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Carrier Collaborative Networks: Hybrid Hub Location Algorithms

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CARRIER COLLABORATIVE NETWORK: HYBRID HUB LOCATION AND ALGORITHM

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ABSTRACT

Within the context of the Logistics and supply chain and management, the Hybrid Hub and Spoke system has certain complexities regarding the selection of the hub location in the supply chain facility system. The performance and efficiency of the network route selection and hub location depends upon the percentage savings that has been made by choosing the appropriate location for the hub to maintain the efficient flow of the goods within the network. Hub location selection mostly depends on the profit margins shared by the carrier, supply and demand status of the facility and amount of flow of the goods through the facilities. This research develops a mathematical model using Centralized Carrier Collaborative and Multi-Hub Location Problem. The model encompasses various cost like costs of transportation for Direct Transport and Collaborative Transport, cost related to loading, unloading and operations, holding costs and maintenance cost, these are incorporated in taking decision for locating hub within a set of nodes/facilities. A Genetic algorithm meta–heuristic is used to solve the large size problems. The solution obtained using this meta-heuristics are compared with solution obtained from using Lagrangian Relaxation approach. An experimental study evaluates the sensitivity of the problem and analyses the hub location behavior of the problem by varying the profit margins and level of willingness of the carriers to collaborate subject to the percentage saving made.

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CHAPTER 1: INTRODUCTION

Since the advent of the Internet in the 1990s, the less-than-truckload (LTL) industry has become more competitive than ever before. Shippers, usually larger manufacturers and retailers have increased their transportation requirements due to innovative inventory practices and increased activity in e-commerce, have spurred the competition (Song and Regan, 2004). In addition, the Internet, along with information communication technologies (ICT), is prompting changes to the structure of transportation marketplaces by fostering more spatially spread demand (Anderson et al., 2003). These innovations have created new challenges for LTL carriers in the form of increased costs related to deadheading (moving empty) and increased energy prices. The greatest economic impact has been felt in the small- to medium-sized LTL trucking industry, which has endured increased costs that affect their ability to sustain profits. Low margins of profitability, spatially spread demand, and intense competition have incited a trend to seek solutions through information communication technologies (ICT) and the Internet (Mowery, 1999). One manifestation of this is the increase in small- to medium-sized LTL carrier-carrier collaboration. That is, the small- to medium-sized LTL carriers have begun to develop a new generation of strategies that exploit synergies (such as excess capacity, overlapping lanes, and facilities), which form the basis for some forms of collaboration and the motivation for this study.

1.1 Background

Dai and Chen (2011) stated that Carrier Collaboration can be an important new standard for improving operations and reducing supply chain costs. In collaborative logistics, multiple carriers may form an alliance or group by sharing their transportation requests and vehicle capacities in order to increase vehicle utilization rates and reduce empty back hauls to raise vehicle utilization rates and thus to increase the profit of each carrier involved. Driven by cost reduction requirements due to fierce competition in the transportation market and increased environmental concerns, improving operational efficiency through resource sharing and

collaborative transportation planning is becoming a new business model for transportation industry. There are mainly two methods to solve the collaborative logistics problems: Centralized and Decentralized methods. In case of centralized methods all the transport is concentrated at certain allocated fixed location or facility which acts as a port or Hub for sorting dispatching and transferring loads to different destinations. Whereas in decentralized method mostly direct transport is preferred rather than concentrating goods at one place as in case of centralized one. In this thesis, centralized method to solve the collaboration of logistic problem is being used to solve the problem, named as Centralized Carrier Collaboration Multi Facility Location Problem (CCCMLP).

1.2 Objective

The Idea behind the development of the formulation for CCCMLP is to have an efficient methodology and formulation to optimize the location of facility (Hub) and vehicle routes network by using both Direct and Hub-and-spoke system methods of Distribution, designed for multiple carriers to act collaboratively seeking for more profit at different collaborative profit margins for a single commodity (single product). Objective of this research work is to formulate the CCCMLP and test its sensitivity with respect to many parameters, like varying profit margin, collaboration percentage, number of Hubs / facilities selected, and their effects on the percentage saving, route selection i.e., Direct routes / Collaborative routes.

1.3 Research Scope

Even for a single commodity problem with large number of facilities (nodes), multiple carriers, varying profit margins between carriers for collaboration and availability of numerous routes, it is difficult to decide the appropriate shortest economical route. This problem is formulated as variant of the p-median problem and solved using two different approaches / methods, namely, Lagrangian relaxation method and Genetic Algorithm. A sensitivity analysis is conducted and the results of the sensitivity analysis of both solution methods are studied and discussed in the chapters in this research work.

1.4 Thesis Organization:

The research project entails several steps to adequately execute the analysis so as to meet the objective. The first step of the research work was to conduct a literature review, which is summarized in the next chapter (2), Chapter (3) consists of research methodology, in this chapter we will be discussing the various methods that were being used to solve the problem. Further Chapter (4) consists of the study of Lagrangian Relaxation method and its sensitivity analysis, Chapter (5) is about study and generation of the solution obtained by solving the problem in Genetic Algorithm method. In further chapters the comparison study is done and discussed in Chapter (6) and the research work is concluded in the last chapter i.e., Chapter (7).

CHAPTER 2: LITERATURE REVIEW

This chapter provides the literature review conducted for the research work. The literature review covers carrier collaboration, hub location, hybrid hub-and-spoke system of distribution and their significance in the logistics industry respectively. For the research work the literature reviews were conducted in three different headings. The literature is relatively sparse in regards to the above mentioned topics; however, the following are our attempts to review the state of the art.

2.1 Hybrid Hub and Spoke system of Distribution

The increasing trend of Logistic Service Providers (LPPs) has enabled the formation of hub-and-spoke networks in the physical goods industry. Hub-and-spoke networks have been classified into two types: Pure and Hybrid.

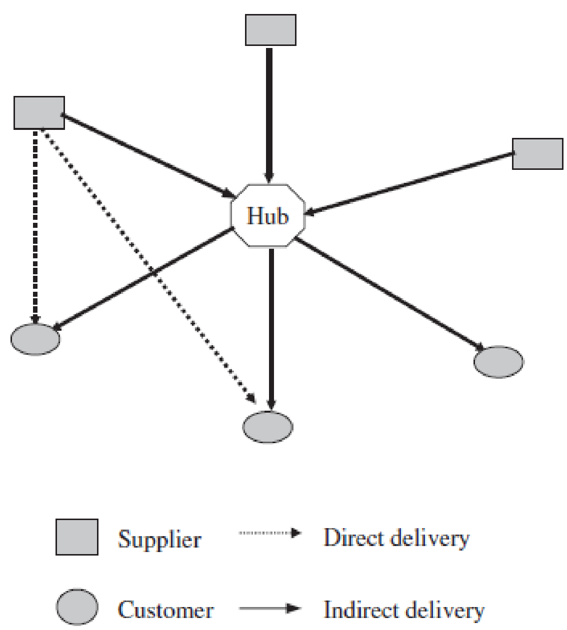


Figure 2.1: Concept of Hybrid Hub and Spoke System of Network (Direct and Indirect Routes)

The concept of hybrid hub-and-spoke is a relatively new one. Although not explicitly collaboration, (Zhang et al., 2007) introduced the concept of hybrid hub-and-spoke for a single LTL carrier trying to minimize transportation costs. In their work, hybrid refers to the addition of

direct routes to a pure hub-and-spoke system. The authors formulate the problem as a combinatorial one and solve it using a genetic algorithm solution methodology. Similarly, Zäpfel and Wasner (2002) developed a hub-and-spoke system for cooperative third party logistics firms.

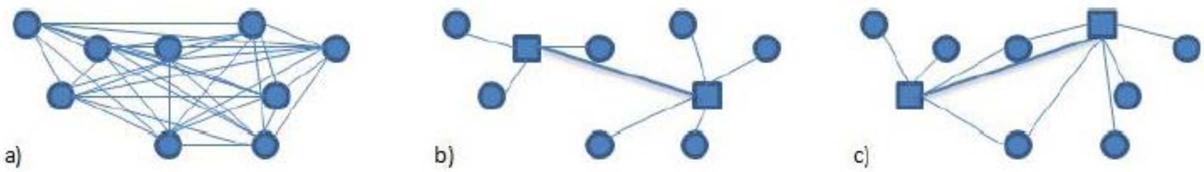


Figure 2.2: a) fully connected network b) single allocation hub and spoke design c) multiple allocation hub and spoke design.

From an LTL and pure hub-and-spoke perspective, Cunha and Silva (2007) focused on configuring a hub-and-spoke network for an LTL trucking company in Brazil. They sought to determine the number of consolidation terminals (hubs), their locations, and the assignment of the spokes to the hubs, while aiming to minimize the total cost. The authors used a genetic algorithm and local improvement procedure to solve the problem.

Zäpfel and Wasner (2002) stated that the operative planning task of a hub-and-spoke network is a challenging task for the management of such transportation networks. They developed the mathematical models for the operative planning tasks and applied to a real case of an Austrian parcel service provider. From a pure hub-and-spoke perspective, (O'Kelly, 1986 and 1987) formulated and solved a hub-and-spoke facility location problem as a quadratic integer program and developed enumeration heuristics to solve the problem. The initial formulation was developed among multiple directions to add new features consistent with various applications of hub-and-spoke facilities. The following studies by Aykin (1994), Ernst and Krishnamoorthy (1999) and Ebery et al. (2000) considered capacities on hubs whereas Pirkul and Schilling (1998) and Klincewicz (1996) and Topcuoglu et al. (2005) studied the uncapacitated case. Hub-and-

spoke facility locations problems can also be classified as single assignment Ernst and Krishnamoorthy (1999) where a specific origin-destination flow is assigned to one hub only and multiple assignment (Ebery et al., 2000) and where a specific origin-destination flow is split among multiple hubs. The studies by Kuby and Gray (1993) and Aykin (1995) developed models which captured the flexibility of flows being sent directly without passing through hubs. Recently, Elhedhli (2005) and Elhedhli and Wu (2010) developed non-linear programming formulation to capture congestion at hubs. In terms of solution methodologies, Lagrangean relaxation has been widely used to solve different variations of the hub-and-spoke facility location problem (Aykin, 1994; Pirkul and Schilling, 1998; Elhedhli, 2005; Elhedhli and Wu, 2010). Other solution techniques which have been explored include heuristic methods (Klincewicz, 1996; Klincewicz, 1991), meta-heuristics (Topcuoglu et al., 2005; Klincewicz, 1992), and exact methods such as branch and bound (Klincewicz,, 1996; Aykin, 1995).

