By further substituting into eq. (10), we obtain

\[
\begin{bmatrix}
G_1 + G_3 + G_6 & 0 & -G_3 & -G_6 & 0 \\
0 & G_4 + G_5 + G_2 & -G_4 & 0 & -G_5 \\
-G_3 & -G_4 & G_8 + G_3 + G_4 + G_7 & -G_8 & -G_7 \\
-G_6 & 0 & -G_8 & G_6 + G_8 & 0 \\
0 & -G_5 & -G_7 & 0 & G_5 + G_7
\end{bmatrix}
\begin{bmatrix}
v_1 \\
v_2 \\
v_3 \\
v_4 \\
v_5
\end{bmatrix} = \begin{bmatrix} 0 \\
0 \\
0 \\
I_e \\
I_g
\end{bmatrix}
\]

or, in matrix notation

\[ G \mathbf{v}^0 = \mathbf{i}^0. \]  \hfill (12)

Since \( \mathbf{i}^0 \) and \( G \) are known, we can solve for \( \mathbf{v}^0 \) in eq. (12),

\[ \mathbf{v}^0 = G^{-1} \mathbf{i}^0. \]  \hfill (13)

Substituting back in eq. (11), we obtain the predicted values of recreational flows in each park:

\[ \hat{I}_1 = G_1 v_1, \]

\[ \hat{I}_2 = G_2 v_2. \]  \hfill (14)

These simulated values, \( \hat{I}_1 \) and \( \hat{I}_2 \), represent predicted effective demand (given the elastic supply schedule) for recreation associated with the two parks.

For example, assume the following values for road impedance and park attractiveness:

\[
R_1 = 2, \quad R_2 = 1, \quad R_3 = 8, \quad R_4 = 5, \quad R_5 = 2, \quad R_6 = 6, \quad G_7 = 1/3, \quad G_8 = 1/4.
\]

The flows from the two population centers are constant, \( I_e = 50 \), \( I_g = 20 \). Using eq. (10) we obtain:
the solution is given by eq. (13) yielding the following values for \( y^0 \):

\[
\begin{align*}
v_1 &= 61.1, \\
v_2 &= 39.4, \\
v_3 &= 108.0, \\
v_4 &= 209.3, \\
v_5 &= 90.9.
\end{align*}
\]

The solution \( y^0 \), in turn, yields the solution to the flow of visitors into the two parks of the system:

\[
\begin{align*}
\hat{I}_1 &= v_1 G_1 = 30.5, \\
\hat{I}_2 &= v_2 G_2 = 39.4.
\end{align*}
\]

Finally, by multiplying the appropriate voltages and resistances we obtain the flow levels on each of the road links (eq. (11)).

3.4.2. Calibration

Since data on the number of recreationists in the various parks are collected simultaneously with data on origin flows (e.g., from origin-destination surveys), it could serve as a check in testing for the goodness-of-fit of the model and the associated analytical solution (eq. (13)). This is done by comparing the observed and predicted flows of recreationists, \( I_f \) and \( \hat{I}_f \), respectively. Deviations could be corrected by varying \( G_i \)'s (for parks or for roads) and resolving the system for the new set of \( G_i \)'s. This is the essence of the calibrating procedures for improving the fit between the observed and simulated predictions. The calibrating procedure is described below in more detail in connection with the real data.
4. Modifications of the static model

4.1. Shortcomings of the static model

The example given above deals with an analytical solution to the prediction problem in a static model of a simple outdoor recreation system. We now present a more complicated system, showing some of the modifications we believe necessary to enable the model to handle more realistic situations.

A crucial omission in the hypothetical example is the absence of capacity limits on parks. Omitting capacity might not affect attendance predictions for time periods long enough to average out demand peaks of relatively short durations. Thus, for example, annual predictions could disregard peak weekend demand levels. In fact, the RECSYS model has been used for providing such annual predictions (Ellis and Van Doren, 1966). However, in dealing with weekend predictions, the neglect of these aspects may give rise to misleading results. For example, when characterizing a road’s flow by Ohm’s Law only, it is obvious that there is no upper limit on $I_j$.

