$$

$$li\in I,j\in J,m\in N,q\in Q \tag{6}$$

$$\begin{aligned}&[\![(\varsigma]\!]_{ijlm}+R_{lq}+R_{mq})Y_{ijlmq}\le w_{ijq}\\&(lil\in I,j\in J,l\in N,m\in N,l\ne m,q\in Q\end{aligned} \tag{7}$$

$$[\![(\varsigma]\!]_{iju}+R_{lq})\,Y_{ijllq}\le w_{ijq}(1-V_{ijq})(1-\gamma)li\in I,j\in J,l\in N,q\in Q \tag{8}$$

$$\begin{aligned}&F_{\downarrow}lq=l_{\downarrow}(i\in l)ll_{\downarrow}(j\in J)\equiv[\![d_{\downarrow ijq}Y_{\downarrow ijllq}]\!]+l_{\downarrow}\\&(i\in l)\equiv l_{\downarrow}(i\in l)\,|\sum{}_{\downarrow}(m\in N\setminus\{l\}\equiv[\![\ [\![(d]\!]\end{aligned} \tag{9}$$

$$X_l\in\{0,1\},\ 1l\in N \tag{10}$$

$$Y_{ijlmq}\in\{0,1\},\ li\in I,\ j\in J,\ l\in N,\ m\in N,\ q\in Q \tag{11}$$

$$V_{ijq}\in\{0,1\},\ li\in I,\ j\in J,q\in Q \tag{12}$$

The objective function, equation (2), comprising of four terms, seeks to minimize the total collaborative transportation costs in the system. The first term represents the total collaborative carrier transportation costs; the second part represents the total costs associated with carriers shipping directly and third represents the total collaborative consolidation facility location costs and the fourth part represents the total processing costs at consolidation facilities.

Constraint (3) represents the number of candidate collaborative consolidation hubs is less than or equal to a pre-specified number. Constraint (4) ensures that shipment corresponding to every origin destination pair and every carrier is either assigned to one consolidation hub pair or transported directly without participating in the collaboration. Note since l may equal m under this constraint, we do not preclude the possibility that the shipment between and origin-destination pair (i, j) may only go through a single hub. Constraint sets (5) and (6) state that shipments from origin $i \in I$ to destination $j \in J$ cannot be assigned to a hub at location $l \in N$ or $m \in N$ unless a hybrid consolidation hub is located in these candidate sites. Constraint (7) and (8) states that a specific carrier $m \in N$ for each origin-destination pair $q \in Q$ will participate in the collaboration only if their routing costs together with processing costs are lower than the standalone costs by a pre-specified margin. Constraint (9) represents that the total volume of goods for a specific carrier $q \in Q$at a hub lN.

Constraint sets (10), (11) and (12) represent the 0-1 integrality conditions for the decision variables.

SOLUTION METHOD

Tabu search (Glover, 1990) is a metaheuristic that is intended to overlay a core search heuristic and seeks to help heuristics break out of local optima and explore other regions of the solution space. The move heuristics of the CCCMLP with hub processing cost are particularly amenable to this structure. The basic tabu search employs "tabu" restrictions which inhibit certain moves and aspiration criteria which allow very good solutions to overcome any tabu status. The tabu restrictions are generally implemented with a short term memory function to make them time-dependent. Designing tabu search heuristics involves defining what types of moves to restrict and the nature of the aspiration criteria and short term memory to utilize. In addition to these features, most tabu search designs include other strategies such as a long-term memory function to diversify the search into other areas of the solution space.

STUDY EXPERIMENTS

The experimental set up consists of three collaborating carriers for the CCCMLP problem with hub processing cost. A 10-node network was randomly generated using MATLAB. As the data is simulated, ten randomly generated data sets consistent with the small- to medium-sized LTL industry observed ranges are created and averaged to create a single data set. For each scenario, the collaborative rates, non-collaborative costs and locational costs are randomly generated in addition to the demand.

ANALYSIS OF RESULTS

The CCCMLP with hub processing cost is addressed under a static planning context and insights can be obtained on how varying degrees of expected profit margins affect the centralized carrier collaborative network. From the central entity's perspective, the selection of the hybrid collaborative consolidation candidate transshipment hubs can only be made if the collaborative routing and hub location costs coupled with the direct route costs (non-collaborative costs) for the system are minimized.