In the context of the CCCMLP problem addressed here, the current literature either addresses collaboration without consideration of multi-hub location or addresses the multi-hub location from the context of a single LTL carrier. In addition, the hybrid hub-and-spoke definition differs from the current literature in that we define it as a set of collaborative consolidation transshipment hubs from a current point-to-point network structure. In essence, a hub-and-spoke system is formed without costly investments in new facilities. With this structure, the centralized carrier collaborative network can benefit from the hub-and-spoke system in that it can consolidate shipments at specified locations to increase efficiency of the member carrier operations. To the best of our knowledge, this is the first study to model a centralized carrier collaboration problem for the development of hybrid hub-and-spoke system. In addition, this work differentiates itself from previous hub location literature by assuming a real world rate setting behavior strategy. Addressed from a planning perspective, the CCCMLP represents a starting point for studying the effects of rate setting by collaborative carriers in a centralized carrier collaborative network

2.2 Carrier Collaboration

LTL carrier collaboration is a relatively unexplored concept within the ground freight domain. Past studies have focused on collaboration within the truckload (TL) carrier, liner shipping, and rail industries (Song and Regan, 2004; Agarwal and Ergun, 2008; Kuo et al., 2008; Voruganti et al., 2011). Recently, Hernandez and Peeta (2010), Hernandez et al. (2011) and Hernandez and Peeta (2011) introduced and examined the viability of LTL carrier collaboration from a static and dynamic context for a single carrier, and centralized planning perspective for multiple carriers. Their studies explored the potential benefits of the LTL carrier collaborative paradigm based on the degrees of collaboration, and for the centralized work rate setting strategies. In addition, Voruganti et al. (2011) studied partial and full collaboration among carriers and used shapely value principle to distribute the profits. The network topology was found to have a significant impact on the success of the collaboration. In Bailey and Unnikrishnan (2011), the authors developed integer programming models and heuristic algorithms which can be used by medium level freight companies to evaluate savings obtained by entering into collaboration with other shippers/carriers to minimize deadheading. Additionally, Bailey (2011) also developed cardinality and capacity constrained lane covering formulation for shipper collaboration and used tabu search to solve the problem. Proportional and marginal cost based allocations mechanisms were used to distribute the transportation costs among the participating shippers. However, the above studies either did not assume an explicit network or formulated the problem as a network design problem. Additionally, the location of hubs to facilitate collaboration was not addressed as separate objective component.

2.3 P-Median / Hub Location Problem

Hub location or P-Median Problem is one of the major complex problems in supply chain management and logistics industry. It involves locating facilities and designing hub networks. The hub location problem has a goal to minimize total cost (as a function of distance) of

transportation between hubs, facilities and demands. Rather than serving every origin-destination demand with a direct link, a hub network provides service via smaller set of links between origin/destinations and hubs, and between pairs of hubs. Hub network allows large set of origins to be connected with fewer links, via central hub facilities. Use of fewer links in the network concentrates flows and allows economies of scale to be exploited.

Several algorithms for the p-median problem have been proposed like exact methods based on linear programming, Constructive algorithms, dual based algorithms and local search procedures. Tabu search procedure has been proposed by Vob and Rolland et al. (1996). Further methods were compared by Rosing et al. (1979) with the heuristic concentration method, Hansen and Mladenovic (2001) proposed a VNS (Variable neighborhood Search) for the problem, Heuristics based on the linear programming were studied by du Merle et al. (1999) and by Senne and Lorena (2000 and 2001).

2.4 Lagrangian Relaxation in Network Optimization and Hub location Problems

Lagrangian Relaxation has many applications in the different Optimization problems, Planning and Scheduling, network routing, Hub location, etc. Lagranginan Relaxation is a Heuristic method which is use to solve large number of NP-hard problems (Non-Deterministic Polynomial-time Hard Problems), Aykin (1994) introduced the capacitated hub-and-spoke network design problem in which hubs have limited capacity for channeling flows between the nodes served by the system. Akio et al. (2007), developed a sub-gradient heuristic based on a Lagrangian relaxation which enables us to identify a near optimal solution. Huang and Chi (2007) developed a recursive heuristic algorithm for the consolidation problem of airfreight forwarders. Zhu et al. (2010), introduces a new problem called the capacitated plant location problem with customer and supplier matching (CLCSM) and developed a heuristic solution procedure based on Lagrangian relaxation. Hande Yaman (2008) has proposed two formulations and a heuristic algorithm to find the hub locations and the connections to minimize the link

installation cost. Lin et al. (2012) has proposed the general capacitated p-hub median model, with economies of scale and integral constraints on the paths. In their paper they explored the problem structure and developed a genetic algorithm using the path for encoding and compared the optimality bounds that obtained using Lagrangian relaxation lower bounds. Lin et al. (2009) studied the price planning simultaneous that determines the service demand and an operational plan to maximize a carrier's profit. They modeled the integral-constrained concave program in the link formulation and proposed an implicit enumeration embedded with Lagrangian relaxation upper bounds to determine the optimal prices. Lee et al. (1996), develops a graph-based model and a Lagrangian relaxation scheme to find a provably good solution for the problem of designing Digital Data Service (DDS) Networks described earlier in Lee et al. (1996)

2.5 Genetic Algorithm in Network Optimization and Hub location problems

I. Rechenberg in 1960s introduced the idea of evolutionary computing in his work called "Evolution strategies". Further this idea was then developed by other researchers. John Holland in 1975 has invented Genetic Algorithms (GAs) which was developed by him and his students and colleagues. Later in 1992 John Koza used the Genetic Algorithm to evolve programs to perform certain tasks and called these programs as "Genetic Programming" (GP).

Genetic Algorithm is a Meta-Heuristic approach of finding best possible solution for an Optimization problem. It has a wide range of applications in the field of Optimization, Planning and scheduling; Network designing, Routing problems, computer applications, Hub-Locations, etc. Ho et al. (2008), focused on the VRP with multiple depots, or multi-depot VRP (MDVRP), two hybrid genetic algorithms (HGAs) are developed and results were compared, Mohammadi et al. (2011), they present a nonlinear mathematical programming to find an optimal solution for the Hub location problem in Cargo delivery system, further they improved meta-heuristic based on Imperialist Competitive Algorithm and Genetic Algorithm to find near optimal solution of the problem. Zäpfel and Bögl (2008), considered short-range weekly planning on the part of

postal companies that must decide about pickup tours and delivery tours for fluctuating volume (number of shipments), with time windows for the demand points, in consideration of variable vehicle capacities and personnel planning, and including outsourcing decisions for tours and drivers. They proposed a hybrid meta-heuristic combined with a construction heuristic. Geroliminis et al. (2011) presented a model and a heuristic solution for the optimal deployment of many emergency response units in an urban transportation network and an application for transit mobile repair units (TMRU) in the city of Athens, Greece. Chan et al. (2005), developed a hybrid genetic algorithm for production and distribution problems in multi-factory supply chain models. Cunha and Silva (2007) in there paper proposed the problem of configuring hub-and-spoke networks for trucking companies that operate less-than-truckload (LTL) services in Brazil.

CHAPTER 3: RESEARCH METHODOLOGIES

3.1 Mathematical model of the CCCMLP

3.1.1 Problem Description and Assumptions:

The CCCMLP seeks to determine a set of hybrid collaborative consolidation transshipment hubs for a central entity (e.g., third party logistics firm) to help establish a collaborative hybrid hub-and-spoke system that minimizes that total collaborative costs for the set of collaborating carriers. Hence, a carrier in this system is classified as either a collaborative carrier (shares the costs to set up hybrid hubs), or non-collaborative (decides to ship directly). The operational networks of the collaborating carriers can be completely identical geographically or overlap in some segments relative to other carriers in the collaborative.

The collaborative rate structure of the collaborative carriers is represented by revenue oriented. If a collaborative opportunity cannot be identified with regards to hybrid collaborative consolidation transshipment hubs, a non-collaborative option is considered. It is assumed that the costs of shipping directly fall upon the carrier itself.

The following assumptions are made in the CCCMLP: (i) candidate hybrid collaborative consolidation transshipment hubs are uncapacitated, and (ii) homogenous products are shipped. In addition, the problem is deterministic in the sense that the demand is known and the available holding times at facilities are time invariant. By contrast, a stochastic version of the problem would entail stochasticity of demand of the collaborating carriers.

3.1.2 Problem Formulation

This section describes the mathematical formulation of CCCMLP. The notation, constraints, and objective function are presented, followed by the characterization and solution methodology of the formulation.

3.1.2.1 Sets

Let a shipment from collaborative carrier $q \in Q$ enter the collaborative network through an origin facility $i \in I \subseteq N$ and travel via hybrid collaborative consolidation candidate transshipment hubs $l, m \in N$ and exit through a destination facility $j \in J \subseteq N$. For each collaborative carrier $q \in Q$ shipment, its origin facility $i \in I$ and its destination facility $j \in J$ constitutes its origin-destination pair. Here, an origin and destination facility can represent a supplier or DC/warehousing, or retailer.

3.1.2.2 Parameters

Each collaborative carrier $q \in Q$ has an associated demand d_{ijq}. Let ς_{ijlm} be the collaborative carrier $q \in Q$ revenue oriented cost associated to a unit of demand d_{ijq} to travel between origin facility $i \in I$ to destination facility $j \in J$ when going via hybrid collaborative consolidation candidate transshipment facilities at node $l \in N$ and $m \in N$. The revenue oriented cost structure follows (4) and is represented here as the functional form:

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

In equation (1), δ represents the collaborative discount between hybrid consolidation collaborative candidate transshipment facilities $l, m \in N$.

Further, the number of hybrid facilities the centralized carrier collaborative network wishes to locate is p. The cost to a carrier to establishing a hybrid collaborative consolidation candidate transshipment hub is φ_{lq} and is as follows:

$$\varphi_{lq} = \vartheta_{lq} + \phi_{l} \tag{2}$$

In equation (2), ϑ_{lq} represents the holding costs as defined in (5) (captures congestion effects), and ϕ_{lq} represents the costs associated with establishing connections at a hub.

