MEASUREMENT OF URBAN COMMODITY MOVEMENTS

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An analytical framework for summarizing small commodity movements within an urban area is described. This methodology for measuring urban goods movements consists of a series of operations that process data on commodity shipments and the activity system to provide an input-output summary of selected urban commodity flows. Initially freight service zones are established for the study area, and classification systems are developed for commodity flow origins and destinations and for categories of small commodities. Commodity movements are represented in terms of temporal, volumetric, and spatial dimensions to show variations in demand for commodity transport. Relationships are then developed between commodity demand (flows) and activity units to establish the input-output model. The resulting information aids the development of a forecasting methodology of the demand for urban goods movements. The areal flow measures are analogous to the outputs of the distribution phase of the urban transportation planning process and, accordingly, give loadings that can be simulated on alternative delivery system designs to render measures of performance for evaluative purposes. A direct firm-based commodity shipment survey procedure is recommended to obtain the essential planning data currently lacking on goods movements.

• THE TRANSPORTATION of goods within an urban area is a costly operation. A recent article on the problem (1) stated that the cost of local delivery is about eight times that of local people movement by public transport and that 40 percent of the total national freight bill is consumed by this phase of distribution. On the same subject, the Tri-State Regional Planning Commission has estimated that $95 million could be saved annually if all New York metropolitan area pickup and delivery operations were coordinated.

A major segment of intraurban goods movements, which is the subject of this paper, is the small shipment weighing less than 500 lb. Technological improvements in the local collection and delivery of small shipments would considerably reduce total goods transport costs. The evaluation of improvements to local goods transport is very difficult because there is a lack of adequate data on local freight movements and, hence, little understanding of local delivery requirements. In most cases, the information on hand specifies the origins and destinations of goods movements relative to individual means of transport and is thus means specific (2). [Means is used to include measures of service that reflect distinctions in characteristics of the truck mode and methods of handling various commodities (4).]

The objective of this paper is to develop procedures for measuring local goods movements that will show how various fragmented deliveries can be collected and consolidated so that ultimately a coordinated local delivery system providing required levels of service and reduced costs can be developed. This methodology could be used to study use of urban transit for goods delivery during off-peak hours. The need for descriptive measures of local goods movement is particularly evident in this case inasmuch as the concept has been widely discussed, but it has been impossible to measure potential merits without knowledge of the actual loads imposed on the system.

The framework developed to measure and monitor urban goods movements consists of the following phases:

1. Establishment of freight service zones (in study area),
2. Classification of commodity flow origins and destinations,

3. A small commodity classification system,
4. Commodity demand characteristics,
5. Relationship between commodity demand (flows) and activity, and
6. Synthesis of land use and commodity systems (input-output model).

FREIGHT SERVICE ZONES

To properly define urban goods movements in a spatial perspective requires that a proper interface be established with the land use-activity system. Inasmuch as personal travel analyses use traffic zones for a frame of reference, a similar frame of reference is necessary for commodity movement study. Whereas in the former context traffic zones are established over a study area to reflect homogeneous centers of activity, the freight service zone represents an areal tract that exhibits uniform commodity-shipment needs among its constituent units. With these zonal bases it is possible to assess general trends indicative of generators of urban freight traffic.

The freight service zone is established in view of the major economic commodity flow generator categories (at an urban, small shipment level) listed below.

Origin	Destination
External	Wholesale
	Retail
Wholesale	Institutions
	Retail
Retail	Institutions
	Residential

With these classifications, a rudimentary system of freight service zones is derived in view of homogeneous conglomerations of the following activities: external (dummy peripheral terminal), wholesale, retail, major institutional development (e.g., offices, universities, hospitals, and governmental agencies), and residential.

In many respects this classification scheme for zonal land use is sufficient to specify a complete zonal system. However, the typical service zone system should be finalized in terms of zonal size and intensity of commodity movement. For example, a retail zone is conceivably much smaller geographically than, say, a residential area, for the former will exhibit a higher intensity of movement per developed acre. The breakdown of large retail and residential centers is based on the following considerations: intensity of flow, homogeneity of flows, access links to transport network, and vehicular or system capacity.

CLASSIFICATION OF COMMODITY FLOW ORIGINS AND DESTINATIONS

Each economic unit that serves as a terminus of goods flow (i.e., business or household) is referenced to the service zones and classified according to the coding system given in Tables 1, 2, and 3 to indicate the type of site development (building structure and type), major activity (store, office, etc.), and explicit economic function (3).

