An Optimizing Model for Recreational Road Planning

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ABSTRACT

In recent years, big loads on many near-Metropolitan roads within the State highway networks have derived recreational travel demands. The growth of demand for outdoor recreation occurs within a context of rising incomes and leisure. Road improvements are capable of substantially increasing the accessibility of many outdoor recreational areas. Policy conflicts can arise, however, where the overloading of recreational destinations involves degradation of the quality of facilities, either through pure crowding effects or through physical damage and degeneration of ecological systems and the quality of natural resources. It follows that the benefit flowing from a given recreational site depends critically on the number of recreators at the site, together with the effects of congestion on access roads. Linear and dynamic programming models are developed to reflect these factors. Essentially, the model assumes that recreational trips are distributed so as to maximise the total utility flowing to resource users.

INTRODUCTION

Recreational travel demand is a major contributor to loads on many elements of State highway systems whose significance appears to be growing relative to many other elements of total traffic. At the same time, management and protection of outdoor recreational facilities is increasingly viewed as a regional planning problem in which the value of a recreational system can be maximised by maintaining diversity of facilities and a range of levels of crowding, by separating non-compatible activities, and by exploiting multiple use of some resources for compatible activities where these exist.

Consequently the problem of traffic forecasting which faces the highway authority is intimately connected with the questions of facility management, pricing, and access control which face the recreation authority. While the model outlined in this paper was designed to meet the requirements of a highway authority, its structure was developed along lines which permit road planning and recreational planning problems, both of forecasting and evaluation, to be handled simultaneously and consistently. The model is built on an optimal programming framework and is designed to accept as parameters empirical values derived from traffic counts and small scale surveys of recreational behaviour.

The model proceeds by first disaggregating the population into geographical divisions and then, within each geographical division, by disaggregating into a number of socio-economic groupings. It is hoped that within the subgroups arising from this two-fold disaggregation it is possible to derive a quantitative measure of the relationship between, on the one hand, the value a typical member places on a given recreational resource, and on the other hand, a number of readily measured variables associated with the site: for example, beach area or picnic facilities. The model will assume that this value declines with crowding. That is, the value an individual places on a resource decreases as the resource becomes over-crowded.

The model examines the pattern of trip making that emerges if recreators act so as to maximise the net value of all trips, that is, the total perceived value of *all* trips less *all* the expenditure necessary to achieve them. The expenditure we envisage is travel costs, together with the value the individual places on the time spent in reaching the resource.

In the next section we shall present an abstract formulation of the model, and in the concluding section an indication of the use which will be made of the model.

THE ABSTRACT MODEL

The model considers a network, each node of which may be either a source of recreators or a destination for recreators, or both. We assume that potential recreators are divided into a set of classes c. The base variable is

$$V = V(i,j,c)$$

which we define as the volume of recreators of class c who reside at i and recreate at j. The value a recreator at i of class c places on the recreational facilities at j is

$$d = d(i,j,c,Y_j)$$

Here Y_j represents the total number of recreators at j. It is assumed that d is a *decreasing* function of Y_j. One has further

$$Y_j = \sum_{i,c} V(i,j,c).$$

It follows that the gross benefit flowing to recreators from their trips is

$$Z_G = \sum_{i,j,c} V(i,j,c) \cdot d(i,j,c,Y_j).$$

Let h be a given link of the network. Then we write $T_h(N)$ for the time taken to pass over h when the volume of traffic on h is N. Further, we put

$b(i,c)$ = per mile car costs to a member of c at i
$m(i,c)$ = the value of 1 hour to a member of c at i
J = a typical path from i to j
$J(i,j)$ = the set of paths from i to j
$s(J)$ = the distance along path J
$o(i,j,c)$ = mean car occupancy for members of c en route to j from i
$p(i,j,J)$ = the proportion of trips from i to j which choose path J

The total cost of all recreational trips is now

$$\sum_{i,j,c} \sum_{J\varepsilon J(i,j)} p(i,j,J) \{(\sum_{h\varepsilon J} T_h(N_h) m(i,c) V(i,j,c)) + V(i,j,c) s(J) b(i,c)/o(i,j,c)\}$$

where the first term on the right represents the value of elapsed time in reaching the site, and the second represents car costs. The quantity N_h is the number of vehicles passing over h. We could write

$$N_h = \sum_{i,j,c} \sum p(i,j,J) V(i,j,c)/o(i,j,c)$$

where the second summation is, given i,j and c, over all journeys J from i to j which involve passing over h.

