Abridgment

Linear Systems Model of Freight Demand Within a Comprehensive Planning Approach

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The problems of urban freight transportation today can be identified as follows: (a) poor analytic concepts and lack of a methodological framework; (b) increasing proprietary ownership of private trucks and the lack of coordination or cooperation among carriers, shippers, and receivers; (c) increasing and continuous freight transportation demand with strong temporal and spatial preference for small shipments; (d) neglect of planners and public officials in providing and managing freight transportation facilities; and (e) lack of public policy on urban goods movements. The purpose of this paper is to develop a new methodology for urban goods movement studies.

STRATEGY FOR URBAN GOODS MOVEMENT STUDIES

The conventional freight urban transportation planning (UTP) process has been characterized by the exclusive use of the truck trip as the unit of analysis. This convention has allowed the freight study to proceed in close analogy with the standard UTP process, neglecting the cause-effect hypothesis in demand models. Recently, the analyst's attention has been directed toward the development of an urban goods movement study approach (1,2,3). So far, however, no specific and explicit model has been developed in this area that is readily applicable to the freight UTP process.

Problems involved in the conventional approach will be reviewed briefly. First, the indiscriminate use of friction factors for the truck trip distribution, a standard procedure in the UTP process, has been inadequate. Subsequent studies have attempted to stratify the truck trips themselves for the purpose of deriving a distribution (4). Second, the traditional gravity-type trip distribution rationale has questionable validity when applied to multistop vehicle movements. Third, the usefulness of the regression method for truck trip-generation analysis is severely limited, not only on a regional basis but also on a selected area basis. The general regression method on a regional basis would be far less valid than that on a selected area basis because of the large between-zone variation of unincluded important variables. Finally, a recent attempt to attack the problem through the urban goods movement approach shows almost the same shortcomings as does the standard method. As a measurement technique, the carrier-oriented freight survey cannot provide sufficiently reliable data on urban goods movements to serve the needs of the urban goods movement study (5). Moreover, the results of a carrier-oriented survey tend to be severely limited for freight demand analysis because mode choice in goods movement, coupled with double-counting by modal interface, may significantly mislead the analyst (6). The only way to solve this problem is to get freight information directly from the shippers or consignees.

It is argued that economies can be achieved by combining the freight UTP process with other studies. This paper, therefore, concentrates on developing a freight UTP process within a combined regional planning framework. The basic inputs for the proposed process can be provided by regional social accounting studies and truck traffic surveys. The latter are comparable in basic design to those in the Tri-State Study (7).

OBJECTIVES AND SCOPE OF FREIGHT UTP PROCESS

The rather superficial treatment of freight UTP to date conflicts with the goal of developing the study of urban transportation as a branch of science. Both for the direct relationship of freight movement with economic and business activity and for the strategy of the planning process, the objective of freight demand analysis need not be limited to a transportation facilities plan.

Forecasts must be made of commodity movements as well as of the movements of vehicles hauling the commodities, i.e., their relation to regional development (8). Goss also identifies four major categories for urban goods movement study areas:

1. Regional goods movement,
2. Area or subregional goods movement,
3. Facility goods movement, and
4. Waste goods movement.

For the purpose of the urban transportation planning process, it is necessary to define the scope of an urban freight transportation study so that it is complementary to that of a passenger transportation study and a total transportation facilities plan (1). Freight flow can be classified broadly according to fundamental motives of flow and direct channels of shipment.

Classification by motive or purpose for commodity flows is necessary to enable the development of demand analysis that conforms to economic theory through the social accounting system. Commodities flow for the purpose of capital formation, consumption, or disposal at an ultimate destination (9).

SOCIAL ACCOUNTING SYSTEMS APPROACH

The adoption of the commodity classification of the social accounting system seems necessary. It is a prerequisite not only for regional economic and business analysis but also for freight analysis. It seems to be impracticable or uneconomical to establish a single homogeneous classification scheme of commodities, given the multiple aspects of physical and economic characteristics of goods and the behavioral characteristics of shippers and consignees (10).

The idea of multiple classification in a social accounting system, originally proposed by Stone (11) and recently adopted by the United Nations Statistical Commission, seems to be extremely useful for freight demand analysis. One procedure developed to interconnect the multiple classification systems with the linear systems model is described here.

Tables 1-3 show how multiple classifications could effectively be used in freight transportation analysis in line with the social accounting system. According to any specific attribute desired, such as

Table 1. Commodity flow coefficient matrixes.

