CONSOLIDATION OF URBAN GOODS MOVEMENTS: A CRITICAL ANALYSIS

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This paper investigates the desirability of consolidation terminals as a means to lower the cost and ease the congestion of urban goods movement. A detailed simulation of alternative configurations of pickup and delivery services is used based on a unique set of data obtained from operators of actual consolidation facilities. The alternatives analyzed are no consolidation, the prevailing mode of operation; route consolidation, which eliminates duplication in the pickup and delivery area; and complete consolidation using consolidation terminals. Because of the high costs of handling goods in consolidation terminals, they are shown to be relatively uneconomic. Route consolidation, however, appears to be the most effective solution and offers savings of up to 30 percent. These results were verified by extensive sensitivity analyses, reported in detail, that provide guidelines on the desirability of each form of pickup and delivery service. No new program of consolidation now appears likely to reduce urban congestion or pollution significantly inasmuch as consolidation has already been implemented in many of the industries for which it offers the greatest potential. Consolidation does appear, however, to offer potential for industries that are quite uncoordinated, e.g., the garment trade and the air cargo business.

•THE DEVELOPMENT of consolidation terminals has been frequently advocated by knowledgeable observers, in particular by those in the Tri-State Transportation Commission (10). To examine this proposal, we define the possible forms of consolidation for goods movement and compare their relative effectiveness over the range of possible circumstances. The analysis is validated by detailed data on actual operations of consolidation services in New York City.

The results show that consolidation terminals can be cost-effective, but only for a very limited, although important, form of goods movement. These facilities are especially desirable when great savings in transport cost can be obtained relatively cheaply. This is particularly the case for garbage collection. New York City has already achieved considerable savings in the costs of collecting solid wastes by operating consolidation facilities. In general, however, consolidation terminals seem too expensive to be desirable.

A different form of consolidation does appear desirable for a broad range of situations. This is route consolidation or the coordination of multiple pickups and deliveries by a single shipper, so as to eliminate duplication of travel along common routes. This alternative appears promising, especially for relatively small shipments made to or from many shippers (e.g., parcel service and air cargo). Route consolidation represents an economical solution to many of the problems of urban goods movement.

INTRODUCTION

A consolidation terminal is a facility at which many small shipments are assembled into fewer, larger shipments to permit goods to be shipped by fewer vehicles than would otherwise be possible. This leads to significant reductions in the costs of transport and to savings in fuel. Fewer vehicles also mean less congestion, less noise, less pollution, and generally a more enjoyable environment.

The advantages of consolidation terminals are offset, however, by the large costs associated with their operation. Furthermore, any form of consolidation requires some coordination of the pickup and delivery of goods, which may be impractical because of the conflicting interests of the individual shippers. Without a detailed analysis, such as reported here, it is impossible to know when or whether the disadvantages of consolidation are smaller than the advantages.

This study analyzes alternative forms of consolidation for urban goods movements and attempts to answer the following questions.

1. What kind of consolidation activities are possible?
2. What are the relative economics of these alternatives?
3. How do the economics vary for different types of load and for different distributions of pickup and delivery points?
4. What kinds of environmental benefits does consolidation provide?
5. What types of consolidation, if any, are desirable for which situations?

The immediate objective of this work is to develop guidelines on when and what type of consolidation of urban goods movements should be promoted. In a larger sense, the results have implications for the optimal design of transportation and communication networks of all sorts and constitute an integral part of ongoing work on network systems planning at the M.I.T. Civil Engineering Systems Laboratory (1, 2, 6).

CURRENT PROBLEMS

Most trucking within a large city, such as New York, consists primarily of pickup and delivery (PD) operations. Essentially, all local goods movements are of this sort, and many long-distance shipments have PD components of interurban movement by rail, air, and even truck.

Typically, PD operations involve considerable duplication of effort. Urban goods movements are characterized by a large number of both shippers and carriers. On any day, many different carriers dispatch their trucks to provide similar services to the same shippers or to their neighbors. Either way, the PD vehicles follow each other over approximately the same routes. This duplication is an important cause of inefficiency in urban goods movement.

A second problem of PD operations is that they are typically unable to achieve economies of scale. Although the distance between the pickup and delivery areas in a city is often great, cartage between these points is most usually done by small PD vehicles rather than by larger vehicles that could be more economical over the distance. For example, most shippers in the New York area are 15 miles or so from the container ports or from the cargo center at Kennedy Airport; likewise the garbage disposal sites are far from where the waste is collected. The lack of coordination often forces people to use small PD vehicles for such trips, even though larger vehicles could haul the cargo more cheaply.

