Warning Flashers at Rural Intersections

Final Report

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16. Abstract (Limit: 200 words)

This project sought to understand the effects of warning flashers on the safety of rural intersections. Researchers conducted four separate studies: a literature review; an opinion survey of a sample of Minnesota motorists who lived outside urban areas; an analysis of accident data for rural intersections comparing accident rates three years before and three years after the installation of various configurations of warning flashers; and a field study at the intersection of U.S. 14 with MN 52 in Eyota, Minn. This last study included a baseline period, followed by a phased implementation of various warning flasher configurations, with a week or so between phases.

Researchers concluded that none of the four studies unequivocally supported the effectiveness of warning flashers at rural intersections in promoting safety at rural intersections. While driver alertness or awareness to potential hazards at the intersection may have been enhanced by the installation of warning flashers, this project did not provide data that would demonstrate such enhanced alertness or awareness.

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Executive Summary

The project, "Warning Flashers at Rural Intersections," was sponsored by the Minnesota Department of Transportation and performed jointly with the University of Minnesota. The objective of this project was to understand the effects of flashers on the safety of rural intersections. Four separate studies were done to meet this objective. First the literature relevant to flashers at intersections was reviewed and analyzed. There was little published work directly bearing on the objective for this project and the results were not in agreement from report to report. Effects suggesting that flashers improved safety were small such as speed reductions of three miles per hour (mph) in approaching an intersection on a through road where the intersecting road had a stop sign.

The second study was an opinion survey of a sample of Minnesota Motorists who lived outside urban areas. This survey showed that while drivers in general understood that flashers near or at an intersection implied potential danger, there were troublesome misconceptions. One such misconception was that some drivers believed that an overhead flasher implied a four-way stop at the intersection when in fact only one road had stop signs. An additional interesting finding from the survey was that there were some clear age-related differences between younger and older drivers.

The third study was analysis of accident data for rural intersections comparing accident rates three years before and three years after the installation of various configurations of flashers. Because accidents are infrequent, it is difficult to demonstrate large effects. The analysis presented here did not strongly support the effectiveness of flashers at rural intersections.

The final study was done in the field at Eyota, MN at the intersection of US 14 with MN 42. This study was hampered by the theft, vandalism and failure of the sensors used to measure traffic counts and traffic speeds as well as by a resurfacing project. In this study there was a baseline period followed by a phased implementation of various flasher configurations with a week or so between phases. There was insufficient data for the road with the stop sign to demonstrate potential effects from flashers. For the through road, US 14, the changes in speed caused by the flashers were very small for all configurations. This finding held for drivers at or above the speed limit of 55 mph as well as for those below the speed limit.

We concluded that none of the four studies unequivocally supported the effectiveness of flashers at rural intersections in promoting safety at rural intersections. While driver alertness or awareness to potential hazards at the intersection may have been enhanced by the installation of flashers, this project did not provide data which would demonstrate such enhanced alertness or awareness.

Introduction

This project which was concerned with the efficacy of flashing lights at rural intersections has several parts which were reported previously. Brief summaries of these earlier reports are included in the text of this report with supporting information documented in the appendices. The field study is the center of attention in this report. The field study in Eyota, Minnesota was not previously reported. This study used the phased introduction of five configurations of flashing lights at the Eyota intersection.

Objective

The objective of this project was to add to the understanding of the effects that flashing lights have on traffic safety at intersections. During the course of this project the potential effects were narrowed to rural intersections at which two lane roads intersected at right angles and there was a through road and an intersecting road with stop signs. The project focused on three flashing light installations: 1) A pedestal mounted yellow flashing light at the sign warning that there was an intersection ahead, 2) A pedestal mounted red flashing light at the stop sign, and 3) An overhead light flashing yellow in both directions for the through road and flashing red for both directions on the intersecting road with stop signs.

Literature Review

The project began with a survey and analysis of the relevant literature. This annotated literature review is Appendix A. This review covered published papers which fell in the following categories: Lighting at Rural Intersections, Pavement Markings and Rumble Strips at Rural Intersections, Sight Distance and Visual Field at Rural Intersections, Traffic Signals at Rural Intersections, and Traffic Signs at Rural Intersections.