SMALL COMMODITY CLASSIFICATION SYSTEM

In this stage, an array of small commodity types is selected and classified to provide a framework for coding, aggregating, and processing data on urban small goods movements. This classification commodity listing given in Table 4 is derived from those used in the Standard Industrial Classification Code of the U.S. Bureau of Budget and Transportation Commodity Classification of the Bureau of Census. Although the code uses indexes different from those used in the major source codes, a direct correspondence can be established between them if desired.

COMMODITY DEMAND MEASURES

Measures that characterize the typical consignment of a given goods movement between certain origin-destination types must be established. In this initial investigation

Table 1. Classification of site adaptation.

Code	Class
00	No structure or nonbuilding structure
10	Office and bank building
22	One- or two-story factory or warehouse building, not fireproof
24	One-story factory or warehouse building, fireproof
25	Multistory factory or warehouse, fireproof
27	Specialized laboratory building
31	Produce warehouse
33	Rail and truck transfer shack
34	Refrigerated warehouse
35	Small one-story distribution warehouse
36	Large-area, single-floor distribution warehouse
37	Trucking terminal dock building
38	Wharf and dock shed
41	Free-standing one-story store building
42	One-story store building in a row
43	Single supermarket building
44	Supermarket complex
45	Multistory department store building
46	Two- or three-story building, store and residence overhead
47	Two- or three-story, store and office overhead
48	Two- or three-story building, store and loft space overhead
51	Residential buildings, single-family houses
57	Apartment building, 1 to 4 stories
58	High-rise apartment building or hotel
59	Dormitory building
61	Theater building or movie house
62	Sports area
63	Church building
64	Concrete hall
65	Bowling alley
67	Terminal building (air, rail, bus)
68	Stadium
71	Hospital building
72	Medical clinic building
73	School building
74	Museum or library building
75	Fire station
76	Police station
88	Motel building

Table 2. Major activity index.

Code	Class
00	No activity
01	Office activity, public oriented
02	Office activity, non-public oriented
04	Store activity
05	Shop activity
07	Eating and drinking
08	Residential, multiple-unit dwelling
10	Play and active recreation
11	School activity
12	Mass assembly and spectatorship
13	Passenger assembly
14	Other forms of public assembly

Table 3. Economic "over use" (function).

Code	Function
10	Residences
20	Finance, insurance and real estate
50	Wholesale trade
52	Retail trade, hardware
54	Retail trade, food
55	Retail trade, automotive
56	Retail trade, apparel and accessories
57	Retail trade, furniture, house furnishings, and equipment
58	Retail trade, eating and drinking places
59	Miscellaneous retail trade
60	Department stores
61	Mail-order houses
62	Limited price variety stores
63	Drug stores and proprietary stores
64	Merchandise vending machines
65	Dry goods, fabric and yarn
70	Hotels, rooming houses, camps, etc.
71	Laundries, dry cleaning, tailors, clothing rental
72	Photographic studios
73	Beauty shops
74	Barber shops
75	Duplicating, blueprinting, photocopying, stenographic services
76	Miscellaneous repair services
78	Motion pictures
79	Other amusement and recreational activities
80	Medical and health services
81	Legal services
82	Engineering and architectural services
84	Accounting, auditing, and bookkeeping services
85	Research development and testing labs
86	Advertising
91	Federal government
92	State government
93	City government
94	County government

into the problem, three basic flow dimensions are considered: temporal, volumetric, and spatial measures.

Temporal and Volumetric Characteristics

The demand for goods transport is assumed to derive from the characteristics and operational policies of shippers and/or receivers of the goods. It is further assumed that "routines" or goods delivery patterns develop that reflect repetitive scheduling over an appropriate time period (e.g., day, week). Also, different shippers and receivers exhibit different goods demands in view of goods types and characteristic shipment sizes. For example, business and household shipment ends will exhibit different consumption demands. Thus average measures for the temporal and volumetric dimensions of a typical goods consignment are applicable only to specific shipper-receiver combinations.

These observations are summarized by the following relationship:

$$F_j^{klT} = f(O_k,\ D_l,\ C_j,\ T) \tag{1}$$

where

F_j^{klT} = a measure of the flow of good j between origin type k and destination type l during time period T,
O_k = characteristics of freight shipment origin (firm),
D_l = characteristics of freight shipment destination (firm or household), and
C_j = commodity type.

