Abridgment

Urban Goods Consolidation Terminal Investment and Location Decisions

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The goods movement industry has become aware of significant diseconomies in the goods movement system, particularly for small shipments in urban areas (1,2). One reason for these diseconomies is that pickups and deliveries (P/Ds) made by any given truck in urban areas tend to be small in size and relatively few in number. Many trucks are used, but few of them utilize their full load capacity (3,4,5). Also, because these trucks are operated by a large number of independent freight carriers, extensive duplication in routing occurs.

In addition, external diseconomies are generated by the urban goods movement system. Inefficient truck utilization causes increased traffic congestion, air pollution, noise pollution, and energy consumption. Moreover, these environmental effects occur in the central business district (CBD) where environmental conditions are frequently at undesirable levels.

Goods movement planners have suggested that carriers organize and coordinate their activities in order to increase the efficiency of P/D operations and thereby reduce their urban operating costs. One means of achieving this coordination would be to route all small shipments—that is, those less than 453.6 kg (1000 lb)—going to or from the urban area through one or more consolidation terminals serving all carriers. Then P/Ds for all carriers can be consolidated to make effective use of vehicles. To eliminate overlapping routes the urban area would be divided into a number of P/D zones, each containing shippers and consignees; each zone would be assigned to a specific consolidation terminal for all small-shipment P/D operations. In addition, the consolidation terminals would operate trucks to deliver shipments to carrier terminals and to pick up shipments from the carriers destined for consignees in the urban area.

The benefits of a consolidation terminal can be determined by comparing the total terminal and P/D costs expected if one or more consolidation terminals were in operation with the total costs incurred by the present system. Terminal costs depend on the throughput volume through each terminal, the timing of capital expansion investment, the location of each terminal, and the terminal design or the material-handling system employed. Total P/D costs depend on the required number of truck trips, the distances trucks must travel, and the amount of time drivers must expend picking up and delivering goods at the shipper, carrier terminal, consignee, and consolidation terminal locations. In turn, these variables are directly related to the spatial and temporal distributions of demand for P/Ds. Moreover, P/D costs are related to the spatial relationships among consolidation terminals, carrier terminals, shippers, and consignees. These relationships are certainly dependent on the characteristics of the urban area served and the design of the consolidation terminal system. However, what is good for one urban area may not be desirable for another.

Consequently, this paper presents a model, called the Urban Terminal Investment Model (UTIM), that can be applied in diverse urban areas to evaluate the economic feasibility of the consolidation terminal concept and to determine the following preferred system design variables based on a least-cost criterion:

1. Number of terminals;
2. Terminal locations, e.g., sites selected;
3. Timing of terminal capacity investments; and
4. Terminal zone assignments.

Moreover, iterative application of UTIM for alternative variable sets will yield preferred values of these system design variables: limitation on shipment sizes consolidated and urban zonal boundaries.

Least cost is the basic criterion for selecting preferred system designs because the terminal system will not be implemented without economic benefits. Also, social benefits are directly correlated with economic benefits because the savings in truck utilization will result in reduced congestion, air and noise pollution, and energy consumption.

COMPARISON OF SINGLE- AND MULTIPLE-TERMINAL SYSTEMS

The structure of UTIM is dependent on whether multiple terminals offer potential cost savings over a single terminal. This is true because a single-terminal system can be located and analyzed by a relatively simple model; but situations permitting two or more terminals present a very large number of possible alternatives (e.g., location, terminal-zone assignments, and construction plans) that require a mathematical optimization model to determine the least-cost system design. Accordingly, a simple but representative system is analyzed to indicate the potential for two terminals instead of one.

Comparison of a single-terminal system with a two-terminal system is essentially a trade-off between terminal costs and truck travel costs. One terminal is cheaper to build than two; however, truck travel costs should be less for a properly located two-terminal system. The terminal costs should dominate for a small urban area, whereas the truck travel cost savings will make a two-terminal system more economical for a larger urban area. The interaction among these variables is analyzed using the system depicted in Figure 1 where the distance between all system components is proportional to the distance D. The single-terminal systems have a terminal located at site S2, and the two-terminal systems have terminals located at sites S1 and S3. For analytical purposes, the carrier terminals are grouped into carrier clusters containing carrier terminals located near each other. S1 and S3 are colocated with carrier terminal clusters C1 and C2. The performance measure of interest is the distance D* where two-terminal systems with $D > D^*$ become less expensive than single-terminal systems.

