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Publication of this paper sponsored by Committee on Transportation Planning Needs and Requirements of Small and Medium-Sized Communities.

Estimating OD Tables Using Empirical Route-Choice Information with Application to Bicycle Traffic

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ABSTRACT

A new method for estimating origin-destination (OD) tables is presented that uses road counts and route-choice information. The innovative feature of the estimation method, a refined version of the information-minimizing approach, is the use of empirical route-choice information. The method has been applied in an evaluation study of a cycleway network in a medium-sized city in the western part of The Netherlands. In this study, OD matrices were estimated to determine changes in travel patterns of bicycle users caused by the implementation of a new bicycle network scheme. The method that proved to be useful can be applied equally well to automobile traffic by using route information derived from, for example, license-plate surveys.

Unlike in the United States, the bicycle is a major transportation mode for urban travel in The Netherlands. A modal share of 50 percent is not uncommon. After a period of steady decline of bicycle use, policies are being designed to enhance this inexpensive, low-energy mode without any negative effects on the environment.

BICYCLE NETWORK SCHEME

In October 1982, the public works department of Delft, a medium-sized city with a population of 100,000 in the western part of The Netherlands, started implementing an ambitious bicycle network scheme. This scheme consisted of a considerable extension and improvement of existing bicycle facilities in such a way that a citywide, comprehensive, and hierarchical cycleway network was generated. The plan was intended to make cycling safer, faster, and more comfortable, in particular for those groups of the population that are captive users of the bicycle mode (e.g., pupils and younger students). The second, more general, objective was to promote the bicycle mode to reduce usage of cars for local trips.

The basic idea was to realize a comprehensive cycleway network. In this respect, the project was unique even by Dutch standards. The characteristic feature of the planned system was that the network would consist of three subnetworks hierarchically related: an urban network, a district network, and--at the lowest level--a local network. The urban level network would consist of a grid of corridors that traverse the entire urban area and would be connected with regional bicycle facilities. The district level network mainly would have two functions: providing access to major, specific district facilities (e.g., schools and shopping centers) and linking the districts with the urban network. The facilities at the local level would provide access to houses and other adjoining land development.

The bicycle network scheme involved a variety of measures, related both to infrastructure (new cycle tracks and constructions such as bridges and tunnels, improvement of cycleways and intersections, extension of bicycle park facilities) and operations (various traffic signal control changes, exempting cyclists from one-way traffic systems).

EVALUATION STUDY

In view of the experimental nature of the bicycle network scheme and the huge amounts of expenditures involved ($25 million), a careful evaluation of the plan needed to be made. A number of studies were performed to this end: an analysis of changes in safety, an evaluation of the use of the network, and an in-depth attitudinal survey with the purpose of determining potential modal shifts. In this paper, discussion is limited to the evaluation of the use of the new network.

The effects of the network scheme on travel patterns of bicycle users were determined by using a comprehensive before-and-after survey. The main evaluation items were the changes in origin-destination (OD) pattern and in the route choice behavior of these travelers. More specifically, evaluation of network use needs to address the following aspects:

- Effectiveness of the network scheme: What are the effects on the travel patterns of various groups of bicycle users? What are the changes in the accessibility of various activity centers?
- Structure of the network: Do bicycle users choose routes according to the hierarchical principle of the network? Do they use the most direct routes? How does the network perform in view of the spacing of the urban corridors?
- Route-choice behavior of bicyclists: Which factors influence route-choice behavior?

In this paper, only the establishment of OD tables of bicycle trips will be addressed.

A NEW METHOD FOR ESTIMATING OD MATRICES USING EMPIRICAL ROUTE INFORMATION

To determine changes in travel patterns of bicycle users, an OD matrix has to be estimated before and after the scheme is implemented. A new method for estimating OD matrices was developed that uses road counts and empirical information on routes followed by bicycle users. Use of this empirical route information is the innovative feature of this estimation technique.

In view of the specific nature of bicycle travel, it was decided to set up a manifold measuring program to determine actual bicycle use in a study area within the city of Delft before and after the realization of distinct facilities. The program consisted of extensive continuous and periodic traffic counts, short roadside interviews, and a mail-back route-choice survey. The most essential part of the approach was the determination of the routes that were actually followed during bicycle trips. The resulting information played a crucial role in the evaluation study of the use of the network in both the route choice analysis and the estimation of OD matrices.

It is worth mentioning that the method presented can, in principle, also be applied to automobile traffic. The necessary route-choice information of automobile drivers can be gathered by roadside interviews or license-plate surveys. The only essential difference is that with automobile travel the procedure should be able to take account of congestion effects.