As comparative measure to the collaboration, the non-collaborative costs of moving a shipment of demand d_{ijq} between an origin facility $i \in I$ to a destination facility $j \in J$ directly is w_{ijq}. These costs are comprised of distance, labor (includes deadheading), and fuel costs associated to the shipment.

3.1.2.3 Variables

If a shipment originating from $i \in I$ headed to destination $j \in J$ by collaborative carrier $q \in Q$ travel via consolidation hubs at node $l \in N$ and $m \in N$, we define Y_{ijlmq} to take the value 1, and 0 otherwise. This variable represents the collaborative carrier participation. In addition, we note that participation is not mandatory.

If a shipment originating from $i \in I$ headed to destination $j \in J$ by carrier $q \in Q$ who does not participate in the collaboration, V_{ijq} takes the value 1, and 0 otherwise.

If a hybrid collaborative consolidation candidate transshipment hub is located at node $l \in N$, X_l takes the value 1, and 0 otherwise.

3.1.2.4 Constraints

Next, we formulate the constraint set of the CCCMLP. It consists of two sets of constraints. The first set of constraints (3, 4, 5, and 6) model the hybrid collaborative consolidation candidate hub location. The second set of constraints (4 and 7) establishes lower bounds on the revenue potential for the carrier collaborative network. The constraints are as follows:

$$\sum_{l \in N} X_l = p \qquad \forall l \in N \qquad (3)$$

$$\sum_{l \in N} \sum_{m \in N} Y_{ijlmq} + V_{ijq} = 1 \qquad \forall i \in I, j \in J, q \in Q \qquad (4)$$

$$\sum_{m \in N} Y_{ijlmq} \leq X_l \qquad \forall i \in I, j \in J, l \in N, q \in Q \quad (5)$$

$$\sum_{l \in N} Y_{ijlmq} \leq X_m \qquad \forall i \in I, j \in J, m \in N, q \in Q \quad (6)$$

$$\varsigma_{ijlm} Y_{ijlmq} \leq w_{ijq}\left(1 - V_{ijq}\right)(1 - \gamma) \qquad \forall i \in I, j \in J, l \in N, m \in N, q \in Q \quad (7)$$

$$X_l \in \{0,1\} \qquad \forall l \in N \quad (8)$$

$$Y_{ijlmq} \in \{0,1\} \qquad \forall i \in I, j \in J, l \in N, m \in N, q \in Q \quad (9)$$

$$V_{ijq} \in \{0,1\} \qquad \forall i \in I, j \in J, q \in Q \quad (10)$$

Constraint (3) represents the number of candidate hybrid collaborative consolidation hubs to be located. Constraint (4) ensures that for each origin-destination (OD) pair (i, j) and each collaborative carrier must either be assigned to exactly one hub pair or may not participate in the collaboration and transport their goods via their usual route. 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 collaborative consolidation hub is located in these candidate sites. Constraint (7) represents the carrier collaborative revenue and states that a specific carrier $q \in Q$ for each origin-destination pair (i, j) will participate in the collaboration only if their costs are lower than the standalone costs by a pre-specified margin. Note, in constraint (7), γ represents the profit margin expected by a collaborative carrier $q \in Q$ in order to participate in the collaboration. Constraint sets (8), (9) and (10) represent the 0-1 integrality conditions for the decision variables.

3.1.2.5 Objective Function

$$Min \quad \sum_{i\in I}\sum_{j\in J}\sum_{l\in N}\sum_{m\in N}\sum_{q\in Q} \varsigma_{ijlm} d_{ijq} Y_{ijlmq} + \sum_{i\in I}\sum_{j\in J}\sum_{q\in Q} w_{ijq} d_{ijq} V_{ijq} + \sum_{l\in N}\sum_{q\in Q} \varphi_{lq} X_l \tag{11}$$

The objective function seeks a set of candidate hybrid collaborative consolidation hubs as to minimize the total transportation collaborative costs in a supply chain. It consist of three terms, the first term represents the total transportation costs associated to the carrier collaborative, the second part represents the total costs associated with carriers not collaborating and shipping directly, and third represents the total carrier collaborative costs associated with locating a collaborative candidate hybrid consolidation facilities. The collaborative transportation costs are obtained as the summation of the product of the cost of travel for a shipment ς_{ijlm}, the collaborative carrier demand d_{ijq}, and Y_{ijlm} (the decision on whether a shipment travels via the collaborative hubs). The non-collaborative costs are obtained as the summation of the cost of shipping directly w_{ijq}, the collaborative carrier demand d_{ijq}, and the V_{ijq} (the decision on whether to ship directly). The collaborative candidate hybrid consolidation hub location costs are obtained as the summation of the product of the costs of locating a collaborative hub φ_{lq}, and the X_l(the decision on whether a collaborative facility is located). Equation (11) subject to constraints (3) to (10) represents the mathematical formulation of the centralized carrier collaborative multi-hub location problem (CCCMLP).

3.1.3 Properties

This section discusses some properties of the proposed TD-MCCP formulation.

3.1.4 Classification

The mathematical programming formulation of the CCCMLP belongs to the class of P-hub median location problems (18,19,32,33). This is the case since constraints (3), (4), (5), and (6)

without V_{ijq} (the decision on whether to ship directly) reduces to a P-hub median problem. This class of problems is found to be NP-hard as the network and number hubs increases (i.e., for p >2) (32, 34). Hence, we propose a solution methodology based on Lagrangian relaxation to solve this problem (32).

CHAPTER 4: SOLVING CCCMLP USING LAGRANGE RELAXATION METHOD.

4.1 Lagrangian Relaxation Method

The number of binary variables and constraints in the above integer program explodes with increase in problem size. For example, in a 10 node network, the number of binary integer variables is of the order of 104. Therefore the number of variables might become too large for regular solvers for problem instances of reasonable sizes. A Lagrangian Relaxation based heuristic is thus used to solve the model. In the above formulation, constraints (5) and (6) are relaxed with $\alpha_{ijlq}\ \forall\ i \in N, j \in N, l \in N, q \in Q$ and $\beta_{ijmq}\ \forall\ i \in N, j \in N, l \in N, q \in Q$ being the corresponding non-negative lagrange multipliers. For any specific value of (α, β) where $\alpha = (\alpha_{ijlq}\ \forall\ i \in N, j \in N, l \in N, q \in Q)$ and $\beta = (\beta_{ijmq}\ \forall\ i \in N, j \in N, l \in N, q \in Q)$, the corresponding Lagrangian relaxed problem formulation is given below:

$$Z(\alpha,\beta) = Min \sum_{i\in I}\sum_{j\in J}\sum_{l\in N}\sum_{m\in N}\sum_{q\in Q}\bar{C}_{ijlmq}Y_{ijlmq} + \sum_{i\in I}\sum_{j\in J}\sum_{q\in Q} w_{ijq}d_{ijq}V_{ijq} + \sum_{l\in N}\bar{F}_l X_l$$

subject to: (3), (4), (7), (8), (9), (10)

where:

$$\bar{C}_{ijlmq} = \varsigma_{ijlm}d_{ijq} + \alpha_{ijlq} + \beta_{ijmq} \qquad \forall\ i \in N, j \in N, l \in N, m \in N, q \in Q$$

$$\bar{F}_l = \sum_{q\in Q}\varphi_{lq} - \sum_{i\in I}\sum_{j\in J}\sum_{q\in Q}\alpha_{ijlq} - \sum_{i\in I}\sum_{j\in J}\sum_{q\in Q}\beta_{ijlq} \qquad \forall l \in N$$

The above formulation can be decomposed into two sub problems **[SUB-I]** and **[SUB-II]**:

[SUB-I]

$$Z_{R1}(\alpha,\beta) = Min \sum_{i\in I}\sum_{j\in J}\sum_{l\in N}\sum_{m\in N}\sum_{q\in Q}\bar{C}_{ijlmq}Y_{ijlmq} + \sum_{i\in I}\sum_{j\in J}\sum_{q\in Q} w_{ijq}d_{ijq}V_{ijq}$$

subject to : (4), (7), (9), (10)

[SUB-II] $Z_{R2}(\alpha,\beta) = Min \sum_{l\in N}\overline{F}_l X_l$

subject to : (3), (8)

Sub-problems **[SUB-I]** and **[SUB-II]** can be solved using the heuristics shown below. Let $\underline{Y}_{ijlmq}$, $\underline{V}_{ijq}$ and $\underline{X}_l$ denote the solution to **[SUB-I]** and **[SUB-II].**

Solving [SUB-I]

SUB-I decomposes into $|N|^2|Q|$ minimization problems for each $(i \in N, j \in N, q \in Q)$ tuple.

(i) The first step in solving [SUB-I] is pre-screening for variables which do not satisfy constraint (7).Thus for every $i \in I, j \in J, l \in N, m \in N, q \in Q$, if $\varsigma_{ijlm} > w_{ijq}(1-\gamma)$ then $\underline{Y}_{ijlmq}$ can be fixed

to zero. This is because it is always more beneficial for the carrier to send their goods directly than through hubs l and m.

(ii) In the second step, for each $i \in I, j \in J, q \in Q$ the minimum value $\bar{C}_{ijq}^{min} = \min\{\bar{C}_{ijlmq} : l \in N, m \in N$ such that $\underline{Y}_{ijlmq} \neq 0\}$ is found. Let l' and m' be the hub locations on the route corresponding to $\bar{C}_{ijq}^{min}$. If $\bar{C}_{ijq}^{min} \leq w_{ijq}d_{ijq}$ then set $\underline{Y}_{ijl'm'q} = 1, \underline{V}_{ijq} = 0$ else set $\underline{Y}_{ijl'm'q} = 0, \underline{V}_{ijq} = 1$.

Solving [SUB-II]

SUB-II can be solved by sorting the value of $\bar{F}_l$ in ascending order and choosing the p minimum values and setting the corresponding $\underline{X}_l$ to be equal to 1.

Note that the solution obtained from the above procedures by solving SUB-I and SUB-II may not be feasible for the original formulation as constraint (5) and (6) may not be satisfied, i.e. carriers might be routing goods through unopened hubs. For any set of values for α and β, the solution ($\underline{Y}_{ijlmq}$, $\underline{V}_{ijq}$ and $\underline{X}_l$ $\forall\, i \in N, j \in N, l \in N, m \in N, q \in Q$) can be used to find a lower bound to the original problem as:

$$Z_{R1}(\alpha, \beta) + Z_{R2}(\alpha, \beta) \leq Z(\alpha, \beta)$$

The solution obtained from solving SUB-I and SUB-II can be converted to a feasible solution ($\bar{Y}_{ijlmq}, \bar{V}_{ijq}$ and $\bar{X}_l$ $\forall\, i \in N, j \in N, l \in N, m \in N, q \in Q$) using the procedure given below.

