A METHODOLOGY FOR COMPUTATION OF THE ENVIRONMENTAL CAPACITY OF ROADWAY NETWORKS

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In evaluating alternative transportation systems for the Urban Corridor Demonstration Program in Louisville, Kentucky, it became necessary to develop a procedure that would directly correlate the transportation system with the environment through which it passes. This methodology was necessary because all roadway and transit improvements could only be made to surface streets; no freeway facility directly serves this area. Changes in traffic on surface streets directly affect the environment of those people living, working, or shopping adjacent to the facility. These environmental effects must be quantified in order to properly evaluate the transportation improvements. A methodology was developed whereby street segments were stratified based on roadway and land use characteristics. People residing, working, or shopping adjacent to these street "prototypes" were questioned in such a way as to develop an annoyance index for each prototype. This annoyance index related people's perceptions of noise, air pollution, and safety to the level of traffic on the street. Through previous questionnaires the environmental criteria of noise, air pollution, and safety were found to be most significant when related to traffic. Similar street prototypes with various levels of traffic were studied, and relationships between annoyance and traffic volume were then developed for each prototype. From these relationships, an "environmental capacity" expressed in vehicles per day was established for each roadway segment in the study area. These results were used to evaluate the effect on the environment of various transportation improvements considered.

• THE CONCEPT of environmental capacities was developed as one part of the transportation planning process utilized on an Urban Corridor Demonstration Project for an area within the City of Louisville, Kentucky. In developing a viable transportation system for Louisville's South Corridor area, it became evident that only surface street facilities were available to serve the 144,000 people residing in this area. Because only surface facilities were available for improvement, the problem of the environmental effect of increased traffic had to take into account the consequences of alternate strategies on the entire corridor.

To deal with the complex relationship between the environmental aspects of a community and its transportation network, it was necessary to develop a quantifiable systematic technique of relating automobile networks with adjacent land uses. The criteria chosen to define this relationship were noise, air pollution, and pedestrian safety. After identifying all combinations of road types and land use types, classes or prototypes were established. Interviews were then conducted to ascertain if correlations could be obtained between people's annoyance concerning the three criteria and the characteristics of the traffic on the road. Success was obtained in enough cases to allow the

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generalization of the results to the entire corridor study area and all streets and activities within it. Thus, the traffic improvements recommended for implementation not only accounted for a set of specific environmental impacts but were supported by them. It was, therefore, possible to deduce the total number of people that would be annoyed over the aspects tested, if given a description of their environment and the ADT on their street.

THE CONCEPT OF ENVIRONMENTAL CAPACITIES

Environmental capacities are based on the idea that there is a relationship between transportation systems and the natural, man-made, and social environment. The environment the transportation system passes through and serves must be related to that transportation system in common terms. The methodology relating transportation to the environment must be capable of articulating and evaluating alternative solutions that not only represent the best, safest, and most convenient means of moving people but also represent a compatible total environment.

The environment does not have an infinite ability to accept transportation systems. The endeavor outlined here attempts to view people's annoyance with specific environmental criteria as having quantifiable limitations and also attempts to show that the attributes of transportation systems are related to this annoyance and that this relationship can be quantified.

The term "environmental capacities" was chosen purposefully as a name analogous to the term "capacities" as now used by transportation planners, defined (1) as follows:

> The maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or a roadway. . . during a given time period under prevailing roadway and traffic conditions. . . . The capacity would not normally be exceeded without changing one or more of the conditions that prevail. In expressing capacity, it is essential to state the prevailing roadway and traffic conditions under which the capacity is applicable.

The major characteristics of concern in defining a roadway's capacity involve the physical characteristics, design, and control of the roadway itself and the nature of traffic on the roadway.

Environmental capacities can best be described through a definition that reads as follows: "The maximum number of vehicles that should be permitted to pass through a given environmental situation over time and under prevailing environmental conditions. The capacity should not normally be exceeded without changing one or more conditions that prevail. In expressing capacities, it is essential to state the prevailing environmental conditions under which the capacity is applicable and the criteria utilized to establish them."

OVERVIEW OF THE CONCEPT

There are two ways of looking at the environment:

1. Examine it as an artifact in a detached systematic fashion (its distribution of activity types, distribution of structures, geology, accident rates, crime rates, ambient noise levels, family incomes, topography, the attributes of traffic passing through it, etc.); and
2. A perceptual evaluation of environment by the people living and working in it and/or passing through it ("it's noisy," "uncomfortable," "a nice place to live," etc.).

These two approaches are obviously interrelated, yet the method of articulating and evaluating them is quite different.