ORGANIZATION OF THE PAPER

In this paper, the authors confine themselves to the estimation problem of an OD matrix using various sources of information, although these sources are incomplete. First, the approach adopted in the before survey of the evaluation study of the network use is described. Second, the problem of estimating OD matrices from traffic counts is discussed in a general setting. The discussion is meant to demonstrate that route-choice behavior is the key link between the desired information (the OD matrix) on the one hand and the available observations (link volumes) on the other. In other words, route-choice information is essential to the estimation problem posed. Further, how the method of information minimization can take into account the route-choice information is indicated.

In the section on Application, the procedures used to estimate an OD matrix of bicycle traffic within the scope of the evaluation study are described in detail. Attention is given to the processes of data collection and preparation and to the ways in which the various kinds of information are used. Empirical route-choice information is continuous throughout the section. In the final section, some estimation results are presented.

STUDY APPROACH

The study focused on the actual use of the cycleway network in the northwest part of Delft (an area with a population of 20,000) before and after the realization of the bicycle network scheme. The study area (approximately 250 hectare) encloses several activity centers (primary and secondary schools, shopping center, hospital, railway station, etc.) and adjoins the inner city (see Figure 1).

Because it was expected that a substantial part of the relevant bicycle trips were made by noninhabitants of the study area passing through (some 30 to 40 percent), it was decided to collect data mainly from traffic counts and a cordon roadside interview coupled with a mail-back route-choice survey. Specifically, the data collection program consisted of the following:

- A cordon roadside interview. A random sample

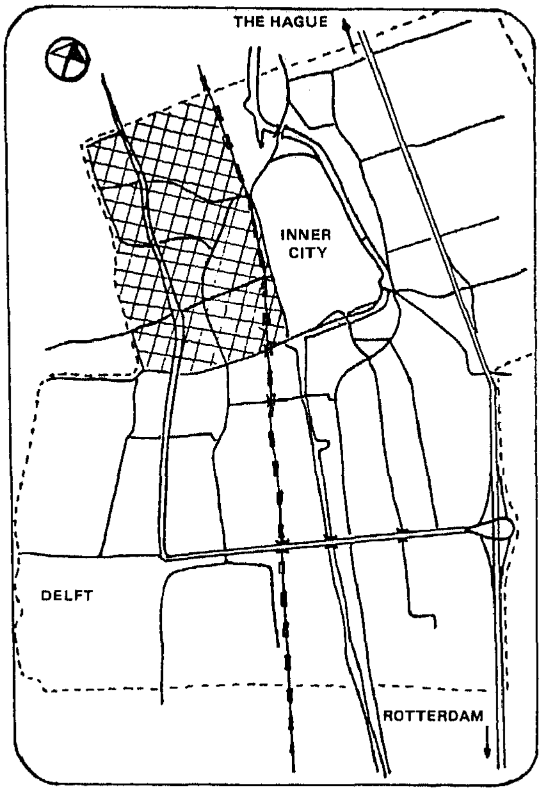


FIGURE 1 Study area.

of bicyclists leaving the study area was stopped at roadside interview stations located at the cordon line; information was obtained regarding origin, destination, purpose, gender, and age.

• A mail-back route-choice survey. In addition, a route-choice questionnaire was handed out to each person interviewed; he was asked to complete the form and to return it by mail. The main question concerned plotting on a city map the route followed for the trip during which the traveler was interviewed.

• Continuous traffic counts. During the whole survey day, all bicycle trips leaving and entering the study area were counted in 15-min intervals to determine the extent of and daily fluctuations in the traffic volumes in question.

• Periodic traffic counts. Traffic volumes were counted inside the study area at a large number of intersections and links during each of five short time periods (25 min) scattered throughout the day. The locations of the counts were selected in such a way that the study area was intersected by a number of imaginary screenlines, which divided the area into 10 zones. As a consequence, it was impossible to ride from one zone to another without passing one or more counting points.

In addition, some information (although incomplete) was available from previous traffic counts as well as from a recent home interview taken from a random sample of inhabitants of the study area. All these fairly diverse pieces of information were used for the establishment of the OD matrices. For the purpose of analysis of the OD pattern of bicycle trips that make use of the cycleway network in the study area, the city of Delft and the surrounding area were divided into 63 zones, 25 of which were situated inside the study area; the latter zones were subzones of the 10 screen-line building zones mentioned earlier.

According to the location of the trip ends, that is, OD zone inside or outside the study area, the bicycle trips can be subdivided into 4 categories:

Origin-destination zone	Inside study area	Outside study area
Inside study area	Internal trips	Outbound trips
Outside study area	Inbound trips	Through trips

The roadside interview together with the continuous traffic counts provided reliable and detailed information with respect to through traffic and outbound traffic (i.e., trips leaving the study area). In other words, a part of the OD matrix, the shaded cells in the matrix, could be estimated directly from the results of the roadside interview.