4.2 Obtaining Feasible Solution

For each $(i \in N, j \in N, q \in Q)$ tuple, if $\underline{V}_{ijq} = 1$ the carrier is sending goods directly and the route is feasible and set the corresponding $\overline{V}_{ijq} = 1$. If $\underline{V}_{ijq} = 0$, then find the hub locations l' and m' through which the carrier routes the goods. Depending on the values of $\underline{X}_{l'}$ and $\underline{X}_{m'}$, four cases are possible.

Case 1: If $\underline{X}_{l'} = 1$ and $\underline{X}_{m'} = 1$ then the carrier is routing the goods through opened hubs and therefore the route is feasible. Set $\overline{Y}_{ijl'm'q} = 1$.

Case 2: If $\underline{X}_{l'} = 1$ and $\underline{X}_{m'} = 0$, then the carrier is routing goods through unopened hub m'. In this case determine $\bar{C}^{min}_{ijl'q} = \min \{ \bar{C}_{ijl'mq} : m \in N$ such that $\underline{Y}_{ijl'mq} \neq 0$ and $\underline{X}_m = 1\}$ and let m'' be the hub corresponding to $\bar{C}^{min}_{ijl'q}$. We are comparing the modified costs of all routes $(i - l' - m - j)$ with open hubs $\{m \in N: \underline{X}_m = 1\}$ which have not been fixed to 0 in the pre-screening stage, $\underline{Y}_{ijl'mq} \neq 0$, and finding the minimum cost route. We then set the corresponding $\overline{Y}_{ijl'm''q} = 1$. Note that if there are no routes $(i - l' - m - j)$ with open hubs $\{m \in N: \underline{X}_m = 1\}$ which have not been fixed to 0 in the pre-screening stage, then we set the corresponding $\overline{V}_{ijq} = 1$.

Case 3: If $\underline{X}_{l'} = 0$ and $\underline{X}_{m'} = 1$, then the carrier is routing goods through unopened hub l'. In this case determine $\bar{C}^{min}_{ijm'q} = \min \{ \bar{C}_{ijl'mq} : l \in N$ such that $\underline{Y}_{ijlm'q} \neq 0$ and $\underline{X}_l = 1\}$ and let l'' be the hub corresponding to $\bar{C}^{min}_{ijm'q}$. We are comparing the modified costs of all routes $(i - l - m' - j)$ with open hubs $\{l \in N: \underline{X}_l = 1\}$ which have not been fixed to 0 in the pre-screening stage, $\underline{Y}_{ijl''m'q} \neq 0$, and finding the minimum cost route. We then set the corresponding $\overline{Y}_{ijl''m'q} = 1$.

Note that if there are no routes $(i - l - m' - j)$ with open hubs $l \in N$ which have not been fixed to 0 in the pre-screening stage, then we set the corresponding $\overline{V}_{ijq} = 1$.

Case 4: If $\underline{X}_{l'} = 0$ and $\underline{X}_{m'} = 0$, then the carrier is routing goods through unopened hub l' and m'. In this case determine $\bar{C}^{min}_{ijl'm'q} = \min \{ \bar{C}_{ijl'mq} : l \in N, m \in N$ such that $\underline{Y}_{ijl'm'q} \neq 0$ and $\underline{X}_l = 1$ and $\underline{X}_m = 1\}$ and let l" , m" be the hubs corresponding to $\bar{C}^{min}_{ijm'q}$. We are comparing the modified costs of all routes $(i - l - m - j)$ with open hubs $\{ \; , m \in N: \underline{X}_m = 1$ and $\underline{X}_l = 1\}$ which have not been fixed to 0, $\underline{Y}_{ijl''m''q} \neq 0$, in the pre-screening stage and finding the minimum cost route. We then set the corresponding $\overline{Y}_{ijl''m''q} = 1$. Note that if there are no routes $(i - l - m - j)$ with open hubs $l, m \in N$ which have not been fixed to 0 in the pre-screening stage, then we set the corresponding $\overline{V}_{ijq} = 1$.

4.3 The Lagrangian relaxation procedure can be summarized in the following steps

Step 1: [Initialization]: Set $\alpha_{ijlq} = 0$, $\beta_{ijlq} = 0 \;\; \forall i \in N, j \in N, l \in N, q \in Q$. Set the value of current best upper bound, $UB = \infty$ and the current best lower bound $LB = -\infty$. Set $\Delta = 2$.

Step 2: [Lower Bound]: Solve SUB-I and SUB-II for current values of α_{ijlq} , β_{ijlq} $\forall i \in N, j \in N, l \in N, q \in Q$ and determine $Z_{LB}(\alpha, \beta)$. If $Z_{LB}(\alpha, \beta) > LB$ then update $LB = Z_{LB}(\alpha, \beta)$.

Step 3: [Upper Bound]: Transform the lower bound solution $(\underline{Y}, \underline{V}, \underline{X})$ to a feasible solution $(\overline{Y}, \overline{X}, \overline{V})$ using the procedure described above to determine a feasible upper bound Z_{UB} . If $Z_{UB} < UB$ then update

$UB = Z_{UB}$.

Step 4: [Updating Lagrange Multipliers]: Update the multipliers based on the lower bound solution as follows.

$$s_{ijlq} = \sum_{m \in N} \underline{Y}_{ijlmq} - \underline{X}_l \qquad \forall i \in I, j \in J, l \in N, q \in Q$$

$$r_{ijmq} = \sum_{l \in N} \underline{Y}_{ijlmq} - \underline{X}_m \qquad \forall i \in I, j \in J, m \in N, q \in Q$$

$$t = \Delta \frac{[Z_{UB} - Z_{LB}(\alpha, \beta)]}{(\sum_{i \in I} \sum_{j \in J} \sum_{l \in N} \sum_{q \in Q} s_{ijlq})^2 + (\sum_{i \in I} \sum_{j \in J} \sum_{m \in N} \sum_{q \in Q} r_{ijmq})^2}$$

$$\alpha^{+}_{ijlq} = \alpha_{ijlq} + t\left(\sum_{m \in N} \underline{Y}_{ijlmq} - \underline{X}_l\right) \qquad \forall i \in I, j \in J, l \in N, q \in Q$$

$$\beta^{+}_{ijlq} = \beta_{ijlq} + t\left(\sum_{m \in N} \underline{Y}_{ijlmq} - \underline{X}_l\right) \qquad \forall i \in I, j \in J, l \in N, q \in Q$$

The parameter Δ is halved if there are no updates in lower bound objective function for 10 iterations. If the upper bound is updated Δ is reset to 2.

Step 5: [Convergence]: The algorithm is assumed to converge if any of the three conditions are satisfied: (i) the number of iterations is equal to a pre-specified maximum number of iterations (1500), (ii) Δ becomes lesser than a pre-specified minimum value (0.0025), and (iii) There is no improvement in upper bound for a fixed number of iterations (200). If the algorithm has not converged, go to step 2.

4.4 Study experiments

The study experiments analyze the performance of the CCCMLP under an individual rate-setting behavioral strategy (all carriers in the collaborative system assume the same rate-setting behavior). In addition, varying degrees of γ, the profit margin expected by a carrier in order to

participate in the collaboration will be studied. This is done to determine the point at which collaborating is cost effective to carriers considering the various network sizes.

4.5 Data Generation and Solution Method Implementation

The data for the CCCMLP problem was simulated using industry ranges and values introduced in (6) for: (i) the revenue oriented rate setting behavior, (ii) the costs of establishing a hybrid collaborative consolidation candidate transshipment hub, (iii) the origin-destination demand for multiple shipments, and (iv) the collaborative costs. A diesel fuel price of $3.79 per gallon is assumed.

The CCCMLP was coded in C++ using a standard compiler and computing environment consisting of a DELL T710 machine with Intel Xeon® X5680, under Window 7 Enterprise 64-bit operating with 3.33 GHz and 8GB of RAM.

4.6 Experiment Setup

The experimental set up consists of three collaborating carriers for the CCCMLP problem. The additional problem parameters take values according to the following ranges: network size in terms of the number of nodes (10 and 20) and the number hubs (2, 3, 4, and 5). The 10-node network and the 20-node network were 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 network size and number of hubs scenario, the collaborative rates, non-collaborative costs, and locational costs are randomly generated in addition to the demand.

4.7 Analysis of results:

The CCCMLP 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 (see Equation (7)). These margins are reflected through the parameter γ, which takes the values 9%, 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 γ the greater the profit margin. The values where chosen arbitrarily in increments of 9% to try to capture changes in the totals savings. The following tables illustrate the results of the analysis.

TABLE 4.1: Comparison of the Number of Hubs and Total Savings with Respect to Changes in γ for the 10 Node Network with 3 Collaborative Carriers (Lagrangian Relaxation Approach).

