Abridgment

Comprehensive Evaluation of Nonsignalized Control at Low-Volume Intersections

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A common practice by traffic authorities is to install stop signs at low-volume rural and urban intersections. This action generally is taken to ensure safety and in response to the lack of any clearly defined signing mandate. However, overuse of stop signs needlessly increases driver disobedience, travel time, and gasoline consumption. A recent research project conducted at Purdue University determined the most efficient signing policy for traffic flow through low-volume, unsignalized intersections.

DEVELOPMENT OF ANALYSIS TOOLS

The research examined the influence intersection conditions have on safety, travel time, fuel economy, and exhaust emissions. Low-volume flows necessarily precluded full reliance on field measurement of the many variable combinations. Computer algorithms were therefore used to aid in the study of emissions, fuel use, and travel time. Probability-of-conflict techniques, used in conjunction with accident records, supported the safety portion of the analysis.

Two properly validated simulation aids were required. One was a traffic model sufficiently detailed to reproduce accurately the flow characteristics of low-volume, unsignalized intersections. The second tool needed was a program that could process the traffic simulation output on an individual vehicle basis and estimate the gasoline consumption and resulting exhaust products. The traffic model selected was the Urban Traffic Control Simulation (UTCS-1S) model of the Federal Highway Administration (FHWA) (1). An appropriate aid to fulfill the second function was the Automotive Exhaust Emission Modal Analysis Model of the U.S. Environmental Protection Agency (EPA) (2).

The EPA model (which is calibrated in U.S. customary units of measurement) estimates grams per mile of four exhaust emission products: nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2). The EPA model, operating in close conformity with the microscopic level of the UTCS model, calculates these quantities by analyzing the unique velocity-acceleration pattern characteristic of an individual vehicle trajectory. Knowledge of the carbon-based products emitted also permits the gasoline quantity consumed to be calculated by use of a carbon balance relation. Appropriate modifications were made to the UTCS package to provide the EPA program with the model year of each vehicle under consideration as well as the corresponding time-velocity pattern.

Only those vehicles that traverse the minor (lower volume or controlled) street at an intersection are affected by the type of control implemented. The behavior of drivers on the major road was assumed not to be influenced by the sign type on the minor road. Automobiles on the minor road, on the other hand, were forced to slow or stop, which resulted in a substantial deviation from their preferred trajectory and a subsequent increase in fuel consumption, emissions, and travel time.

STUDY ANALYSES AND COMPARISONS

Fuel Consumption

Each hour of intersection traffic flow, simulated by the modified and validated UTCS-1S program, produced a set of time-velocity profiles equivalent in number to the total traffic volume on the minor road. An estimate of the gasoline consumption of each vehicle on that road was then calculated by using the carbon balance equation. Finally, averaging fuel use data within each hour produced one value representative of the combination of major-road volume, minor-road volume, and type of control peculiar to that cell. This derived mean approximated the amount of gasoline required by the average minor-road automobile to traverse a distance measured from 61 m (200 ft) upstream of an intersection to an exit point 61 m downstream, including any slowing, turning, or stopping.

Statistical tests indicated a highly significant difference between the average amounts of gasoline consumed by automobiles on the minor street as a function of the type of control implemented. A single automobile requires 0.026 liter (0.0068 gal) to traverse a stop control, 0.023 liter (0.0062 gal) to yield, and 0.021 liter (0.0055 gal) at an unsigned intersection. Considered on an individual vehicle basis, the difference in gasoline use between a restrictive control such as a stop sign and a less positive, rules-of-the-road approach appears inconsequential. Adopting a daily or annual perspective for that same single intersection changes this conclusion markedly, however. It can be shown, for example, that one minor street that carries a total volume of only 200 vehicles/d but is controlled by a stop sign requires 170.4 liters (45 gal) more gasoline per year than it would if controlled by a yield sign.

The energy implications inherent in various regional signing policies were extended to the state of Indiana. A procedure based on urban population and rural area was developed to derive an estimate of 120 000 unsignalized intersections across Indiana. The analyses indicated an annual potential savings of several million liters of gasoline given a signing policy that emphasizes yield signs and no sign control rather than stop signs at low-volume intersections that have adequate sight distance.

