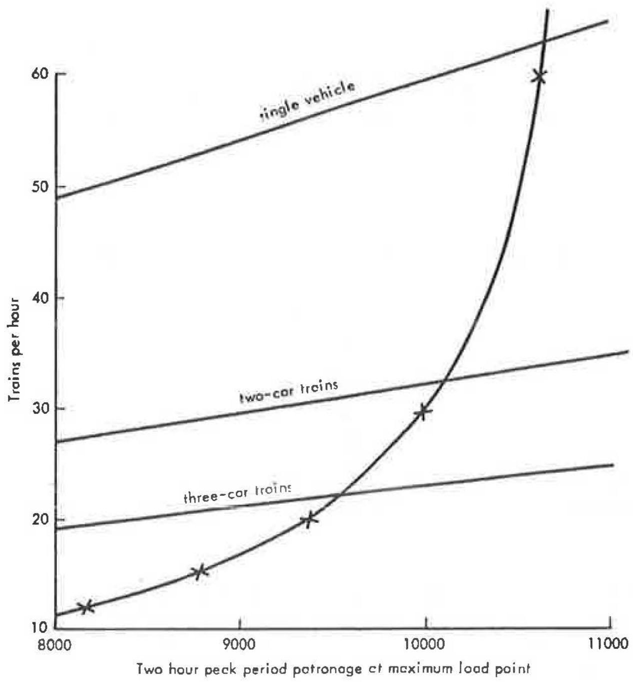
Figure 7. Patronage and supply characteristics of light-rail alternative 1.



the initial level of screening. Some evaluation has also taken place. One can clearly conclude from Figure 7 that operating light rail trains with more than three cars is undesirable. The three points of intersection between supply and demand are also acceptable from both (a) the supply side, in that frequency of train operation is technically feasible, and (b) the demand side because more patrons are attracted by the service than by the existing corridor service.

To continue to evaluate the alternative, one determines whether any of the intersecting points between supply and demand is dominated by another intersecting point. But, in this example, clear dominance probably does not occur because of the trade-off between frequency of service and patronage. Operating costs are probably moving in opposition to user savings. Figure 7 does offer guidance when one is considering which alternatives should be compared with one another. For example, the modest drop in patronage caused by going from one- to two-car trains may be overwhelmingly offset by savings in operating costs. To complete the preliminary screening, the analysis of Figure 7 is directly extended to include other modal alternatives.

ACKNOWLEDGMENT

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Method for Highway Location Selection

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The professional costs associated with developing, tabulating, and evaluating alternatives in the execution of a highway location planning study have now become large enough to be considered a problem. A method is presented that minimizes the wasted efforts (and project costs) associated with testing in location planning studies and at the same time makes the study process more accurate and precise. This method of highway location selection offers the transportation planner a computer-assisted technique that can generate and then search through a large number of generated highway locations to identify optimal solutions. The traffic analysis zone is the basic element of which generated locations are composed. Zone deficiencies are determined for each zone and then used to determine zone-pair connectivities that represent the degree of importance of connecting deficient zones by a highway. A measure of effectiveness, defined as the aggregate connectivity of a location divided by its length, is used to approximate benefit/cost ratios in evaluating each generated location. The process also includes methods to account for highway-related costs (or benefits) of social, environmental, and economic impacts. This process allows an estimate of the highway benefits of a large number of location alternatives without running traffic assignments for each generated location.

The urban transportation planning (UTP) process guides the highway planner through incremental levels of detail as a project evolves. These levels begin with comprehensive urban planning and go on to sketch transportation planning, subarea transportation planning, corridor transportation planning, project location planning, and finally project design (1, 2). This paper deals with the corridor transportation planning and project location planning phases of the UTP process.

In corridor location planning, the planner must consider all reasonable solutions to an area's transportation needs. In most highway planning studies, this means the study of many potential locations and configurations for the highway system. Even after all of these preliminary alternatives have been examined, there is no certainty that the optimal (user-defined) location has been considered (the "user" referred to in this paper is the user of the method of highway location selection).