Equation 1 gives the volume of flow of a specific good between a given origin-destination set over a certain time period (e.g., day, week).

This relationship can be used to show the temporal variation of a commodity flow during any period of time. For example, for T = 24 hours,

$$F_j^{lkT} = \sum_{t=1}^{24} F_j^{klt} \tag{2}$$

for i = 1, ..., 24 and where t indicates each hour during the day.

This formulation can also be taken to give the total flow of goods between any pair of activity units (k, l), the total flow of good j in the region, and the total freight received or sent from a particular place as follows:

$$F^{klT} = \sum_{j=1}^{P} F_j^{klT} \tag{3}$$

$$F_j^{T} = \sum_{k}^{M} \sum_{l}^{N} F_j^{klT} \tag{4}$$

$$F^{lT} = \sum_{j}^{P} \sum_{k}^{M} F_j^{klT} \tag{5}$$

$$F^{kT} = \sum_{j}^{P} \sum_{l}^{N} F_j^{klT} \tag{6}$$

where

P = number of commodities considered,
N = number of shippers, and
M = number of receivers.

Spatial Characteristics

The spatial characteristics of urban goods movements are assumed to be dependent on the corresponding shipper-receiver set and the commodity class. The total areal demand for a product will give an indication of the number of shipping firms involved. The number of shippers is assumed to be relatively small compared with the population of receivers (consumers), and each shipper is concerned with a given market area. The distribution of delivery trip lengths is then a function of a seller's viable market area. In the case of multiple sellers, this conceptualization becomes complex as shown in Figure 1. A model at this stage must therefore be sensitive to the market relative to

1. Location of sellers,
2. Location of receivers,
3. Areal product demand,
4. How competitive each firm is relative to the other,
5. Brand advantages, and
6. Economic self-containment of subareas.

The proposed analysis of market areas is based on data on the deliveries and locations of a firm's customers (information on both carried and delivered goods is required). Because many businesses provide sales receipts, it is feasible to proceed in this manner. An example of the output of this phase is given in Table 5 as a frequency distribution of goods movements according to distance. The amount of product j originating at firm k, shipped to destination l during period T, and traveling distance s is

$$F_j^{k_{T_s}} = F_j^{k_T} f_j(s) \qquad (7)$$

and the average distance that shipments of commodity j are transported within the study area is

$$\bar{S}_j = \sum_{w=1}^{W} s_w f_j(s) \qquad (8)$$

where W = total set of discrete trip length intervals.

GOODS FLOW AND O-D ACTIVITY MAGNITUDES

The development of a mechanism for relating goods flow measures with certain O-D activity linkages is now considered. The subscript j is assigned a digital value to correspond with the commodity code given in Table 4. Specific O-D types are examined to establish sets of common desire patterns. The k and l superscripts previously used to indicate an O-D pair are replaced by generalized characteristic vectors Z_o and Z_d, which are derived from the site adaptation measures given in Tables 1, 2, and 3.

$$\begin{aligned} Z_o &= [SA_o,\ AI_o,\ EF_o] \\ Z_d &= [SA_d,\ AI_d,\ EF_d] \end{aligned} \qquad (9)$$

where

SA = site adaptation code,
AI = major activity index,
EF = economic function,

Table 4. Group and item descriptions of major commodity groups.

Code	Group Description	Item Description
0	Mail	
01		Letters, U.S. Postal Service
02		Packages, U.S. Postal Service
03		Courier, private delivery
1	Food and kindred products	
10		Food and kindred products
11		Baked goods
12		Beer, wine, alcoholic beverages
13		Tobacco
2	Laundry, dry cleaning, etc.	
20		Laundry, dry cleaning, etc.
3	Printed matter	
30		Newspapers
31		Books, magazines
32		Other printed matter
4	Building furnishings, equipment, and appliances	
40		Furniture and home furnishings
41		Floor coverings
42		Electrical appliances
43		Housewares
5	Building operation, equipment and improvement items, automotive items	
50		Automotive
51		Paints
52		Glass
53		Hardware and home repair items
54		Plumbing and heating
55		Airconditioning and refrigeration
6	Apparel and accessories	
60		Apparel and accessories
61		Fabrics, yarn, thread
62		Footwear
63		Jewelry
64		Leather goods
65		Optical goods
7	Office supplies and equipment	
70		Office equipment
71		Paper products
72		Equipment and supplies for service establishments
73		Professional, scientific, and controlling instruments and supplies
8	Drugs	
80		Drugs, cosmetics, etc.
9	Recreation equipment and gift items	
90		Toys and amusement goods
91		Sporting goods
92		Flowers, florists
93		Nursery products
94		Religious goods
95		Music
96		Bicycles
97		Cameras and photographic supplies

Figure 1. Competition among firms for a market.