Exhaust Emissions

Velocity and model year data developed by UTCS-1S and input to the EPA model permitted statistical comparisons to be conducted on CO, HC, and NO_x pollutants. Primary attention was given the impact of the type of sign on the quantity of CO emitted by automobiles traversing the lower volume road. The important conclusion reached was that each successive step toward more positive, restrictive control causes a significant increase in the CO emitted by the average minor-road automobile. CO emissions created by an automobile traversing 122 m (400 ft) of observation area were 66 g/km (107 g/mile) at a stop, 59.6 g/km (96 g/mile) at a yield, and only 52 g/km (84 g/mile) given no sign control. Similar, although less pronounced, trends were found in the comparison of unburned HC; very little impact on NO_x was exhibited.

Travel-Time Delay

Travel times through intersections under various nonsignalized controls were computed from the velocity profiles output by the modified UTCS model. For the purposes of this analysis, delay was defined as the difference between the actual time required to traverse the 122-m (400-ft) observation area and the time that would have been needed if the automobile had maintained the velocity recorded when it first appeared in the observation area.

A highly significant difference in minor-street travel time or delay was proved for different types of controls. Approximately 4 s more travel time was required for the average vehicle that faced a stop rather than a yield sign and over 5 s more by a vehicle that faced a stop instead of no sign at all.

An idea of the average annual delay that can be expected at one intersection is shown in Figure 1 as a function of minor-road traffic volume and the type of control implemented. The graph shows, for example, that a minor road that carries 200 vehicles/d and has a stop sign will cause an average annual delay of 160 h. If the road has a yield sign, however, only about half that amount of time will be required, and if it is not signed at all—assuming sight distances warrant no sign—an average annual delay of about 60 h can be expected.

Figure 1. Effect of type of intersection control on annual delay to minor-road traffic.

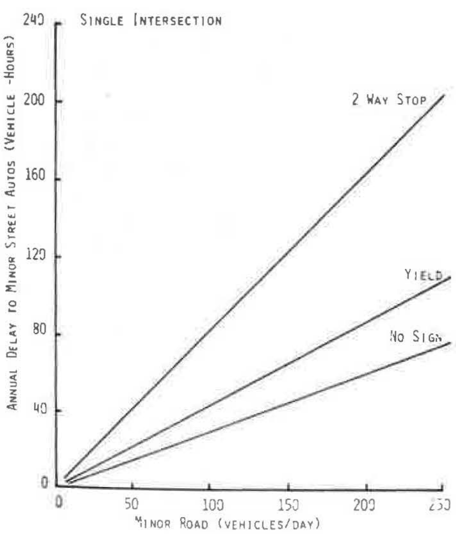


Table 1. Expected annual number of accidents by traffic volume and type of intersection control.

Control	Average Daily Traffic for Minor Road	Number of Accidents per Year — Average Daily Traffic for Major Road: 100	200	300	400
No sign	100	0.087	0.174	0.259	0.345
	200		0.345	0.516	0.686
	300			0.772	1.026
	400				1.363
Yield sign	100	0.052	0.104	0.155	0.207
	200		0.207	0.310	0.412
	300			0.463	0.616
	400				0.818
Stop sign	100	0.044	0.087	0.130	0.173
	200		0.173	0.258	0.343
	300			0.386	0.513
	400				0.682

Safety and Accidents

In support of the hypothesis that more efficient traffic flow can be attained by proper application of STOP and CROSS ROAD signs, Stockton, Mounce, and Walton (3) performed a comparison of two-way-stop and unsigned intersections based on probability-of-conflict concepts as well as accident and operating costs. That effort did not consider the effects of yield signs, but knowledge of accident reduction attributable to yield signs compared with no sign made it possible to incorporate all three control techniques.

Perkins (4) has shown the ratio of accidents to conflicts to be 0.000 33. Using that estimate and the conflict values computed by probability analysis yields the expected number of accidents per year at an unsigned road crossing. The literature search indicated that yield signs rather than no signs may reduce accidents anywhere from 20 to 60 percent. Therefore, an average accident reduction of 40 percent was assumed for yield signs in comparison with no control.