The available Federal Highway Administration (FHWA) and Urban Mass Transportation Administration (UMTA) computer packages in transportation facilitate the evaluation of preliminary location alternatives (3). However, because various state departments of transportation (and other users of computer packages) appreciate the relative ease with which network modifications and traffic assignments can now be made, extensive testing becomes the order of the day. Much of this testing could be reduced while the focus is kept on the transportation solution.

PURPOSE AND OBJECTIVE

The purpose of this paper is to present a technique that would identify highway locations that satisfy user-defined transportation objectives in areas such as congestion, energy consumption, and air and noise pollution. It is not anticipated that all possible objectives could be addressed, but at least those that are usually associated with transportation problem solving in location planning could be. The technique is designed to use the variables available in preassignment or postassignment from the FHWA and UMTA program batteries. Users familiar with these batteries will have all necessary input data.

The objective of the study is to minimize the efforts (and project costs) associated with location planning studies while at the same time making the study process more accurate and precise.

METHODOLOGY

The methodology consists of four sequentially integrated phases: (a) zone deficiency, (b) zone-pair connectivity, (c) location generation, and (d) location evaluation. These steps are shown in flowchart form in Figure 1. Computer programs were developed for each phase and then synthesized into a complete package—the highway location selection model (HLSM)—that features simple data preparation and flexible parameters.

Zone Deficiency

A project area is defined by its traffic analysis zones. The traditional approach to determining traffic deficiencies in a system is to assign a design-year trip table on a maintenance-null (do-nothing) network and then determine the levels of service on the network links.

Highway location planning determines general locations rather than exact alignments of each alternative. Therefore, it is more appropriate at this level of planning to analyze zones rather than individual links provided the zone structure is not too gross. A zone deficiency may be defined in terms of

1. Kilometers of arterial system over capacity,
2. Through vehicle kilometers of travel on the arterial system (or local system),
3. Zonal accessibility from regional markets,
4. Accidents on the street system,
5. Air pollution emissions on the street system,
6. Total energy consumption,
7. Number of trucks on the local system, and
8. Other factors.

Connectivity of Zone Pairs

Zone deficiencies identify which zones have transportation problems and are potential areas for traffic improvements. The determination as to whether these problems are isolated and thus require local improvements or are contiguous and thus require major improvements is addressed by zone-pair connectivity.

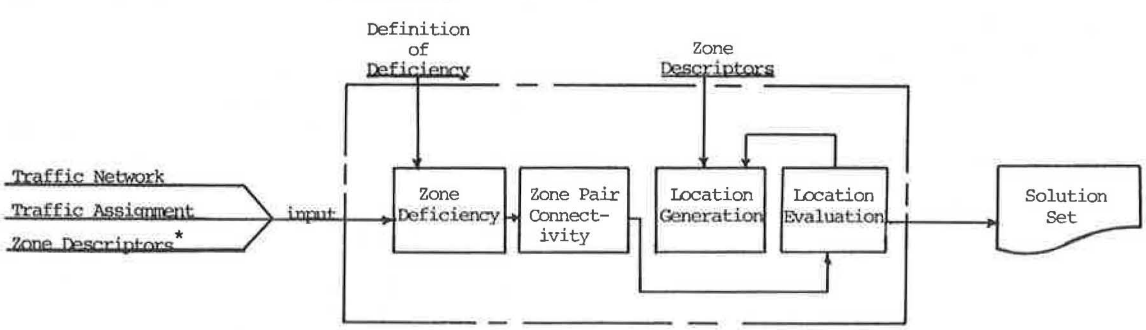
The index of zone-pair connectivity is a measure that represents the degree of importance of connecting a pair of zones by a highway. This measure uses a deficiency index in constructing a measure that rates the relative attractiveness of linking a zone pair. Connectivity is also a function of trip interchange. If a pair of highly deficient zones are adjacent to each other but have little trip interchange, then the method will give low priority to connecting them.

The analytic definition of zone-pair connectivity is

$$C_{ij} = \overline{T}_{ij} \times D_i D_j \quad (1)$$

where

Figure 1. Highway location selection methodology.



Note: Coding of zone descriptors include specifying border zones and x-y coordinates of each zone centroid.

