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URBAN FREIGHT AND LAND USE INTERACTION

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ABSTRACT: *The economic importance of freight movements within Australia's urban areas is well recognised - a recent estimate by the Bureau of Transport Economics put the value as high as $3700m for 1975/6, of which all but $100m was carried out on the urban road system. This economic importance is recognised in the evaluation of urban road construction proposals where typically up to half the long-term user benefits accrue to commercial vehicle operations. It is the forecasting procedures (i.e. models) leading up to these evaluations that this paper is concerned with. The models currently used are aggregate (i.e. zonal) and are based on commercial vehicles rather than on freight tonnages; a situation dictated by the manner in which data has been collected in the past. This paper examines ways of improving this aggregate technique both from the statistical and behavioural viewpoints using the 1964 Melbourne data. From the behavioural view-point, it is found that precision is improved by stratification of trips by the purpose of the trip. Micro-economic production theory is used to add a behaviourally theoretical justification for the urban freight/land usage relationship. Finally, the current method-ology (i.e. consideration of each trip as an isolated event) is examined for its reality.*

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INTRODUCTION

Relatively little attention has been paid to the development of theories of freight flow or to the development of freight flow forecasting models, given the economic importance of the freight task. In urban areas this freight task is predominantly accomplished by truck - Quinlan and Short (1977) put the cost of urban freight movement in Australia for 1975/76 at \$3700 M, of which all but \$100 M was attributable to the road system. For this reason transport analysts have largely focussed on truck movements instead of commodity tonnages, resulting in the stunted development mentioned above. In Australia the focus on truck movements has resulted in most data collection attempts ignoring urban commodity tonnages completely (Dumble 1979*a*). This paper takes one such typical data set of aggregate truck movements - Melbourne 1964 - and demonstrates that the aggregate models of truck movements in common use can be improved by the use of different specifications, at the same time paying strict attention to the requirements of the estimating technique - ordinary least squares (OLS) regression. Before presenting the results it is necessary to relate the model to economic theory if possible.

FREIGHT DEMAND AND THE THEORY OF THE FIRM.

The theory of the firm which is to be found in any standard reference on micro-economics (e.g. Henderson and Quandt 1971), postulates that the firm's production is a function of its variable inputs. Clearly both commodities input to the production process and labour are variable inputs. Provided that the firm is rational, i.e. that it does not employ workers in excess of those that it requires to produce any given level output with its existing capital equipment, then there is a relationship between the amount of labour employed and the tonnage of commodities to be input. Most theoretical treatments will allow some trading-off between variable inputs i.e. allow there to be the substitution of say more labour for less capital whilst still maintaining the same level of output, but under a fixed pricing system the relationship is uniquely determined (e.g. Henderson and Quandt 1971 - Fig. 3.5). Over the range of this curve (relationship) at which the firm will produce, an increase in the input of one variable (e.g. labour) will require an increase in the input of the others (e.g. commodities) although not necessarily at the same rate. Since commodities arrive at the firm's site on the back of a truck in the vast majority of cases, there should exist a similar relationship between truck trip ends and the number of job places (labour).

Past practice has been to assume that (zonal) truck trip ends are a linear function of the (zonal) explanatory variables being tested. There has been little investigation into the appropriateness of other functional forms. Starkie (1967) in fact makes the point that, as one of the assumptions of OLS regression, analysts should have done some preliminary investigation, if only to satisfy themselves that the linear form was appropriate. Starkie (1974) later suggests that the relationship between truck trips generated and the size of the labour force is curvi-linear for individual manufacturing plants. Watson (1975) confirmed this curvi-linear relationship at the individual plant level.

If we return to the theory of the firm once again we find that, assuming that individual firms pursue certain objectives, e.g. profit maximisation, and that their production function is of a specific form it is possible to compute their demand function for each factor of production. Henderson and Quandt (1971- p69) assume the following production function.

$$q = Ax_1^{\alpha} \cdot x_2^{\beta} \tag{1}$$

where q = quantity output

A = a constant

x_1, x_2 = quantities of factor inputs (normally labour and capital)

α, β positive parameters.