A related weakness of the static model lies in its being stationary. It ignores the dynamic or transient aspects of the system which are extremely important for the planner. An analysis of transient behavior aids in predicting traffic volumes and park attendance during, say, a typical weekend. It is the transient stage which is vital for detecting congestion conditions and their consequences which are averaged out in the static aggregate model.

In addition, the static model incorporates capacity levels into $G_j$, the attraction index of park $j$. We believe it is preferable, and consistent with economic theory, to include such information in the supply schedule, rather than in the quality index (attractiveness) on the demand side.

4.2. A second illustration

Let us now illustrate these points with a more complex and realistic example simulating the dynamic characteristics of the recreational system employing capacitors. The system is identical to the previous one except that the two parks are each represented by a resistor and a capacitor (fig. 3). There are now two additional nodes, 6 and 7, whose Kirchoff equations are:

$$\text{node 6: } I_9 - I_1 = 0, \quad \text{node 7: } I_{10} - I_2 = 0.$$

(10a)
The Ohm’s Law equations, eq. (11), remain as before, except that $I_1$ and $I_2$ are now represented as

\begin{align*}
I_1 &= G_1(v_1 - v_6), \\
I_2 &= G_2(v_2 - v_7). & \text{(11a)}
\end{align*}

Furthermore, since $u(0) = 0$, the potential difference across the capacitor, by eq. (4), is:

\begin{align*}
V_6 &= v_6 = \frac{1}{C_1} \int I_9 \, dt, \\
V_7 &= v_7 = \frac{1}{C_2} \int I_{10} \, dt.
\end{align*}

But from eq. (10a) we have

\begin{align*}
v_6 &= \frac{1}{C_1} \int I_1 \, dt, \\
v_7 &= \frac{1}{C_2} \int I_2 \, dt.
\end{align*}

---

Fig. 3. A representation of an outdoor recreational system with dynamic elements.
Substituting for \( v_6 \) and \( v_7 \) in eq. (11a), we obtain

\[
I_1 = G_1(v_1 - \frac{1}{C_1} \int I_1 \, dt),
\]

\[
I_2 = G_2(v_2 - \frac{1}{C_2} \int I_2 \, dt).
\]

We now rewrite eq. (12) using the dynamic behaviour of the inflows, \( I_1 \) and \( I_2 \) from eq. (15):

\[
G_2 v^1 = \begin{pmatrix}
\frac{G_1}{C_1} \int I_1 \, dt \\
\frac{G_2}{C_2} \int I_2 \, dt \\
0 \\
I_e \\
I_g
\end{pmatrix} = I^1.
\]

(16)

If we denote

\[
I^2 = \begin{pmatrix}
\frac{G_1}{C_1} \int I_1 \, dt \\
\frac{G_2}{C_2} \int I_2 \, dt \\
0 \\
0 \\
0
\end{pmatrix}
\]

then \( I^1 = I^0 + I^2 \), and the solution vector \( v^1 \) is

\[
v^1 = G^{-1}(I^0 + I^2) = G^{-1}I^0 + G^{-1}I^2 = v^0 + G^{-1}I^2.
\]

(17)
At time $t = 0$, we obtain identical solutions for the two systems since then $I^2 = 0$. When $t \neq 0$, the voltage at nodes 6 and 7 increases as a function of $t$.

The solution for the entire system, $y^1$, being now a function of $v_6$ and $v_7$, also changes with time, and the same holds for the respective currents in each of the links. Using the values of $I_e$, $I_g$, $R_i$, and $G_i$ as in the first example, and $C_1 = 0.5$, $C_2 = 1.0$, the values of $I_9$, $I_{10}$, $V_6$ and $V_7$ are described in fig. 4.\(^9\) Since $Q_2 = V_2$ in this example, $V_2$ also describes the net accumulation of visitors in park 2.

It is also interesting to note that the steady state solution for the two parks, $I_9$ and $I_{10}$ (at about $t = 10$), differs from that obtained in the first example. The inflow into park 1 is lower, and into park 2 is higher. This is explained by their different $C$ values: The higher value of $C$ implies a shorter average stay in the corresponding park (see Appendix A); the resulting high rate of recreationist turnover indicates a lower tendency to crowding conditions and therefore, a situation less inhibiting as far as subsequent potential flows of recreationists are concerned.