C_{ij} = index connectivity between zones i and j,
T_{ij} = two-way design-year daily trip interchange between zones i and j, and
D_i and D_j = deficiencies of zones i and j.

A connectivity table (or matrix) that includes all zone-pair connectivities is developed and used to evaluate alternative highway locations. Several connectivity tables can be constructed and used to evaluate alternatives from various perspectives of transportation-related deficiency, such as congestion, accessibility, safety, air pollution emissions, and energy consumption.

Whereas zone deficiency identifies which zones have user-defined transportation problems (primarily traffic congestion), zone-pair connectivity determines which zones should be linked together. Location evaluation shows how these connectivities can be aggregated to form an index that represents the total connectivity of a highway location.

Location Generation

The objective of location generation is to automatically generate all reasonable locations by connecting zones in the project area together. Because of the large number of combinations, this is done by use of a computer algorithm. Searching for the combination of contiguous zones that maximizes aggregate connectivities requires a many-to-many zone search. But, because an exhaustive search of all zone combinations on a moderately sized network (100 zones) requires more storage allocation than most computers provide and is too expensive to run even if the storage is available, alternatives to an exhaustive search had to be developed.

Methods to reduce the number of generated highway locations include restricting the number of zones to be included in a location, eliminating locations that are not geometrically feasible, and deleting inefficient locations from consideration.

The algorithm generates all two-zone combinations of border zones, evaluates these locations, and yields a best set to be generated into three-zone locations. The best locations that are three zones and longer and that satisfy geometric constraints are generated in a similar way until an upper limit of n zones is reached. The most efficient locations should total a manageable number (e.g., fewer than six) so that they can be assessed in more detail in the project design phase.

Location Evaluation

The efficiency of alternative locations is determined in the location evaluation phase. The efficiency of highway projects is typically measured by traditional benefit/cost methods. In most cases, a location incrementally accrues system road-user benefits as its length is increased. But highway costs also rise with increased length. Benefit/cost ratios indicate which locations are most economically desirable. The proposed method does not include techniques to evaluate system road-user benefits and highway costs. It does, however, offer a measure of zone-pair connectivity that represents the degree of importance of connecting a pair of zones by a highway. An aggregate connectivity index can be constructed by adding all zone-pair connectivities within the location. An analysis was performed to determine whether or not the aggregate connectivity index is correlated with road-user benefits. A correlation coefficient (r^2) of 0.47 resulted for a congestion measure of deficiency on a test project area. A highway location affects not only the problems of the zone through which the highway passes but also those of its border zones.

Connectivity of border zones is defined as the additional index of connectivity between zones within a location and zones in the location's area of influence. The inclusion of border zones in the aggregate index broadens the analysis from a location to a subsystem perspective. The combination of location-zone and border-zone connectivities is referred to here as total highway connectivity (THC) (see Figure 2). As Figure 3 shows, the correlation coefficient of total highway connectivity (based on a congestion measure of deficiency) and system road-user benefits peaks at an influence-area bandwidth 4.8 km (3 miles) distant from location-zone centroids (r^2 = 0.87):

$$\mathrm{THC}(k) = \sum_{\substack{\text{all zones } i\\ \text{of location } k}} \; \sum_{\substack{\text{all zones } n\\ \text{of location } k\\ \text{where } n > i}} C_{in} + \sum_{\substack{\text{all zones } i\\ \text{of location } k}} \; \sum_{\substack{\text{all zones } b\\ \text{within}\\ \text{influence area}}} C_{ib} \quad (2)$$

where

THC(k) = total highway connectivity index of location k,
C_{in} = zone-pair connectivity of each zone i and zone n within location k where n > i, and
C_{ib} = zone-pair connectivity of each zone i with zone b within influence area of location k.

Double counting of zone-pair connectivities is avoided by specifying n > i.

THC for each generated highway location is computed and compared with the highway's length. The ratio of THC to length serves as a measure of the efficiency of an alternative. Location length is the sum of the air-line distances between the centroids of the sequential zones of a highway alternative.

The efficiency measure replaces the benefit/cost ratio with the THC/length ratio. Whereas benefit/cost ratios determine the economic feasibility of highway alternatives, THC/length ratios determine the "degree of importance" of constructing a highway facility within a location of connected zones.