From this literature review some conclusions were made on the state of the art in rural intersection traffic research. The works and methods [1] of Bruede, U., & Larsson, J. in 1992, from the National Swedish Road & Traffic Safety Research Institute, [2] Lyles, L. W. in 1980 from the Maine University Social Science Research Institute, and [3] Pant, P. D., Park, Y., & Neti, S. V. (1992) from Cincinnati University's Department of Civil and Environmental Engineering appear to be protocols likely to be influential in this project. In [4] Mounce, J.M. in 1981, placed an interesting emphasis on means of influencing drivers' behavior.

Additionally, [5] Pline, J. L. in 1988 appears to have produced a greater awareness of the US Manual on Uniform Traffic Control Devices' ambiguity or lack of standardization in addressing the traffic control device needs of rural motorists and may have been the stepping stone for research such as ours regarding such significant problems as uniformity of flashers at rural intersections.

Opinion Survey

A mail survey was conducted for obtaining drivers' opinions on the effectiveness and meaning of flashing lights at rural intersection. There were 144 respondents consisting of older and younger drivers of both genders. There were 25 questions in the survey and the results for each of these questions was presented. Specific conclusions relevant to each question are given in Appendix B which contains the survey, the results, and a discussion of the results.

The major conclusion drawn from this survey was that for most drivers, all the flashing light configurations used at rural intersections have the desired effect. That is, they warned drivers that the intersection they were approaching was potentially more dangerous than an intersection without flashing lights. This finding did not show that drivers responded to flashing lights by reducing their speed *because of the flashing lights*. Rather this finding implied that traffic engineers should be parsimonious in the use of flashing lights. If there were flashing lights at all rural intersections, they might lose their value in warning of particularly dangerous intersections.

A secondary, and less pleasing, conclusion that was drawn from this survey was that many drivers misconstrued the meaning of the flashing lights used in some configurations. Some of these misconceptions could well be the cause of some the accidents which occurred at rural intersections.

The final conclusion we could draw was that there were a few striking age differences in the interpretation of flashing lights. Although neither age group was consistently correct in interpreting the meaning of flashing lights at intersections.

This survey data failed to provide a uniform preference for a particular configuration of flashing lights. Given the usually slight differences of opinion for any particular configuration as well as the differences in opinion based on age, the survey data cannot uniformly support even the use of flashing lights in any configuration compared to not using flashing lights at all. There was always some amount of disagreement among the respondents. This outcome implies that traffic engineers should be concerned with providing the greatest good for the greatest number while at the same time urging the adoption of means for better educating the driving public to the meaning of flashing lights at rural intersections and correct responses to flashing lights.

Intersection Accident Analysis

An analysis of accident data was done comparing accident rates and total accidents at rural Minnesota intersections. The analysis was based on accident experience three years before and three years after the installation of flashing lights. Twelve intersections were examined. Each met the MnDOT Technical Advisory Panel definition of rural intersection. The definition established was: 1) All intersections must be four-way and intersect perpendicularly, 2) Average Daily Traffic (ADT) less than 12,000 vehicles, and 3) Only two-way stop intersections - no four-way stops.

The accident data tables and the presentation of the results are in Appendix C.

Field Study

Introduction

A resurfacing project and a desire by District 6 of the Minnesota Department of Transportation to improve safety at an intersection in Eyota, Minnesota enabled the experiment. The intersection was US 14, an east-west through highway, with MN 42/Olmsted County 7 which is the north-south Highway. MN 42/Olmsted 7 (a single roadway whose name changes) has stop signs at their intersections with US 14. MN 42 is north of US 14 and Olmsted County 7 is south of US 14. Methods

