Strategic Network Design for Time Definite Trucking

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1 Introduction

Strategic network design for time definite transportation is an important problem in modern economies. The need for highly reliable time definite transportation services is growing with the rise of time-based competition and with concerns about the reliability of air transportation. Time definite trucking firms offer very reliable, scheduled service (1 day, 2 day, 3 day, 4 day) between major cities, generally for smaller freight shipments (several hundred to several thousand pounds). Their combination of higher service levels than general motor carriers, and lower cost than airfreight carriers provides a strong competitive advantage in an environment of decreasing cycle times and increasing uncertainty. This presentation describes research using a parallel algorithm for strategic design of optimal networks for time definite trucking. This algorithm modifies the hub arc location and network design algorithm from Campbell et al. (2003) that uses parallel computing to efficiently evaluate possible designs. Computational experiments are reported with a 64-processor Beowulf cluster using real-world data sets from the U.S. and Australia. The results indicate how time definite trucking firms should configure their networks to be both efficient (low cost) and effective (provide high levels of service).

2 Background and Motivation

Trucking is the most important mode of freight transportation in the U.S., accounting for 81% of the U.S. freight bill ($372 billion per year in revenues), 60% of the freight volume (6.7 billion tons per year) and nearly 430 billion miles traveled per year. LTL (less-than-truckload) firms are the largest part of the motor carrier industry. LTL carriers consolidate many small shipments (each generally between 100 and 10,000 pounds) from many different shippers to make efficient vehicle loads. LTL carriers route shipments via a network of consolidation and break-bulk terminals. (Delorme et al. 1988 and Roy 2001 provide details on trucking operations.)

Time definite motor carriers are a small, but growing segment of LTL carriers that provide very reliable scheduled service between specified terminals. These carriers seek to compete with airfreight carriers for higher value, lower weight products that need fast, reliable transportation, but do not require the immediacy of emergency or "next-flight-out" service. Typical freight includes electronic and electrical equipment (especially telecommunications and high technology equipment), trade show materials, machinery and parts, and wearing apparel. Given truck highway speeds and safety regulations (e.g., from the U.S. Department of Transportation), a time definite ground transportation firm is able to provide one day (overnight) service at a distance of up to 300-400 miles, two day service to about 600 miles, and at most four day service between all major origins and destinations in the U.S. and Canada (by using sleeper teams with two drivers).

The success of a transportation carrier depends on its ability to attract and retain business via competitive rates and quality service. The cost for carrying freight (and the rate charged to shippers) and the level of service offered are both affected by the design of the physical network over which the carrier operates. Time definite trucking firms use a network of terminals to consolidate small shipments into economic truckloads, as do other more general LTL carriers. However, the lack of strict service schedules for regular LTL carriers provides them more flexibility in constructing routes. For example, a regular LTL carrier may achieve lower costs via greater consolidation by routing a shipment over a more circuitous path, or by holding shipments at a terminal until a large load is accumulated. These measures may reduce costs, but will increase the time until delivery and degrade service. Thus, the networks for time definite trucking firms must respond to the competing pressures of better service (faster deliveries via smaller shipments, less circuitous routes and smaller delays at terminals) and lower costs (from larger shipments providing economies of scale).

3 Strategic Network Design

Crainic (2003), Fleischmann (1998) and Kim and Barnhart (1997) review freight transportation network design. Much of this research has focused on tactical service network design models for load planning in LTL trucking and express package delivery (see for example, Barnhart and Schneur 1996, Lin 2004, Powell and Sheffi 1989 and Roy and Delorme 1989). Strategic network design models focus more on locations of terminals and network topologies, rather than routing vehicles or empties. Campbell (2004) reviews strategic network design models for motor carrier applications. Hub location models are one approach to strategic design of networks for many-to-many transportation where consolidation is paramount (Campbell et al. 2002). Hub location and network design models generally include two types of nodes and arcs reflecting the use of two types of vehicles. Local vehicles (smaller trucks) operate on *access arcs* connecting origin/destination terminals to hubs. Linehaul vehicles on *hub arcs* connecting two hubs. The larger more efficient linehaul vehicles exploit the economies of scale in transportation and provide the incentive for consolidation and break-bulk activities at hub nodes (break-bulk terminals). A hub network includes origin/destination nodes (terminals), hub nodes (which may also be origins and destinations), access arcs connecting non-hub nodes to hub nodes, and hub arcs connecting two hubs.

