Evaluating Plan Alternatives: Energy, Safety, and Air Pollution

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The development and "selling" of a thoroughfare plan generally tests to the limit both the technical and public relations skills of the transportation planner. A method is presented by which energy, accident, and air pollution indices may be developed for the evaluation of alternative plans. These indices can be related in a positive manner that somewhat offsets the general negative feelings aroused by talk of widenings, building new facilities, and displacing homes and businesses. The results obtained by applying the proposed analysis method were very good. The method is extremely efficient: Since all three indices are developed from the same vehicle-miles-of-travel summary, only one summary needs to be developed for each alternative to be tested.

In recent years, citizen involvement in the urban transportation planning process has been more vocal than in the past and has had a significant impact on the decision-making process (1). During the period of public meetings in which the plan is "sold" to the citizenry, tough questions are often posed to the engineer-planner, who must defend the merits of his or her work before a generally antagonistic forum. It is imperative that all available, applicable analysis tools be used in the process of evaluating plan alternatives so that a good defense of the recommended plan can be made. The analysis tools need not be complex or intricate to be useful. The purpose of this paper is to illustrate how existing techniques can be used to produce viable energy, safety, and air pollution indices by which alternative transportation system plans can be compared.

The use of the word "system" is important in that the numerical values presented in this paper involve some rather significant assumptions that would not be generally valid in the individual project-level analysis. For example, delay at individual traffic signals is assumed to be common to all alternatives; in other words, a base signal system and resulting average delays are assumed. The relations between functional classification, volume/capacity (V/C), level of service, and operating or overall travel speed are generally related to Highway Capacity Manual (2) definitions; however, the numerical indices presented are based on very average, generalized conditions. Therefore, the analyses suggested in this paper will give more reliable results when applied to the entire highway network, where deviations within analysis units will tend to offset one another.

Typically, three major areas are addressed in the analysis of alternative transportation system plans. They are existing or future capacity deficiency, damage to both public and private property, and the estimated costs of alternative improvements. The public, as well as elected officials, often have some difficulty relating these factors to the need to endorse recommended highway improvements. Maybe this is because these factors tend to foster negative thoughts: poor travel service and congestion, the taking of property, and the impact of capital expenditure on the municipal coffer. On the other hand, the use of some additional indices that generate more positive thoughts may help to dissipate some of the traditional negative feelings that often arise. For example, the amount of energy that could be saved, the number of accidents that might be prevented, and the prospect of cleaner air are all positive things that should result from the implementation of a sound, well-developed thoroughfare plan. Incorporating these concepts into our current evaluation methodology is very desirable.

METHODOLOGY

The highway network is coded in the normal manner as required in the PLANPAC/BACKPAC battery of programs (3) available from the Federal Highway Administration (FHWA). In developing the node-numbering sequence, individual facilities should be coded with consecutive node numbers to the extent possible. As will be explained later, speed adjustments will be made as a function of the V/C ratio, and consecutive numbering of facility link nodes by use of the LIBRARIAN/VS software developed by Applied Data Research, Inc., greatly facilitates these adjustments. In addition, column 65 of the standard link data format is coded to indicate one of the following functional classifications:

1. Freeways and expressways are by definition those facilities that are built to Interstate, freeway, or expressway standards.
2. Arterial facilities are those major facilities used by both local traffic and large, significant portions of the external-internal and through traffic.
3. Collector facilities are those facilities that carry major traffic volumes consisting primarily of local traffic. This is to mean everyday users of the facility.
4. Local and centroid connector facilities are those facilities that basically serve the land access function and provide access to the collector and/or arterial system.