Third, PD services operate under restrictions that severely raise costs by degrading productivity. These constraints have to do with the fact that the inputs to the PD operations come in fixed sizes:

1. A truck fleet, once bought, cannot be contracted during off-peak hours and is thus relatively idle during those periods.
2. Trucks have maximum loads and volumes [e.g., 5 tons (4550 kg) and 1,200 ft^3 (34 m^3)]; an operator may waste time because he cannot use his truck to pick up or deliver more shipments.
3. Drivers and crews have fixed workdays, typically 8 hours per day, which, converse to the above, may not give them enough time to fill up a truck.

The net effect of all these constraints is to lower the load factors of the trucks and to raise unit costs exponentially.

The problem of shipping goods from the New York garment center to La Guardia illustrates the effect of these constraints. The travel time between the two points is about 1 hour each way, leaving the driver at most 6 hours for pickups and deliveries. At 15 minutes or more per stop, he may not have enough time to assemble a full load; the truck then is used inefficiently. This bad situation worsens considerably if the terminus (or disposal point, for garbage) is farther away. For deliveries from the garment center to Kennedy Airport, the round trip may take more than 3 hours, which reduces effective PD time by about 20 percent. From a mathematical point of view, the shadow prices on these constraints may be extremely high. This was demonstrated by de Neufville et al. who performed detailed calculations for actual cases (3).

Finally, all urban goods movements are subject to strong variations in demand, for they force the carriers to maintain substantial reserve capacity to handle peak traffic, which thus reduces the overall productivity of the fleet. Traffic peaks are also surprisingly large as demonstrated by detailed analysis of actual waybills obtained from a PD operator in New York (3). There are strong imbalances in traffic both over time, with ±30 percent variation in a week let alone over a month or a year, and in direction, with flow in one direction being 100 percent greater than in the other. Such imbalances in flow inevitably lead to low average truck use (load factors ≈30 percent).

ALTERNATIVE NETWORK CONFIGURATIONS

The three basic alternatives for organizing PD operations are

1. No consolidation, similar to what prevails currently,
2. Route consolidation, and
3. Complete consolidation.

Route consolidation, a term introduced here, only addresses the problem of duplication. It represents an attempt to achieve maximum savings at minimum cost. Complete consolidation introduces intermediate (or consolidation) terminals into the network and thus leads to economies of scale and lessens the effect of the constraints. A basic question is whether the advantages are worth the extra costs of the consolidation terminal, which may be considerable.

The elements of the PD system need to be defined before we can illustrate the alternatives precisely. These elements are as follows:

1. Shippers, the individual merchants or households who originate or finally receive a shipment (these are likely to be scattered all over an urban area);
2. PD operators, the several outfits that carry shipments from the shippers to a main terminal within the metropolitan area;
3. The main terminal, which is either a gateway to the city for the long-distance portions of a trip (i.e., an airport or a container port) or the end of a trip (i.e., a garbage dump or a manufacturing plant); and
4. Carriers, such as airlines, who transport the shipments long distances to and from the city.

A PD system thus always involves shippers, operators, and main terminals; it may or may not include carriers. With these definitions in mind, the three alternative configurations are described below.

No Consolidation

In this system, competing PD operators serve shippers independently. This option is illustrated in Figure 1, which shows a situation similar to that faced by the airlines delivering cargo to Manhattan or, in reverse, by garment manufacturers sending their goods to Kennedy Airport. Each individual operator probably functions as efficiently as he can in this situation, but it is quite likely that the service for the entire system is inefficient because of extensive duplication.

This is the simplest alternative to manage because no special cooperation is necessary among either the shippers, operators, or carriers. Handling charges may also be expected to be relatively low because shipments are only loaded and unloaded once and there is no need for special sorting. An attractive feature of this arrangement from the shipper's point of view is that he has a choice of PD operators; he can thus expect the competitive element to keep them on their toes.

But no consolidation may be expensive. Individual operators will have their customers spread over a wide area, and their trucks will have to travel long distances in relation to the number of shippers they serve. Because of the large amount of time spent traveling, a driver will be able to make relatively few stops in a day. The resultant low truck use must inevitably lead to higher unit costs.

Route Consolidation

Route consolidation eliminates duplication in the PD area; all shippers in a zone are served by a single truck (Fig. 2). This kind of operation is typical of garbage collection services (which rarely have to worry about a multitude of different carriers and thus have little motivation for competitive, redundant services in an area) and freight forwarders.