\(^9\) This solution was obtained by IBM-ECAP program. See description on p. 352.
4.3. Generating demand schedules

Assuming infinite elasticity of the supply curve at zero marginal cost (the absence of both effective capacity limitations and entrance fees), the above solution values represent equilibrium points at the intersection of the demand curves for the various parks and the respective quantity axes. We should note that these equilibrium figures are determined simultaneously, given the price of the whole recreational experience for the given park and that of competing parks. This approach thereby accounts for the entire spectrum of competing and intervening opportunities in the system. By holding everything else fixed, and changing the $R_i$ and $G_i$ values of a given park $i$ (see eq. (2)) we could generate the demand schedules for that particular park.

Alternatively, by systematically changing the price of the recreational experience at other parks (via their attraction indexes or the resistors simulating the roads leading to them) we might generate a schedule showing demand for the given park as a function of its substitutes' prices.

Changing resistance levels is thus analogous to varying the price of the recreational product. These changes disturb the existing equilibrium and cause the system to move to a new equilibrium under the modified set of relative prices. By systematically varying $R_i$ we generate the following schedule which is in fact a demand schedule for park $i$ (graph $D_1$ in fig. 5).\(^\text{10}\)

When capacity limitations, such as $V_{\text{max}}$ in fig. 1, become effective, (graph $D_2$) changes in $R_i$ have almost no effect on $V_i$. The value of $R_i$ at which capacity is reached ($\bar{R}$) can be derived by the systematic changes in $R_i$. Assuming zero marginal costs, the height $QR$ represents the price which, if it existed, would have rationed the existing capacity among potential users.\(^\text{11}\) By successive marginal changes in $V_{\text{max}}$, we can derive a schedule of marginal (shadow) values of capacity.

Physical capacity, however, does not necessarily imply an absolute upper limit to inflow of visitors. By appropriate manipulation of the resistor activated by the switch (see fig. 1), the new demand schedule will be something like $D_3$ in fig. 5. This means that visitors continue to enter the park, but at a reduced rate due to severe crowding conditions.

\(^{10}\) Alternatively, by changing the price of a competing park, we would generate a family of demand schedules for park $i$.

\(^{11}\) For an analytical derivation of this quantity, see Brown (1971).
In this case, the vertical distance between the curves $D_1$ and $D_3$ measures the alternative cost of congestion of the marginal visitors.\textsuperscript{12}

The information thus derived is extremely useful for economic analysis and planning. It enables the prediction of attendance levels at given parks in the system as well as the prediction of variations thereof resulting from changes of road conditions, park improvements, and entrance fees. It also enables the analysis of economic problems associated with evaluating investments in outdoor recreation facilities.

It is also possible to use this model to predict attendance levels at a new park, with a known attraction index, in any given location. The introduction of such a component into the network requires adding or changing some of the equations describing the system (eqs. (9) and (10)). However, this procedure is much simpler than modifying a simultaneous equations model. In the latter case the modification may require rather spurious assumptions (Burt and Brewer, 1971; Mansfield, 1971).

5. Application to the Judean Hills region

In this section we apply the electrical analog using simulation techniques to analyze the Judean Hills recreational region, and incorporating some of the modifications discussed above.

Because of the additional mathematical complexities introduced by the inclusion of more realistic features, simulation is used to derive

\textsuperscript{12} On this problem see the study by Hastings and Tolley (undated).
predictions, and to analyze the system. Predictions on the behaviour of the modelled system are thus experimentally derived through simulation methods and not analytically deduced. We then attempt to induce general and specific predictions concerning the recreational system of population centers, roads, and parks in the real system from results of the simulation experiments on the electrical analog.

The Judean Hills is a mountainous region in the center of Israel between two of the largest population centers — Tel Aviv-Yafo and Jerusalem. A field survey was conducted in five recreational parks in the region in 1969 (Landscape Architecture, Urban and Regional Planning, Ltd., 1971). The sites included two picnic areas in the Hanassee Forest and Shen-Hapil Woods; a nature and landscape reserve, Hamasreik; a picnic area adjacent to an historical monument, Kennedy Memorial; and a national park containing picnic grounds, an archaeological monument, and a nature reserve, Aqua Bella National Park. Traffic enters the region from four main highways, as depicted in fig. 6. There are a few secondary roads traversing the region itself.