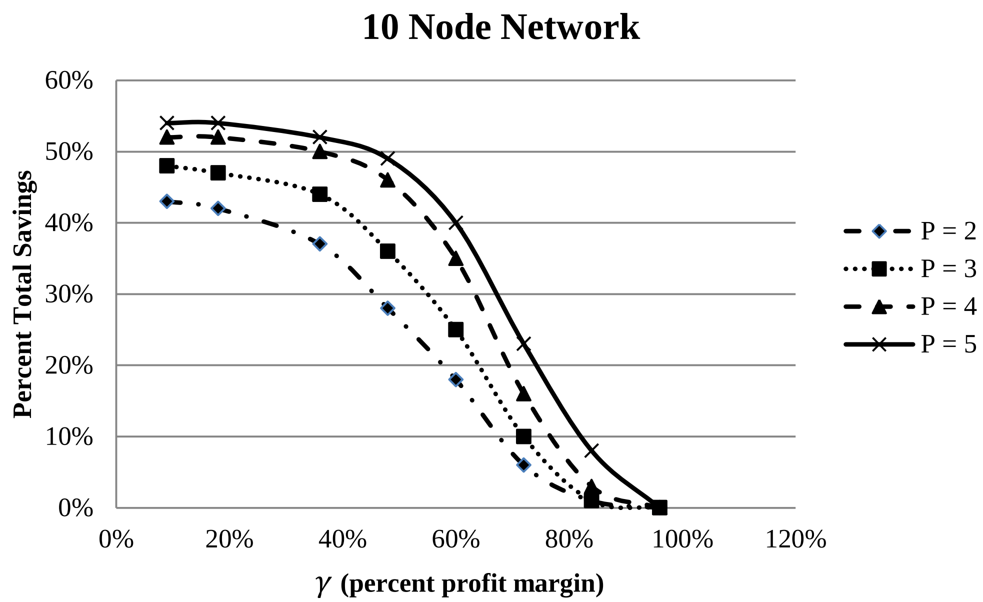
No. of Hubs (P>=2)	**γ value (Profit margin)**	**Selected Collaborative Hubs**	**No. of Direct Routes**	**No. of Collaborative Routes**	**Percent of Routes Collaborated**	**Total Percent Savings**
2	9.00%	1,4	22	248	91%	43%
	18.00%	1,4	45	225	83%	42%
	36.00%	1,4	95	175	64%	37%
	48.00%	1,4	152	118	43%	28%
	60.00%	1,4	198	72	26%	18%
	72.00%	1,4	246	24	8%	6%
	84.00%	1,4	264	6	2%	1%
	96.00%	1,4	270	0	0%	0%
3	9.00%	1,4,9	12	258	95%	48%
	18.00%	1,4,9	24	246	91%	47%
	36.00%	1,4,9	61	209	77%	44%
	48.00%	1,4,9	108	162	60%	36%
	60.00%	1,4,9	164	106	39%	25%
	72.00%	1,4,9	223	47	17%	10%
	84.00%	1,4,9	252	18	6%	1%
	96.00%	1,4,9	270	0	0%	0%
4	9.00%	1,4,7,9	8	262	97%	52%
	18.00%	1,4,7,9	18	252	93%	51%
	36.00%	1,4,7,9	39	231	85%	50%
	48.00%	1,4,7,9	68	202	74%	46%
	60.00%	1,4,7,9	124	146	54%	35%
	72.00%	1,4,7,9	195	75	27%	16%
	84.00%	1,4,7,9	234	36	13%	3%
	96.00%	1,4,7,9	270	0	0%	0%
5	9.00%	1,2,4,7,9	4	266	98%	54%
	18.00%	1,2,4,7,9	11	259	95%	53%
	36.00%	1,2,4,7,9	28	242	89%	52%
	48.00%	1,2,4,7,9	50	220	81%	49%
	60.00%	1,2,4,7,9	99	171	63%	40%
	72.00%	1,2,4,7,9	168	102	37%	23%
	84.00%	1,2,4,7,9	210	60	22%	8%
	96.00%	1,2,4,7,9	270	0	0%	0%

TABLE 4.2: Comparison of the Number of Hubs and Total Savings with Respect to Change in γ for a 20 Node Network with 3 Collaborative Carriers (Lagrangian Relaxation Approach).

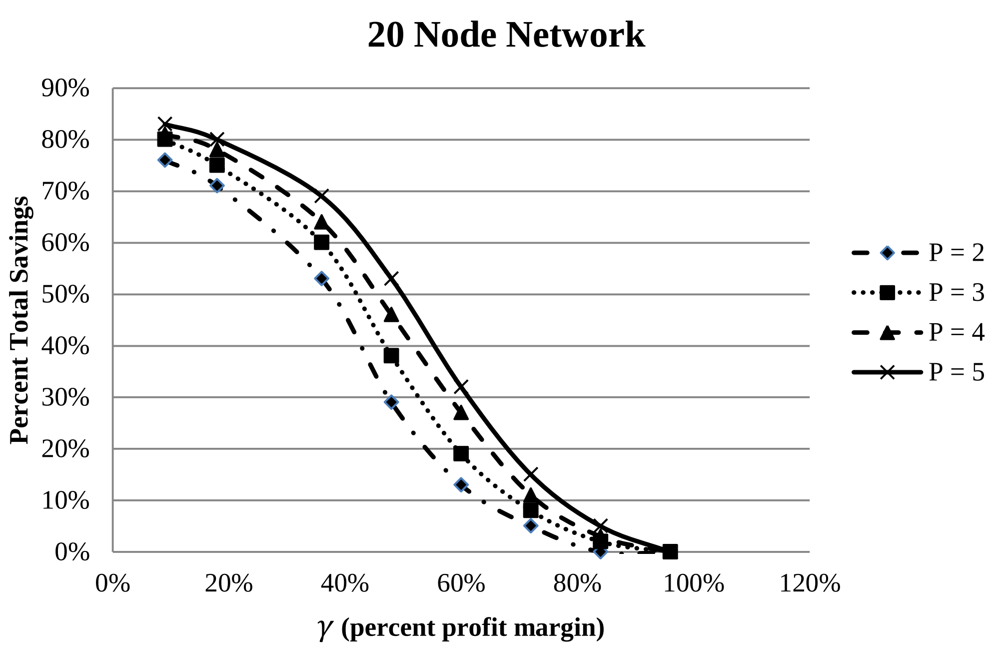
No. of Hubs (P>=2)	γ value (Profit margin)	Selected Collaborative Hubs	No. of Direct Routes	No. of Collaborative Routes	Percent of Routes Collaborated	Total Percent Savings
2	9.00%	7,15	121	1019	89%	76%
	18.00%	7,15	222	918	80%	71%
	36.00%	7,15	507	633	55%	53%
	48.00%	7,15	798	342	31%	29%
	60.00%	7,15	997	143	12%	13%
	72.00%	7,15	1092	48	4%	5%
	84.00%	7,15	1134	6	0%	0%
	96.00%	7,15	1140	0	0%	0%
3	9.00%	7,11,15	82	1058	92%	80%
	18.00%	7,11,15	169	971	85%	75%
	36.00%	7,11,15	418	722	63%	60%
	48.00%	7,11,15	686	454	39%	38%
	60.00%	7,11,15	917	223	19%	19%
	72.00%	7,11,15	1057	83	7%	8%
	84.00%	7,11,15	1122	18	1%	2%
	96.00%	7,11,15	1140	0	0%	0%
4	9.00%	7,11,12,15	65	1075	94%	81%
	18.00%	7,11,12,15	138	1002	87%	78%
	36.00%	7,11,12,15	359	781	68%	64%
	48.00%	7,11,12,15	591	549	48%	46%
	60.00%	7,11,12,15	836	304	26%	27%
	72.00%	7,11,12,15	1026	114	10%	11%
	84.00%	7,11,12,15	1104	36	3%	3%
	96.00%	7,11,12,15	1140	0	0%	0%
5	9.00%	7,11,12,14,15	46	1094	95%	83%
	18.00%	7,11,12,14,15	109	1031	90%	80%
	36.00%	7,11,12,14,15	284	856	75%	69%
	48.00%	7,11,12,14,15	505	635	55%	53%
	60.00%	7,11,12,14,15	770	370	32%	32%
	72.00%	7,11,12,14,15	983	157	13%	15%
	84.00%	7,11,12,14,15	1080	60	5%	5%
	96.00%	7,11,12,14,15	1140	0	0%	0%

Interpreting the results of the experiments from Table 4.1 and Table 4.2, which illustrate the comparison of the number of hubs and total savings with respect to changes in γ for a 10-node and 20-node networks. 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 γ increases the number of direct route increases. This shows the sensitivity of carrier shipments to changes in expected profits. Akin, the lower the γ the greater the percent of routes collaborated and total percent savings. The collaborative hubs selected for each scenario are shown on Table 4.1 and Table 4.2, respectively. A trend to note is that as profit margins decreased, direct routes became the preferred route for the carriers; however, hubs were still selected since the formulation did not preclude their selection. The hubs selected indicate the locations that would best facilitate the collaboration. In a future extension, Equation (3) will be omitted and a corresponding weight utilized for collaborative candidate hybrid consolidation hub location costs in the objective function to analyze tradeoffs with the other objective cost components.

With regards to the percent total savings for both the 10-node and 20-node networks, Figure 1 illustrates the comparison of γ to the percent total savings for varying number of collaborative hubs (P). As seen in Figure 4.1, for a greater number of hubs the net gains start to level off. This indicates that if the hybrid consolidation hub location costs remain constant, the overall savings differences in route collaboration and direct route at the lower level margins is limited to magnitude of the locational costs. This is especially true for the smaller network sizes (Figure 4.1a); still, for the 20 node network (Figure 4.1a) a larger percent savings is observed. This is the case since there are more carrier shipments that need to be made indicating that the costs associated to the collaboration and direct routes are outweighing the costs to place a collaborative candidate hybrid consolidation hub.



(a)



(b)

Figure 4.1: comparison γ to percent total savings for varying number of collaborative hubs (p) for: a) 10 node network, and b) 20 node network

In summary, the study experiments provide insights into the various expected profit margins and their ability to induce collaboration in the centralized carrier collaborative network to form a hybrid hub-and-spoke system. The sensitivity results indicate that at higher levels of expected profit margins the carriers are more apt to participate in the location of candidate hybrid consolidation hubs and for the routing of the collaborative shipments.

CHAPTER 5: SOLVING CCCMLP USING GENETIC ALGORITHM

5.1 Genetic Algorithm

I. Rechenberg in 1960s has introduced the idea of evolutionary computing in his work called "Evolution strategies". Further this idea was then developed by other researchers. John Holland in 1975 has invented Genetic Algorithms (GAs) which was developed by him and his students and colleagues. Later in 1992 John Koza used the Genetic Algorithm to evolve programs to perform certain tasks and called these programs as "Genetic Programming" (GP).

5.2 Introduction and Background

Genetic Algorithm is inspired by the Darwin's Theory of Evolution. At every iteration it gives the Evolved the Solutions from the set of Solutions called Population. The space of all the feasible solutions (it means objects among those the desired solution is) is called search space. There are many methods to find the suitable solutions like (Tabu Search, hill climbing, simulated annealing, ant colony optimization, etc.) but the solution found by the genetic Algorithm method is often considered as a good solution, because it is not often possible to prove what the real optimum is.

The algorithm starts with a set of solutions (represented by chromosomes) called population. In this research work the Population set was restricted to 200 and with 50 numbers of iterations / generation. The Solutions obtained from one population are taken and used to form a new population. The new population is better than the old one. The solutions which are selected to form new solutions (Offspring) are selected according to their fitness. This repeated until some conditions or stopping criteria is met.