The essence of the process of establishing environmental capacities involves the specification of the first environmental definition and relating characteristics under the second environmental definition to it in a systematic fashion for transportation-related phenomena. As an example, it is technically feasible to ascertain and describe the traffic volumes and types in various areas of Louisville's South Corridor, but the essential information for setting a standard is a perceived quality and the establishment of acceptability of different traffic volumes as a function of perceived attributes.

This process becomes more complicated when it is realized that many variables are involved as an individual evaluates his perception of his environment or various aspects of it.

It is apparent that one would find wide variation between individuals concerning any perceived environmental criteria, given a particular environment and transportation situation. Many imponderables present themselves. If, for example, people in a community are proud and happy with their area, they will be inclined to pass over a particular environmental problem. If recreational facilities are scarce in a given area, then the street may represent a real problem for child safety. But the magnitude of the problem cannot be compared to other similar situations unless we can determine the adequacy of recreational facilities in all communities studied.

People who rent or see their stay as short-term are less concerned with many issues than people who own or are long-term residents. The age of the individual may concern him with different priorities. Income, family size, the degree to which he lives outdoors, his background and previous experiences, all may mitigate against consistent attitudes about similar or even identical phenomena.

Of equal importance are difficulties in quantification of the physical phenomena themselves. The criteria on which environmental capacities can be related to people's annoyance levels are as follows:

1. Sight,
2. Smell,
3. Pressure,
4. Sound,
5. Taste,
6. Pedestrian safety,
7. Conflicts and desired movement patterns,
8. Disturbance in television and radio reception,
9. Imagined qualities,
10. Dirt and litter, and
11. Damage to vegetation and wildlife.

Through a series of questionnaires, it was found that the criteria that people directly relate to transportation and from which an annoyance level could be ascertained are

1. Noise,
2. Air pollution, and
3. Child safety.

The process utilized to establish which environmental issues (criteria) were most important to the people in the various communities within the South Corridor was begun in an earlier phase as part of the community goals analysis begun November 10, 1970. At that time, 20,000 questionnaires were distributed. Several questions referred to "environmental problems caused by transportation in your community." The results present acceptable evidence that, of all transportation-associated environmental problems, three are mentioned in the substantial majority of cases: noise, air pollution, and child and pedestrian safety.

We must caution at this point that, simply because we received a certain common set of environmental issues, we have no guarantee we will be able to find consistency in the kind and degree of complaints in any given environmental situation.

ENVIRONMENTAL PROTOTYPES

The need existed to test the perceptual response to stimuli in the environment caused by vehicular transportation systems. It was clearly established thus far that questionnaires from inhabitants of the environment were a reliable perceptual response source. The problem now was how to categorize streets and their environments into homogenous units for collection of detailed response data. The relationship between traffic and environmental problems must be measured across like street situations (environments). That is, all aspects of the environment should be alike except the traffic.

The initial step in the establishment of prototypical transportation environments was to divide the vehicular arteries graphically by directional lanes into "street types." Further division resulted from spatial analysis of the artery.

The next step was a stratification based on the functional land use. The street types and land uses were then combined to obtain environmental samples. Those spatial differences that must be considered are more specific in scale than just land use. For example, distance from streets to dwelling units and whether trees were growing between the streets and dwelling units might serve as a basis for breaking down street categories. Photographic studies taken at approximately 7.5 feet above the roadway with a 24-mm lens further clarified this differentiation in environmental attributes.

Essentially, the "prototype" is the classification of environmental attributes of a street. Questionnaires were distributed to people residing, working, or shopping adjacent to each prototype. After evaluating the questionnaires, it became necessary to develop an even finer breakdown of prototypes because of mixed land use and demographic data.

APPROACH UTILIZED IN ASCERTAINING ENVIRONMENTAL CAPACITIES

The actual physical entity (transportation) and people's perception of that entity's environmental attributes (noise, pollution, safety) are confounded by many uncontrolled variables that involve differences in the observers, the contexts within which observations are made, and the variability of the entity itself.

Our approach to this problem has consisted of a rigorous attempt to isolate environmental prototypes (street categories) in terms of their main attributes and then attempt to plot responses concerning noise, air pollution, and pedestrian safety as a function of traffic characteristics (ADT and percentage of trucks and buses) over environmental prototypes with similar attributes. We would then test the degree to which responses concerning the established transportation-related environmental criteria vary as a function of transportation characteristics across similar environmental situations and contexts.

If acceptable correlations are achieved, it is then possible to set limitations on the traffic, based on the degree of acceptable nuisance within a given environmental situation (prototype).