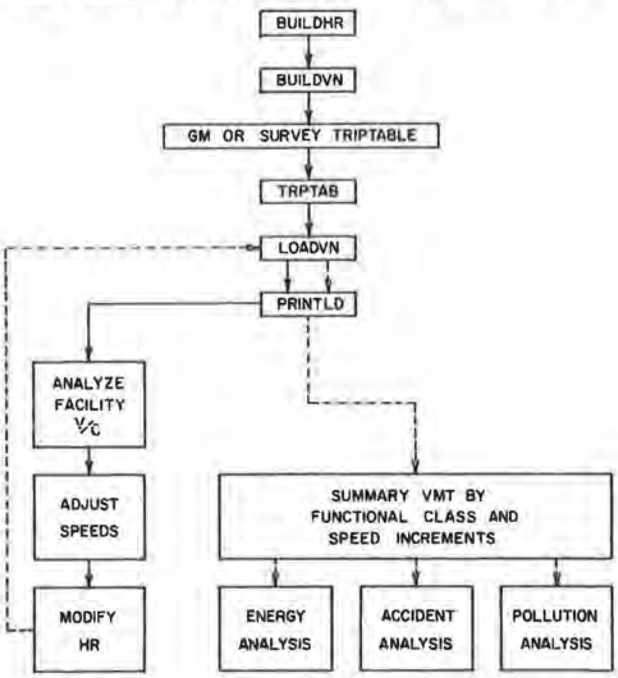
When the PLANPAC/BACKPAC planning battery is used, the following basic sequence of programs will lead to a loaded network: (a) BUILDHR, (b) BUILDVN, (c) GM (or survey trip table), (d) TRPTAB, (e) LOADVN, and (f) PRINTLD. In the base-year calibration procedure, link speeds and trip generation rates are adjusted in order to achieve good agreement between modeled and surveyed traffic volumes. The calibrated network is then ready to be loaded with the design-year trip demand. When loaded with future trips, the existing network is typically analyzed for deficiencies, and alternatives to improve traffic flow are developed and analyzed. The procedure described above is well documented and widely used and needs no further explanation.

The analysis techniques outlined in the remainder of this paper begin after the development of the calibrated network and loading of future trips on the existing or proposed alternative networks. Figure 1 shows a simplified flowchart for the suggested analysis procedure. Once future trips are loaded on the existing and proposed networks, then a good analysis of volume versus capacity is performed that may involve the application of capacity-restrained assignments. The resulting V/C ratios form the basis for adjusting the link speeds to reflect future levels of congestion and increased travel times. The speeds (travel times) initially coded, or as calibrated, in the historical record are modified to reflect the average speed indicative of the future level of service as suggested by the V/C ratio.

The objective now is to enter the new speeds into the loaded network records. Since it is not desirable to alter the calibrated trip routings at this point, the historical record containing the modified speeds for a particular network, the "original" calibrated trees and paths for a particular network, and the final "original" trip table for a particular network are used to produce the loaded network file reflecting the new speeds, which have been modified to reflect the anticipated congestion levels caused by future trip desires.

The North Carolina Department of Transportation (NCDOT) has developed computer capability for summing vehicle miles of travel (VMT) by functional classification and speed increments. The literature provides works on energy consumption rates (4-6), accident potential rates (6-11), and pollution rates (12), all based on VMT, speed, and/or functional classification. The key to correctly applying the rates, however, is the development of VMT by the proper speed increments. Following the procedure outlined in Figure 1 will produce VMT by speed groups consistent with anticipated levels of congestion.

Figure 1. Simplified flowchart for energy, accident, and pollution analyses.



ENERGY ANALYSIS

The proposed energy analysis will provide an estimate of total gallons of gasoline used daily on a systemwide basis. Functional classification and operating (or overall) speed are the key parameters. Data published in two reports (4,6) were combined with level-of-service qualifiers (12,13) to develop the information given in Table 1.

The rates given represent very average conditions and should not be used to evaluate individual projects that vary greatly in operating particulars. The published gasoline consumption rates (11) were assumed to be representative of level-of-service B operating conditions on a daily basis, and factors (3) were developed to adjust the consumption rates as a function of four average levels of congestion. For the arterial, collector, and local classifications, the level-of-service B rate was based on 5.75, 6.25, and 4.50 stops/mile, respectively.