Description of Experiment

The objective of the experiment was to measure the effect on drivers' behavior of five flashing light configurations. Driver's behavior was measured by recording changes in drivers' speeds as they approached the intersection. The speeds were recorded for each of the five flashing light configurations. Data was collected for one or more weekdays for consecutive 30 minute intervals. No data was collected for at least one week following the change of a flashing light configuration. Speed and traffic counts were measured by NuMetrics NC-90A™ magnetic sensors placed on the roadway surface well in advance of the intersection and near the intersection (see Figure 1 for a diagram of sensor locations). Three sensors were place on US 14 west of the intersection at 100 feet (for effect of overhead flasher), 600 feet (for effect of pedestal flasher at the warning sign) and 1100 feet (approach speed unaffected by flashing lights or the warning sign) from the intersection. On MN 42 two sensors were placed 1500 feet (approach speed)and 100 feet (effect of pedestal flasher at the stop sign) before the intersection.

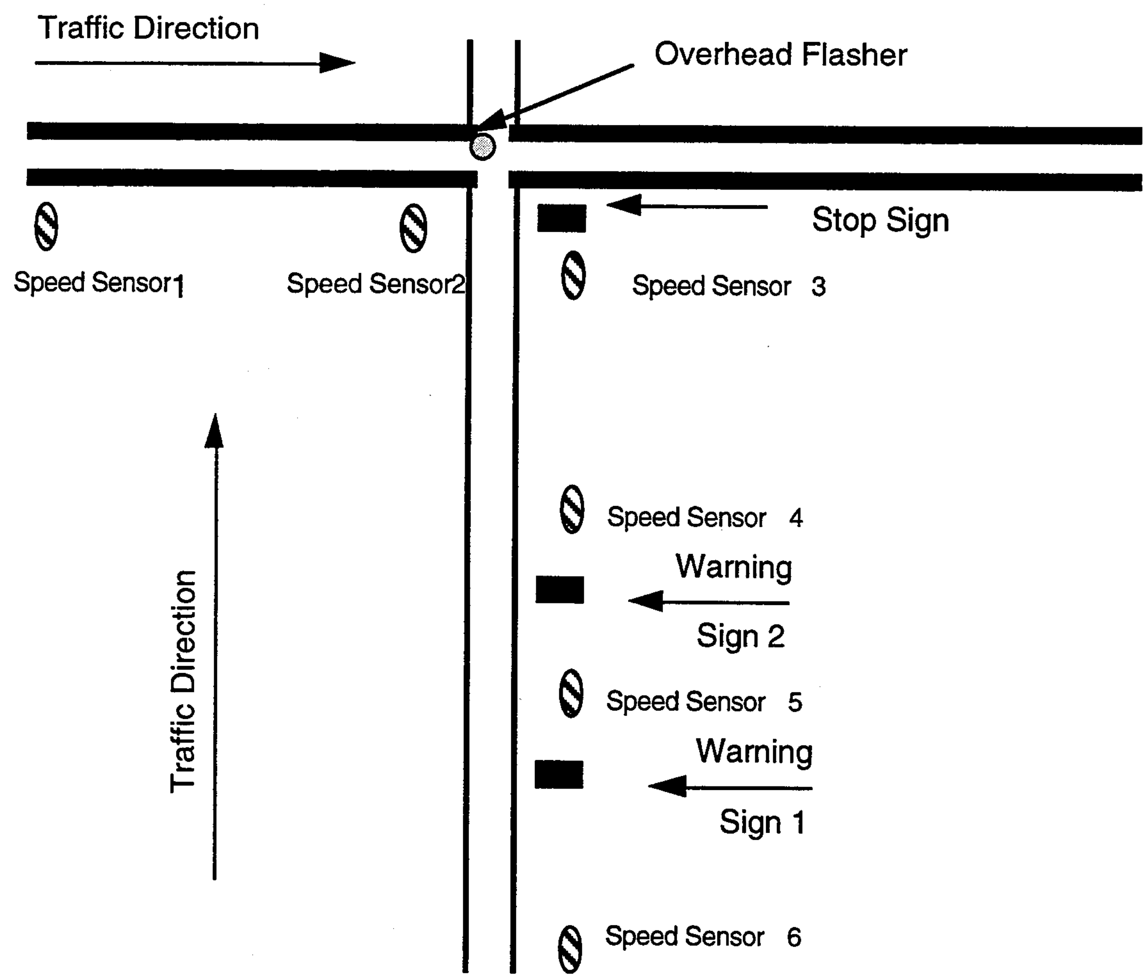

Figure 1. Locations of magnetic sensors for traffic speed and volume measurements.