METHOD TO ESTABLISH CAPACITIES

The method utilized and described herein approaches this problem by initially dividing responses to particular criteria and testing for correlations with traffic characteristics stratified by environmental contexts. Environmental capacities are calculated for each criterion and then assembled in chart form for each prototype, allowing examination of variation between criteria. This is important because it does yield an indication of which characteristics of the transportation system are the most disrupting to the environment through which it passes and to what degree this might be alleviated by particular actions.

A Response Scale

Based on the nature of the responses to a second round of environmental interviews, three questions proved the most useful. All other questions received answers which could be interpreted in varying ways, yielding a low consistency for scaling. The following three questions were utilized:

6. How would you describe the noise caused by traffic on your street?
   Quiet____ Acceptable____ Bothersome____ Bad____ Terrible____
9. How would you describe the air pollution caused by traffic on your street?
   Not noticeable____ Acceptable____ Bothersome____ Bad____ Terrible____
13. How much of a problem does the traffic on your street represent to you (or your family) as pedestrians? (If business, use "or your customers")
   No problem____ Acceptable____ Bothersome____ Bad____ Terrible____

The questions were initially set up so that each response represented our subjective estimates of equal jumps in perception and the responses were weighted numerically from 0 through 4 in equal steps of 1.0. The mean for each prototype/each question was then calculated and was utilized in testing annoyance (mean/question/prototype) variations as a function of variation of the stimulus index.

A Stimulus Scale

Several descriptions of transportation characteristics are commonly utilized, usually referring to the amount and types of vehicles passing over a given section of roadway over time: average daily travel (ADT); vehicles per hour; percent trucks; percent buses; and peak-hour volume. Of these, the only measure available across all the established prototypes was average daily travel. Where data were available for other descriptions, they were utilized only as a means of identification and elimination of particular cases that failed to respond to the norm for ADT.

In each attempt at correlating the respondent annoyance index as a function of the transportation characteristic index for each of the stratifications, the following check was made: The validity of r_s (regression coefficient for sample data) from the samples as an estimate of r_p (regression coefficient for actual population) for the population, with the null hypothesis $p = 0$, was tested at significance level 0.05 using the Fisher and Yates statistical tables for critical r values published by Freund (2). Any correlation that did not pass this test was discarded. A sample curve developed by this method is shown in Figure 1.

Computation of Capacity

The method was used to compute the environmental capacity for all prototypes. For each prototype an acceptable response curve resulted from at least one environmental criterion (noise, air pollution, public safety). If more than one criterion yielded an acceptable curve, the environmental capacity was chosen as the lowest figure; e.g., noise may have yielded a capacity of 10,000 VPD whereas public safety may have yielded a capacity of 5,000 VPD for the same prototype, and therefore the capacity of this street segment would be set at 5,000 VPD. Because the street prototypes were chosen so as to represent all major roadways within the corridor, a "capacity" could then be established for all major roadways in the study area. A sample of the resulting environmental capacities and the existing ADT is given in Table 1.

ANALYSIS

With "environmental capacities" established for all streets in the study area, the effect on the environment of each recommendation could be established. Each improvement will change the street prototype (e.g., two lane to four lane) or traffic volume or both. These changes can be analyzed as to their effect on the environment by comparing the predicted traffic on the street segment with the environmental capacity of that prototype.

Total systems can be compared by establishing the number of miles of roadway above environmental capacity. The street segments now over environmental capacity are shown in Figure 2. The segments that would be over environmental capacity in 1975 with no roadway or transit improvements (Fig. 3), with roadway improvements only (Fig. 4), and with both roadway and transit improvements (Fig. 5) were compared to ascertain the effect of the proposed transportation system on the environment of Louisville's South Corridor.

This analysis tool proved to be an extremely useful vehicle for assuring the best transportation system for the environment while still allowing the flexibility of considering several alternatives at low cost. Although this work is only a beginning step and only applicable to Louisville's South Corridor, it is felt that this same concept and methodology could and should be used whenever transportation system improvements are being considered.

Figure 1. Annoyance at noise versus average daily traffic.

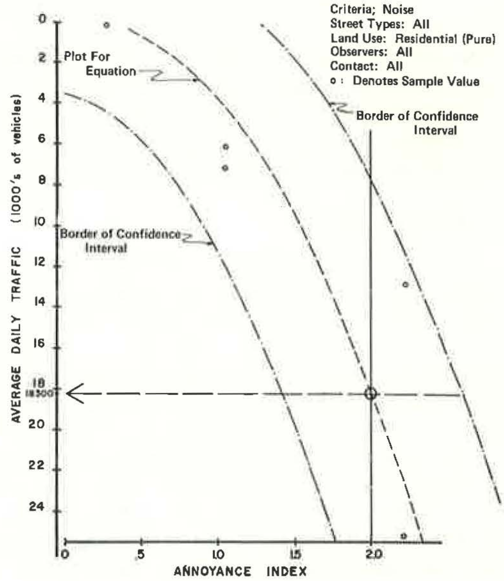


Table 1. Sample of environmental capacities obtained.