The principal advantage of route consolidation is that, by reducing the number of miles that must be driven and the distances between consecutive stops, productivity of the drivers and the use of the trucks are increased. This, of course, reduces the unit costs of PD operations. Further, less driving means less air pollution and less congestion on the streets.

Another advantage of this alternative, and actually of all forms of consolidation, is that it reduces the variability in the level of flows, and this lowers costs. Because the peaks of traffic from some shippers must inevitably overlap with the off peaks of others, the relative variation of a collective activity will be less than the variation of the individual shippers. A reduction in the size of the peaks means that the PD operation needs less reserve capacity to handle the peak flows and can consequently raise average truck use and lower unit costs.

A high degree of cooperation between carrier and PD operator is essential for this type of operation. By definition, PD operators now work for several carriers, and trucks must make several stops at the main terminal. Conversely, each carrier must sort its shipments geographically so that they can be picked up by the appropriate PD vehicle. This may be both expensive and time-consuming, especially when the number of participating carriers is large. Route consolidation may then be desirable for small groups of carriers rather than simultaneously for all carriers at a terminal.

Complete Consolidation

The key feature of this alternative is a consolidation terminal placed between the main terminal and the PD area. This intermediate node permits not only consolidation of routes, as above, but also consolidation of traffic from each zone of the PD area. Consolidation terminals are relatively rare, but several do exist in New York City: National New York Packing in the garment center, Rydair in Long Island City for air cargo, and several facilities for garbage collection. For best effect, the consolidation terminal should be placed near the PD area (Fig. 3).

Use of consolidation terminals leads to savings in transport costs and raises driver productivity. A consolidation terminal is most obviously a facility for aggregating the loads of the PD trucks, generally onto larger, more efficient vehicles (or vice versa). At a minimum, one can operate with full vehicles between the consolidation and main terminals; more often one can achieve some economies of scale by using larger vehicles. These savings may sometimes be quite significant. Garbage collection, for example, requires a driver plus two or three loaders in the pickup operations, but only a driver for the haul to the dump. Use of a transfer point, at which the extra men can be left off, cuts transport costs in half. In most cases, however, the savings in transport costs turn out to be of marginal importance.

The more important effect of consolidation terminals appears to be increases in driver productivity and thus decreases in unit costs. To the extent that they are close to the PD area, consolidation terminals reduce the time the PD vehicles must spend driving and increase the time that can be spent in picking up shipments. This effect is

Figure 1. General no-consolidation PD operations.

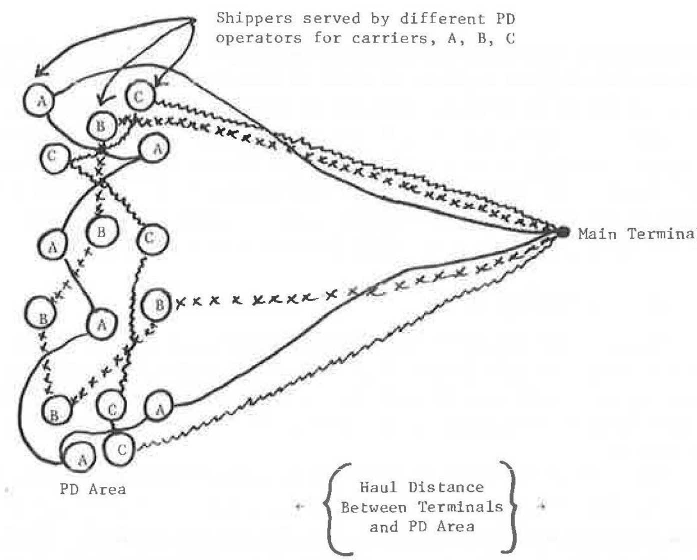


Figure 2. Route consolidation.