Under conditions of maximising profit the demand for x_1 and x_2 can be expressed as:

$$x_1 = \left(\frac{\alpha}{r_1}\right)^{(1-\beta)/\gamma} \left(\frac{\beta}{r_2}\right)^{\beta/\gamma} (Ap)^{1/\gamma} \tag{2}$$

$$x_2 = \left(\frac{\alpha}{r_1}\right)^{\alpha/\gamma} \left(\frac{\beta}{r_2}\right)^{(1-\alpha)} (Ap)^{1/\gamma} \tag{3}$$

where p = price of output, q

r_1, r_2 = price of inputs, x_1, x_2

$\gamma = 1 - \alpha - \beta$

Further, x_2 can be expressed in terms of x_1 by manipulating equations (2) and (3) to yield equation (4).

$$x_2 = x_1 \left(\frac{r_1}{r_2} \quad \frac{\beta}{\alpha}\right) \tag{4}$$

As r_1, r_2, α and β are constants, equation (4) states that the demand for input x_2 is a linear function of the quantity of x_1 input.

Substituting equation (4) directly into equation (1) yields:

$$q = A.\ x_1^{\alpha} \cdot \left(x_1 \frac{r_1}{r_2} \quad \frac{\beta}{\alpha}\right)^{\beta} \tag{5}$$

An homogeneous production function - i.e. one in which $\alpha + \beta = 1$ - is a commonly accepted proposition. If homogeneity is accepted, then

$$q = A \left(\frac{r_1}{r_2} \quad \frac{\beta}{\alpha}\right)^{\beta} x_1 \tag{6}$$

It should be pointed out that equation (6) only holds along the path of efficient production. That is, a doubling of the quantity of factor x_1, will not result in a doubling of the output, unless accompanied by the *correct* increase in the quantity of factor x_2 input - correct in the sense of maintaining the firm on its path of efficient production. Furthermore, the doubling of the firm's demand for x_1 must be caused by an increase in the level of demand for the firm's output just sufficient to make its new quantity of output the *correct* level at which to maximise profits. The firm cannot *unilaterally* double its inputs and still expect to maximise profit.

Equations (4) and (6) suggest that, under certain conditions, both x_2 and q are linear functions of x_1. It remains now to place some interpretations on these three variables. The variables x_1 and x_2 normally stand for labour and capital, which have unit prices r_1 and r_2 respectively. In the short-run, capital can be considered fixed (and therefore incorporated into the constant term A). If x_1 stands for labour x_2 can stand for the quantity of inputs and q, as before, is the quantity of output. As both inputs x_2 and output q must be transported to and from the site, they represent inbound and outbound shipments respectively, ignoring temporary distortions due to stock level changes. Thus equations (4) and (6) can be given the interpretation that inbound shipments, outbound shipments and consequently, total shipments are a linear function of the size of the labour force, at the individual plant level.

To estimate or test such relationships should surely involve some stratification of plants into groups where like processes are carried out. Watson (1975), in a study of light manufacturing and engineering companies in Evanston/Skokie (USA), found that the linear relationship between total shipments and labour force performed better than the log-linear form using OLS regression. Linear forms for inbound and outbound shipments separately produced quite acceptable results also. Watson did not attempt to estimate log-linear models for inbound and outbound separately. As Watson concluded; 'simple linear models are better than lon-linear transformations'.

The curvi-linear relationship between truck trip ends and size of labour force at the individual plant level discovered by Starkie (1974) and confirmed by Watson (1975) can be explained in terms of being a reflection of economies of scale achieved at the distribution stage - the larger the firm, the larger its throughput, the larger its storage facilities, the larger the size of consignments it can handle, and so on. The question is whether or not this curvi-linear relationship will be maintained at a zonal level - which, it will be recalled is the only level at which we have comprehensive data - even if the sample is stratified into relatively homogeneous types of deliveries. Homogeneous in this sense, must refer to the type of process likely to befall the goods being shipped, not to the means of shipping them (e.g. type of truck, etc.). Thus in terms of available data, this meant stratifying by the classification of the goods themselves or the recorded trip purpose. For this exercise trip purpose was used largely because of the relative homogeneity of each purpose. The name of each trip purpose appears later in Table 2 along with the results. The definition of each purpose is reproduced in Dumble (1979b), along with the definition of a single trip.