Commodity	Consuming Establishment: Intermediate[a]	Final[b]	Distributing Establishment: Warehouse[c]	Wholesaler With Stock[d]	Retailer[d]
1					
.					
.					
i			M_a	M_w	M_r
.					
.					
m					
Total	q'	y^*	s'_a	s'_w	s'_r

Notes: M = merchandise goods flow matrixes in monetary terms; s = M' u: column vector of sales; ' = transpose throughout this study unless otherwise specified; u = unit column vector throughout this study unless otherwise specified; q = column vector of outputs by industry of commodity; y* = Y' u: column vector of categorized final demand.

[a] By industry classification. [c] By type of equipment for warehousing.
[b] By category of final consumer. [d] By kind of business classifications.

Table 2. Commodity-industry flow matrixes.

From	To: Industry	Commodity	Final Consumer	Total
Industry	X_{dd}	X_{dc}	Y_d	q_d
Commodity	X_{cd}	X_{cc}	Y_c	q_c
Final consumer	z'_d	z'_c	0	y^*

Notes: X = matrixes of product flows in monetary terms; Y = matrixes of final demand either by industry or commodity and by category; z = column vector of primary inputs into industries or commodities; and y = Y_d u.

Table 3. Commodity-industry input coefficient matrixes.

From		To: Industry 1 . . . d	Commodity 1 . . . c	Final Consumer 1 . . . f
Industry	1 . . d	0	A_{dc}	0
Commodity	1 . . c	A_{cd}	0	F_c

physical or chemical state of commodities (e.g., liquid, gaseous, bulky), the incidence matrix can be defined in terms of elements that are either zero or unity according to the proper attribute or in terms of shares of the total, if the commodity itself is aggregated. Thus, they can be combined with each other for integration, whenever necessary.

Table 2 describes how the freight demand analysis could proceed under the social accounting scheme for intermediate and final consumption establishments by combining the classification schemes for industry and commodity. Using the industry outputs (q_d), the commodity outputs (q_c), and the consumer expenditures by category (y^*), the input coefficient matrixes (see Table 3) can be defined by Equations 1 through 5. [Throughout this paper, capital letters refer to matrixes; lower-case letters refer to vectors; hatted letters refer to diagonal matrixes obtained from vectors; -1 equals inverse, otherwise specified; I equals identity matrix.]

$$A_{dc} = X_{dc}\hat{q}_c^{-1} \quad (1)$$

$$A_{cd} = X_{cd}\hat{q}_d^{-1} \quad (2)$$

$$F_c = Y_c\hat{y}^{*-1} \quad (3)$$

By definition,

$$q_d = A_{dc}q_c \quad (4)$$

From accounting properties,

$$q_c = A_{cd}q_d + Y_c u \quad (5)$$

$$q_c = A_{cd}A_{dc}q_c + Y_c u \quad (6)$$

$$q_c = (I - A_{cd}A_{dc})^{-1} Y_c u \quad (7)$$

Therefore,

$$q_d = A_{dc}(I - A_{cd}A_{dc})^{-1} Y_c u \quad (8)$$

$$q_d = (I - A_{dc}A_{cd})^{-1} A_{dc} Y_c u \quad (9)$$

$$q_d = (I - A_{dc}A_{cd})^{-1} A_{dc} F_c y^* \quad (10)$$

which gives q_c or q_d in terms of y^* with a matrix multiplier of order equal to the number of commodities or the number of industries. The procedures are valid whether matrixes A_{dc} and A_{cd} are square or rectangular. The number of commodities (size of commodity classification) is most likely much larger than that of industries (size of industry classification) in empirical studies.

The multiple classifications not only provide a unified scheme for production and consumption analysis with the input-output framework for regional economic and business analysis as such, but also directly relate the results with freight demand analysis by translating the monetary outputs into the physical quantities by commodities. This can be done by using the value-ratio matrix and then the commodity density matrix to determine the vehicle-loading capacities in terms of weight or volume as shown in Equations 11 and 12.

$$Q_i = \sum_{j}^{n} q_i s_{ij}/p_i \quad (11)$$

$$V_i = Q_i/d_i \quad (12)$$

where

Q_i = weight of the i^{th} commodity,
V_i = volume of the i^{th} commodity, and
q_i = products of commodity i in monetary terms.

The estimation of inbound freight at intermediate consumption establishments has to be made on the basis of commodity-to-commodity input coefficients rather than either on the commodity-to-industry input coefficients or on the industry-to-industry input coefficients. Thus, problems related to intraindustry commodity mix in establishing coefficients must be solved (5).