After the V/C analysis, facilities are assigned a speed that corresponds to the indicated level of service. VMT is summarized by computer by functional classification and new speed increments. Next, a manual calculation is made by using the following equation:

$$\text{TOTGAL} = \sum_{i=1}^{4} \sum_{j=1}^{n} (\text{VMT}_{ij})(\text{rate}_{ij}) \qquad (1)$$

where

TOTGAL = estimated total gallons of gasoline used daily,
rate = rate of gasoline consumption,
i = functional classification index, and
j = speed increment index.

Two points concerning this analysis need to be made. The fuel consumption rates are representative of early 1970 vehicles. Since system alternatives are to be compared, it is the relative difference

Table 1. Energy factors for alternative plan analysis.

Functional Classification	Factor	A	B	C	D
Freeways and expressways	Avg operating speed[a] (mph)	55	50	40	30
	V/C ratio	0.50	0.62	0.75	1.00
	Level of service	B	C	D	E
	Fuel consumption (gal/mile)	0.0801	0.0817	0.0841	0.0865
	Avg miles per gallon	12.48	12.24	11.89	11.56
Arterials	Avg overall speed[b] (mph)	35	30	25	20
	V/C ratio	0.70	0.80	0.90	1.00
	Level of service	B	C	D	E
	Fuel consumption (gal/mile)	0.0931	0.1010	0.1084	0.1195
	Avg miles per gallon	10.74	9.90	9.23	8.37
Collectors	Avg overall speed[c] (mph)	30	25	20	15
	V/C ratio	0.70	0.80	0.90	1.00
	Level of service	B	C	D	E
	Fuel consumption (gal/mile)	0.0950	0.1032	0.1104	0.1216
	Avg miles per gallon	10.53	9.69	9.06	8.22
Locals and centroid connectors	Avg overall speed[d] (mph)	20	15	10	<10
	V/C ratio	0.75	0.85	0.95	1.00
	Level of service	B	C	D	E
	Fuel consumption (gal/mile)	0.0910	0.0940	0.1025	0.1165
	Avg miles per gallon	10.99	10.64	9.76	8.59

[a]Desirable operating speed = 55 mph.
[b]Desirable overall speed = 35 mph.
[c]Desirable overall speed = 30 mph.
[d]Desirable overall speed = 20 mph.

Table 2. Accident rates for alternative plan analysis.

Functional Classification	Factor	A	B	C	D
Freeways and expressways	Avg operating speed (mph)	55	50	40	30
	V/C ratio	0.50	0.62	0.75	1.00
	Level of service	B	C	D	E
	Fatalities[a]	0.68	0.84	1.39	2.65
	Nonfatal injuries[a]	27.26	33.65	55.52	106.33
Arterials	Avg overall speed (mph)	35	30	25	20
	V/C ratio	0.70	0.80	0.90	1.00
	Level of service	B	C	D	E
	Fatalities[a]	1.71	2.41	3.64	6.00
	Nonfatal injuries[a]	131.40	185.07	279.46	460.82
Collectors	Avg overall speed (mph)	30	25	20	15
	V/C ratio	0.70	0.80	0.90	1.00
	Level of service	B	C	D	E
	Fatalities[a]	1.60	2.42	3.99	7.62
	Nonfatal injuries[a]	158.42	240.03	396.05	756.09
Locals and centroid connectors	Avg overall speed (mph)	20	15	10	<10
	V/C ratio	0.75	0.85	0.95	1.00
	Level of service	B	C	D	E
	Fatalities[a]	0.42	0.80	1.98	1.98
	Nonfatal injuries[a]	59.90	115.20	285.70	285.70

[a]Per 100 million vehicle miles of travel.

between TOTGAL values that will be evaluated; these rates, even though somewhat dated, will correctly indicate the most fuel-efficient plan. Evaluated on a percentage basis, these rates versus 1980 rates should provide essentially the same numerical results. However, as new rates, in a desirable form, are published, Table 1 should be updated.