The quantity to be maximized, the net benefit to users, is

(1) $Z = Z_G - Z_T$

The two principal constraints of the model are

(i) *The Capacity Constraint.* Each site may only absorb a limited number of vehicles and recreators. This may be expressed in terms of parking or accommodation, by

(2) $\sum_{i,c} V(i,j,c) \leq K_j$

where K_j is the appropriate bound.

(ii) *The Total Recreation Constraint.* Each individual has an upper limit to the amount of time he may devote to recreation. Accordingly we have a constraint:

(3) $\sum_j V(i,j,c) \leq r_{ic}$

where r_{ic} is the upper limit to available recreation time. The most general formulation of the model is now:

maximise (1) subject to (2) and (3).

The model outlined above is similar to a very general form outlined in Beckmann and Golob (1974): at least it confronts the same problems. A divergence between our approach and theirs is that we allow for the *congestion effect of crowding at the site on recreator satisfaction,* as well as congestion effects on travel costs.

AN APPLICATION

In this section we propose to present two simplifications of the abstract model which reduce it in one direction to a linear programming problem, and in another to a non-linear separable programming problem. We shall give also some idea of the scope of the problem for which the model was developed.

The Network

The network chosen is represented in figure 1 below.

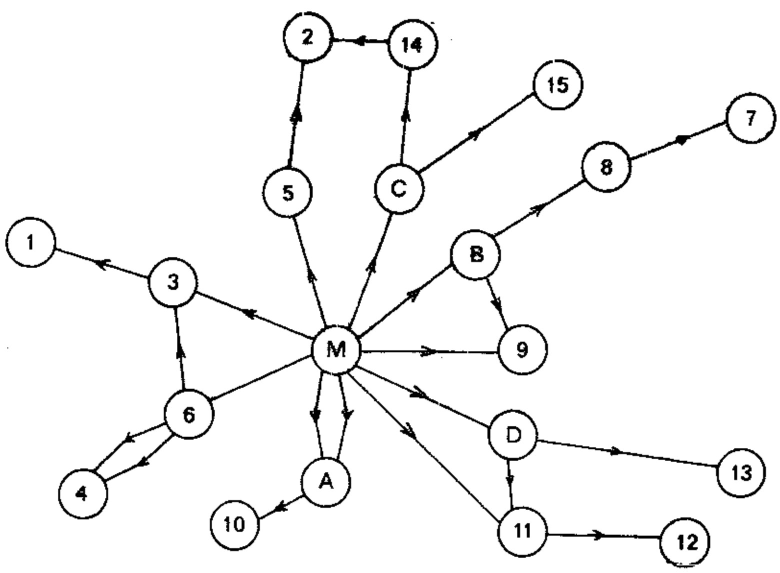

FIGURE 1

THE NETWORK

The nodes M, D and 6 are generators of traffic, and all other nodes are recreational resources. It will be observed that the network is multi-connected. This is handled by assuming a constant proportional split between alternative routes. In List 1 the recreational journeys we have considered significant are tabulated. These are a subset of all possible recreational journeys. The constants b_{ij} represent the proportionality constants for multi-access sites. In List 2 the various *link volumes* are given in terms of the base variables V(i,j). The index c has been suppressed for brevity.

The Model

As a first approximation to the model outlined above, we have considered the following simplification.

As before, let V(i,j,c) be the number of recreators of class c who drive from i to j, and let C_j be the crowding level of j. We define $V_1(i,j,c)$ as the volume flowing to j up to crowding level.

Formally, $V_1(i,j,c)$ will be defined by the relationship

(4) $V(i,j,c) = V_1(i,j,c) + V_2(i,j,c)$

the constraint

(5) $\sum_{i,j,c} V_1(i,j,c) \leqslant C_j,$

and the maximisation procedure we are describing.

We assume that recreators of a given class and origin place two distinct values on a given site j, $d_2(i,j,c)$ when crowded, $d_1(i,j,c)$ when not, as indicated by Figure 2 below.