Campbell et al. (2004a,b) describe new hub arc location models for strategic design of transportation systems. These models relax some of the restrictions in earlier hub location models and allow hub arcs (i.e., the larger more efficient linehaul vehicles) to be used in the network where they are most beneficial. These models determine the locations of hubs as well as the placement of hubs arcs to minimize total transportation costs. Figure 1 presents an optimal network with three hub arcs and five hubs serving 10 cities in the eastern U.S. (from the CAB data set) with α=0.2. (Hub arcs are shown as thick lines and hub nodes are the endpoints of hub arcs.)

Note that in the cost minimizing solution shown in Figure 1, shipments between Denver and Dallas are routed via Chicago to take advantage of the great economies of scale (with α=0.2, linehaul transportation is one-fifth as expensive as local transportation). For time definite trucking, such a circuitous route is not competitive and the optimal network would be adjusted, either by adding new access arcs or relocating the hub arcs.

Figure 2 shows direct origin-destination (o-d) distances and travel distances via the hub arc network for the optimal solution to a larger problem with three hub arcs serving 25 cities across the U.S. with α=0.2. For this figure the o-d pairs are grouped in 200-mile increments based on the direct o-d distance. The graph displays how the average and maximum travel distance via the network can far exceed the average direct o-d distance. For example, the 25 cities provide 300 o-d (city) pairs and 26 of these o-d pairs are separated by 800-1000 miles. For these 26 pairs, the average and maximum travel distance via the optimal network with three hub arcs is 1190 miles and 2478 miles respectively, compared to an average direct o-d distance of 913 miles. Such circuitous routings allow flows to be consolidated to exploit the economies of scale in transportation - at the expense of additional travel distance and time. An optimal network for time definite trucking would produce a graph with a much reduced distance between the lines for the maximum travel distance and the average direct distance.

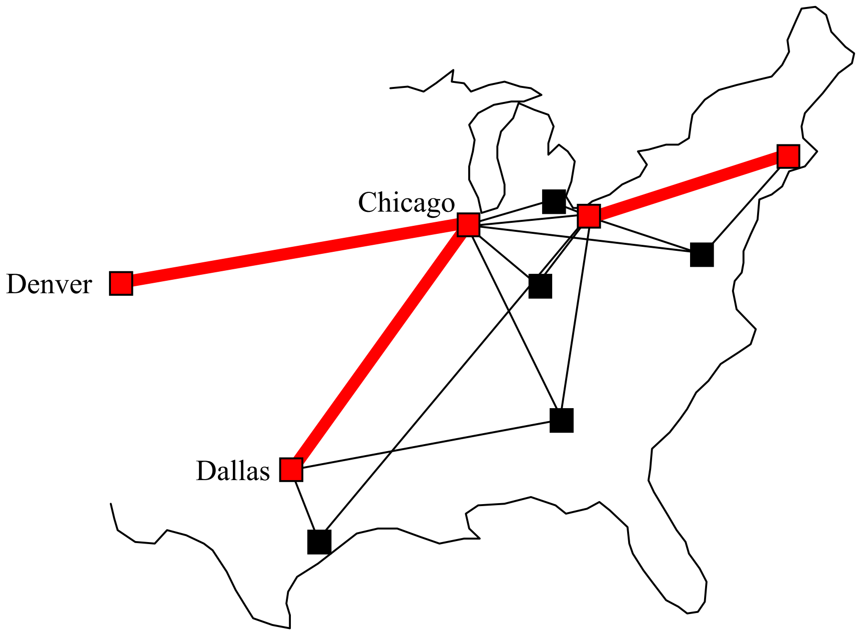

Figure 1: Optimal hub arc network with α=0.2.