The main problem with the study design that was adopted was the determination of the internal traffic flows and to a lesser extent the inbound traffic flows of the study area (the nonshaded cells of the OD matrix). Information with respect to the flows in both quadrants had to be derived primarily from the periodic traffic counts (on the screen lines inside the study area) and from the continuous counts on the cordon line of the trips entering the study area. However, a simple estimation of these nonshaded parts of the OD matrix from these counts was not possible because of the interference with through and outbound trips.

For this reason, in order to derive estimates for the nonshaded cells in the OD matrix, an approach was chosen in which the entire OD matrix, at an aggregate level, was estimated simultaneously by using all the available information. In this approach, a crucial role was played by the empirical route information obtained from the mail-back route-choice survey. For example, it was possible to derive information on the number of outbound and through trips that pass a particular counting point from this survey.

For estimation purposes, the authors developed and used an extended version of the information minimizing approach, which is described in detail in the next section.

THEORY OF OD MATRIX ESTIMATION

OD Matrices and Traffic Counts

Essentially, the estimation of OD flows from traffic counts is the inverse process of that of assignment, in which link volumes are estimated given an OD matrix [e.g., Willumsen (1), Bell (2)]. The key issue is the absence of a unique solution to the equivalent mathematical problem: in general, several OD tables may be constructed that reproduce the same set of link volumes. This stems from the number of OD pairs (unknown variables) usually being significantly larger than the number of independent observations. The information contained in traffic counts may be called incomplete in this respect.

Let V_a denote the observed volume at link a; then the fundamental equations of the estimation problem are given by

$$V_a = \sum_{i,j} p_{ij}^a T_{ij} \quad \text{for all a} \qquad (1)$$

where T_{ij} denotes the number of trips from zone i to zone j; and p_{ij}^a, $0 \leq p_{ij}^a \leq 1$, is the proportion of traffic from zone i to zone j that uses the counted link a. For the time being, assume that these proportions are known. Subsequently, this assumption will be reconsidered in detail.

In practice, the number of unknown quantities T_{ij} is usually substantially larger than the number of independent observations [i.e., the number of mutually independent linear equations in Willumsen (1)]. Then the mathematical problem is ill specified and many solutions exist. The problem of interdependency between the counts and the resulting potential inconsistency of the data will not be discussed here [see van Zuylen (3)].

Within the practical limits of an investigation, it is recommended that the number of independent observations be maximized, which requires a sophisticated plan for the counting program. Furthermore, it is worthwhile to reduce the set of solutions by adding essentially new information of a different kind (see also a succeeding section on Application). Unfortunately, this approach still is not nearly a guarantee for a unique solution to the estimation problem and it will be necessary to choose among the set of alternative feasible solutions according to some rule.

The Information-Minimizing Method

One approach to tackling this problem of choosing one solution is to calculate the information contained in the trip matrix (T_{ij}). Because the information available in the set of traffic counts is insufficient for determining a unique trip matrix, it appears reasonable to choose a trip matrix that adds as little information as possible to that contained in Equation 1. This approach has been followed by van Zuylen (3-5) using Brillouin's information measure. In the information-minimizing approach, the original estimation problem is transformed into a mathematical optimization problem: minimize the associated information measure with respect to the independent variables T_{ij} under the constraints given in Equation 1. The solution to the optimization problem can be written in the form

$$T_{ij} = t_{ij} X_o \prod_a X_a^{p_{ij}^a} \quad \text{for all i and j} \tag{2}$$

where t_{ij} denotes an a priori estimate of T_{ij} (e.g., an old trip matrix). In the absence of any a priori information, one simply substitutes $t_{ij} = 1$ for all i and j. The quantities X_o and X_1 (for all a) have to be computed numerically by substituting Equation 2 into the fundamental Equation 1. This numerical problem can be solved using some recursive algorithm, or in particular, the computer program NEST (Network flow ESTimation) developed by van Zuylen (5).

Route Choice

A serious problem in estimating OD matrices from traffic counts is the determination of the proportion of the trips between a particular OD pair that takes a specific counted link, that is, p_{ij}^a. The fundamental Equation 1 shows that the route-choice proportions p_{ij}^a determine the mathematical relationship between the measurements V_a and the unknown quantities T_{ij}.

In case each OD pair uses only one route (and it is known which one), the proportions p_{ij}^a having values 0 or 1 indicate which of the OD pairs use link a. However, in many applications many alternative routes are used for a considerable number of OD pairs, which makes the problem much more complex. In this context, a route should be seen as some ordered sequence of counted links.