The second point is that a common basic level of stop delays, side friction, traffic control functions, etc., is inherent in all of the alternatives to be compared. The assumption has been made that, on a systemwide basis, deviations in traffic operations will average out and that the results of the analysis will be valid for the comparison of system alternatives.

ACCIDENT POTENTIAL ANALYSIS

The proposed accident analysis will provide an estimate of annual potential accidents as a function of functional classification and level of service being provided. Table 2 (7-12) was developed from rates published in the literature (8,10). Factors were developed, following the work of May (9) and Rykken (7,11), to modify the published accident rates to reflect four basic levels of congestion.

The rates thus developed are given in Table 2. The published rates were assumed to be representative of level-of-service C operating conditions. The data currently available address only fatal and non-fatal-injury accident rates, and the level-of-service factors developed were applied equally to both categories. In addition, the rates used to develop Table 2 are for North Carolina where available; otherwise, they are national average rates.

The functional classification, the V/C ratio(s) for a facility, and the same VMT summary developed for the energy analysis are used to estimate annual fatal and non-fatal-injury accidents by means of the following equation:

$$\text{ANNACC} = \sum_{i=1}^{4} \sum_{j=1}^{n} [(\text{VMT} \times 365)/10^8]_{ij} \times \text{RF}_{ij} + \sum_{i=1}^{4} \sum_{j=1}^{n} [(\text{VMT} \times 365)/10^8]_{ij} \times \text{RNFI}_{ij} \quad (2)$$

where

ANNACC = annual estimated fatal and non-fatal-injury accidents,
RF = fatal accident rate per 100 million VMT,
RNFI = non-fatal-injury accident rate per 100 million VMT,
i = functional classification index, and
j = level-of-service (V/C) index.

The NCDOT Traffic Engineering Division has the capability to develop accident rates, including property-damage-only rates, by functional classification and operating characteristics. Based on the results obtained during this research, it is expected that Table 2 will be updated with actual observed rates wholly applicable to North Carolina.

POLLUTION ANALYSIS

The rates used in the pollution analysis were derived directly from the Mobile 1 Mobile Source Emission Model of the Environmental Protection Agency (12). The rates represent a composite factor for a specified vehicle mix and initial running conditions. Typical emission factors are given in Table 3. The key parameters are speed and VMT.

The daily amount of pollutants emitted from mobile sources is obtained by the successive application of the following formula for each specific pollutant:

$$P_{ik} = \sum_{j=1}^{n} (\text{VMT}_j)(\text{EF}_{ijk}) \quad (3)$$

where

P = total daily mobile pollutant emitted,
EF = emission factor,
i = pollutant index,
j = speed increment index, and
k = year index.

When they become available, emission factors from the Mobile 2 program should be substituted for the Mobile 1 factors. The new factors will not change the results in evaluating alternative plans; however, the absolute values of pollutants emitted will be of use in determining the ability of the chosen alternative to meet the mobile air-quality standards.

The purpose of presenting the pollution analysis is to illustrate the significant difference in air-quality estimates when initial calibrated speeds are used in lieu of speeds adjusted to reflect the more realistic future estimated operating conditions. The procedure for deriving VMT by the "correct" speed increments recommended in this paper will pro-

Table 3. Typical emission factors for alternative plan analysis.

Speed (mph)	Pollutant (g/mile)								
	CO			HC			NO_x		
	1980	1981	1999	1980	1981	1999	1980	1981	1999
20	63.19	57.77	21.30	6.71	5.94	2.40	3.61	3.39	1.94
25	52.30	47.96	18.14	5.76	5.08	1.95	3.80	3.57	2.09
30	44.17	40.58	15.62	5.07	4.45	1.61	4.01	3.76	2.23
35	38.21	35.15	13.72	4.57	3.99	1.36	4.19	3.94	2.35
40	34.34	31.66	12.52	4.22	3.67	1.20	4.35	4.10	2.45
45	32.40	29.94	11.97	4.02	3.49	1.11	4.53	4.27	2.55
50	31.72	29.38	11.80	3.91	3.39	1.06	4.79	4.54	2.69
55	30.73	28.45	11.34	3.80	3.29	0.99	5.25	4.99	2.94