The Truck Trip Generation Model

Ogden (1977) stratified truck trips by purpose and estimated linear truck trip generation models at the zonal level. Both dependent and independent variables entered the equation in zonal aggregate form. Slavin (1976) reported that he got better results when he entered the (same) variables only after first dividing each by the zonal area. For short hand, Ogden used 'absolute' values and Slavin, 'densities'. The independent variables in both cases can best be described as land use activity descriptors, which, according to the theory sketched out above, should be the levels of the labour force (i.e. number of job places) stratified into groups corresponding to the type of process relative to each particular truck trip purpose.

Herein lies another data problem; how to get hold of labour force stratified in this manner. Fortunately the Australian Bureau of Statistics (ABS) has an excellent classification of jobs by industrial category which was used by the survey team that collected the original data. Unfortunately, ABS have since slightly altered its classification system. Some 13 categories of job type were thus available for use in the model. Those actually used are listed in the appendix along with their abbreviations used in reporting the results. As many truck trips begin or end at residential addresses it was necessary to use descriptors of residential activities (e.g. population, number of households, etc.) as explanatory variables. These are also listed in the appendix.

The selection of land use activity descriptors appropriate to each purpose was based largely on Ogden's work in which he determined the most important land uses associated with each purpose, and upon his estimated models (Ogden 1977). Occasionally where it seemed logical some modifications were made.

TABLE 1

Comparison of Linear with Log-Linear
Truck Trip Generation Models

<u>Linear</u>

Model	R^2	$F_{2,66}$
RETPD = .0144 TOTJD + .339 POPD	.96	895
(39.5) (15.0)		
RETAD = .0182 WCJD + .0360 POPD	.96	889
(34.96) (20.79)		
WHLPD = .153 BCJD + .0688 WHSLJD	.99(4)	5758
(15.35) (2.62)		
WHLAD = .125 + .352 RETJD + .107 JCJD	.99(7)	10175
(3.2) (11.1) (12.6)		

<u>Log-Linear</u>

Model	R^2	$F_{2,66}$
LRETPD = -1.38 + .482 LTOTJD +		
(-5.4) (3.6)		
.154LRETJD + .0875LPOPD	.51	22.2
(1.5) (.72)		
LRETAD = -1.54 + .619LWCJD + .215LPOPD	.66	62.5
(-7.6) (7.2) (2.50)		
LWHLPD = -.809 + .468LBCJD + .384LWHLSJD	.58	40.9
(-3.9) (4.1) (5.7)		
LWHLAD = -.819 + .408LRETJB + .523LBCJD	.61	50.4
(-3.9) (4.1) (5.7)		

<u>Notes</u>: (1) The physical quantity that each variable represents can be obtained from the appendix.

(2) Figures in parentheses are Student - t values. A Student - t value of 1.96 (2.57) represents significance at the 5% (1%) level.

(3) The critical value of $F_{2,66}$ at the 1% level is 4.98.

Linear versus curvi-linear: Three functional forms were investigated:

1. Linear

2. Semi-log

3. Log-linear

Initially the *home-base* purpose was investigated and the results (using densities) clearly showed that the semi-log form performed poorly compared to the other two. These results are presented elsewhere (Dumble 1979b). The semi-log form was dropped from subsequent investigations. The results for the other two are presented in Table 1 for the trip purposes of *retail delivery* and *wholesale delivery*. Models were estimated for trip productions and trip attractions for both purposes.

Table 1 makes it quite clear that the linear models are superior to the log-linear models. It should be pointed out that the log-linear models are still very significant overall. Another point is that a high level of correlation was to be found between certain pairs of explanatory variables. Subsequent estimations eliminated this problem however, as the results in Table 2 show.

Table 2 presents the 'best' result of the linear model for each purpose. A fuller discussion of these results and of the method used to obtain them is given by the author elsewhere (Dumble 1979b).

Each equation is easily significant at the one per cent level as is each individual variable. In fact the variables with the lowest level of significance are the constants[1], which are nevertheless still significant at the one per cent level when they appear in Table 2.