As stated earlier, the potential for collaboration among carriers is investigated by focusing on the level of monetary savings due to expected profit margins (Equation (7). These margins are reflected through the parameter γ which takes the values 18, 36, 48, 60, 72, 84 and 96%. In general, a lower profit margin value leads to greater levels of collaboration. Specifically, as seen from Equation (7), $(1-\gamma)$ is the true profit margin so the lower the greater the profit margin. The values where chosen arbitrarily in increments of 12% -18% to try to capture changes in the totals savings. The following tables illustrate the results of the analysis.

Now turning to the results of the experiments both GAMS/CPLEX (exact solutions) and the TABU search heuristics. Table 1 illustrates the comparison of the number of hubs and total savings with respect to changes in γ for a 10-node network. Here, the total savings represent the cost differences between the non-collaborative (or direct route) vs. the collaborative (collaborative routes) as a percent. The overall trend of the results for each number of hubs scenario and network size indicates that as the increases the number of direct route increases. This shows the sensitivity of carrier shipments (column 4) to changes in expected profits. Akin, the lower the γ the greater the percent of routes collaborated and total percent savings (columns 6 and 7). The collaborative hubs selected for each scenario are

Table 1: Comparison of the number of hubs and total savings with changes in γ with 3 collaborative carriers

		Selected hubs		No. of direct routes		No. of collaborative routes		Total savings (%)		
No. of hubs	γ value	CPLEX	Tabu	CPLEX	Tabu	CPLEX	Tabu	CPLEX	Tabu	Difference (%)
3	0.18	1,4,7	1,4,7	33	33	237	237	45.07	45.07	0.0
	0.36	1,4,7	1,4,7	67	67	203	203	41.90	41.90	0.0
	0.48	1,4,7	1,4,7	118	118	152	152	33.78	33.78	0.0
	0.60	1,4,7	1,4,7	173	173	97	97	23.25	23.25	0.0
	0.72	1,4,7	1,4,7	238	238	32	32	5.18	5.18	0.0
	0.84	1,2,4	1,2,4	253	253	17	17	0.61	0.61	0.0
	0.96			270	270	0	0	0.00	0.00	0.0
4	0.18	1,4,7,9	1,4,7,9	23	23	247	247	48.25	48.25	0.0
	0.36	1,4,7,9	1,4,7,9	47	47	223	223	45.99	45.99	0.0
	0.48	1,4,7,9	1,4,7,9	88	88	182	182	39.73	39.73	0.0
	0.6	1,4,7,9	1,4,7,9	141	141	129	129	29.95	29.95	0.0
	0.72	1,4,6,7	1,4,6,7	214	214	56	56	8.94	8.94	0.0
	0.84	1,2,4,5	1,2,4,5	237	237	33	33	2.68	2.68	0.0
	0.96			270	270	0	0	0.00	0.00	0.0
5	0.18	1,4,5,7,9	1,4,5,7,9	12	12	258	258	50.31	50.31	0.0
	0.36	1,4,5,7,9	1,4,5,7,9	28	28	242	242	48.74	48.74	0.0
	0.48	1,2,4,6,7	1,2,4,6,7	62	62	208	208	43.86	43.86	0.0
	0.60	1,2,4,7,9	1,2,4,7,9	113	114	157	156	35.27	34.98	0.8
	0.72	1,2,4,6,7	1,2,4,6,7	189	189	81	81	14.23	14.23	0.0
	0.84	1,2,4,5,9	1,2,4,5,9	214	214	56	56	6.92	6.92	0.0
	0.96			270	270	0	0	0.00	0.00	0.0

shown on Table 1. A trend to note is that as profit margins decreased, direct routes became the preferred route for the carriers.

CONCLUSION AND FUTURE WORK

This research proposed a mathematical programming formulation for centralized Carrier Collaboration Multi-hub Location Problem (CCCMLP) with hub processing cost. A centralized entity (third party logistic company) seeks to establish a set of hybrid consolidation transshipment hubs with capacities in a collaborative freight networks. The LTL operators participating in the collaboration have the option of routing their goods directly or through the collaborative transshipment hubs depending on their expected cost reductions at the shipment level. The goal of the mathematical programming formulation was to minimize the total collaborative transportation and facility location costs.

As the expected cost reduction at the shipment level needed to incentivize collaboration decreases, likelihood of carriers entering into collaboration increases. If the carriers expect significant cost reductions to enter into a collaborative strategy, then the potential savings from the collaboration will decrease.

This study will be extended in multiple directions. Future will involve studying the impact of demand uncertainty and dynamic travel times and costs on the resiliency of the collaboration.

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