In summary, once the output commodities comprised of products and sales in monetary terms and thus activity intensity are projected on a zonal basis, the zonal input commodities and waste flow can be consistently estimated by the linear models as follows:

$$\hat{p}^{-1}\, g \rightarrow e \qquad (13)$$

$$\hat{e}\, \dot{E} \rightarrow E \qquad (14)$$

$$t'\, L \rightarrow v' \qquad (15)$$

$$\hat{v}\, \dot{V} \rightarrow V \qquad (16)$$

and

$$p' \bar{E}_g A_{dc} u \rightarrow q_g \qquad (17)$$

$$A_{cc} q_g \rightarrow r_g \qquad (18)$$

$$W_f a + W_d q_g \rightarrow d_g \quad \text{for } g = 1, \ldots, h \qquad (19)$$

$$C\, V_g \rightarrow Z_g \qquad (20)$$

where

a = number of households in zone g;
q_g = zonal output vector by commodity (c x 1);
r_g = zonal input vector by commodity (c x 1);
d_g = zonal waste vector by type (v x 1);
z_g = zonal sales vector by commodity (c x 1);
e = regional employment vector by industry (a x 1);
v = regional sales vector by kind of business (b x 1);
q = regional output vector by commodity (c x 1);
t = regional sales vector by commodity (c x 1);
$\dot{E}$ = employment share matrix (s x h), i.e., E_{ig} is the proportion of zone g of the regional employment for industry i-- $\sum_g [E_{ig} = 1$, for all i];
$\dot{V}$ = sales share matrix (b x h), i.e., V_{ig} is the proportion of zone g of regional sales by kind of business i-- $\sum_g [V_{ig} = 1$, for all i];
L,C = sales merchandise coefficient matrixes based on fixed-row and fixed-column assumption respectively (c x b);
A_{dc}, A_{cc}, W_d, W_f = as shown in Table 2;
p = employment productivity vector (s x 1); and
E_g, V_g = vectors made of g^{th} column of zonal employment matrix E (s x h) and zonal sales matrix V (b x h) respectively.

CONCLUSION

As an alternative to solving the problem involved in urban freight demand analysis, this study has discussed the linear systems model according to the social accounts approach and completely separate from the passenger travel demand model. At first glance, it would seem this alternative method would impose an enormous burden, but the magnitude of economies that can be achieved by combining the freight UTP processes with other studies within a comprehensive urban-regional planning process can be demonstrated (5).

In developing a methodology for the freight UTP process, this paper attempts to demonstrate that the basic freight UTP process may be designed within a combined comprehensive planning approach. The freight UTP process developed here is characterized by the spatial-general-equilibrium implementation of regional aggregate analysis, locational analysis for allocation of activities, and commodity (goods and services) and freight demand analysis.

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REFERENCES

1. A. H. Meyburg and P. R. Stopher. A Framework for the Analysis of Demand for Urban Goods Movement. Transportation Research Record 496, 1974, pp. 68-79.
2. A. H. Meyburg, E. Diewald, and G. P. Smith. An Urban Goods Movement Planning Methodology. ASCE, Journal of Transportation Engineering, Vol. 100, No. TE4, Nov. 1974, pp. 791-800.
3. A. H. Meyburg and P. R. Stopher. Urban Goods Movement: A Study Design. ASCE, Journal of Transportation Engineering, Vol. 102, No. TE4, 1976, pp. 651-664.
4. L. A. Hoel. A Study of the Utilization of Trucks for Transport in Urban Areas. Univ. of California, Berkeley, PhD dissertation, 1963.
5. K-W. Lim. The Urban Freight Transportation Planning Process: An Input-Output Approach to a Methodological Framework. Cornell Univ., PhD dissertation, 1974.
6. M. Chisholm and P. O'Sullivan. Freight Flows and Spatial Aspects of the British Economy. Cambridge Univ. Press, Cambridge, England, 1973.
7. Truck Freight in the Tri-State Region, Vol. 2. Tri-State Transportation Commission, ITR 4143-1610, 1969.
8. D. N. Goss and others. Urban Goods Movement Demand. Battelle Memorial Institute, Columbus, 1967.
9. S. Kuznets. Commodity Flow and Capital Formation, Vol. 1. National Bureau of Standards Research, New York, 1938.
10. L. A. Schumer. The Elements of Transport. Butterworth and Company, Ltd., London, 1955.
11. R. Stone and others. A Program for Growth. Chapman and Hall, London, 1963.

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