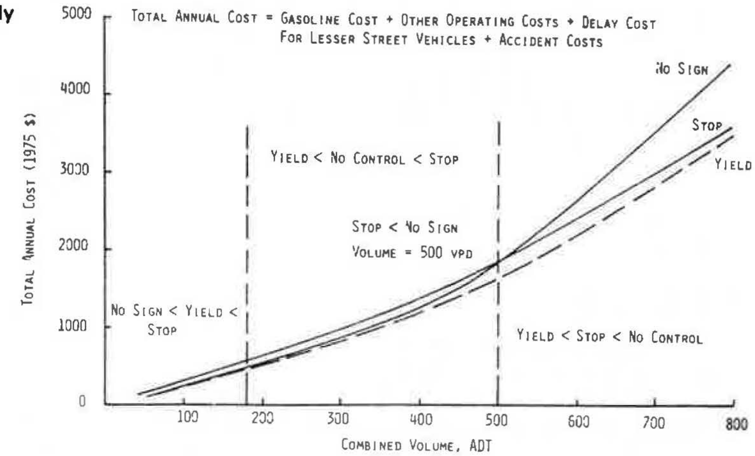
Contrary to common opinion, available literature based on accident records indicated that using a stop sign rather than a yield control had little effect on accidents. But the intent in this analysis to examine the stop sign in the best possible light permitted the assumption of a 10 percent accident reduction for stop signs in comparison with yield signs. Applying the 40 percent reduction descriptive of yield control or the approximate 50 percent reduction for stop signs allowed the appropriate accident figures to be derived from the no-control values. Table 1 gives a summary of the resulting annual accident count as a function of volume and intersection control. It is clear that a very small number of accidents can be expected at the typical low-volume intersection regardless of the type of control installed.

SELECTION OF PROPER INTERSECTION CONTROL

It was apparent at this stage of the research that, given adequate sight distance, yield signs are the most desirable form of control at low-volume intersections. Yield signs provide the optimal trade-off between the safety factor and the variables of travel time, gasoline consumption, and exhaust emissions. That conclusion was further substantiated by performing a cost-benefit analysis.

The cost components can be illustrated by the following equation: Total annual cost = gasoline + other automobiles + delay + accidents. Dollar values based on an Indiana study conducted by Hejal and Michael (5) were assigned to accidents by type of severity. These costs, appropriately updated to 1975 values, were combined with intersection accident experience to provide an average accident cost per intersection of $2242. Applying this average unit cost to the expected accident counts given in Table 1 provided possible savings resulting from the increased safety attributable to more

Figure 2. Expected annual cost per intersection for approximately equal split in traffic volume between crossing streets.



positive control at low-volume intersections.

Gasoline costs in 1975 were estimated at $0.16/liter ($0.60/gal) of which only $0.13 ($0.48) was actual cash outlay and $0.03 ($0.12) was refunded to the user through road-tax benefits. Other operating expenses include tires, oil, maintenance, and depreciation. These costs were estimated by updating the information given by Winfrey (6).

Delay costs were computed on the basis of a travel-time value study conducted by Thomas and Thompson (7). Using the census-estimated median income of Indiana families, given as $9970/year, permitted the adoption of a set of the Thomas and Thompson travel-time values. The time values were prorated down to the average delay periods associated with stop, yield, and no control.

Figure 2 shows a graphical dollar trade-off between types of signs. It can be seen that, at total volumes from the upper limit [average daily traffic (ADT) of 800] of the low-volume crossings to roughly 200 ADT, the yield sign offers the lowest overall annual cost.

Yield signs provide a suitable compromise between the minimum operating cost of no signs and the minimum accident costs of stop control (this excludes consideration of the expense of sign installation and maintenance). Including installation and maintenance costs would show no sign at all to be the least expensive control at very low traffic volumes—perhaps intersection volumes in the range of less than 200 total vehicles/d.

ACKNOWLEDGMENT

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**D. L. Hall was with Purdue University when this research was performed.*