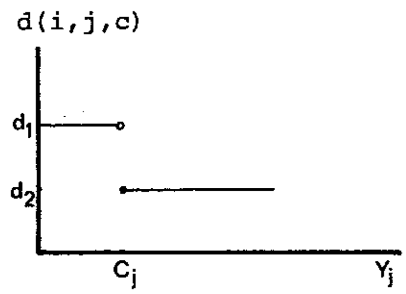

Figure 2

A measure of the gross value of recreational trips is

$$Z_G = \sum_{i,j,c} (d_1(i,j,c)\ V_1(i,j,c) + d_2(i,j,c)\ V_2(i,j,c))$$

It will be observed that this quantity is unrealistic in that it does not diminish d for the group of recreators up to crowding level once crowding level is passed. Nevertheless Z_G is only inaccurate for volumes slightly exceeding C_j.

In a similar vein we calculate the cost of recreational travel. Let us assume that $m(i,c) = m_c$ and $b(i,c) = b_c$ do not depend on i. Write L(h,c) for the number of travellers of class c on link h and $L_1(h,c)$ for that element up to congestion level. Then we have as in the case of the variables

(6) $\quad L(h\ c) = L_1(h,c) + L_2(h,c)$

and

(7) $\quad \sum_c L_1(h,c) \leq g_h$

In List 2 we have written down each L(h,c) as a linear combination of the base variables. If we assume that the link takes T^1_h hours when uncongested and T^2_h hours when congested, as indicated in figure 3 below,

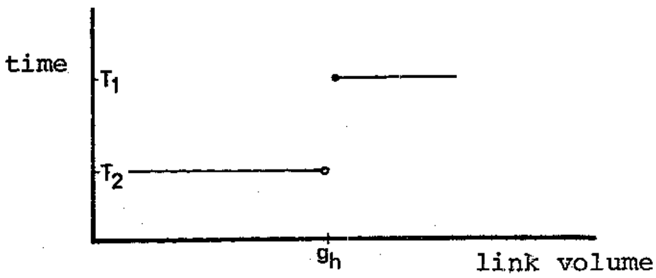

Figure 3

then the cost of all recreational journeys is

$$\sum_{i,j,c} \sum_{J\varepsilon J(i,j)} p(i,j,J)(\{\sum_{h\varepsilon J} T^1_h L^1(h,c) + T^2_h L^2(h,c) m_c\} + V(i,j,c) s(J)/o(i,j,c))$$

As above, the problem is to maximize $Z = Z_G - Z_T$ subject to the constraints given in that section, namely (2) and (3), together with (5) and (7). We set the problem out formally:

maximize the linear function

$$Z = Z\ (V_1(i,j,c),\ V_2(i,j,c),\ L_1(h,c),\ L_2(h,c))$$

subject to

$$\sum_{i,c} V_1(i,j,c) \leqslant C_j$$

$$L_1(h,c) + L_2(h,c) = L(h,c)$$

$$\sum_c L_1(h,c) \leqslant g_h$$

$$\sum_{c,i} (V_1(i,j,c) + V_2(i,j,c)) \leqslant K_j$$

$$\sum_j (V_1(i,j,c) + V_2(i,j,c)) \leqslant r_{ic}$$

Where the base variables are V_1, V_2, L_1 and L_2.

The linear relationships between these variables are set out in List 2.

A More Advanced Model

Whereas the model just outlined leads to a small L.P. problem (about 200 x 2000) it has a major drawback in that it does not reflect the *gradual* deterrent effect of increasing crowding: we refer to the discontinuity indicated in Figure 2. (This is not the case for congestion effects. In Figure 3, if the larger value represents queing speed and the lesser value free speed, the graph is a fair approximation to actual traffic behaviour.) We feel that a closer approximation to actual behaviour is represented in Figure 4.

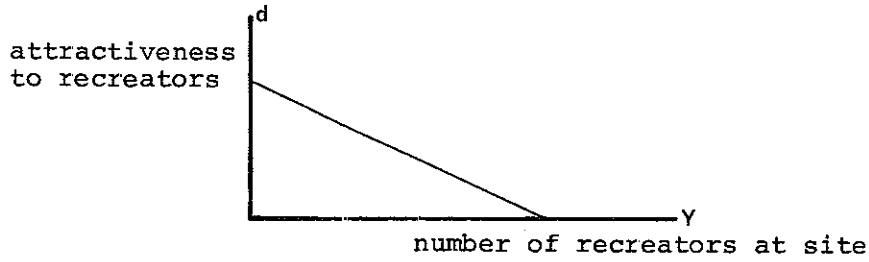

Figure 4

Accordingly we write

$$d(i,j,c,Y_j) = A_{jc} Y_j + B_{jc}$$

where A_{jc} and B_{jc} are parameters which might be estimated.