Fig. 6. A schematic representation of the Judean Hills recreational region.
The model assumes that all trips into the region originate at points where the four major highways intersect with the region, rather than at the true population origins. This is not a restrictive assumption because our main purpose was to estimate the spatial distribution of a given volume of recreation demand, and not traffic loads in the road network.

In modelling the road network it was assumed that average speed, average expenditures for fuel per mile, and road quality are equal for all the road links in the networks. This simplifying, albeit rather strong, assumption was nevertheless acceptable in the initial phase of the investigation and enabled us to assign the \( R_i \)'s values proportional to the lengths of the corresponding road links.

The parks are represented by a serial connection of resistors and capacitors. The former measure park attractiveness while the latter are associated with the average duration of the recreational activity at the relevant parks. A simple score-sheet approach was employed in arriving at attractiveness values, \( G_i \), for the parks. A park's score is a weighted average of individual scores, based on ordinal scales, for each of the various factors contributing to the park's attractiveness: landscape, shade, availability of parking space, picnic and sports facilities, water faucets, national and historical importance, etc. Table 1 lists the relative attraction index computed for each park. The index is the park's score divided by the total score for all the parks. These values serve as initial values for the \( G_i \)'s in the calibration procedure.

As detailed above, the capacitor parameters are based on the computed average length of the recreation stay at each of the parks. These values appear in table 2.

The flow of recreationists into the system at the four intersection points is simulated by current sources. The size of these currents was computed from the data in the original survey schedules. The information on the system is summarized in fig. 6. Here resistor levels are indicated near each road link. The best values for the remaining parameters, \( C_i \) (\( i = 1, \ldots, 5 \)), were determined in the calibration procedure.

### Table 1

<table>
<thead>
<tr>
<th>Park</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqua Bella National Park</td>
<td>0.242</td>
</tr>
<tr>
<td>Hanassee Forest</td>
<td>0.193</td>
</tr>
<tr>
<td>Hanasrek Nature Reserve</td>
<td>0.193</td>
</tr>
<tr>
<td>Shen-Hapil Woods</td>
<td>0.161</td>
</tr>
<tr>
<td>Kennedy Memorial Picnic Grounds</td>
<td>0.209</td>
</tr>
</tbody>
</table>
Table 2
Computed C values.*

<table>
<thead>
<tr>
<th>Park</th>
<th>C value</th>
<th>Average stay (A) (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqua Bella</td>
<td>1.4982</td>
<td>7.3</td>
</tr>
<tr>
<td>Hanassee</td>
<td>1.6183</td>
<td>6.0</td>
</tr>
<tr>
<td>Hamasrek</td>
<td>2.1262</td>
<td>3.7</td>
</tr>
<tr>
<td>Shen-Hapil</td>
<td>2.7854</td>
<td>2.6</td>
</tr>
<tr>
<td>Kennedy Memorial</td>
<td>5.8330</td>
<td>1.2</td>
</tr>
</tbody>
</table>

* Source: Appendix A, eqs. (4) and (7), for N=7.

In estimating the C_i's, we examined four time periods by which to depict the arrival and departure pattern of the park. The time periods were the first 4, 5, 6 and 7 hours\(^{13}\) of one day and related to the number of visitors the parks contained at those times i.e., the number of visitors who had arrived up to and during those times.

A computer program ECAP (Electronic Circuit Analysis Program; IBM, 1970) was used to solve the model for the values of V_i and I_i for each hour of the typical weekend day, such as that on which the survey was conducted. This program is essentially a digital simulation of an electrical circuit analog. The simulation is executed on a digital computer rather than on the actual analog. The inputs to the program consisted of the following: The topology of the network, the values of the currents at the four origins as functions of different time intervals during the day, R_i's for all the road links and parks, and estimates of C_i's for all the parks in the system. The output consisted of values for I_i and V_i at each of the parks as functions of time (hour of the day). These values were compared to the actual numbers of recreationists entering the park during the day and the actual number of visitors at the park at each point of time. By iterative changes of values of the C_i's we obtained successive values for the I and V vectors. Using Theil's inequality coefficient (Appendix B) we evaluated these successive vectors in relation to the corresponding vectors of observed values. This search procedure was continued until no marked improvement was obtained in the values of the inequality coefficients. The values of the C_i parameters accepted as being the 'best' represent the relevant characteristics of their corresponding components in the real system.