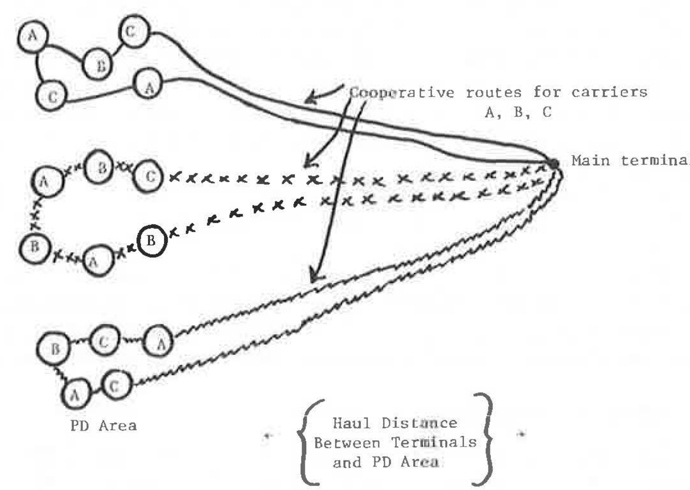
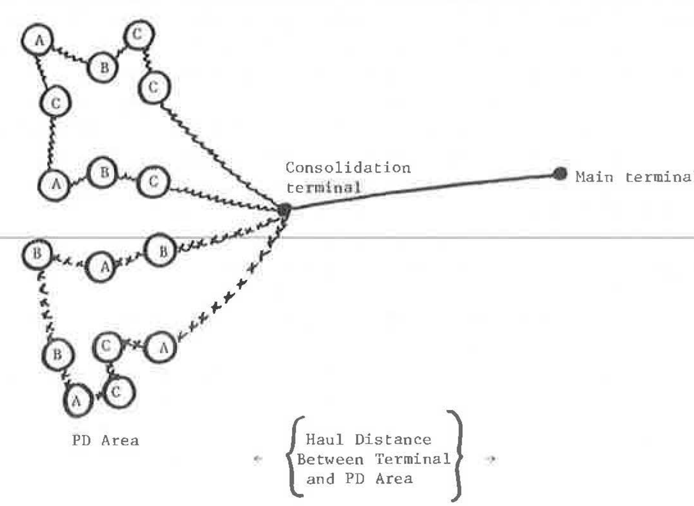


Figure 3. Complete consolidation.



important both when the shipments are small and the productivity is constrained by the time that can be spent loading the truck and when shipments are large and the truck fills up quickly and could do several round trips a day.

Balancing these advantages, however, are the costs of handling shipments at the consolidation terminal, as well as the rent and upkeep of the facility itself. These may be very high. For small shipments, costs of $1 a package or $80/ton ($0.09/kg) are quite common (1, 3, 5). These costs do fall to about $10/ton ($11/Mg) for packages of about 500 lbm (230 kg) and to less than $1/ton ($1.10/Mg) for bulk shipments of several tons (7). But the consolidation or transfer costs would generally be quite significant for most shipments of urban goods.

EVALUATION OF ALTERNATIVES

Procedure

To compare the alternative modes of PD operations, we developed a simple computer model. This is basically an unpretentious device for keeping track of and adding up all the costs associated with any realistic description of a situation. The model is a deterministic simulation capable of handling the pervasive nonlinearities and integer nature of the problem. It calculates total costs, the necessary number of trucks, and total truck-miles per day to serve any specified distribution of shipments in any particular area (3). If the appropriate data are supplied, the model can evaluate any number of alternative configurations, the effect of different locations for the terminals and shippers, different levels and distributions of traffic, and different kinds of shipments. The model can thus be used to compare the alternatives and to select the best solution for any situation.

The procedure used was straightforward. We selected a particular situation as a base against which we would measure all other alternatives. In practice this was an actual PD operation in New York City for which we had abundant data. We then calculated the effectiveness of alternative configurations for this situation. Finally, we carried out extensive sensitivity analysis to determine when any of the alternatives might become more desirable (4).

Data

Extensive, detailed information is required for an effective evaluation of alternative modes of PD operation. Because of the complex interaction of the constraints on these operations, any gross analysis that overlooks these subtleties will be erroneous. Because only aggregated data were previously available (11), it had not been possible to evaluate the desirability of consolidation terminals. We were most fortunate, however, to be able to obtain the kind of data necessary.

We were able to obtain unique information concerning the distribution of demands for PD services from the Rydair Company. They generously gave us complete access to their waybills, which specify which shipper was served by which truck, the weight and number of pieces in the shipment, the carrier serviced, the date, and so on. These data enabled us to determine fluctuations in demand over time and from place to place. We were also able to reconstruct in detail how the PD trucks operated, how long they took to make each stop, and what routes they actually traveled. All this empirical evidence was verified by M.I.T. personnel who rode with the trucks. These data are described more fully elsewhere (3) and are available for study from M.I.T. Although the data cover only a small portion of urban goods movements in the city, it is believed that they are generally representative.

Data on the costs of transportation and handling were also obtained from Rydair. These were supplemented by public sources and private interviews with local truckers. Detailed information about traffic speeds was fortunately available from the 1968 Kennedy Airport access study (8), which determined, by actually driving the routes, the peak and off-peak travel times on hundreds of route segments in the city.