Then gross benefit attributable to recreation is

$$Z_G = \sum_{jc} (A_{jc} Y_j + B_{jc}) Y_{jc}$$

where Y_{jc} is the number of recreators at the site of class c. We may now use this Z_G in the procedure outlined in the previous section. It is important to note that the presence of terms $Y_j Y_{jc}$ make the problem non-linear - in fact nonseparable. The variables may be separated, however, by a substitution of the form

$$M_1(j,c) = \tfrac{1}{2} (Y_j + Y_{jc}), \; M_2(j,c) = \tfrac{1}{2}(Y_j - Y_{jc})$$

As outlined, the problem considered is about 400 x 10,000 *with a non-linear separable objective function.*

It could happen that the non-linearity and the increased number of constraints of the model just presented may increase computing time by a factor of four or five over the model outlined in the previous section. This notwithstanding, one feels that the mechanism by which the present model distributes trips is quite realistic and should have a greater potential for calibration to an accurate predictor of optimal allocation of recreational travel time than the former.

REFERENCES

Beckmann, M.J., and Golob, T.F. (1974). "Traveller decision and traffic flows: A behavioural theory of network equilibrium". Proceedings 6th Int. Symposium, Transportation and Traffic Theory. Sydney. pp. 453-482.

LIST 1

JOURNEYS (SEE NETWORK) [a]

From M	2	MC14 2	b_{11}	M52	b_{12}
	15	MC15			
	7	MB87			
	9	MB9	b_{21}	M9	b_{22}
	8	MB8			
	13	MD13			
	11	M11	b_{31}	MD11	b_{32}
	12	MD11 12	b_{41}	M11 12	b_{42}
	10	MA(1) 10	b_{51}	MA(2) 10	b_{52}
	6	M6			
	4	M64(1)	b_{61}	MC4(2)	b_{62}
	3	M3			
	1	M31			
	5	M5			
	14	MC14			
From 6	4	64(1)	b_{71}	64(2)	b_{72}
	3	63			
	1	631			
From D	13	D13			
	11	D11			
	12	D11 12			

(a) This list does not include all *possible* journeys, but only those considered important. Omissions result since

(i) A, B and C are road forks and not recreational resources
(ii) Link (6,3) is used only by residents of 6, and not as a detour from M.

LIST 2

LINKS EMANATING FROM MELBOURNE

link	link volume L(h,c)
M,5	$V(M,5) + b_{12}V(M,2)$
M,C	$V(M,15) + V(M,14) + b_{11}V(M,2)$
M,B	$V(M,8) + V(M,7) + b_{21}V(M,9)$
M,9	$b_{22}V(M,9)$
M,D	$V(M,13) + b_{32}V(M,11) + b_{41}V(M,12)$
M,11	$b_{31}V(M,11)$
M(1)A	$b_{51}V(M,10)$
M(2)A	$b_{52}V(M,10)$
M,6	$V(M,6) + V(M,4)$
M,3	$V(M,3) + V(M,1)$

OTHER LINKS

5,2	$V(M,2)$
C,14	$V(M,14) + b_{11}V(M,2)$
14,2	$b_{11}V(M,2)$
C,15	$V(M,15)$
B,9	$b_{21}V(M,9)$
D,11	$b_{32}V(M,11) + b_{41}V(M,12) + V(D,11)$
D,13	$V(M,13) + V(D,13)$
11,12	$V(M,12) + V(D,12)$
A,10	$V(M,10)$
B,8	$V(M,8) + V(M,7)$
8,7	$V(M,7)$
6(1)4	$b_{61}V(M,4) + b_{71}V(6,4)$
6(2)4	$b_{62}V(M,4) + b_{72}V(6,4)$
6,3	$V(6,3)$
3,1	$V(M,1) + V(6,1)$