So far, it has been assumed that the route-choice proportions are known. In normal practice, however, these proportions are often unknown just as is the trip matrix. The question arises about how to choose the proportions p_{ij}^a in more complex applications. Although until now little research has been done about the consequences of an erroneous choice of these proportions, the fundamental equations suggest that these errors carry over into the estimated trip matrix considerably.

Refining the Method

In more complex applications, and as in the authors' case favorably circumstanced by available (incomplete) route-choice information, it is plausible to treat the route-choice proportions in the same way as the unknown trip matrix. The information-minimizing approach can be adapted accordingly, simply by splitting up the cells in the OD matrix. The following two definitions apply:

T_{ijr} = route flow, the number of trips from zone i to zone j that use route r (the total number of routes may differ for each OD-pair); and

δ_{ijr}^a = 1 if link a is part of route r of OD pair (i,j) and 0 otherwise.

Then, the fundamental equation can be written as

$$V_a = \sum_{i,j,r} \delta_{ijr}^a \quad \text{for all a} \tag{3}$$

where the variables T_{ijr} represent the quantities to be estimated.

Note that the problem of identifying the OD route flows that take a specific counted link, that is, the determination of the route-choice indicators δ_{ijr}^a, is still present. In the authors' case, this information was derived from the mail-back route-choice survey.

However, the proportions p_{ij}^a are estimated simultaneously with the unknown trip matrix; they are given by

$$p_{ij}^a = \left(\sum_r \delta_{ijr}^a T_{ijr}\right) \Big/ \left(\sum_r T_{ijr}\right) \quad \text{for all i, j, and a} \tag{4}$$

Following the information-minimizing approach, it can be shown (6) that the solution to this estimation problem is given by

$$T_{ijr} = t_{ijr} X_o \prod_a X_a^{\delta_{ijr}^a} \quad \text{for all i, j, and r} \tag{5}$$

where t_{ijr} represents some a priori estimate for T_{ijr}. Hence, the numerical solution can be derived in a way similar to that done previously. Finally, the unknown trip matrix satisfies

$$T_{ij} = \sum_r T_{ijr} \quad \text{for all i and j} \tag{6}$$

Equation 6 could also be used as an additional constraint (compare with Equation 3) in case partial information about the OD matrix is available from other sources (e.g., roadside interview).

The main advantage of the latter approach is that all kinds of additional information (such as empirical route-choice information) can be dealt with in a straightforward way, as will be shown in the next section. Moreover, although outside the scope of this paper, the explicit approach in terms of routes allows for an elegant and direct handling of interdependencies between measurements.

The price that must be paid, however, is the largely increased number of unknowns in the estimation problem in more complex applications. Therefore, the use of additional information is strongly recommended. Although the estimates of the route flows T_{ijr} will be relatively less reliable than the estimates of the OD trips in the former approach, the authors believe that the resulting aggregate trip matrix is more reliable because the authors use significantly more information in deriving it and therefore do not have to rely on untested assumptions.

Application of the refined version of the information-minimizing approach is particularly preferable if the problem satisfies the following conditions:

1. The available information is diverse in nature (e.g., counts, routes, trip rates) and incomplete, and a substantial part of the information refers to traffic counts;
2. The information obtained from various counts and other sources cannot be treated as being independent;
3. Several alternative routes are used by the trips between most of the OD pairs (i.e., routes that differ in their ordered sequence of counted links).

This is precisely the case with the evaluation study of the bicycle network scheme.

APPLICATION

Data Collection

According to the data collection program described in the section on Study Approach, the various data were collected on the survey day, September 29, 1982, from 7:00 a.m. to 7:00 p.m. Within this period, more than 25,000 bicyclists were counted leaving the study area at 1 of the 15 roadside interview stations at the cordon line. Approximately 4,000 of these bicyclists (a 16 percent sample) were interviewed and given the route-choice questionnaire. More than 2,500 of these questionnaires were completed and sent back, implying a response of some 60 percent after editing.

In the opposite direction, 24,912 bicyclists were counted entering the study area. Table 1 presents an overview of the net results of the data collected at the cordon line. Moreover, at the screen lines inside the study area, 169 bicycle traffic flows (corresponding to 9 intersections and 33 road links) were counted periodically, during each of 5 25-min time periods scattered throughout the survey day.

