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A GRAVITY ALLOCATION MODEL FOR PARKING DEMAND

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This paper proposes a model for the allocation of unsatisfied parking demand. The model is based on the gravity analogy similar to that for trip distribution. Residual or unsatisfied demand in one analysis zone is allocated to other zones on the basis of the parking supply in those other zones and their distance away. The final, "adjusted" demand is the sum of forecast demand and demand allocated "in" from other zones less the demand allocated "out" to other zones. An iterative procedure is followed whereby alternative plans for design of parking facility locations are tested and an optimum solution is selected. The model is theoretical and untested. It is proposed primarily for use in small urban areas where parking decisions are simplistic in nature so that parking costs are consistent and walking distance is the most significant parameter.

•IT IS unreasonable and sometimes practically impossible to provide sufficient parking facilities within an area to satisfy the parking demand in that area. Because of this, the parking demand must shift to adjacent areas that may, in turn, have parking supply deficiencies. To design a parking supply system that can best meet the needs of a large area requires that some means of rationally estimating the diversion between subareas (which will in fact occur) be developed. It is necessary to have some method of judging whether locations selected for new facilities will be close enough to the demand areas so that they will be used by motorists and not be unused while drivers circulate in nearby areas looking for parking space and creating congestion.

In smaller urban areas it is not uncommon to see vacant curb and lot spaces fringing the business district while vehicles are illegally parked or cruising in the center of the area. The expense of providing the fringe parking is wasted, whereas additional investment might have provided a satisfactory solution. If the location of additional spaces is based on a rational analysis, instead of availability of clear areas, the decision-makers can allocate the additional investment but only if the technicians can establish the basis for their decision. A parking demand allocation model is a critical tool in establishing that basis.

This paper discusses a proposed model for the zonal allocation of forecast parking demand throughout an analysis area based on an application of Newton's law of gravity. Everyone who studied high school physics remembers the familiar expression for gravitational force:

$$F = K\ (m_1 m_2)/(r^2)$$

That is, "The force exerted by one body on another body is directly proportional to the product of their two masses and inversely proportional to the square of the distance between them."

For several years planners have been forecasting urban travel patterns by using the following model:

$$T_{ij} = \left(P_i A_j F_{ij} K_{ij} \Bigg/ \sum_{j=1}^{n} A_j F_{ij} K_{ij} \right)$$

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If this expression is rearranged to

$$T_{ij} = \left(K_{ij} \Big/ \sum_{j=1}^{n} A_j F_{ij} K_{ij} \right) (P_i A_j / t^n)$$

then the reason for the name "gravity model" is evident, for the similarity to the general form of the gravity expression is clear. The distribution model assumes that "the number of trips between any two zones is directly proportional to the product of the total number of trips produced at the origin and attracted to the destination and inversely proportional to an exponentially increasing function of the travel time between the zones."

Formulating an expression for parking demand allocation requires the determination of the variables to be included. If the model is to be of the gravity form, then the variables selected should conform to the variables in the gravity expression, i.e., two mass measurements and a distance measurement. Another decision to be made is the type of allocation. Allocation might be made for gross or forecast demand, or allocation might be made for only the unsatisfied or residual demand for each zone.

The model discussed in this paper was formulated to parallel the gravity analogy trip distribution model. The parallel was selected arbitrarily as a basis for testing by the author, who felt that there was sufficient similarity between the distribution of unsatisfied parking demand and trip productions and attractions to warrant the investigation. To state the model, we made assumptions that may or may not prove valid under analysis. The assumptions are as follows:

1. The gravity analogy does apply to parking decisions.
2. Parking costs are significant only in modal choice. Once vehicular mode has been determined, prevailing parking costs will be accommodated.
3. Duration and other legal restraints as well as cost differentials will balance out in application.
4. Only residual or unsatisfied demand should be allocated to adjacent areas.

The behavioral assumption for the model will thus be stated as follows: An automobile driver will attempt to park his vehicle immediately adjacent to his final destination. If he is unable to do this, he will park as nearby as possible. In searching for a nearby space, he will first investigate those areas where larger numbers of parking spaces are provided.

With these assumptions in mind, the model is proposed as

$$Z_i = D_i + A_i$$

where

Z_i = adjusted demand for zone i,
D_i = forecast demand for zone i, and
A_i = net allocation to zone i from all zones, including the subject zone.