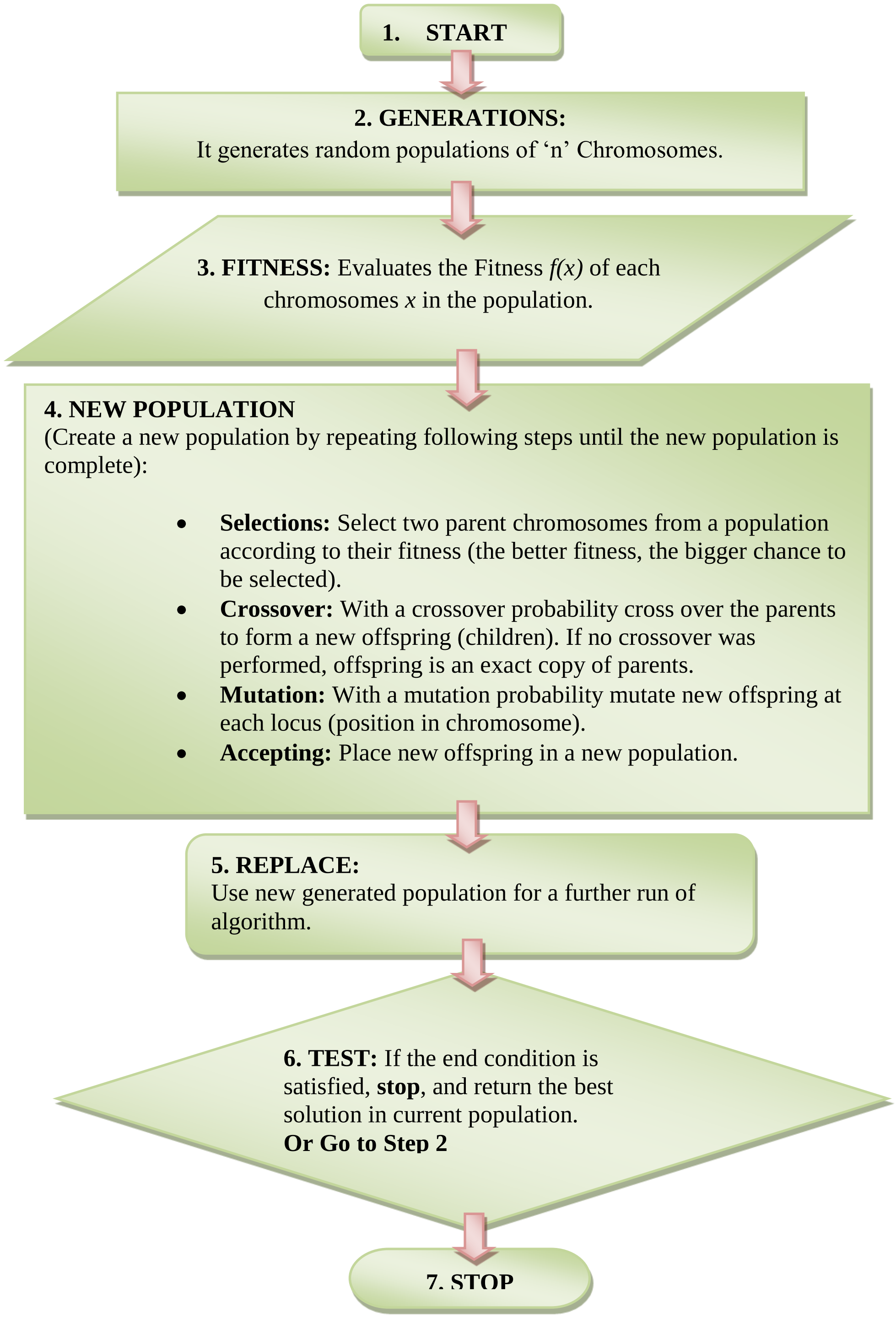


Figure 5.1: Schematic Flow chart of Genetic Algorithm.

5.3 Study Experiment

The study experiments analyze the performance of the CCCMLP under an individual rate-setting behavioral strategy (all carriers in the collaborative system assume the same rate-setting behavior). In addition, varying degrees of γ, the profit margin expected by a carrier in order to participate in the collaboration will be studied. This is done to determine the point at which collaborating is cost effective to carriers considering the various network sizes (10 Nodes and 20 Nodes).

5.4 Experiment Setup

The experimental set up consists of three collaborating carriers for the CCCMLP problem. The additional problem parameters take values according to the following ranges: network size in terms of the number of nodes (10 and 20) and the number hubs (2, 3, 4, and 5). The 10-node network and the 20-node network were randomly generated using MATLAB. In this research work the Population set was restricted till 200 and with 50 numbers of iterations / generation. 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 network size and number of hubs scenario, the collaborative rates, non-collaborative costs, and locational costs are randomly generated in addition to the demand.

5.5 Analysis of Results

The CCCMLP 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. The Sensitivity analysis was performed on the formula, with varying Profit margins and its effect on percentage saving. 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 (see Equation (7)). These margins are reflected through the parameter γ, which takes the values 9%, 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 γ the greater the profit margin. The values where chosen arbitrarily in increments of 9% to try to capture changes in the totals savings. The following tables illustrate the results of the analysis.

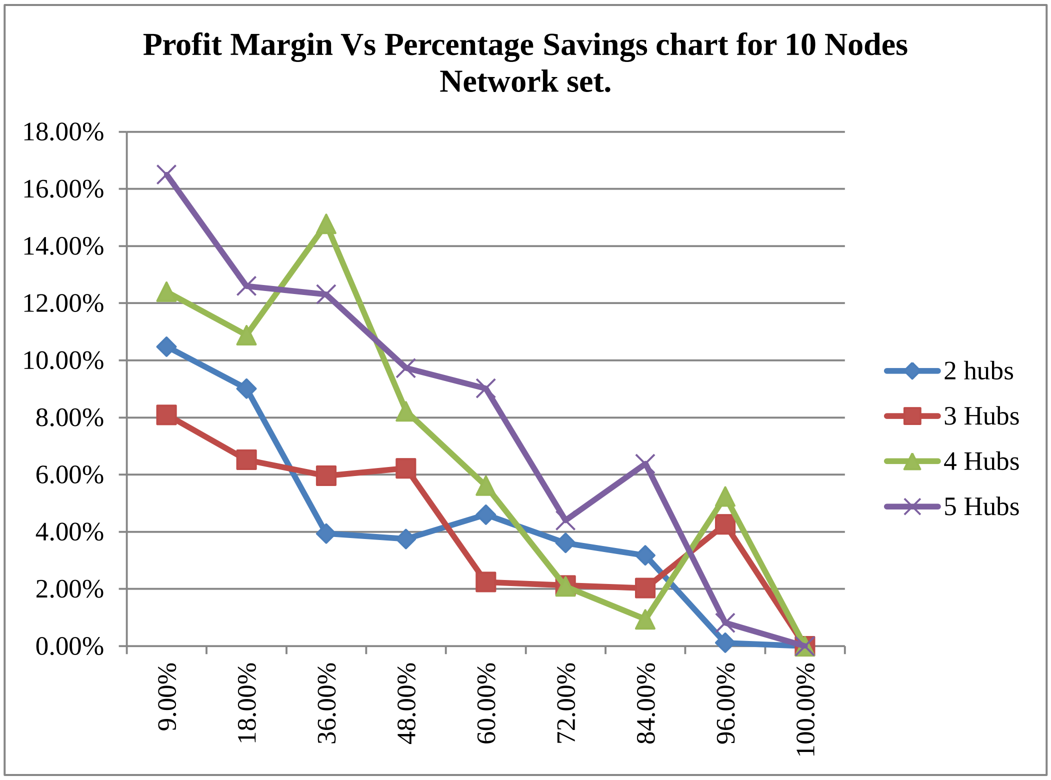


Figure 5.2: comparison γ to percent total savings for varying number of collaborative hubs (p) for 10 node network.

TABLE 5.1: Comparison of the Number of Hubs and Total Savings with Respect to Changes in γ for the 10 Node Network with 3 Collaborative Carriers (GA Approach).

No of Hubs	γ value (Profit Margin)	Selected Collaborative Hubs	Total Cost	Percentage Savings	Time (Sec)
2	9.00%	4 , 9	17933302.10	10.48%	51.54
	18.00%	4 , 9	18227688.10	9.01%	49.33
	36.00%	7 , 9	19244250.18	3.94%	49.14
	48.00%	6 , 10	19282403.98	3.75%	48.53
	60.00%	4 , 9	19111400.70	4.60%	49.30
	72.00%	4 , 9	19310422.90	3.61%	49.75
	84.00%	4 , 9	19397835.90	3.17%	49.73
	96.00%	8 , 9	20010373.30	0.11%	49.84
	100.00%	7 , 9	20033017.70	0.00%	48.68
3	9.00%	4 , 8 , 9	20300553.79	8.09%	49.60
	18.00%	4 , 7 , 9	20648005.66	6.52%	49.93
	36.00%	4 , 9 , 10	20771056.30	5.96%	49.15
	48.00%	4 , 6 , 7	20712645.98	6.23%	49.15
	60.00%	4 , 8 , 9	21592995.30	2.24%	49.23
	72.00%	4 , 5 , 9	21618362.62	2.12%	48.98
	84.00%	6 , 8 , 9	21639310.66	2.03%	48.98
	96.00%	4 , 6 , 9	21145335.42	4.27%	49.13
	100.00%	4 , 8 , 9	22087713.70	0.00%	49.39
4	9.00%	1 , 7 , 8 , 9	21169424.33	12.40%	50.92
	18.00%	2 , 7 , 8 , 9	21536156.22	10.88%	49.78
	36.00%	1 , 6 , 9 , 10	20595088.16	14.78%	49.80
	48.00%	4 , 6 , 8 , 9	22179438.04	8.22%	49.87
	60.00%	5 , 7 , 8 , 9	22809250.60	5.61%	49.54
	72.00%	3 , 4 , 5 , 8	23661126.56	2.09%	51.54
	84.00%	2 , 3 , 6 , 9	23939461.24	0.94%	49.78
	96.00%	2 , 6 , 7 , 9	22899814.00	5.24%	52.33
	100.00%	4 , 5 , 8 , 9	24165762.20	0.00%	55.82
5	9.00%	1 , 2 , 7 , 9 , 10	21971093.90	16.50%	51.90
	18.00%	4 , 6 , 7 , 8 , 9	22997248.50	12.60%	50.54
	36.00%	2 , 6 , 7 , 8 , 9	23073880.14	12.31%	51.41
	48.00%	2 , 3 , 5 , 8 , 9	23753121.14	9.73%	50.34
	60.00%	1 , 4 , 5 , 9 , 10	23939699.30	9.02%	50.52
	72.00%	2 , 5 , 6 , 8 , 9	25155202.02	4.40%	50.47
	84.00%	1 , 2 , 4 , 8 , 9	24632739.74	6.38%	50.50
	96.00%	1 , 3 , 5 , 7 , 9	26098022.50	0.81%	50.61
	100.00%	1 , 4 , 5 , 7 , 9	26312297.10	0.00%	51.86

Table 5.2: Comparison of the Number of Hubs and Total Savings with Respect to Changes in γ for the 20 Node Network with 3 Collaborative Carriers (GA Approach).