TABLE 1 Net Results of Data Collected at Cordon Line

Roadside Station	Entering Bicycle Trips (counts)	Leaving Bicycle Trips		
		Counts	Inverviews	Routes
1	1,592	1,548	288	168
2	3,016	3,254	474	265
3	205	139	74	30
4	480	439	113	52
5	280	521	144	94
6	4,580	4,577	545	265
7	3,121	2,250	384	238
8	1,949	2,888	274	181
9	595	678	145	72
10	3,638	3,578	504	301
11	1,641	767	186	88
12	1,039	1,676	234	119
13	547	832	192	105
14	543	473	113	67
15	1,686	1,677	220	149
Total	24,912	25,296	3,863	2,194

Note: Data were collected on September 29, 1982, from 7:00 a.m. to 7:00 p.m.

Data Preparation

The OD Matrix

The study design--in particular, the partitioning of the study area by the screen lines into 10 zones--only permits estimation of the internal trips at the level of these 10 zones. In addition, in estimating the number of internal trips from the traffic counts inside the study area, the authors were only interested in those parts of through and outbound bicycle trips that were within the study area. For these reasons, the OD matrix to be estimated was defined in such a way that each OD zone corresponded with either 1 of the 10 internal zones mentioned earlier, or 1 of 13 feeding nodes at the cordon line (Roadside Stations 3, 4, and 5 were combined into a single OD zone). Consequently, the OD matrix of interest is a 23-by-23 matrix.

Route Choice Indicators

Having defined all the OD pairs, it was necessary to determine the route-choice indicators δ^{a}_{ijr}, that is, to solve the following identification problem: which routes are used for each OD pair and what are the counting points that each route passes? This problem was solved by using the results of the empirical route-choice survey. (A completed route-choice survey consisted of a map of the study area with an X at the point of origin and the point of destination and a line drawn between these two points, indicating the route chosen.) In general, these results indicate that in urban areas a large number of alternative routes are used for bicycle trips (Figure 2).

For the purpose of route-choice analysis, a network description of the entire cycleway network in the city of Delft (including illegal bicycle links that were actually used) was set up and stored in a computer. (This description of the cycleway network consisted of a map of the study area marked with the counting points, which were numbered, and the routes between these points.) The empirical routes were coded in terms of the network description (an ordered sequence of links and nodes) and also stored. Furthermore, each counted flow was uniquely represented by an ordered set of nodes (two nodes for a link, three or four nodes for an intersection). Searching the routes for these ordered sets yielded a file of aggregate routes that were completely characterized by an ordered sequence of counted links (more precisely, of counted flows). Table 2 gives the distribution of the number of counting points over the set of available routes; on average, each route passed 3.3 counting points, and each counting point was taken on average by some 36 routes.

The routes used for the through and outbound trips (and the corresponding route-choice indicators) can be taken directly from the results of the

FIGURE 2 Selection of empirical bicycle routes passing nodes A and B.

TABLE 2 The Number of Counting Points by Route

No. of Counting Points	No. of Routes	Percentage
1	553	25.2
2	451	20.6
3	207	9.4
4	265	12.1
5	325	14.8
6	273	12.4
7	53	2.4
8	42	1.9
9	24	1.1
10	0	0
11	1	0.0
Total	2,194	100.0

route-choice survey. Routes for the internal and inbound trips, however, were not observed and had to be generated in an automatic fashion by using the data file of the aggregate observed routes and the network description. These routes were generated by applying splitting-up and reversing procedures to original routes. That is, for each route, the OD zones that the route passed were examined; and for each OD pair, a subroute connecting them was subsequently derived (again in terms of an ordered sequence of counted links).

Moreover, the resulting file of subroutes was further extended by reversing the direction of these subroutes and determining the corresponding ordered sequences of counted links (accounting for alternative routes in one-way traffic systems). In this manner, the problem of estimating the routes (and the route-choice indicators) for internal and inbound trips was satisfactorily solved. The data in Table 3 show that the 393 OD pairs that actually occurred or possibly could occur used 953 different routes (at the considered level of aggregation). In particular, note that both the number of OD pairs and the number of actually used alternative routes by OD pair for through trips were relatively small.

TABLE 3 Some Characteristics of the Estimated OD-Matrix

Type of Trip	No. of OD Pairs[a]	No. of Routes[a]	No. of Trips
Through	83	124	8,333
Outbound	105	296	16,589
Inbound	105	257	16,212
Internal	100	276	7,224
Total	393	953	48,358

[a]Actually or possibly used.