The Model

The model initially computes the number of packages each driver to a particular area can handle. First, the productive pickup and delivery times for a truck in a given zone are calculated based on the driver's shift (normally 8 hours) and the driving time between the terminal and the PD area. Next, the average time per stop is estimated for each truck based on the travel speed, the average distance between stops, and the time a truck requires to serve a shipper. The actual number of packages that can be handled is then determined by examining the limits on the weight and volume of the truck compared with the package size, as well as on the driver's time. The most binding of these considerations determines how many stops can be made in a day in that zone by one truck.

After these determinations, the model calculates the total number of trucks required to service a market. Handling, transport, and other costs are then estimated and added to the costs of the trucks and drivers to determine operating costs of the system being considered. Total costs are then found by adding in average overhead expenses.

Additionally, the model derives several other measures of effectiveness to reflect the impact of the alternative systems on the environment. Specifically, the number of trucks required and the number of truck-miles driven lead to an assessment of the contribution of the PD operation to traffic congestion and air and noise pollution.

Base of Comparison

As a base for comparing alternatives we selected an existing situation in New York: the consolidation terminal and PD operations of the Rydair Company. Using an actual operation enabled us to validate the model; we checked to see whether it could replicate the actual operations (it did).

The Rydair Company handles air cargo for some 22 domestic and international carriers. Its consolidation terminal is in Long Island City relatively close to its PD area in downtown Manhattan. It carries shipments between this point and both Kennedy and La Guardia Airports in large, 45-ft (14-m) tractor trailers and performs PD services with smaller 25-ft (8-m) single-unit trucks. All cargo is unloaded, sorted, and reloaded at the consolidation center. Rydair handles about 31 tons (28 Mg) of cargo and makes about 300 PD stops a day in Manhattan alone. Although it accounts for only a small fraction of all the urban goods movements in the city, it is comparable in size to other consolidation operations, e.g., National New York Packing in the garment center.

RESULTS

The analysis confirms that consolidation can lead to dramatic improvements in truck use but shows that complete consolidation with consolidation terminals may be economically inefficient. For many circumstances route consolidation may be the most desirable configuration for urban goods networks.

Increase in Utilization

Consolidation can easily cut the total truck-miles by four-fifths, as shown in Figure 4. This translates immediately into greater truck use. For this case, the average load per vehicle in the system went from 1-2 tons (900-1800 kg) per truck for no consolidation to 3-4 tons (2700-3600 kg) per truck for complete consolidation. Systemwide load factors correspondingly went from 22 to 68 percent. This is as expected.

But there is a surprise. Although route consolidation is explicitly designed to reduce truck-miles in the PD area, it achieves most of the reductions (in this case 70 to 80 percent) in the haul between the PD area and the terminal. As a further anomaly, complete consolidation, which is not especially intended to reduce mileage in the PD areas, is actually as effective in doing that as route consolidation, which is explicitly designed for that purpose.

These findings illustrate the kind of complexities caused by the interaction of several constraints on the operations. In this instance, these results are apparently a consequence of the fact that, as for most PD operations, the shipments are small. The driver of the truck thus comes to the end of his shift before his truck is full. In this situation, savings in time permit the drivers to make additional stops, and this in turn reduces the number of trucks required to serve a given number of stops. Route consolidation, which is developed to reduce mileage in the PD area, actually saves considerable time by doing this because traffic is slow in downtown areas. These savings in time translate into fewer trucks going to the main terminal and considerable reduction in line-haul mileage. Conversely, the complete consolidation option, which is designed to reduce line-haul mileage, saves considerable time for the drivers in the PD area because they need not travel to the main terminal, and this in turn leads to more stops per truck and less mileage in the PD area. If nothing else, these results indicate that a crude aggregate analysis of consolidation would fail to indicate what actually is happening.

These results also suggest an important policy implication: Consolidation of trucking operations does not appear to be a useful tool for reducing pollution in the downtown areas. Indeed, air and noise pollution are both related to mileage. As indicated by Figure 4, PD operations may not involve much downtown mileage so that, even when consolidation leads to relatively significant savings in the PD area, these reductions are actually quite small on the absolute basis.

Reduction in Costs

Although complete consolidation results in the most significant improvements in truck use and driver productivity, it is generally not the most economical solution because of the significant costs of operating a consolidation terminal. As shown in Figure 5, the costs of handling the goods at a consolidation terminal can easily equal the costs of the truck operations and thus wipe out the potential advantage of complete consolidation. This conclusion is naturally sensitive to the costs of consolidation; when it is very inexpensive, as it can be for solid waste, the complete consolidation alternative may be desirable (7).