Note: CO = carbon monoxide, HC = hydrocarbons, and NO_x = nitrogen oxides. Composite factor for vehicle mix of 80.3 percent light-duty vehicle, 5.8 percent light truck 1, 5.8 percent light truck 2, 4.5 percent heavy-duty gasoline-powered, 3.1 percent heavy-duty diesel-powered, and 0.5 percent motorcycle; 60.0° F; 21 percent cold mode catalyst, 21 percent cold mode noncatalyst, and 27 percent hot transient catalyst.

Table 4. Results of energy and accident analyses: Kinston, North Carolina.

Network	VMT	Vehicle Hours	Gallons per Day	Accidents per Year: Fatalities	Accidents per Year: Nonfatal Injury
Kinnet 05	1 428 107	39 111			
Kinnet A5	1 428 107	66 658	157 048	22.34	1872.45
Kinnet 06	1 361 843	36 658			
Kinnet A6	1 361 843	51 436	135 937	12.96	1084.05
Δ(A6-A5)	−66 264	−15 222	−21 111	−9.38	−788.40

Table 5. Results of mobile air-quality analysis: Kinston, North Carolina.

Network	VMT	Vehicle Hours	Amount of Pollutant (kg/day): CO	HC	NO_x
Kinnet 05	1 428 107	39 111	19 394.11	1 906.87	3 444.41
Kinnet A5	1 428 107	66 658	27 675.58	3 046.56	2 912.07
Kinnet 06	1 361 843	36 658	18 356.18	1 796.98	3 309.05
Kinnet A6	1 361 843	51 436	22 736.94	2 397.17	2 998.96
Δ(A6-A5)	−66 264	−15 222	−4 938.64	−649.39	+86.89

vide for more reliable estimates of air quality.

RESULTS

The procedures and analyses recommended in this paper were tested during the Kinston, North Carolina, Thoroughfare Plan update. Kinston, which has a current population of approximately 37 000, is the largest and most important urban area of Lenoir County and lies in the heart of North Carolina's Coastal Plain. In addition, the Kinston urban area supports 14 800 employees and contains 13 100 dwelling units with an average 2.82 persons/dwelling unit.

Before the numerical results of the analyses are discussed, it is appropriate to describe what was analyzed. Four networks were chosen to test the procedure:

1. KINNET 05--The existing 1979 network with the final 1979 calibrated speeds,
2. KINNET A5--The existing 1979 network with the calibrated speeds adjusted for year 2005 V/C ratios,
3. KINNET 06--The recommended thoroughfare plan network with the final 1979 calibrated speeds with capacity-restrained adjustments, and
4. KINNET A6--The recommended thoroughfare plan network with the calibrated speeds adjusted for year 2005 V/C ratios.

Each of these networks was loaded with the estimated 2005 design-year trip table. The thoroughfare plan recommends the construction of 38.25 miles of new facilities along with improvements to some existing facilities to achieve continuity in cross sections.

For the energy and accident analyses, the comparison was made between the existing and recommended thoroughfare plan networks and the speeds were adjusted for V/C ratios. Since energy and accident analyses have not heretofore been used in North Carolina studies, the comparison of unadjusted versus adjusted speeds seemed pointless in attempting to justify the merits of using adjusted speeds. It is sufficient to say that speed adjustments that correspond to estimated future operating conditions are more reasonable and give more realistic analytical results.

The numerical results from the energy and accident analyses are given in Table 4. The recommended thoroughfare plan makes significant contributions to the predicted quality of traffic flow measured in terms easily understood by any audience. In developing a "1-mile/gal gasoline saving" and a "5-mph speed improvement" on a systemwide basis, significant delays and excessive stops due to congestion are eliminated through implementation of the thoroughfare plan recommendations.