No of Hubs	γ value (Profit Margin)	Selected Collaborative Hubs	Total Cost	Percentage Savings	Time (Sec)
2	9.00%	11 , 12	82591767.55	8.32%	186.86
	18.00%	7 , 11	81611586.34	9.41%	193.29
	36.00%	7 , 11	83098460.76	7.76%	188.49
	48.00%	11 , 12	85892085.80	4.66%	209.25
	60.00%	7 , 11	85944820.00	4.60%	196.39
	72.00%	7 , 11	86754321.20	3.70%	186.98
	84.00%	7 , 11	87293363.12	3.11%	197.62
	96.00%	11 , 18	89506987.92	0.65%	188.53
	100.00%	7 , 11	90091397.00	0.00%	194.53
3	9.00%	3 , 11 , 12	87257160.36	10.24%	194.31
	18.00%	3 , 11 , 15	88937580.52	8.51%	195.97
	36.00%	7 , 10 , 15	87300389.08	10.20%	194.72
	48.00%	11 , 12 , 15	89273300.24	8.17%	196.00
	60.00%	7 , 11 , 15	89723730.80	7.71%	200.57
	72.00%	3 , 7 , 11	95339432.52	1.93%	244.55
	84.00%	3 , 11 , 20	95995424.24	1.25%	190.98
	96.00%	7 , 11 , 15	97165955.28	0.05%	196.95
	100.00%	7 , 10 , 11	97215071.00	0.00%	216.84
4	9.00%	2 , 3 , 9 , 11	82580706.26	22.18%	206.39
	18.00%	3 , 7 , 15 , 18	87776918.40	17.28%	201.97
	36.00%	3 , 11 , 15 , 18	91209880.20	14.05%	199.32
	48.00%	1 , 7 , 11 , 15	92806482.44	12.54%	208.16
	60.00%	1 , 7 , 11 , 15	103395079.00	2.57%	204.31
	72.00%	7 , 10 , 11 , 15	96642750.56	8.93%	203.12
	84.00%	11 , 12 , 15 , 18	99798664.00	5.95%	203.74
	96.00%	11 , 12 , 15 , 18	99883858.96	5.87%	206.38
	100.00%	8 , 12 , 16 , 18	106117058.00	0.00%	200.84
5	9.00%	3 , 7 , 11 , 12 , 15	94775360.02	10.20%	210.00
	18.00%	7 , 9 , 11 , 13 , 15	88832185.42	15.83%	209.07
	36.00%	7 , 10 , 11 , 12 , 18	100033286.08	5.22%	204.49
	48.00%	3 , 10 , 11 , 15 , 18	102002188.12	3.35%	203.67
	60.00%	3 , 7 , 10 , 11 , 15	104103549.20	1.36%	204.46
	72.00%	7 , 10 , 12 , 15 , 20	98534402.72	6.64%	206.79
	84.00%	3 , 11 , 15 , 19 , 20	104378611.56	1.10%	207.01
	96.00%	5 , 7 , 10 , 11 , 15	103822739.80	1.63%	197.05
	100.00%	1 , 9 , 11 , 15 , 20	105542324.00	0.00%	198.74

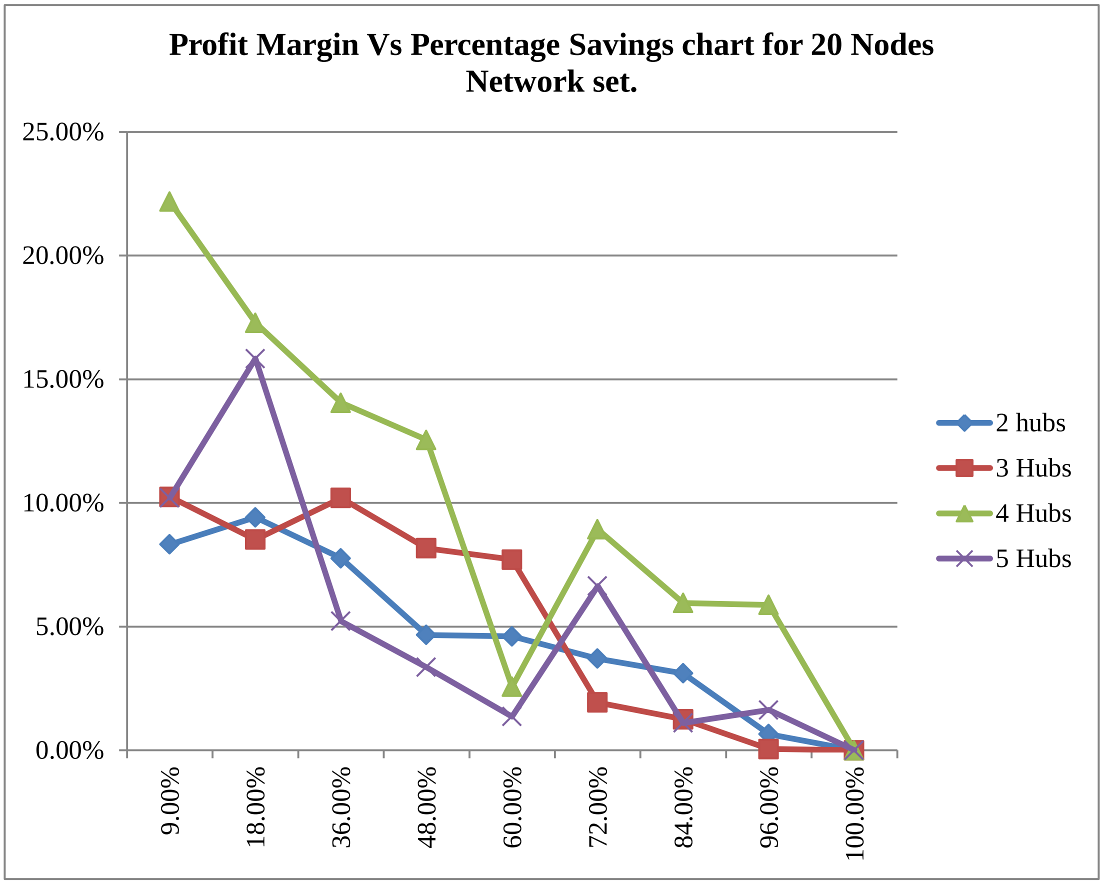


Figure 5.3: Comparison γ to percent total savings for varying number of collaborative hubs (P) for 20 node network.

Turning to the results of the experiments, Table 5.1 and Table 5.2 illustrate the comparison of the number of hubs and total savings with respect to changes in γ for a 10-node and 20-node networks. 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 γ increases the number of direct route increases. This shows the sensitivity of carrier shipments to changes in expected profits. Akin, the lower the γ the greater the percent of routes collaborated and total percent savings. The collaborative hubs selected for each scenario are shown on Table 5.1 and Table 5.2, respectively. A trend to note is that as profit margins decreased, direct routes became the preferred route for the carriers; however, hubs were still selected since the formulation did not preclude their selection. The hubs selected indicate the

locations that would best facilitate the collaboration. In a future extension, Equation (3) will be omitted and a corresponding weight utilized for collaborative candidate hybrid consolidation hub location costs in the objective function to analyze tradeoffs with the other objective cost components.

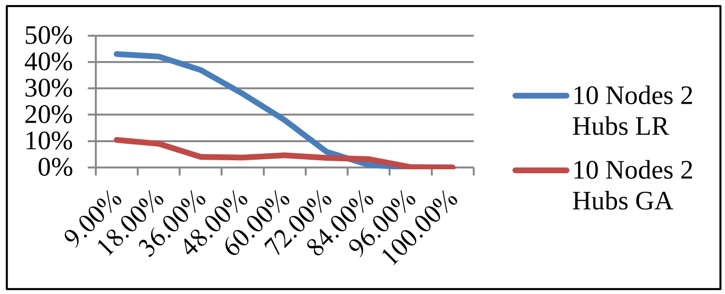
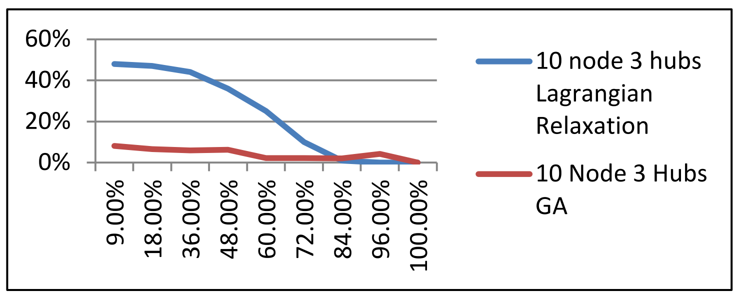
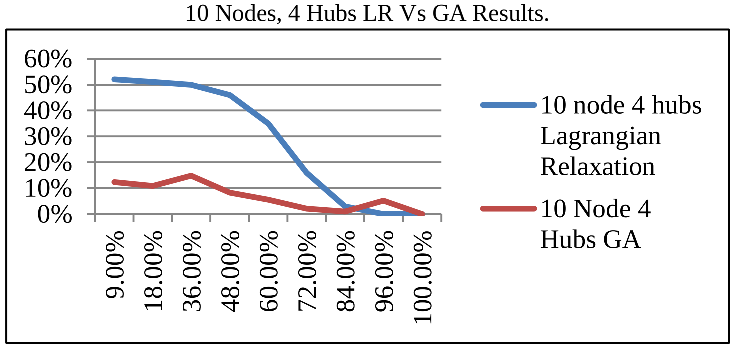
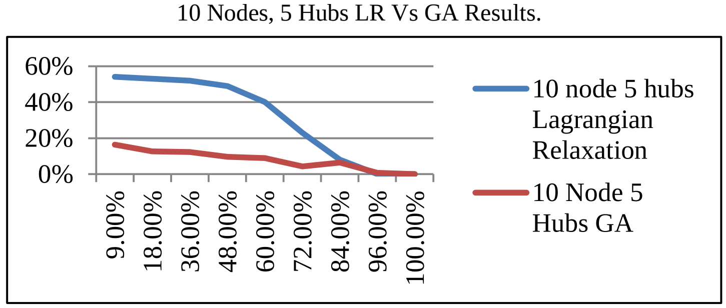
With regards to the percent total savings for both the 10-node and 20-node networks, Figure 1 illustrates the comparison of γ to the percent total savings for varying number of collaborative hubs (P). As seen in Figure 1, for a greater number of hubs the net gains start to level off. This indicates that if the hybrid consolidation hub location costs remain constant, the overall savings differences in route collaboration and direct route at the lower level margins is limited to magnitude of the locational costs. This is especially true for the smaller network sizes (Figure 5.2); still, for the 20 node network (Figure 5.3) a larger percent savings is observed. This is the case since there are more carrier shipments that need to be made indicating that the costs associated to the collaboration and direct routes are outweighing the costs to place a collaborative candidate hybrid consolidation hub.