Each of the land use descriptors appearing in each equation is not illogical. There are possibly more appropriate descriptors in some cases, but when these were tested problems of multi-collinearity, or lack of significance, or both, occurred and they had to be removed from the equation. It was disappointing that fairly aggregate descriptors of land use (e.g. TOTJD, BCJD, WCJD, POPD) tend to 'swamp' finer land use descriptors in this manner, but that is really only to be expected given the still very aggregated nature of trucks trips even when stratified into 11 purposes. However, for the more homogeneous trip purposes of *construction delivery* and *trans-shipment delivery*, construction job density (CONSTJD) and transport and communications job density (TNCJD) were the most significant variables respectively.

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[1]Pardon the use of seemingly contradictory terms.

TABLE 2

The Truck Trip Generation Model

					R^2	F
Home Based						
HBPD	=	.111 BCJD	+	.0241 POPD	.99	3740
		(80.9)		(12.6)		
HBAD	=	.0587BCJD	+	.163 BCWD	.98	2077
		(49.4)		(27.9)		
Pick-up						
PUPD	=	.0904BCJD	+	.042 HHD	.99(6)	8884
		(125.0)		(13.7)		
PUAD	=	.104 BCJD	+	.0271 HHD	.99	4608
		(91.4)		(5.6)		
Retail Delivery						
RETPD	=	.0144TOTJD	+	.0339POPD	.96	895
		(39.5)		(15.0)		
RETAD	=	.0182WCJD	+	.0360 POPD	.96	889
		(35.0)		(20.79)		
Wholesale Delivery						
WHLPD	=	.367	+	.669RETJB	.98	3502
		(59.2)		(4.8)		
WHLAD	=	.333	+	.747RETJB	.99	5945
		(5.0)		(77.1)		
Industrial Delivery						
INDPD	=	.0587MANUJD			.98	3405
		(58.4)				
INDAD	=	.0252	+	.0559MANUJD	.98	3442
		(2.3)		(58.7)		

Maintenance and Repair

MARPD =	.0074 TOTJD + .0437HHD (69.4) (28.3)	.99	3191
MARAD =	.00759TOTJD + .0431HHD (98.9)	.99	6394

Personal Use

PERPD =	.0449MANUJD + .0147POPD (35.6) (18.9)	.97	1138
PERAD =	.248 + .00913TOTJD (7.5) (24.4)	.90	594.3

Employer's Business

EMPPD =	.0181TOTJD + .0526WCWD (93.5) (11.2)	.99	4636
EMPAD =	.0233TOTJD + .0414WCWD	.99(7)	12521

Construction Delivery

CONPD =	.0815 + .165 CONSTJD (6.7) (11.1)	.65	123.6
CONAD =	.0391 + .344CONSTJD (3.6) (25.8)	.91	664.6

Trans-shipment

TRSPD =	.0477 + .111TNCJD (2.75) (55.8)	.98	3112
TRSAD =	.083 TNCJD (20.5)	.86	419.8

Other

OTHPD =	.0388 + .00190TOTJD (5.0) (21.7)	.88	469.7
OTHAD =	.0412 + .00149TOTJD (3.8) (12.1)	.69	146 7

Notes: (1) The physical quantity that each variable represents can be obtained from the appendix

(2) Figures in parentheses are Student - t values.

(3) The critical value of F varies in each case as the degrees of freedom vary. In all cases the equations are significant at the 1% level.

The insignificance or slight significance of the constant term in each equation was satisfying for two reasons. First the lack of constants allows the equations to be easily used on a different zoning system - algebraic manipulation eliminates the need for zonal area completely. Second, if there is no 'activity' in a zone, as indicated by zero values for the appropriate land use activity descriptors, a non-zero constant term would 'predict' some trip ends in that zone - an unlikely situation. Even worse, a negative constant could predict a negative number of trip ends to zones of low levels of acitvity.

The Inclusion of Supply Conditions

The fully estimated model presented in Table 2 suffers from the same defect that all other models of its type suffer from and that is that it takes no account of supply conditions. Any textbook of basic economic geography fairly labours the point that distribution (i.e. transport) costs are important; i.e. price, in effect, is not aspatial. Usually transport cost is depicted as being an increasing function of separation (measured in whatever units), but at a decreasing rate. (Brown 1974). If it is assumed that all firms have to pay the transport costs for their inputs then r_2 in equation (4) is not a constant, but a variable that obeys the conditions set down above and mathematically represented by

$$\frac{\partial r_2}{\partial s} > 0 \qquad (7a)$$

and $$\frac{\partial^2 r_2}{\partial s^2} < 0 \qquad (7b)$$

where s is a measure of separation.