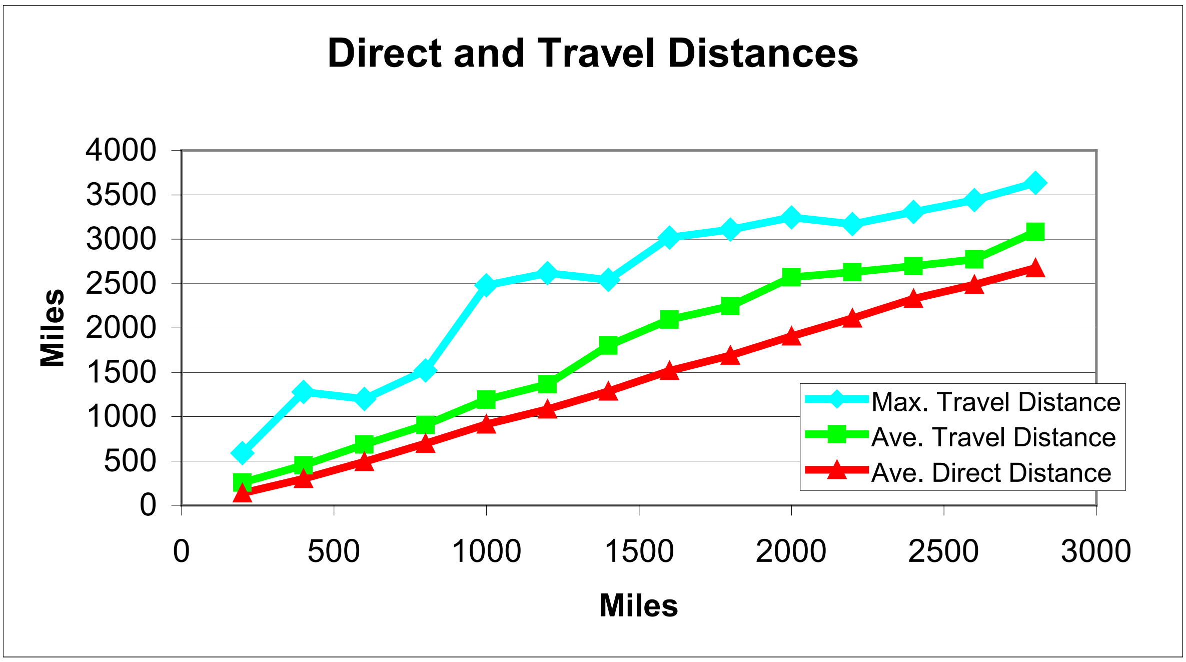

Figure 2: Direct and Travel Distances with 25 cities and α=0.2.

This presentation describes work with new hub arc location models that include service constraints to enforce time definite deliveries. As such, it blends service oriented hub center models (Kara and Tansel 2000) that minimize the maximum o-d travel time or latest arrival time, with cost oriented hub arc location models that minimize the total transportation cost (Campbell et al. 2004a,b). Campbell et al. (2003) used a parallel algorithm to solve hub arc location problems on a twenty-eight node Beowulf cluster. This presentation reports results for time definite trucking using the parallel algorithm modified to include service levels for all origin-destination pairs. Service levels are specified as the number of days (or hours) to travel between various origins and destinations. Optimal hub arc network designs with varying numbers of hub arcs and different levels of service are found for real-world data sets using a cluster of 64 processors (totaling 77.6 GHz of processing power).

The algorithm finds optimal network designs that minimize cost while meeting specified service levels. The results with varying service levels show the impact on network design of tightening service levels, and help highlight the relative importance of different terminals or geographic regions in achieving high levels of service. The results also allow a comparison of optimal networks for time definite trucking with optimal networks for non-time definite operations. This can help evaluate the ability of firms not currently offering time definite service to improve their service without significant changes in their network.

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