In a number of special cases, the advantages of complete consolidation can be obtained without paying for the terminal or for extra handling. These are situations, as for garbage collection, when the crews required for the pickups are larger than those necessary for the haul. It may then pay to establish transfer points where one crew leaves off and the other picks up. Transfer points of this sort have been successfully established by the New York City Department of Sanitation.

With reference to the particular case examined, we can see that the decision to establish the consolidation facility did lead to less expensive operations for the airlines in New York City. But the analysis suggests that a 30 percent increase could have been achieved by simply consolidating their PD routes.

The results shown in Figures 4 and 5 are not, incidentally, sensitive to the location of the consolidation terminal, provided it is reasonably near the PD area. It would not be cheaper to locate the facility in Manhattan, for example, and in particular not at the Chelsea docks, a site that has been repeatedly proposed. That site furthermore suffers from the disadvantage of being on the opposite side of the PD area from the main terminals for air cargo (i.e., Kennedy and La Guardia Airports) and thus requires significantly more trucks and higher expenses.

SENSITIVITY ANALYSIS

The relative desirability of the alternatives naturally depends on the exact nature of the situation. We determined precisely when consolidation might be effective by using the model to calculate the relative costs of the alternatives for a range of possible situations. The results give us some guidelines for deciding what networks to use for urban goods movements.

The sensitivity of results to changes in the environment was examined by changing only one variable at a time. This procedure helps isolate the effects of different variables. It also lets us compare all situations with the same base. It should be carefully noted, however, that because an alternative is desirable when a particular variable is

Figure 4. Reduction in truck-miles due to consolidation.

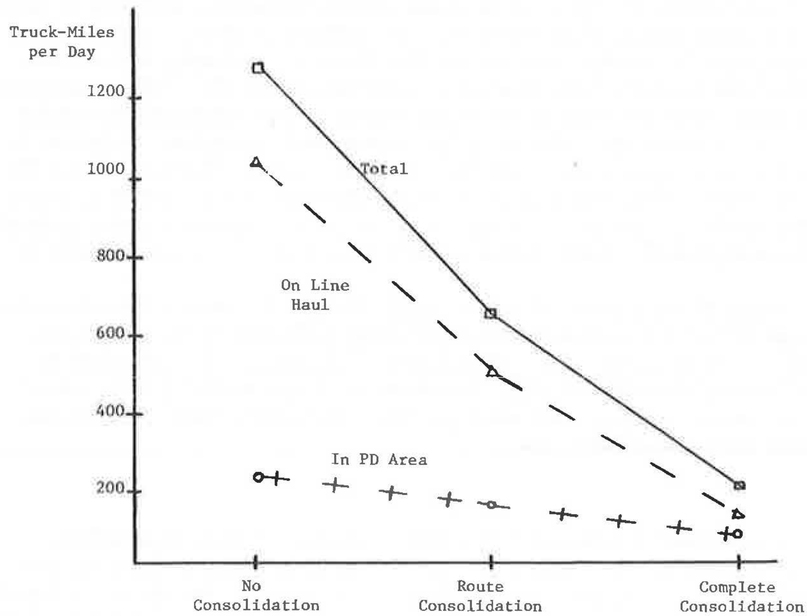
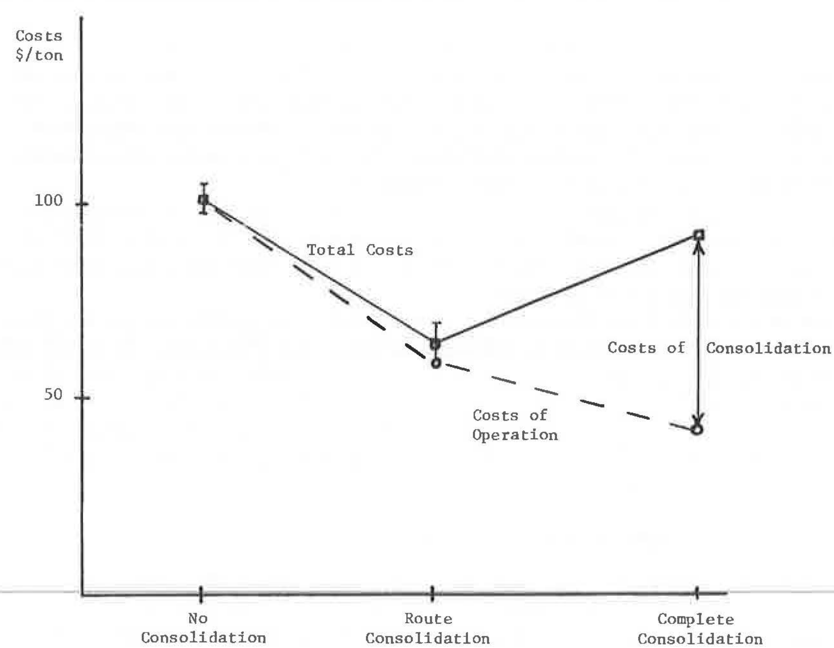