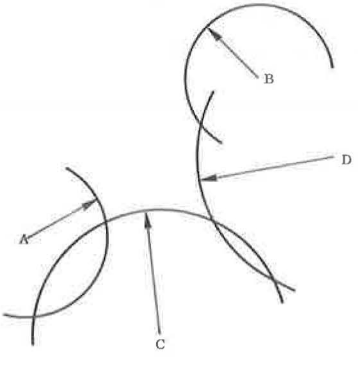


Table 5. Spatial market for firm k, product j.

Distance Category	Distance, s (miles)	Frequency of Occurrence, $f_j(s)$ (percent)
1	0-¼	12
2	¼-½	10
3	½-1	22
4	1-2	10
5	2-4	30
6	4-8	10
7	7-10	6

Z_o = origin characteristics, and
Z_d = destination characteristics.

The generalized commodity flow variable now becomes

$$F_j^{Z_oZ_dTs} \tag{10}$$

which equals the volume of flow of good j between firms o and d during time T and spatial separation s.

If categories for shippers and receivers are established relative to some production surrogate (i.e., employment or floor space for commercial units and population density for residential areas), a unit activity measure can be defined for each category. This unit measure is then a lower limit on the resources required of a firm to be engaged in the distribution of a certain commodity. Thus, if $F_j'^{Z_oZ_dTs}$ is the unit measure relative to Eq. 10, then, for specific O-D combinations, this value can be scaled according to a potential ϕ, which is defined as

$$\begin{aligned} \phi &\sim (E_o,\ P_d,\ R_{od}) \\ \phi &= kE_o^{\alpha}P_d^{\beta}R_{od}^{\delta} \end{aligned} \tag{11}$$

which equals goods per period per unit measure where

R_{od} = a generalized travel impedance factor,
k, α, β, δ = constants of calibration,
E_o = employment at origin firm, and
P_d = population density at destination zone.

$$F_J^{Z_oZ_dTR_{od}} = \phi F_J'^{Z_oZ_dTR_{od}} \tag{12}$$

subject to ϕ = 1 where

$$F_J^{Z_oZ_dTR_{od}} = F_J'^{Z_oZ_dTR_{od}}$$

Equations 11 and 12 are then commodity flow generation and distribution measures.

AREAL SUPPLY-DEMAND CONCEPTS

The interzonal commodity flows for an urban area are summarized by a matrix based on the following considerations.

1. A list of supply nodes for each commodity,
2. A list of supply quantities for each node,
3. A list of demand nodes for each commodity, and
4. A list of demand quantities for each node.

These ideas are shown in Figures 2 and 3 and are summarized by the following measures.

$$V_J^K = \sum_I F[K,\ I,\ J] \tag{13}$$

where

V_J^K = quantity of good J originating at zone K (supply),
J = commodity index,
K = origin zone,
I = industry index, and
F[K, I, J] = quantity of good J originating at zone K from industry I.

A similar relationship can also be shown to hold for the demand nodes. Here F[L, I, J] represents the demand for good J by industry I located in zone L.

Figure 2. Supply summary.