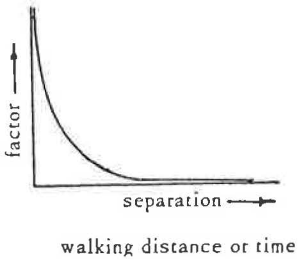
The allocation term A_i is the critical factor in the expression. It is the sum of residual demands from other zones allocated into zone i less the residual demand in zone i allocated out to all other zones. The A_i term is expressed as

$$A_i = \sum_{j=1}^{n} A_{i/j} - \left(\sum_{j=1}^{n} A_{j/i} - A_{i/i} \right)$$

where

$A_{i/j}$ = allocation to zone i from zone j,
$A_{j/i}$ = allocation to zone j from zone i, and
$A_{i/i}$ = residual allocation, that is, the part of the residual demand that remains in zone i.

Figure 1. Marginal propensity to walk from parking space to destination.



The term $\Sigma A_{i/j}$ represents the total allocation into zone i from all other analysis zones. The term $\Sigma A_{j/i}$ represents the total allocation from zone i to other zones and must be a positive number. That is, no allocation of residual demand can be made from a zone if the space supply in the zone is greater than the forecast demand. If there is no residual demand in a zone, then the out allocation $\Sigma A_{j/i}$ will be zero.

Logically, the total residual demand allocated out of all zones must be equal to the residual demand allocated into all zones. Therefore the in allocation for each zone may be accumulated as it is allocated out of other zones.

The gravity analogy is used for the out allocation procedure. The expression is given as

$$A_{j/i} = R_i \left[S_j f_{ij} \Bigg/ \left(\sum_{j=1}^{n} S_j f_{ij} \right) \right]$$

where

R_i = nonzero and positive value of residual demand in zone i,
S_j = space supply in zone j, and
F_{ij} = proportionality distribution factor between zones i and j, which is of the form $1/d^x$, where d is the distance between zones i and j and x is a varying exponent of d.

The similarity of this expression to the trip distribution model is readily apparent.

The form of the proportional distribution factor is unknown. The exponent is assumed to vary with the value of d because experience has shown this to be the case in the trip distribution application. Also, logically, when the factor is considered to be a "marginal propensity to walk," one might postulate a curve of the type shown in Figure 1 in which the propensity to walk decreases sharply until after a certain distance is reached, at which point the rate decreases less rapidly to a point where walking is totally unacceptable. It might be, however, that the converse is true; that is, the factor may decrease slightly for a certain distance and then begin to decrease rapidly. The shape of the curve cannot be assumed until after experimentation and detailed analysis of behavioral patterns.

Experimental results are also needed to determine the appropriate measure of spatial separation. The most reliable measure might be time or distance quantified in feet or number of block units.

In application, it must also be considered that the peak demand for all zones does not necessarily occur simultaneously. The allocation should be made hourly and analyzed for each separate time period.

Special mention should be made of the fact that the space supply term S_i is a factor in the allocation expression. Because the purpose of a parking analysis is to determine an adequate supply system, it follows that allocation is a convergent or trial-and-error procedure. A space supply system is designed and then tested by allocation, the deficiencies (and surpluses) of that system are corrected, and a new allocation is made to the revised system. The cycle is repeated until an adequate and realistic supply design is attained, one that can be achieved within the policy and physical restraints imposed.

The entire model, then, is represented by the expression

$$Z_i = D_i + \sum_{j=1}^{n} A_{i/j} - \sum_{j=1}^{n} R_i \left(S_i f_{ij} \Bigg/ \sum_{j=1}^{n} S_i f_{ij} \right) + A_{i/i}$$

with the restriction that, if $R \leq 0$, then

$$\sum_{j=1}^{n} R_i \left(S_i f_{ij} \sum_{j=1}^{n} S_i f_{ij} \right) + A_{i/i} = 0$$

where the allocation is an iterative process, and allocations are made for a given space supply distribution; deficiencies and surpluses are determined and corrected; and a new allocation is made. The cycle is repeated until a practical and satisfactory supply distribution is determined. Because peak demand time varies between zones, allocations should be made over time and by supply system design to serve for all time periods.

This model is theoretical only and, at the time this paper was written, had not been tested. It is possible that during testing it may be found desirable or even necessary to modify the assumptions and adjust the model accordingly.

The model is not so complex in its approach to allocation as other proposed allocation techniques may be. It may be that this simplistic approach will provide adequate or even more reliable allocation in small urban areas where parking decisions are themselves simple, where parking costs are not significant, where there is no modal choice, and where walking distance is the primary factor in the parking location decision.

As stated, this model is theoretical and has not been tested. A proposal is now pending with the Georgia State Highway Department for a research and development project to continue the development of the model and to determine its usefulness in this critical area of need in parking analysis.