Estimation Constraints V_a and t_{ij}

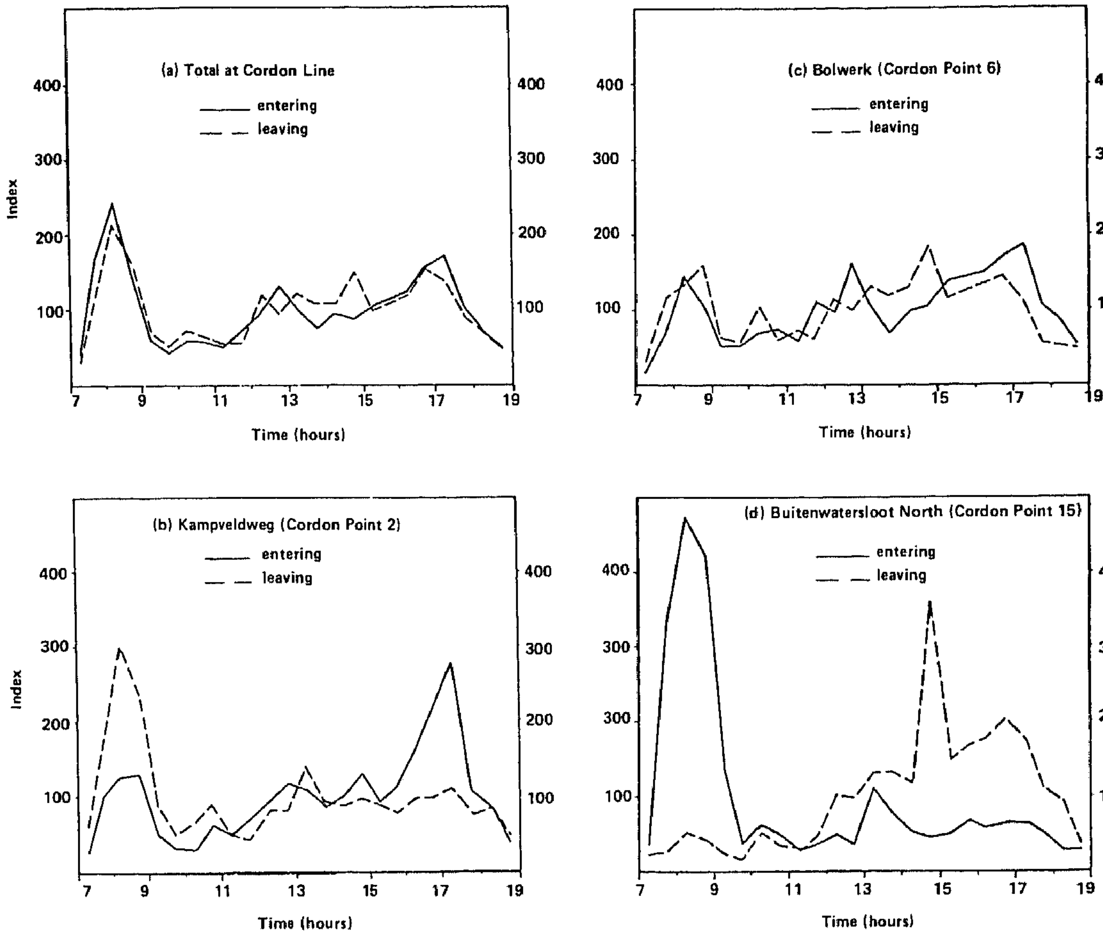
What are the constraints to be imposed on the route-flow estimation problem, that is, specification of Equation 3? First, continuous traffic counts at the cordon line (both traffic leaving and traffic entering the study area) are available, yielding 26 traffic volumes for the feeding nodes (the left side of Equation 3).

In addition, there are periodic counts; however, these have to be expanded to daily totals to be useful as constraints. The periodic traffic counts were expanded by using a special estimation procedure using route information, taking into account the correlation between periodic and continuous counts and the daily fluctuations in continuously measured traffic volumes.

It was found that the daily fluctuations at the cordon line highly depend on the location of the counted link. Figure 3 shows the variation of bicycle traffic intensities during the survey day for the total entering and leaving flows at the cordon line (a), and for a selection of roadside stations at this cordon line (b to d). In these diagrams, successive half-hour intensities are expressed in terms of index figures with respect to the average half-hour intensity on the spot throughout the survey day (index = 100).

Differences in the daily fluctuations among roadside stations could be ascribed mainly to differences in trip purposes; for example, trips at Station 2 (b) are predominantly work trips, trips at station 6 (c) are in the direction of the city center and have mixed purposes, and the flows at Station 15 (d) include a substantial number of school trips.