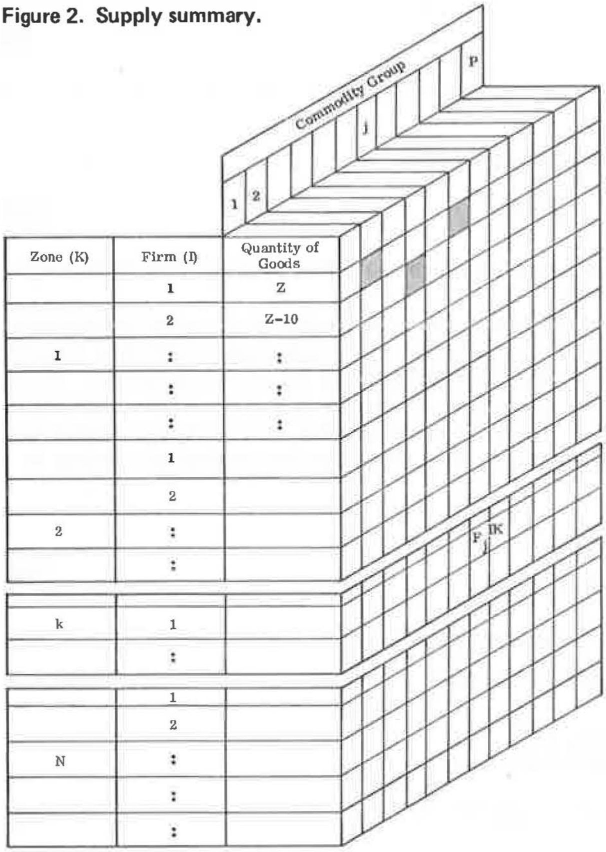
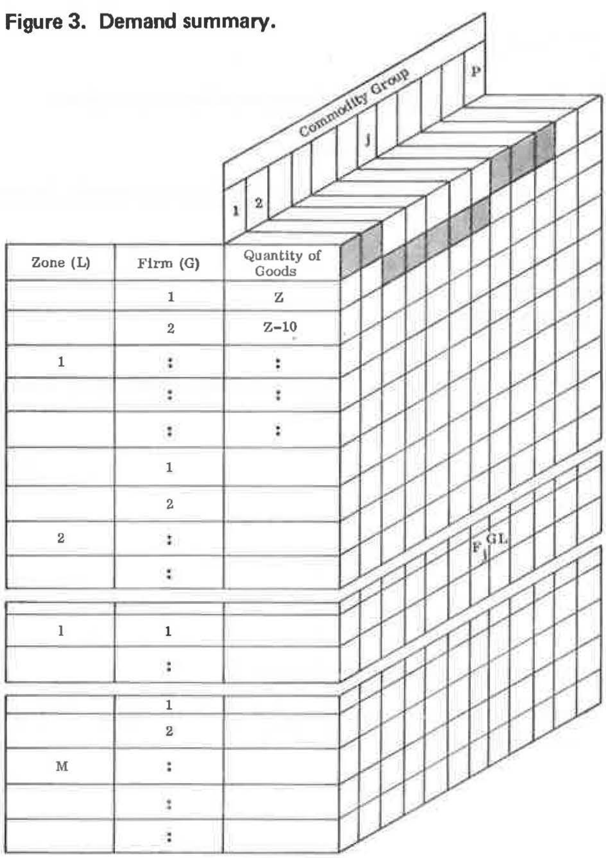


Figure 3. Demand summary.



$$D_J^L = \sum_I F[L, I, J] \quad (14)$$

SYNTHESIS (INPUT-OUTPUT MODEL)

The supply and demand information shown in Figures 2 and 3 is now synthesized by an interaction matrix given in Table 6. This table is directly related to the summary computations previously developed. If we neglect the time stratification, the entries into each cell of the commodity flow matrix are the flows of a given good j from industry I in zone K to industry G in zone L. Thus, this quantity is represented as F^{IKGL}, which has the following correspondence with Eq. 2.

$$F_j^{kl} = F_j^{IKGL} \quad (15)$$

where

k, l = firm indexes,
I, G = zonal firm indexes, and
K, L = zonal indexes.

The association with Eqs. 3 through 7 is similar.

The travel distance factor, $f_j(s)$, or more conveniently a travel impedance factor $f_j(R)$, which derives from a number of travel cost factors such as time, cost, and frequency, is given in Table 7 to show the zone-to-zone (K to L) impedance measure (R_{KL}). If, for example, $R_{KL} = s_{KL}$ (distance), then each row in Table 7 can be taken to give a distance frequency distribution like that given in Table 5. The same can be done columnwise to show the distribution of travel distance for goods received. Equations 7 and 8 are thus satisfied.

The methodology derived provides the operations necessary for processing commodity data (Table 6) with the transportation (Table 7) and activity (Table 8) system measures to show specific goods flow channels, $F_j^{Z_oZ_dT R_{od}}$, relative to the characteristics of shippers and receivers, time periods, and transport impedances. Once a basic data file is created, various generalizations and relationships such as proposed in Eqs. 11 and 12 can be investigated to establish the postulates necessary for the development of a demand forecasting methodology for urban goods movements.