\(^{13}\) Until the fourth hour (10:00) the number of people at the various parks was negligible; and from the eighth hour (14:00) onward the net flow is negative.
The values of the inequality coefficients for the last run are given in table 3.

For comparison purposes we first ran the model with all $C_i=1$. The results of this run (Run 0) are given in table 3. The actual values of $V$ for each park (for $N=7$) are also reported. Although this run gave reasonable results for Aqua Bella, it consistently overestimated, by a factor of 2 to 6, the volumes in the rest of the parks. The values of $C_i$ computed from eq. (7), Appendix A, (see table 2), gave better results for the other parks (Run 1), but worse ones for Aqua Bella. Since this park accounted for a large portion of the total recreational flow, the overall results as reflected in Theil's coefficient, were inferior to those obtained in Run 0.

Consequently, upon reexamination of the original data, we again used $C_i=1$ (Run 2), since the original data show that an overwhelming number of visitors to Aqua Bella stay there rather late ($A = 7.3$) and hence it is reasonable to assume $\sigma \to 1$, yielding $C \to 1$ in eq. (7), Appendix A. This change resulted in an overall improvement on the order of 34% in Theil's coefficient.

Fig. 7 depicts the values of $I_i$ and $V_i$ at the five parks, as obtained in Run 2.

It seems to us that further improvements in the calibration procedure could have been obtained by postulating a different value for $C_i$ after 14:00 hours. On the basis of observed recreationists’ behavior, it would be reasonable to assume that from that hour on the percentage of those staying an additional hour, $\sigma$, decreases substantially. Therefore, the corresponding values of $C_i$ would increase accordingly.
Fig. 7. (a)–(e). Simulated visitor flows and attendances (net accumulations) at each of the five parks. (a) Aqua Bella, (b) Hanasse, (c) Hamasrek, (d) Shen-Hapil, (e) Kennedy Memorial.
Consequently, one would have to change the $C_i$ values for the period after 14:00 hours, using an ‘on—off’ switch. By activating the switch (‘on’ position) we would simulate a higher rate of visitors’ departure and cause a reduction in $V$, the number of recreationists present in the park. This procedure should have improved the $V$ and $I$ estimates in fig. 7. Lack of appropriate data prevented the use of this procedure.

6. Concluding remarks

Due to data limitations (the original data was not gathered specifically for this study but rather collected by others for different purposes) we limited the scope of the present application to the calibration stage incorporating some of the modifications described earlier. Thus, our main interest lay in seeking the best estimates for the parameters characterizing the parks: resistors and capacitors. The criterion employed in assessing the various sets of values for these parameters was how closely they succeeded in predicting the actual flows into the parks during the survey weekend when actual counting was performed. An index — Theil’s Inequality Coefficient — was used in evaluating the relative performance of each set of values and an iterative procedure was used until a satisfactory set of values was obtained, i.e., until no marked improvement in the index was obtained. The calibration stage serves to prepare the model for its ultimate uses: (a) analyzing generated demand schedules, and (b) measuring and appraising the effects of changes such as increased volumes of recreational traffic, changes in road conditions, and changes in the park system due to improvements in existing parks or additions of new parks. Since the data available for this study did not indicate that crowding conditions were reached in any of the parks under investigation, it was not possible to estimate appropriate $R_2$ values (see fig. 1), and therefore this aspect was not incorporated in the present application.

Appendix A

Let us examine the length of stay at the park of visitors who arrived at different hours, and attempt to infer a general pattern of behavior. Following our empirical findings for the Judean Hills region we assumed
a behavior characterized by an exponential function:

$$s_r = I_0 \sigma^r,$$  \hspace{1cm} (A1)

where \(s_r\) is the number of recreationists still at the park in time period \(r\), out of the \(I_0\) recreationists who entered the park at time \(t=0\), and \(\sigma\) is the ratio of people who remain at the park one additional period. \(\sigma\) is completely determined by the average duration for the park, as we now show.