The use of THC allows the highway planner to estimate the traditional highway benefits of a location without ever running a traffic assignment for that location. Actually, this process allows an estimate of the highway benefits of an extremely large number of location alternatives.

ZONE DISINCENTIVE MULTIPLIERS

Highway planning is a complex process composed of interrelated assessments of all highway-related impacts (transportation, environmental, social, and economic). Highways have a far-reaching effect on regions and their residents. Evaluation of alternatives conducted at the location planning stage includes the following considerations (4): (a) efficiency of alternative, (b) environmental practicality, (c) consistency with local goals and objectives.

Whereas transportation efficiency is treated directly by THC per unit of location length, environmental practicality and consistency with local goals and objectives can be approached less directly by means of disincentive multipliers. Disincentive multipliers

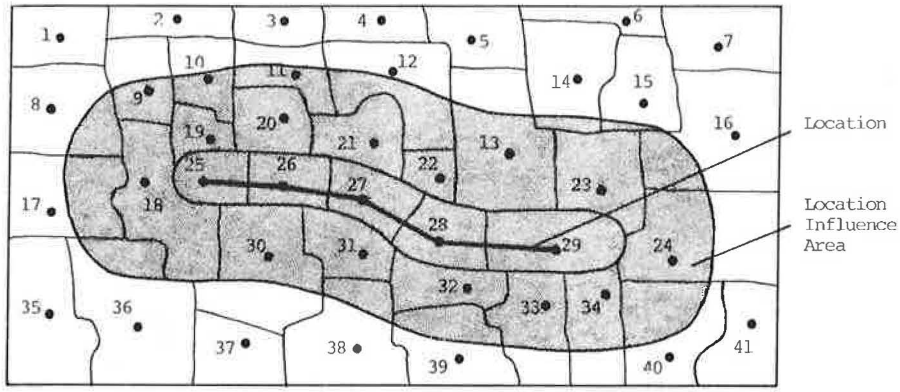


Figure 2. Total highway connectivity.

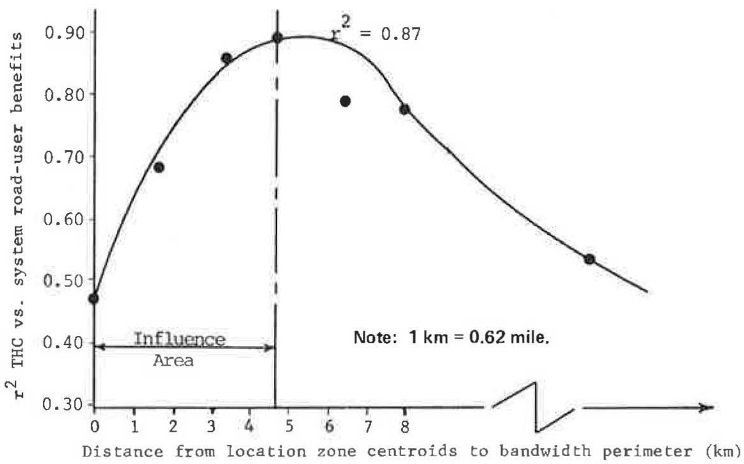


Figure 3. Influence area.

are adjustment factors of location length to represent the difficulty or undesirability of locating a highway through a particular zone. Each zone is assigned a multiplier with respect to a relative datum of unity. Zones in which highway development would be costly or difficult (e.g., high-density residential areas, commercial areas, or environmentally sensitive areas) are assigned high multipliers (e.g., 3, 4, 5), whereas zones in which no unusual disturbance is anticipated are assigned multipliers equal to one. The user has the option to preclude a particular zone from location generation. The zone would still be used to compute border-zone connectivity of generated locations nearby (within the area of influence).

TESTING

In Figure 4, the optimal location selected for a test project area without the assigned multipliers (a) is compared with the optimal location selected with the assigned multipliers (b). The location without disincentive multipliers is a half loop on the west side of the CBD of a test network in Rochester, New York; all zones are located in the urban sector of the project area. The location that results from the use of disincentive multipliers spans the project area in the east-west direction, and less than half of its zones are located in urban areas. This location is similar to an optimal location independently developed in an actual transportation study for the area (5).