APPLICATION

The given methodology has been designed to summarize intraurban goods movements relative to a set of firms (wholesale, retail, households). The basic output provides measures of commodity flows in an urban area to and from specific shippers and receivers. The mechanism is provided for various degrees of aggregation such as interzonal flows or flows among firms or groups of firms.

To implement the methodology requires only firm-related data. In other words, because the objective was to measure goods movements, carrier data sources were assumed to be of secondary importance. The required activity data then include specification of freight service zones and inventory of significant firms with appropriate statistics on each, and the necessary goods movement data include, for each wholesale and retail firm of interest, documentation on each freight arrival and shipment during a specified time period (which must be assumed as repetitive in a cyclic fashion). With these selected data, it is envisioned that local destinations as well as out of town origins for the majority of goods movements will be obtained. Interfirm flow can be used to verify the data.

This information appears sufficient to specify current goods movement in the urban area. The counterpart in urban passenger transportation planning is the output of trip distribution. Once this task is accomplished, the given freight movements can be loaded on various alternative delivery systems and simulated to give measures of performance. These data requirements are given in Tables 9 and 10.

Table 6. Commodity flow interactions.

From V[K, I, J]	To D[L, G, J] 111	112	L G J	NMP
111				
112				
113				
121				
211				
212				
KIJ			F_J^{IKGL}	
NMP				F_P^{MNMN}

Table 7. Travel impedance matrix.

K \ L	1	2	3	4	1	n
1						
2						
3				R_{34}		
k					R_{k1}	
n						

Table 8. Zonal inventory data.

Zone K	Number of Different Industries	Industry KI	Activity Intensity Measure P.., E..	SA AI EF
1	5	11	E_{11}	
		12	E_{12}	
		13	P_{13}	
		.	.	
		.	.	
		.	.	
2	1	21	P_{21}	SA AI EF
.	.	.	.	.
.	.	.	.	.
n	2	n1	E_{n1}	SA AI EF
		n2	E_{n2}	

Table 9. Local firm data.

Data Entry	Class Retail	Wholesale[a]	Institution	Household[b]
1. Firm number	R-	W-	I-	Zonal No.
2. Location	Zone	Zone	Zone	Zone
3. Site adaptation	SA	SA	SA	SA
4. Major activity	AF	AI	AI	08
5. Economic "over use"	EF	50	EF	10
6. No. employed or population	E	E	E	P
7. Gross annual sales	AS	AS	N/A	N/A
8. Annual income or budget	N/A	N/A	B	I
9. Major commodities handled	C	C	N/A	N/A

[a]Includes distributors and manufacturers.
[b]Household measures aggregated in terms of residential zone statistics.

Table 10. Typical commodity shipment data (from retail and wholesale entries).

No.	Shipping Data	Value
1	Shipper or receiver (source firm)	0 = shipper; 1 = receiver
2	Means of transportation	
3	Destination	If 1 = 0
	Origin	If 1 = 1
4	Commodity type	From Table 4
5	Quantity	Lb, number, etc.
6	Distance	Total O-D travel distance
7	Time of departure or arrival	
8	Type of service	Single or multiple commodity
9	Repeat 3 through 7 for all entries if multiple commodity	

SUMMARY

This paper provides a new strategy for analysis of urban goods movements. It is the initial step toward an important objective: development and implementation of an analytical framework for comprehensive analysis and evaluation of innovative solutions to the local delivery problem.

Even though the model is derived from comprehensive considerations, the procedures for measurement of urban goods movements given below are straightforward:

1. Establish zones,
2. Inventory firms and select representative subset for shipment survey,
3. Survey shipment,
4. Process data,
5. Prepare interaction matrix,
6. Prepare interzonal impedance matrix, and
7. Analyze and test causal relationships.

The operational tasks involved concern data processing and manipulation, inasmuch as the goal is to describe existing patterns of urban goods movements. The summary mathematical relationships, which have been given as directing the methodological development, provide for future extensions toward the development of an urban goods forecasting model system.

Because the purpose of this paper was to structure the methodology, specific classifications for firms and goods have been introduced. Emphasis, however, was on strategy, inasmuch as any number of consistent classification schemes may be used within the described framework.

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