One function that obeys these conditions is:

$$r_2(s) = r_2 s^{\gamma} \qquad (8)$$

where $0 < \gamma < 1$

and r_2 is the price of x_2 at the point of production.

Substituting equation (8) into equation (4) and then taking the natural logarithm of both sides results in the following:

$$ln\ x_2 = K + ln\ x_1 - \gamma ln\ s \qquad (9)$$

where $K = ln \left(\frac{r_1}{r_2} \quad \frac{\beta}{x} \right)$

Equation (9) represents an interesting model that has not been estimated by those who have had access to suitable data (e.g. Watson 1975 and Starkie 1974), and it is the author's intention to estimate this model (by OLS regression) using one of the very few suitable Australian data sets in the near future. If γ is found to be signifi-cnat then it would be possible to conclude that transport costs are an important factor in determining the total amount of goods moved.

In terms of the existing data, one model which allows us to look at the possibility that supply conditions (i.e. the road network) affect the equilibrium level of demand for freight movements is the 'direct demand' model where both the truck trip generation and trip distribution sub-models are combined. This model is expressed mathematically as:

$$q_{ij} = K \left(x_{i1}^{\alpha_1} \; x_{i2}^{\alpha_2} \cdots x_{in}^{\alpha_n} \right) \left(x_{j1}^{\beta_1} \; x_{j2}^{\beta_2} \cdots x_{jn}^{\beta_n} \right) C_{ij}^{-\gamma} \quad (10)$$

where q_{ij} is the number of truck trips between i and j

C_{ij} is the cost of travel between i and j

x_{i1}, x_{in} land use activity descriptors of the origin zone,

x_{j1}, x_{jn} land use activity descriptors of the destination zone,

and α_1, α_n; β_1, β_n and γ are constants.

Whilst equation (10) has much intuitive appeal it has not as yet been given any theoretical foundation in micro-economics. At least, not to the best of the author's knowledge, although the author reports a modest start elsewhere. (Dumble 1979b)

The author had previously estimated a direct demand model using 'absolute' values of land use activity descriptors (Dumble 1977). Slavin (1976) has also estimated a 'direct demand' model of goods movement for a single purpose *(Retail delivery)* and reported that the use of 'densities' produced superior results to those using 'absolutes'. In view of Slavin's suggestion the author re-estimated using 'densities'.

There is not sufficient space here to report and discuss the results, but the interested reader is referred to Dumble (1979b) for further information. However, some general points are presented now.

1. In eight out of the 11 purposes the model was improved (i.e. higher R^2 and F values) using densities. For the three purposes that were not improved *(retail delivery, industrial delivery* and *trans-shipment)*, the re-estimations still produced significant equations overall (at the 1% level).

2. Whether 'absolutes' or 'densities' were used, the 'cost' of travel (for estimation purposes this was simply taken to be the travel time) was always very highly significant (e.g. Student t-values in excess of 20 in many cases).

3. The magnitude of γ was higher when 'densities' were used.

4. γ varied considerably with trip purpose, further confirming the distinctness of each trip purpose. For example, using 'densities', γ varied from -.188 for *trans-shipment* to -1.39 for *construction delivery*. Once again a discussion of the implications of varying γ's is given by the author elsewhere (Dumble 1979b).

5. The land use activity descriptors generally became more significant when 'densities' were used, but in either case were quite significant and q_{ij} was found to be quite sensitive to changes in them.

6. Perhaps the only sour note for the 'direct demand' model estimation was that, reasonably frequently, land use activity descriptors that were logically associated with certain trip purposes (as determined by Ogden's analysis - Ogden 1977) and found to be significant during the trip generation exercise reported earlier, were found to be insignificant, or worse still significant, but with the wrong sign. For this reason, as well as their inherently unstable nature, the use of these direct demand models should only proceed with extreme caution.