Figure 1 depicts a system assumed to have a total goods movement volume approximately equal to the small-shipment consolidatable freight volume—362 874 kg/d (800 000 lb/d)—for the CBD of Columbus, Ohio (6). That is, the flow between each carrier cluster and P/D zone is 45 359 kg/d (100 000 lb/d); half reflects pickups in the zone and the other half, deliveries. Other system characteristics are presented in Table 1 (7). Note that the total truck cost includes both the hourly and the distance costs. Also, terminal fixed costs consist of site acquisition, terminal con-

Figure 1. Metropolitan area example.

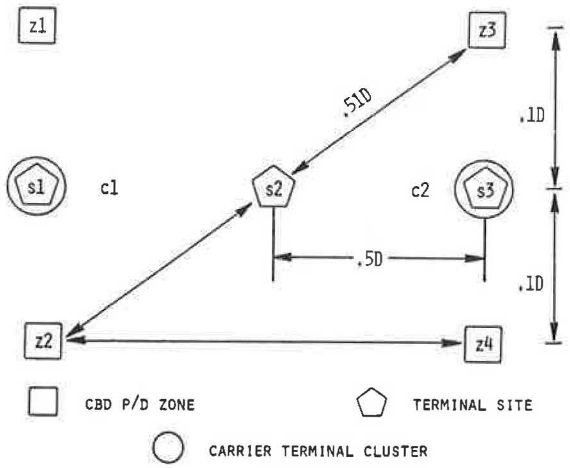


Table 1. System cost data.

Variable	Value
Truck length	8.5-m semitrailer
Maximum truck load	7711 kg
Average truck load	4534 kg
Truck cost/kilometer	\$0.18
Truck cost/hour	\$13.19
Terminal fixed cost	
181 437 kg/d	\$0.005 952/kg
362 874 kg/d	\$0.004 630/kg
Terminal operating cost	\$0.011 02/kg

Note: 1 m = 3.3 ft; 1 km = 0.6 mile; and 1 kg = 2.2 lb.

struction, and administrative costs; operating costs include billing, platform labor, loss, and damage.

The value of D* where two-terminal systems become less expensive is dependent on the average speed assumed for truck travel. Robeson and McDermott (6) recorded an average speed of 8 km/h (5 mph) in the Columbus CBD; however, Blatner (8) estimated the average speed to be 21.2 km/h (13.2 mph) for all classes of trucks in Chicago. The value of D* is 10.8 km (6.7 miles) for an average speed of 8 km/h (5 mph), 19.5 km (12.1 miles) for an average speed of 16.1 km/h (10 mph), and 26.9 km (17.7 miles) for an average speed of 24.1 km/h (15 mph). Thus, multiple terminals may be preferred by even moderately sized metropolitan areas.

URBAN TERMINAL INVESTMENT MODEL (UTIM)

The investment model for the purpose of determining the least costly design of a terminal system is described in this section. Cost here means the present value of all operating construction, and P/D costs are those that occur during a planning horizon of T years, e.g., 12 years. All costs are discounted to reflect the lower value of a dollar expended in the future as opposed to an immediate expenditure; moreover, a constant inflationary rate is assumed to account for higher future costs for identical items.

For the purpose of computing transportation costs, assume that there are I possible sites selected for consideration in locating consolidation terminals. Also assume that there are K total truck clusters and J total P/D zones containing shippers and consignees. Let

e_{ij} = present value of truck costs to transport all freight to and from P/D zone j through terminal site i, for T time periods

These costs are determined from the number of round trips trucks must make between site i and zone j in addition to the round trips between site i and all k carrier clusters.

In addition to the transportation costs, terminal operating and construction costs must be determined as a function of the throughput volume through each terminal and the goods-handling capacity purchased for each terminal. The throughput volume through a given terminal is determined by the zones assigned to the terminal and the P/D volume forecasted for these zones. Let

$$z_{ij} = \begin{cases} 1 \text{ if zone j is assigned to site i} \\ 0 \text{ if otherwise} \end{cases}$$

w_{kjt} = daily P/D volume forecast between cluster k and P/D zone j in year t

d_{it} = daily throughput volume for site i in year t

Then

$$d_{it} = \sum_{k=1}^{K} \sum_{j=1}^{J} w_{kjt} z_{ij}$$

For the entire planning horizon, the vector D_i is used to represent the throughput volume for a terminal at site i, where

$$D_i = (d_{i1}, d_{i2}, d_{i3}, \ldots, d_{iT})$$

In addition to the throughput volume, the present value of terminal costs is determined by the amount of capacity purchased for the terminal and the year in which the investment is made. Let

y_{it} = terminal capacity alternative selected in period t at site i

$y_{it} = 1, 2, \ldots, M_t$

M_t = maximum number of capacity alternatives available in period t

Also, the capacity investment decisions at site i are represented by the vector Y_i, where

$$Y_i = (y_{i1}, y_{i2}, \ldots, y_{iT})$$

Each value of y_{it} has a throughput capacity (which is site independent) associated with it. That is,