Figure 5. Reduction in cost due to consolidation.



at a given level does not mean that it is desirable whenever that level occurs; changes in other variables could counterbalance this effect.

Effect of Consolidation Costs

Anything that reduces the cost of the consolidation facility tends to make complete consolidation more desirable. This is obvious from Figure 5. Available data indicate that handling costs can be quite low for bulk materials but are almost certain to remain high for the small packages that are characteristic of urban goods movements. Worse, analysis of existing cargo centers indicates that they have strong diseconomies of scale even when automation is introduced (1).

Effect of Haul Costs

Consolidation terminals are more desirable when significant economies of scale can be achieved on the line haul between the PD area and the main terminal, but this effect is actually marginal. As shown in Figures 4 and 5, the line haul accounts for only about half of all transport costs, and these are only half of the total costs of complete consolidation. Even the greatest economies of scale in transport would not, by themselves, reduce total costs significantly.

Effect of Haul Distance

Consolidation terminals and transfer stations are more desirable when the main terminals are farther from the PD area. As this distance increases, the costs of the no-consolidation and route consolidation alternatives actually rise rapidly (Fig. 6). This is because increases in the time required to travel over the line haul squeeze the time available to the driver in the PD area, causing dramatic decreases in his productivity and truck use.

Effect of Shipment Size

Consolidation terminals and transfer stations are also relatively more desirable for larger shipments. As before, the costs of the no-consolidation and route consolidation alternatives rise rapidly (Fig. 7), but in this case the cause is different. What now happens is that, after the size of the packages reaches a certain point, the size of the PD truck replaces the driver's time as the binding constraint. We then find that the PD vehicles are forced to make two or more round trips a day; this is, for example, typical of garbage collection. The alternatives requiring that PD vehicles travel all the way from the PD area to the main terminal are then increasingly at a disadvantage. This phenomenon is another reason why consolidation facilities tend to make sense for garbage collection.

Effect of the Number of Carriers

The relative advantage of consolidation increases with the number of participating carriers, all else being equal. Conversely, if there are too few participants, the proportional share of the overhead for cooperation becomes too large for each carrier, and consolidation becomes uneconomic (Fig. 8). Route consolidation is generally the preferred solution although complete consolidation may be preferable when there are enough carriers. It is interesting to note that the United Parcel Service, which does business with many shippers, moves all its cargo according to the complete consolidation scheme on a national scale.

CONCLUSIONS

There are basically three ways to configure a network for the pickup and delivery of urban goods:

1. No consolidation,
2. Route consolidation, and
3. Complete consolidation with a consolidation terminal.

Figure 6. Total costs of PD alternatives as a function of the haul distance.

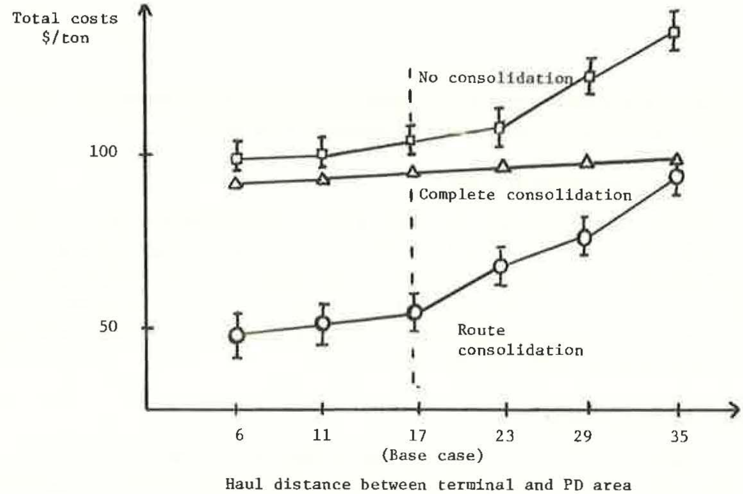


Figure 7. Total costs of PD alternatives as a function of the average shipment size.