Problems with Long Term Forecasting Models

The models reported above, which relate freight movements to land use patterns in an aggregate manner, can only be considered as long run models if they are to be used in any forecasting mode. This is because land use patterns are relatively fixed in the short run. However the use of these models for long run forecasting poses certain problems. As French and Watson (1971) state, 'the building of a long-run implies that we are interested in trying to forecast *changes*[1] in the relationships that we are modelling'. In terms of our models then, we should be attempting to forecast how the co-efficients will change in the long-run. In the long run we know for instance that the capital inputs (assumed to be fixed in equations 1 to 6) are changeable. Focusing on trucks instead of commodities further complicates things as changes in vehicle designs can lead to substantially altered load factors (in terms of Fig. 1, the *means choice* can alter).

[1]Author's emphasis

At the present moment these are the only models available given the state of our knowledge and the dearth of data, so it would be senseless to throw them overboard. They can at least be used as indicative of the likely level and pattern of truck movements in the future. If necessary, sensitivity testing can be used to investigate the consequences of different levels of truck movements.

Another important means of supplementing the forecasts is that of monitoring the value of particular indicators over time. A general and comprehensive discussion of how this maybe done was provided by Wigan (1977). A particular application of the concept is provided by a local example. As part of the Outer Ring Study of Melbourne (see Evans and Dumble (1977) for a brief analytical overview of this project) the author adapted Ogden's truck trip generation model (Ogden 1977). Forecasts were developed for the year 1991 using land use forecasts prepared by Melbourne's metropolitan planning authority, the Melbourne and Metropolitan Board of Works (MMBW). The resultant forecasts equated to a growth rate around 2% per annum in truck flows (depending upon the land use forecasts selected).

The Country Roads Board (Victoria) has for a number of years been conducting traffic counts on many major roads in Melbourne i.e. they have been monitoring the growth of different classes of vehicles over a number of years. When the observed rate of growth of truck travel along several of Melbourne's major industrial traffic routes (e.g. New Footscray Road) was checked, it was found to be of the order of around 2% per annum (Road Planning Liaison Committee 1977). It would appear then, for that particular forecasting problem, that that particular truck trip generation model has produced reasonable long-run results - i.e. all those factors which in the long-run distort the model, more or less, cancelled themselves out. That is not to say that this will be the case for all forecasting problems.

The purpose of the above illustration is to point out that by the careful usage of supplementary data, both of a transport nature (e.g. traffic counts or changes in average load factors) and of a land use nature (e.g. monitoring productivity increases) it should be possible to use these land use/freight transport interaction models to yield reasonably accurate long-run forecasts.

DEVELOPMENTS IN FREIGHT DEMAND CONCEPTUALISATION

It would not be proper to close the paper without some comments about the limitations of the existing conceptualisation of freight demand forecasting. The existing conceptualisation is once again dictated by the twin constraints of firstly, the need to produce a working model and secondly, the necessity to produce such a model from existing data. In essence this has resulted in a focus on each individual trip, that is, on each individual point-to-point movement. Papers at previous ATRFs have pointed out the problems and indeed the fallacies, of this approach when applied to person travel demand (Hensher 1976, Morris, Dumble and Wigan 1978), but it is probably even more fallacious when applied to freight demand. This is because typically freight movement is characterised by the cycle of several deliveries (i.e. drop-off points) before returning to the home base. Person travel is now more and more being analysed in terms of journeys[1] rather than trips, but usually no more than three or four stages[1] occur in any one journey.

In an attempt to investigate freight movements whilst preserving the concept of a *delivery round* - or *journey* to agree with the accepted terminology of person travel demand - the author has re-analysed a sub-set of the 1964 Melbourne data. Stratification has been maintained by adopting the concept of a *pure* journey - a *pure* journey being one in which only one *primary* purpose appears.

Table 3 lists those purposes considered to be *primary* and those considered to be *secondary*.

TABLE 3

Primary and Secondary Journey Purposes

Primary	Secondary
Retail delivery	*Home base*
Wholesale delivery	*Pick up*
Industrial delivery	*Personal use*
Maintenance and repair	*Employer's business*
Construction delivery	*Other*
Trans-shipment	

Once again space does not permit the details of the full analysis to be given, however Table 4 presents some of the findings which best reinforce the fallacy of viewing freight movements as single isolated events - i.e. as trips.

[1] For a definition of 'journey' and 'stages' of a journey see Morris *et al.* (1978). For freight demand purposes, the vehicle's *home base* becomes the start and end of journey.