The use of zone disincentive multipliers is critical to the accuracy of the methodology. The highway location selected without using multipliers (Figure 4a) is inaccurate in that its efficiency (THC/length or benefit/cost ratio) is overestimated. The multipliers assigned to urban areas of the project area guided the methodology to search for a more efficient alternative in terms of implementation costs (Figure 4b).

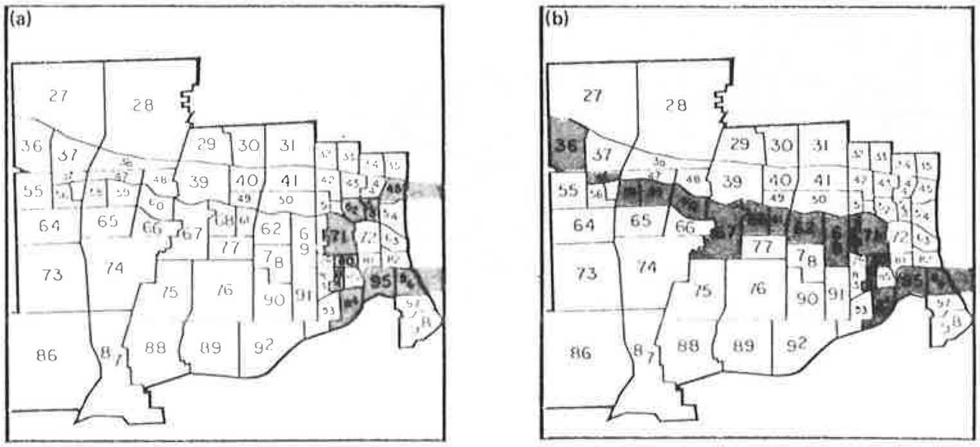
SUMMARY

The purpose of this paper is to present a technique that identifies highway locations that satisfy user-defined transportation objectives. The HLSM can identify those locations in a study area that are most deficient based on a definition of zone deficiency chosen by the user. The objective of the research was to minimize wasted efforts (and project costs) associated with testing in location planning studies while at the same time making the study process more accurate and precise. The HLSM allows the user to quickly evaluate a large number of generated highway locations without having to recode the traffic network and run a traffic assignment for each alternative. All input preparation and running of computer packages require no more than two person days. The testing of such a large number of alternatives—1000, 2000, 3000, or more—improves the accuracy and precision of the study process by broadening the domain of alternatives to include almost any reasonable solution.

APPLICABILITY OF RESULTS

The HLSM is available for further testing, particularly by those who currently use FHWA and UMTA transportation computer batteries. These are state departments of transportation, local metropolitan planning organizations, and planning agencies as well as private

Figure 4. Selected locations (a) without and (b) with zone disincentive multipliers.



consultants. The HLSM offers the transportation planner and engineer a working tool that assists in the highway location planning phase of the urban transportation planning process.

ACKNOWLEDGMENT

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Abridgment

Macroanalysis for Transit Integration

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The purpose of transit integration is to identify the transit services that best fit individual neighborhoods and the best combination of services to meet the needs of an urban area as a whole. The many service options include the following:

1. System options—considering different systems for the same or similar applications;
2. Application options—modifying service areas and system configurations;
3. Integration options—combining feeder-distributor and line-haul services in different ways and different patterns;
4. Level-of-service options—examining different levels of service for particular areas and transit applications;
5. Design options—altering performance characteristics, facility locations, and route alignments within the same general system configuration; and
6. Implementation options—time phasing the services and increments of services in different ways.

To investigate enough integration options to have some hope of finding a good solution, it is necessary to examine 20 or more alternatives. Even so modest a number of investigations is beyond reason if one is compelled to use the traditional network-based algorithms. The macroanalytic regionwide transportation (SMART) model of SYSTAN, Inc., has been specifically designed to explore large numbers of public transit alternatives. This model can provide the first coarse screen by which the number of transit options is reduced to manageable proportions. The model seeks breadth at the expense of detail. It does not take the place of more complex procedures but helps to focus the use of complex models on a small set of highly attractive alternatives.