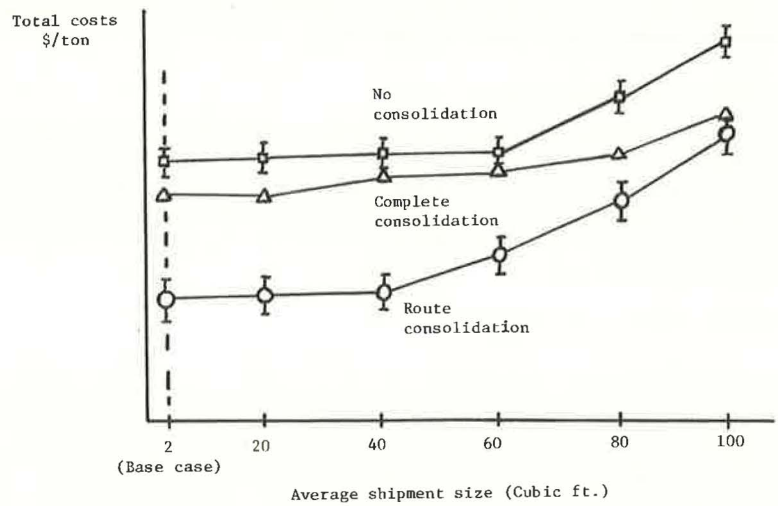
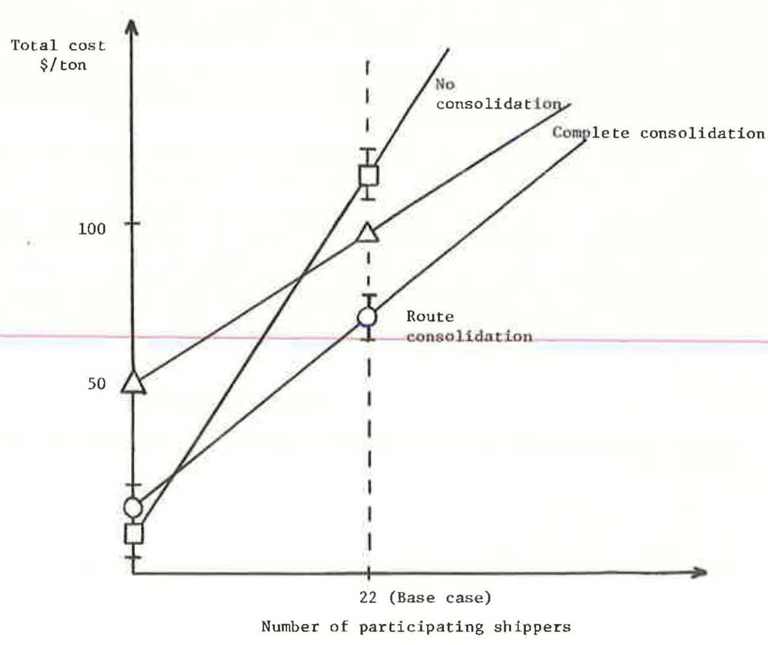


Figure 8. Total costs of PD alternatives as a function of the number of participating shippers.



Route consolidation appears to be generally the best solution.

Consolidation terminals are at a severe disadvantage because of the high costs of handling shipments; they seem to be economical only when these costs can be made very low, when shipments are very large, or when the distance from the PD area to the main terminal is great. Consolidation terminals are thus frequently desirable for garbage collection. They may also be essential for airports located very far from their cities (Stewart Field for New York or Maplin Sands for London). But consolidation terminals do not seem especially attractive for the broad range of problems in urban goods movement.

Consolidation, especially route consolidation, is most advantageous when

1. Consolidation costs and haul costs are low,
2. Haul distances are long,
3. Shipments are large, and
4. There are many carriers to be served.

It would be desirable to encourage consolidation where these conditions are met and where cooperative handling of goods does not already exist. Promising candidates for consolidation are the garment trade and the air cargo business.

These results imply that we cannot expect that new consolidation programs will do a great deal to alleviate current problems in urban transportation. Route consolidation, the best alternative, is already widely practiced for deliveries of mail, newspapers, groceries, and more. These activities would not be affected by a consolidation program. Many activities are furthermore totally unsuited for consolidation. Repair vehicles of all sorts should be excluded from consideration; they are not so much delivery vehicles as mobile repair shops. In short, programs of consolidation of urban goods movements are unlikely to make a real dent in vehicular congestion and pollution in the city.

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