TABLE 4

Average Values of Some Parameters Describing Truck Journeys

Primary Purpose	Stages per Journey	Journey Time (mins)	Travelling Time per Journey (mins)	Stopped Time per Stage (mins)
Retail delivery	6.1	132	42	14.8
Wholesale delivery	6.8	274	114	23.5
Industrial delivery	5.1	248	121	24.9
Maintenance and repair	3.6	271	67	56.7
Construction delivery	3.9	421	101	79.7
Trans-shipment	3.5	95	48	13.4

There are many other aspects of this diagnostic analysis which do not appear in Table 4 (e.g. temporal pattern of deliveries, commodity carried, type of truck, etc.) but it is hoped to document the complete analysis at a future date including the results for *mixed* journeys; i.e. journeys where stages for more than one primary purpose occur. Nevertheless this section of the paper will have served its purpose well if the reader is made aware that truck trips do not occur in isolation from each other and therefore that changes in the conditions under which freight and truck movements take place can give rise to many possible responses on the part of the actors involved. Such changes could be to the network, e.g. changes in the levels of congestion; to the size of trucks; to restrictions on the hours of delivery; to changes in productivity; to changes in supplier; etc. Many of these responses are simply not embodied in the models discussed earlier, particularly those responses induced by short-run changes. However, existing data sources can give valuable insights into the true patterns of freight movements and into the constraints under which they take place.

CONCLUSIONS

The following conclusions are made more by way of assertion, but it is hoped that the contents of the paper support them.

1. Freight demand modelling needs to take place within an agreed upon, and theoretically sound, framework e.g. the framework proposed by French and Watson (1971).

2. The details of this framework have yet to be worked out because of the lack of suitable data brought about largely by the lack of understanding. Existing data can be utilised more fully particularly in the manner described in the last section of the paper. Those data bases that include commodity flow information collected at the level of the firm should certainly prove to be valuable in providing insights into inter-industry linkages.

3. In the meantime the existing long-run sequential aggregate model of truck movement should suffice, but best results will be gained by:

   (a) suitably stratifying the model (e.g. by trip purpose),

   (b) the use of 'density' measures of land use activity, not 'absolute' measures,

   (c) the use of a linear, not curvi-linear, relationship in the trip generation model,

   (d) paying careful attention to the requirements of the assumptions of OLS regression, and

   (e) supporting or modifying the forecasts by careful monitoring of appropriate key indicators.

4. Aggregate direct demand models confirm both the land use and transport network interactions with the patterns of freight demand.

5. Developments in the theory of freight demand founded upon the micro-economic theory of the firm are required at the level of the individual firm. It is important that such developments incorporate the spatial dimension of commodity price in them.

APPENDIX

LIST OF VARIABLES

Land Use Activity Descriptors

BCJD	Blue collar jobs per hectare
BCWD	Blue collar workers per hectare
CONSTJD	Construction jobs per hectare
HHD	Households per hectare
MANUJD	Manufacturing jobs per hectare
POPD	Population per hectare
RETJD	Retail jobs per hectare
TNCJD	Transport and Communications jobs per hectare
TOTJD	Total jobs per hectare
WCJD	White collar jobs per hectare
WCWD	White collar workers per hectare
WHSLJD	Wholesale jobs per hectare

Truck Trip End Descriptors

HBPD (HBAD)	Home base trip productions (attractions) per hectare
PUPD (PUAD)	Personal use trip productions (attractions) per hectare
RETPD (RETAD)	Retail delivery trip productions (attractions) per hectare
WHLPD (WHLAD)	Wholesale delivery trip productions (attractions) per hectare
INDPD (INDAD)	Industrial delivery trip productions (attractions) per hectare
MARPD (MARAD)	Maintenance and repair trip productions (attractions) per hectare
PERPD (PERAD)	Personal use trip productions (attractions) per hectare
EMPPD (EMPAD)	Employer's business trip productions (attractions) per hectare
CONPD (CONAD)	Construction delivery trip productions (attractions) per hectare
TRSPD (TRSAD)	Trans-shipment trip productions (attractions) per hectare
OTHPD (OTHAD)	Other trip productions (attractions) per hectare

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