Prototype Characteristics	Current Volume (ADT)	Environmental Capacity (ADT)	Controlling Environmental Factor
Commercial and institutional, two lanes each way at grade	7,500	14,100	Air pollution
Commercial, institutional, and industrial mixed, two lanes each way at grade	12,500	35,700	Noise
Commercial, institutional, and residential, two lanes each way at grade	17,500	14,100	Air pollution
Commercial, institutional, and recreational, two lanes each way at grade	25,000	14,100	Air pollution
Commercial and institutional, two lanes each way, some at grade and some elevated	25,000	35,700	Noise
Commercial, institutional, and industrial mixed, two lanes each way, some at grade and some elevated	12,500	35,700	Noise
Commercial and institutional, some streets two lanes each way and some two lanes one way, at grade	12,500	14,100	Air pollution
Commercial, institutional, and industrial, some streets two lanes each way and some two lanes one way, at grade	25,000	14,100	Air pollution
Commercial and institutional, some streets two lanes each way and some three lanes one way, at grade	2,500	35,700	Noise
Commercial, institutional, and industrial, some streets two lanes each way and some three lanes one way, at grade	7,500	35,700	Noise
Commercial, institutional, and residential, some streets two lanes each way and some three lanes one way, at grade	12,500	35,700	Noise
Commercial, institutional, and recreational, some streets two lanes each way and some three lanes one way, at grade	17,500	14,100	Air pollution
Commercial and institutional, some streets two lanes each way and some four lanes one way, at grade	7,500	14,100	Air pollution
Commercial, institutional, and industrial, some streets two lanes each way and some four lanes one way, at grade	12,500	14,100	Air pollution
Commercial, institutional, and residential, some streets two lanes each way and some four lanes one way, at grade	17,500	35,700	Noise
Predominantly residential with some commercial and institutional, the streets two lanes each way at grade	15,000	13,300	Noise
Predominantly residential with some commercial and institutional (60 percent or more residential), with streets two lanes each way at grade	15,000	13,300	Noise
Residential with some industrial, the streets two lanes each way at grade	17,500	13,300	Noise
Residential, some streets two lanes each way at grade and some two lanes each way elevated	17,500	14,100	Noise
Residential with commercial and institutional, some streets two lanes each way and some two lanes one way, at grade	12,500	15,500	Public safety
Residential with industrial, some streets two lanes each way and some two lanes one way, at grade	17,500	15,500	Public safety
Residential with some streets two lanes each way and some two lanes one way, at grade	25,000	15,500	Public safety
Residential with commercial and institutional, some streets two lanes each way and some three lanes one way, at grade	10,000	21,300	Public safety
Residential with industrial, some streets two lanes each way and some three lanes one way, at grade	23,200	21,300	Public safety
Residential with some streets two lanes each way and some three lanes one way, at grade	17,500	19,400	Noise
Residential and recreational, some streets two lanes each way and some three lanes one way, at grade	25,000	21,300	Public safety
Residential with most streets two lanes each way and some four lanes one way, at grade	12,500	19,400	Noise
Residential with commercial and institutional, some streets two lanes each way and some one lane each way, at grade	2,500	14,100	Noise
Residential and industrial with some streets two lanes each way and some one lane each way	7,500	14,100	Noise
Residential with most streets two lanes each way and some one lane each way	25,000	14,100	Noise
Residential with streets two lanes and three lanes each way, at grade	12,500	13,300	Noise
Residential with some commercial and institutional, the streets two lanes each way at grade and three lanes each way elevated	12,500	21,300	Public safety
Residential with industrial, the streets two lanes each way at grade and three lanes each way elevated	17,500	21,300	Public safety

Figure 2. Streets over environmental capacity at time of study.