$S_t(y_{it})$ = freight-handling capacity available in period t with alternative y_{it}

$$S_t(1) = 0$$

The present worth of terminal costs is given by the function

$f_i(Y_i, D_i)$ = present worth of terminal investment and operating costs at site i over the planning horizon of length T years given the throughput volume vector D_i and investment vector Y_i

The transportation and terminal costs can be combined to give the overall P/D cost, which is

$$C = \sum_{i=1}^{I} \sum_{j=1}^{J} e_{ij} z_{ij} + \sum_{i=1}^{I} f_i(Y_i, D_i) r_i$$

where

$$r_i = \begin{cases} 1 \text{ if site i has terminal, i.e., if } \sum_{j=1}^{J} z_{ij} > 0 \\ 0 \text{ otherwise} \end{cases}$$

C = present worth of the total P/D costs

Figure 2. Carrier clusters and potential terminal sites, Columbus, Ohio.

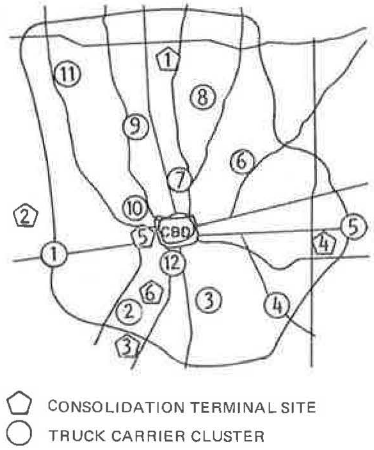
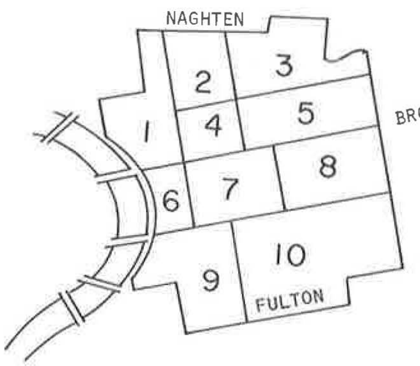


Figure 3. Central business district zones, Columbus, Ohio.



C is the criterion function for UTIM.

This criterion function is subject to a number of constraints. First, a P/D zone is assigned to exactly one terminal. Thus,

$$\sum_{i=1}^{I} z_{ij} = 1 \text{ for } j = 1, 2, \ldots, J$$

Also, a terminal must have adequate capacity to handle its throughput volume in each year of the planning horizon. Thus,

$$\sum_{p=1}^{I} S_p(y_{ip}) r_i \geq d_{it} \quad \text{for } i = 1, 2, \ldots, I;\ t = 1, 2, \ldots, T$$

A partial enumeration algorithm (7) is used to find the minimum value of the criterion function while satisfying the constraints.

APPLICATION TO COLUMBUS, OHIO

To illustrate UTIM capabilities, the CBD of Columbus was analyzed with forecasts for a 12-year period from 1974 to 1985. The forecasts were based on the 1973 estimates of zonal volumes for shipments of less than 453.6 kg (1000 lb) that could be consolidated as specified in Robeson and McDermott (6). A 4.86 percent annual volume growth was assumed to apply during the planning horizon, along with an annual inflation rate of 7 percent and an annual discount rate of 10 percent. Figures 2 and 3 show the location of carrier clusters, potential terminal sites, and CBD zones.

A single terminal at S5 was identified as the preferred system. The optimal solution cost breakdown is shown in the following table:

Cost Component	1974-1985 Present Value ($)
Terminal	15 972 000
Stem travel	3 214 000
CBD zone P/D	6 158 000
Total	25 344 000

These results indicate that a consolidation terminal would reduce the P/D cost of small shipments by approximately 40 percent since the present value of P/D costs for unconsolidated freight is estimated to be $41 940 000.

Examination of the geometry of the metropolitan area in Columbus may explain the superiority of single terminals. The CBD is highly concentrated, but the carrier clusters are dispersed; thus, multiple terminals do not offer savings in stem transportation costs with respect to the CBD zones. However, consolidation of small-shipment P/D operations in a more widely dispersed area such as the entire Columbus urban area or Chicago may be efficiently performed with multiple terminals.

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