CHAPTER 6: RESULTS AND CONCLUSION

6.1 Comparison of lagrangian relaxation and genetic algorithm results

This Research was initiated to do the comparative study of the results obtained by solving the CCCMLP formulae using Lagrangian relaxation method and Genetic Algorithm. The Sensitivity analysis was performed by varying Profit margins and its effect on percentage saving. The potential for collaboration among carriers is investigated by focusing on the level of monetary savings due to expected profit margins. These margins are reflected through the parameter γ, which takes the values 9%, 18%, 36%, 48%, 60%, 72%, 84%, and 96%. In general, a lower profit margin value leads to greater levels of collaboration. $(1-\gamma)$ is the true profit margin so the lower γ the greater the profit margin.

Table 6.1: Comparative Results of Percentage Saving for various Profit margins, obtained from Lagrangian Relaxation Method and Genetic Algorithm approach of solving the Problem.

<table>
<tr><th>No. of Hubs</th><th>γ value (Profit Margin)</th><th>Savings obtained from Lagrangian relaxation Method.</th><th>Savings obtained from Genetic Algorith m.</th><th>Graphical Comparison of Results obtained from Lagrangian Relaxation Vs Genetic Algorithm.</th></tr>
<tr><td rowspan="9">2</td><td>9.00%</td><td>43%</td><td>10.48%</td><td rowspan="9">10 Nodes, 2 Hubs LR Vs GA Results.

</td></tr>
<tr><td>18.00%</td><td>42%</td><td>9.01%</td></tr>
<tr><td>36.00%</td><td>37%</td><td>3.94%</td></tr>
<tr><td>48.00%</td><td>28%</td><td>3.75%</td></tr>
<tr><td>60.00%</td><td>18%</td><td>4.60%</td></tr>
<tr><td>72.00%</td><td>6%</td><td>3.61%</td></tr>
<tr><td>84.00%</td><td>1%</td><td>3.17%</td></tr>
<tr><td>96.00%</td><td>0%</td><td>0.11%</td></tr>
<tr><td>100.00%</td><td>0%</td><td>0.00%</td></tr>
<tr><td rowspan="9">3</td><td>9.00%</td><td>48%</td><td>8.09%</td><td rowspan="9">10 Nodes, 3 Hubs LR Vs GA Results.

</td></tr>
<tr><td>18.00%</td><td>47%</td><td>6.52%</td></tr>
<tr><td>36.00%</td><td>44%</td><td>5.96%</td></tr>
<tr><td>48.00%</td><td>36%</td><td>6.23%</td></tr>
<tr><td>60.00%</td><td>25%</td><td>2.24%</td></tr>
<tr><td>72.00%</td><td>10%</td><td>2.12%</td></tr>
<tr><td>84.00%</td><td>1%</td><td>2.03%</td></tr>
<tr><td>96.00%</td><td>0%</td><td>4.27%</td></tr>
<tr><td>100.00%</td><td>0%</td><td>0.00%</td></tr>
<tr><td rowspan="9">4</td><td>9.00%</td><td>52%</td><td>12.40%</td><td rowspan="9">10 Nodes, 4 Hubs LR Vs GA Results.

</td></tr>
<tr><td>18.00%</td><td>51%</td><td>10.88%</td></tr>
<tr><td>36.00%</td><td>50%</td><td>14.78%</td></tr>
<tr><td>48.00%</td><td>46%</td><td>8.22%</td></tr>
<tr><td>60.00%</td><td>35%</td><td>5.61%</td></tr>
<tr><td>72.00%</td><td>16%</td><td>2.09%</td></tr>
<tr><td>84.00%</td><td>3%</td><td>0.94%</td></tr>
<tr><td>96.00%</td><td>0%</td><td>5.24%</td></tr>
<tr><td>100.00%</td><td>0%</td><td>0.00%</td></tr>
<tr><td rowspan="9">5</td><td>9.00%</td><td>54%</td><td>16.50%</td><td rowspan="9">10 Nodes, 5 Hubs LR Vs GA Results.

</td></tr>
<tr><td>18.00%</td><td>53%</td><td>12.60%</td></tr>
<tr><td>36.00%</td><td>52%</td><td>12.31%</td></tr>
<tr><td>48.00%</td><td>49%</td><td>9.73%</td></tr>
<tr><td>60.00%</td><td>40%</td><td>9.02%</td></tr>
<tr><td>72.00%</td><td>23%</td><td>4.40%</td></tr>
<tr><td>84.00%</td><td>8%</td><td>6.38%</td></tr>
<tr><td>96.00%</td><td>0%</td><td>0.81%</td></tr>
<tr><td>100.00%</td><td>0%</td><td>0.00%</td></tr>
</table>

Construing the results from the data as observed in Table 6.1, percentage savings obtained from solving the CCCMLP formulation using the Genetic algorithm are considerably lower as compared to those obtained from Lagrangian relaxation. This may be due to less number of iterations induced in the Genetic Algorithm coding, which was less than 50 percent than the number of iterations used while coding Lagrangian relaxation. Due to the time limitation for running the simulation it was necessary to incorporate lesser number of iterations in Genetic Algorithm method than Lagrangian Relaxation method. Genetic Algorithm takes more time as compared to Lagrangian relaxation method. This could be a result of the dynamic nature of the chromosome. In addition, a more robust Genetic algorithm is currently being developed. With this said, the results in Table 6.1 may indicate a local optimum. Further testing of the Genetic algorithm may produce better solutions, however due to the scope of this research, this will be left to future research.

Still, due to less number of Iterations the optimum solution given by Genetic algorithm is considerably higher than as compared to Lagrangian relaxation results. Better solution can be obtained by increasing the number of iterations and resolving the bug fixes in Genetic Algorithm Code, but it is more time consuming. Optimum solutions obtained by both the methods has considerable difference due to which also the obtained percentage savings are showing considerable differences for same set of input data.

CHAPTER 7: FUTURE STUDY

7.1 Summary and future work

A centralized collaborative carrier multi-hub location problem (CCCMLP) is introduced that provides a planning framework to analyze the benefits of a centralized multiple carrier collaborative network for the creation of hybrid hub-and-spoke system. It addresses the operational issues related to transfer locations and shipment consolidation by introducing the concept of hybrid consolidation hubs from existing locations without the need to construct or invest new consolidation facility infrastructure. This is done by leveraging the current service locations of existing LTL collaborative carriers, synergized by novel opportunities provided through advances in ICT and e-commerce. An uncapacitated P-hub median location mathematical programming formulation was presented for a rate setting behavioral strategy for the collaborative system. The corresponding formulation was shown to be NP-hard and solved using a Lagrangian relaxation solution and Genetic algorithm approach.

The study results indicated that larger expected profit margins from the collaborative carriers under a revenue generating behavior would increase the likelihood of carriers collaborating. In addition, as the network size increases the effect of hybrid hub locational costs was less. A key inference of this study is that carrier collaboration in terms of a collaborative hybrid hub-and-spoke system can become a critical strategy for small- to medium-sized LTL carriers to remain competitive. That is, by decreasing their operational costs when shipping across a point-to-point network.

In future work, we are currently addressing various rate setting behaviors coupled with studying the effect of centralized carrier costs on the number of hubs selected (i.e., not predefining the number of hubs). In addition, we are incorporating facility capacities increasing the complexity of the problem.

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CURRICULUM VITA

Satyen Awale was born and raised in Nagpur, India. He is the Second born child from Suresh Awale and Shobha Awale. He attended Paranjape High School, due to his academic achievements, he received the Scholarships from the State Board of Education Maharashtra to continue his education in Science and Technology field and was helped financially by the government's scholarship and funds Dept. to pursue Bachelor's Degree in Engineering from Nagpur University. He pursued his education in Bachelors of Engineering in Civil Engineering and obtained his degree in 2007. Further he opted to sharpen his skill on job training and joined a construction company located in Gulf of Oman, He worked for a year, later he left the company to do some work in his own country where he was born and raised. He further left his country, and went to work with a contracting firm located in Dubai, U.A.E. to shine his mettle and gain more international working experience. Later he got the admission in University of Texas at El Paso in Master's Program of Civil engineering. Satyen was involved in student organizations such as the American Society of Civil Engineers (ASCE), Institute of Transportation Engineers (ITE). He was one of the active members for both ITE and ASCE. Satyen enrolled at UTEP in the fall semester of 2010 to pursue a Master's of Science in Civil Engineering Degree. He continued to work as a part-time research assistant at the BIG lab under the supervision of Dr. Hernandez from spring 2011 until the spring of 2012. In the spring 2011, Satyen presented a poster titled "A Centralized Carrier Collaboration Multi-hub Location Problem: A Hybrid Hub-and-Spoke Network" at the 91st Annual Transportation Research Board meeting and Published his first paper in TRB (Transportation Research Board) in 2012 under guidance of Dr. Salvador Hernandez and Dr. Avinash Unnikrishnan. He traveled to Washington DC for the 91st Annual Transportation Research Board Conference. Satyen received his Master's of Science in Civil Engineering in May 2012.

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