The mobile air-quality analysis used all four network options. A comparison should be made not only between A5 and A6 but also between 05 and A5 and 06 and A6. Air-quality analyses have normally been made by using the calibrated speeds for existing as well as future networks. The latter suggested comparisons will show significant differences between emission estimates using calibrated versus V/C adjusted speeds. Although the absolute value of pollutants, particularly CO and HC, increases when the adjusted speeds are used versus the calibrated speeds, it is felt that these are the most realistic values and, consequently, should be the values that are reported.

The numerical results of the mobile air-quality analysis, determined by using Mobile 1 factors, are given in Table 5. The most critical and most often cited pollutant violations in North Carolina with respect to transportation are for CO and HC.

CONCLUSIONS

The analyses described in this paper are extremely time-efficient to perform and provide alternative plan comparisons that are easily understood by any audience. In addition, the absolute numerical results obtained by the outlined procedure are superior to those obtained by the "old way of doing things". Efforts should now be directed toward updating the energy consumption rates and improving the accident rate format so that even more reliable results might be obtained.

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Mobile Source Emissions and Energy Analysis at an Isolated Intersection

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A simplified technique is presented for evaluating the effect improvements will have on mobile source emissions and energy use at an isolated intersection. The procedure relates emissions of CO, HC, and NO_x and energy analysis to traffic-flow conditions at an intersection. A level of service is determined by using the critical movement analysis technique. By use of empirical data from a Federal Highway Administration report, stopped delay per vehicle is converted to the number of vehicles idling, slowing down, and stopping. Based on an NCHRP project, stopped delay per vehicle is related to level of service. The change from a base condition in idling time and vehicles stopping and slowing down as a result of an intersection improvement is used as the basis for determining the total reduction in pollutant emissions and energy use. The reductions are stated in terms of pounds and gallons as well as percentage reduction from the base condition. The procedure is designed to be a sketch planning tool for planners in small urbanized areas who have limited technical resources and data. The information necessary to use the procedure includes (a) total traffic entering the intersection, (b) turning movements, (c) number of approach lanes, (d) exclusive-use lanes, (e) approach speed, and (f) an estimate of the average upstream and downstream distance from the intersection where vehicle speeds are affected.

The procedure described in this paper will relate the emissions of air pollutants and energy to traffic-flow conditions at an isolated intersection. Traffic flow will be analyzed under the following classifications:

1. "Idling"--Vehicle hours of stopped delay,
2. "Slowdowns"--Total number of speed changes, and
3. "Stopping"--Total number of vehicles stopping.

By determining the changes in the number of vehicles idling, slowing down, and stopping, and by applying appropriate energy and emission rates, it will be possible to estimate the reduction in energy use and pollutants emitted as a result of the improvement of traffic operations at an intersection.

ENERGY USE AND EMISSION RATES

The table below (1) indicates fuel consumed and pollutant emissions for every 1000 vehicle-h of idling (January 1975 conditions for fuel consumption):

Item	Amount per 1000 Vehicle Hours
Gasoline (gal)	650
Pollutants (lb)	
Carbon monoxide (CO)	2430
Hydrocarbon (HC)	160
Nitrogen oxides (NO_x)	50

Figure 1 shows the additional fuel consumed for 1000 speed changes for various speeds [fuel consumption rates prevailing in January 1975 (2)]. This graph is used to determine the additional fuel consumed by vehicles that slow down as they approach an intersection. As a driver approaches an intersection, he will slow down his vehicle if there is a queue or if the light he approaches is in a red phase. If the queue dissipates or the signal changes before the vehicle reaches the intersection, the driver may only slow down and then return to his original speed. Figure 1 determines the additional fuel consumed based on this type of speed change.

For vehicles that stop completely, Figure 1 can also be applied. In this case, a stopped vehicle would be considered as going from the initial speed to 0 mph and then returning to the initial speed.

Figures 2-4 indicate the CO, HC, and NO_x emissions per 1000 speed changes. As was the case for fuel consumption, these figures can be applied for vehicles that slow down and stop.