Therefore, it was concluded that it was necessary to develop an appropriate estimation procedure to expand the periodic counts to daily totals. For each periodic counting point, the set of matching routes in the route-choice survey was selected and the distribution of these routes among the roadside stations at the cordon line (the continuously counted links) was examined. Having determined the correlation between the periodic counting point and each of the continuously counted links at the cordon line and by using detailed results of the continuous counts, a weighed bicycle-traffic intensity pattern throughout the day was derived for each periodic counting point. Based on this representative intensity pattern and by using the counts in the measurement periods scattered throughout the day, a rather reliable estimate was derived for the daily total at each periodic counting point.



Note: Index = 100 refers to the average half-hour intensity on the spot.

FIGURE 3 Time-of-day pattern of bicycle flows at four spots.

A third group of constraints has to do with the observed trip flows. Previously, it was noted that the roadside interview yields reliable estimates for that part of the OD matrix that corresponds with through and outbound trips. Let t_{ij} denote the estimate of the number of (through or outbound) trips corresponding to OD pair (i,j) based on the results of the roadside interview. It is then plausible to pose the following constraint:

$$t_{ij} = \sum_r T_{ijr} \qquad (7)$$

for each OD pair forming through or outbound traffic. The authors obtained 188 of these constraints.

In summary, three categories of constraints can be distinguished:

1. 26 continuously counted link volumes,
2. 125 estimated daily link volumes of periodically counted traffic flows (some small counts were combined), and
3. 188 estimated OD volumes of through and outbound trips.

All constraints are linear equations in the unknown route flows T_{ijr} with coefficients having values 0 or 1, and allow for a straightforward application of the refined version of the information-minimizing approach.

A Priori Information t_{ijr}

It is well-known that a priori information affects the estimation results to a considerable degree and that its use is generally highly recommended. The authors are in the favorable position that a considerable part of the route-flow matrix could be estimated in advance by using the roadside interview and the route-choice survey. Thus, reliable a priori information is available with respect to those route flows t_{ijr} that correspond to through and outbound trips. A priori information with respect to inbound flows was derived from the a priori estimates of the traffic flows in the opposite direction.

Finally, the missing a priori information (the internal trips) was taken from the available results of a recent home interview. This interview contained various kinds of information from a 26-percent sample of households within the study area, including information about the main characteristics of all bicycle trips made during a single working day. Only internal trips were selected and, after expansion, an a priori route-flow matrix for internal trips was constructed and used in the estimation process, assuming that internal trips were made primarily by inhabitants of the study area.

ESTIMATION RESULTS

The information-minimizing approach was applied by using the computer program NEST (Network flow ESTi-

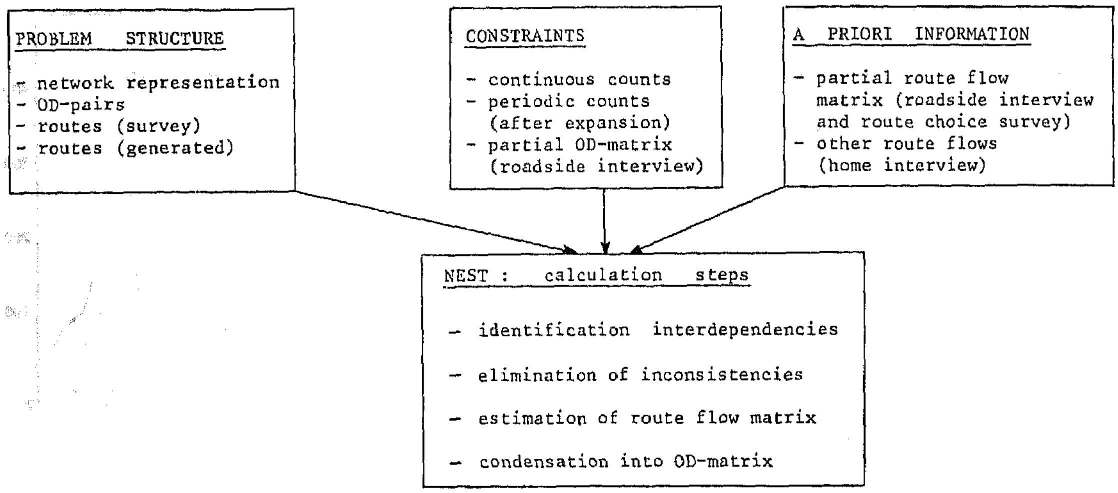


FIGURE 4 Outline of the estimation process.

mation) developed by van Zuylen. This program requires the following input (Figure 4):

- Definition of OD pairs to be estimated (in the authors' case, OD pairs by route yielding 953 unkown variables T_{ijr}).
- Definition of observed links (the left side in the constraints, and in the authors' 339 observations).
- Coupling of observations with route OD pairs, that is, listing for each observed link the route OD pairs included in the link flow; or, alternatively, listing for each route OD pair the observed links it takes. (In fact, this corresponds to indicating the value of the route-choice indicators δ^a_{ijr}.)
- Observed link volumes (the actual values for the left side in the constraints) V_a and t_{ij}.
- A priori estimates of the route flows for each cell of the route OD matrix (optionally) T_{ijr}.
- Some program parameters.