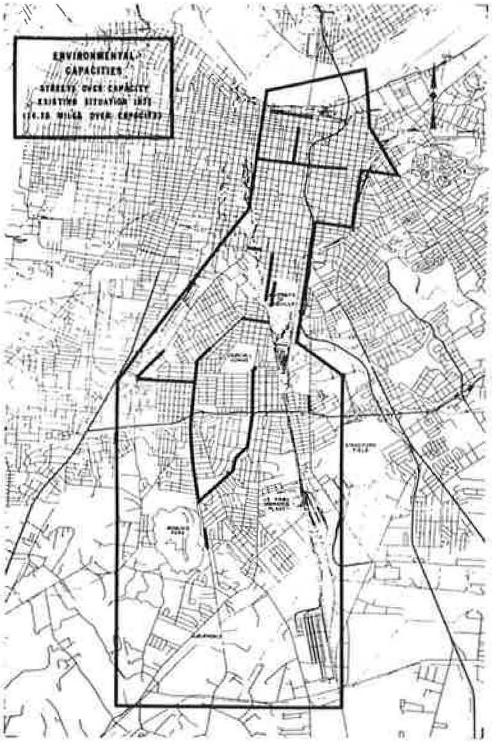


Figure 3. Streets over environmental capacity in 1975 with no improvements.

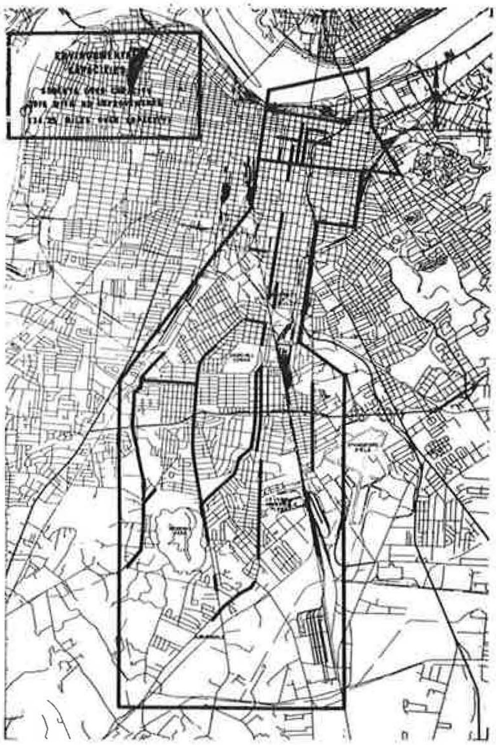


Figure 4. Streets over environmental capacity in 1975 with roadway improvements only.

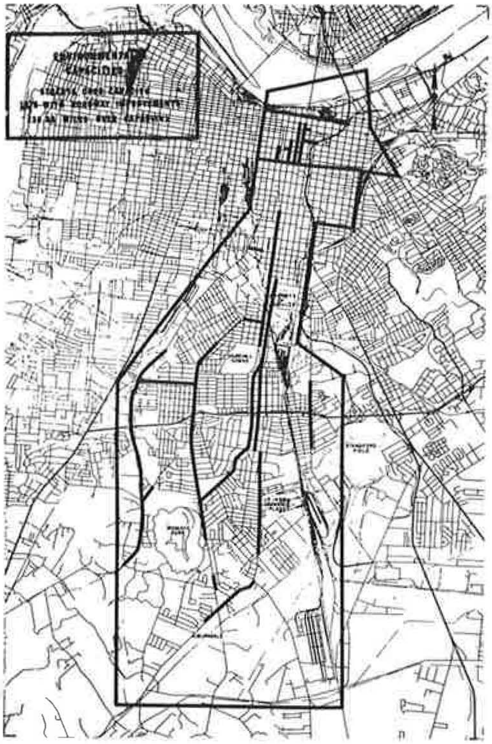
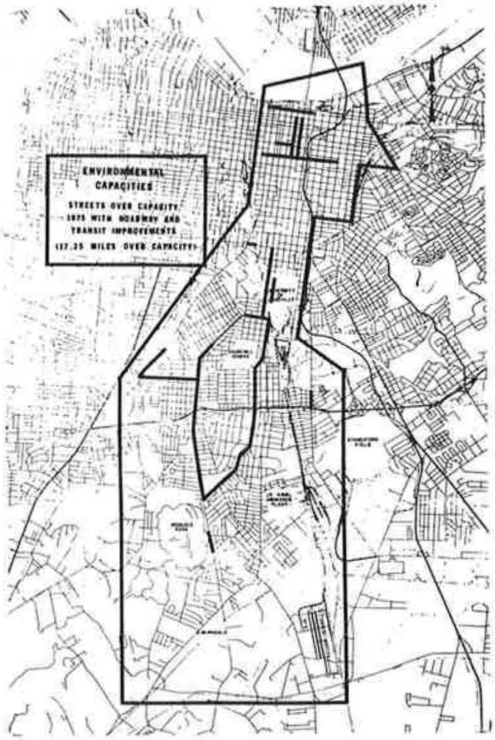


Figure 5. Streets over environmental capacity in 1975 with both roadway and transit improvements.



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