The number of people out of the initial \(I_0\) leaving the park during a single period, \(l_t\), is equal to the difference between the numbers present at two successive periods, i.e.,

$$l_t = s_{t-1} - s_t.$$  \hspace{1cm} (A2)

Since \(\sigma < 1, l_t > 0\). The average duration of stay at a park, \(A\), is defined as the following weighted sum:

$$A = \frac{1}{I_0} \sum_{t=1}^{N} l_t \cdot t = \frac{1}{I_0} \sum_{t=1}^{N} (s_{t-1} - s_t) \cdot t =$$

$$= \frac{1}{I_0} \sum_{t=0}^{N-1} s_t - Ns_N = \frac{(1-\sigma^N)}{1-\sigma},$$  \hspace{1cm} (A3)

where \(N\) is the number of time intervals (say, hours) in the whole recreation period (say, day); \(l_t\) is the number of people who stayed \(t\) time intervals, and this is multiplied by the number of hours they stayed in the park. It is of course assumed that all \(s_{t-1} - s_t = 0\) for \(t > N\), since everybody has left the park by then (specifically, \(s_N = 0\)).

Letting \(N \to \infty\), we get (since \(\sigma < 1\))

$$A \to \frac{1}{1-\sigma}$$

hence,

$$\sigma \cong \frac{A-1}{A}$$  \hspace{1cm} (A4)

that is, \(\sigma\) is completely determined by \(A\), as claimed above.

We now show the relation between \(C\), the capacitance value, and \(\sigma\).
This will enable, in turn, to estimate the $C_i$'s from empirical data on the $A$'s.

Let us assume the following: (a) a constant rate of recreational flow into the park; (b) this constant flow is maintained throughout the recreation period. Therefore, the number of people present at the park at any given time is the accumulated sum of all the visitors who arrived previously and have not yet left. We have already designated this number $V_t$. Thus, after one time interval, $V_1 = I_1 + I_0 = I(1 + \sigma)$ (since $I_t = I$ for all $t$ by assumption (a)). After $N$ time periods we have

$$V_N = \sum_{t=0}^{N-1} I\sigma^t = I \frac{1 - \sigma^N}{1 - \sigma}. \quad (A5)$$

By assumptions (a) and (b), the total number of visitors up to time period $N$ is

$$Q_N = \sum_{t=0}^{N-1} I_t = N \cdot I. \quad (A6)$$

By eq. (4) in the text, we obtain

$$C = \frac{Q_N}{V_N} = \frac{N \cdot I}{I \frac{1 - \sigma^N}{1 - \sigma}} = N \frac{1 - \sigma}{1 - \sigma^N}. \quad (A7)$$

That is, $C$ is a function of the parameter $\sigma$ and, hence, $A$, which is a characteristic of the park, and $N$, the number of time periods passed from the beginning of the recreation period. A higher rate of visitor turnover (lower $\sigma$ and $A$ values) and high values of $N$ would tend to yield higher $C$ values, except maybe for very small values of $\sigma$. These values imply a lower tendency to crowding conditions, higher $C$ values are equivalent to a high $Q_N/V_N$ ratio, that is, the number of visitors at the park is only a small fraction of all that arrived during the $N$ time periods. We also note that as $N$ increases, $V_N$ increases but at a much lower rate ($(1 - \sigma^N)/I$ compared with $Q_N(N \cdot I)$).
Appendix B

Theil's Inequality Coefficient (1955, pp. 31–33) is

\[ U = \frac{\sqrt{\frac{1}{n} \sum (P_i - A_i)^2}}{\sqrt{\frac{1}{n} \sum P_i^2 + \frac{1}{n} \sum A_i^2}} \]

where \( P_1, \ldots, P_n \) are predicted values, and \( A_1, \ldots, A_n \) are actual values. The advantage of using this coefficient rather than the correlation coefficient is due to the fact that the former is not invariant to a linear change or the addition of a constant.

Its values lie between 0 and 1. \( U = 0 \) when \( P_i = A_i \) for all \( i \). \( U = 1 \) if either \( P_i = 0 \) or \( A_i = 0 \) for all \( i \), or when there exists a negative dependence between \( P_i \) and \( A_i \) such as \( rP_i + sP_i = 0 \), for all \( i \) \( (r, s > 0) \).

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