The program carries out the following calculation steps successively (Figure 7):

1. Identification of interdependencies between link flow observations by setting up a Gram-Schmidt orthogonalization process;
2. Elimination of inconsistencies in observed link volumes assuming Poisson-distributed link volumes and by using a maximum likelihood approach [compare with van Zuylen and Branston (5)];
3. Estimation of the route-flow matrix by using a recursive algorithm to solve Equation 2, starting from an a priori trip matrix [compare with van Zuylen and Branston (5)]; and
4. Condensation of route flows into OD trips.

For the estimation problem considered, the identification of interdependencies between observations was most time consuming; this part of the calculations took approximately 24 hours of running time on a microcomputer (Televideo TS-802H). When this was done, the computer processing time was reduced significantly. Leaving the structure of the estimation problem unchanged, it was possible to rerun the program with different data (link volumes and a priori estimates) in less than one-half hour of computing time. The program detected 15 interdependencies between observations. Related inconsistencies between observed link volumes were eliminated, which was extremely useful in the authors' case in which most of the link volumes were estimates.

Application of the method described yielded satisfactory estimation results, especially considering that this was the first time (at least to the knowledge of the authors) that both the information-minimizing method and the computer program NEST were applied to a problem of this size (953 unknown variables and 339 constraints). The estimation results are presented at an aggregate level in the last column of Table 3.

CONCLUSION

It is concluded that no detailed assumptions on route-choice behavior should be made in estimating trip matrices, but instead empirical information should be collected. An extended version of the information-minimizing approach was developed that is based on routes in terms of ordered sequences of observed links. This method allows for an explicit consideration of interdependencies between measurements and, what is much more important, for a straightforward processing of various types of additional information.

The approach is developed and applied within the framework of an evaluation study of a bicycle network scheme. In this study, empirical route-choice information with respect to bicycle trips was successfully used. This information plays a crucial role in various parts of the estimation procedure.

The application shows that no part was only specific to bicycle travel; thus, the estimation method is, in principle, equally well applicable to automobile traffic. The only difference with bicycle travel is that congestion should be taken into account in the procedure (e.g., Fisk and Boyce 7).

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Publication of this paper sponsored by Committee on Transportation Planning Needs and Requirements of Small and Medium-Sized Communities.

Is Urban Planning Education Necessary for Civil Engineers?

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ABSTRACT

The Education Committee of the Urban Planning and Development Division of the American Society of Civil Engineers undertook a nationwide survey of undergraduate civil engineering programs to investigate whether civil engineering graduates were sufficiently prepared to practice in the urban planning arena. The findings of this survey are presented and discussed in this paper. The interface between urban planning and civil engineering as well as the appropriate role of civil engineers in urban planning are also discussed. The results of the survey indicated that almost 90 percent of the respondents believed that civil engineers should participate in urban planning activities; 88 percent believed that urban planning education should be obtained by taking either a required or elective course. Minor changes in civil engineering curricula were also suggested.

Historically, the civil engineer has been involved in many aspects of city, urban, and regional planning. This involvement ranges from the technical aspects of land development, transportation systems, and utility systems to the socioeconomic and political aspects of presenting proposals at public meetings or working with community groups in the analysis of alternatives. In such a context, the fundamental question arises: How should civil engineers be prepared for such activities? More specifically, are civil engineering graduates currently sufficiently prepared to practice in the urban planning arena, or should there be planning courses in the typical civil engineering undergraduate curriculum?

OBJECTIVES

Given the basic question, the Education Committee of the Urban Planning and Development (UP & D) Division of ASCE undertook a nationwide survey of civil engineering programs to investigate this question. The primary objective of this paper is to present and discuss the results of this survey.

Other questions germane to this topic are, What is the interface between civil engineering and urban planning? What is the appropriate role of civil engineers in urban planning? What changes (if any) are necessary in civil engineering undergraduate curricula for civil engineers to fulfill their appropriate role in urban planning? In this paper, the author attempts to answer these questions as well.

SCOPE OF URBAN PLANNING

Planning is a basic human activity that involves thinking ahead or organizing to get things done. The term "urban planning and development" covers those activities concerned with the planning and development of towns, cities, and regions. Planners deal with problems people have holding their communities together, coping with pressures of urbanization and development, and trying to provide an opportunity for everyone to improve the quality of life. Apart