Flashing Light Configurations

There were three locations for the flashing lights: 1) at the intersection ahead warning sign on US 14 (pedestal mounted); 2) at the stop sign on MN 42 (pedestal mounted); and 3) overhead at the intersection. Five flashing light configurations were used. The pedestal mounted lights always flashed red at the stop sign and yellow at the intersection warning sign on US 14. The overhead light flashed red for MN 42 and yellow for US 14.

1. Baseline. No flashing lights at any location.
2. Both pedestal lights. Yellow flashing lights were turned on over the warning sign on US 14 and red flashing lights over the stop sign on MN 42.
3. Only Overhead lights. The lights flashed yellow for US 14 and red for MN 42.

4. Overhead and Red Pedestal lights. Yellow flashing lights and intersection warning sign removed.

5. All Flashers turned on, warning sign replaced with pedestal yellow flashers turned on and red pedestal flashers turned on at stop sign as well as the overhead flashers.

Descriptive statistics for the data collected for each of the conditions will be analyzed and tabulated so that comparisons among flashing light configurations can be made.

Results

The experimental plan called for a complete design in which data would be collected from each sensor for the baseline condition and each of the flasher configurations. Vandalism, sensor theft and sensor failures reduced the amounts of data which were actually collected. Thus the results were not complete and not all comparisons which were planned could be made. This will become clear from the data shown in the following. Frequency histograms showing vehicle speeds for each of the conditions for which measurements were made are shown in Appendix D.

The usual reason that flashing lights were installed at rural intersections was to reduce the speed of traffic approaching the intersection and to increase motorists awareness of potential danger at the intersection. Table 1 shows the effect of flashing lights on reducing the speed of eastbound traffic on US 14 as it approached the intersection with Minnesota 42. The posted speed limit was 55 mph. For each condition the speeds of about 1,000 vehicles were recorded. Speed reduction for the baseline condition was presumably due to random fluctuations in the data or to the presence of the intersection since no flashing lights were installed.

Table 1. Percent of vehicles exceeding 55 mph on US 14 approaching MN 42.

	100 feet	600 feet	1100 feet
Baseline	36%	--	32%
Overhead	40%	37%	25%
Pedestal	24%	27%	29%
All Flashers	--	46%	30%

In Table 2 the average speeds and speed standard deviations are shown along with the differences between the average speeds for the baseline conditions and the average speed for each of the flasher conditions.

Table 2. Mean speed (mph),standard deviation and speed reduction from the baseline, US 14.

	100 feet	600 feet	1100 feet
Baseline Mean	53 ± 11	--	55 ± 7
Overhead Mean	53 ± 11	55 ± 8	53 ± 7
Overhead Change	-1	+1	-1
Pedestal Mean	50 ± 12	53 ±8	54 ± 7
Pedestal Change	+4	-1	0
All Flashers Mean	--	56 ± 8	55 ± 7
All Flashers Change	--	+2	+1

(The rows labeled "Change" show the differences between the Baseline mean values and the mean values for the various flasher conditions. The mean of the two Baseline values was used to obtain the differences.)

Much more data was lost for MN 42. The data which was collected is only for the baseline condition and this is shown in Tables 3 and 4 which correspond to Tables 1 and 2 for US 14.

Table 3. Percent of vehicles exceeding 55 mph on MN 42 approaching US 14.

	100 feet	1500 feet
Baseline	0%	21%

Table 4. Mean speed (mph) and standard deviation for the baseline condition, MN 42.

	100 feet	1500 feet
Baseline	6 ± 5	53 ± 9

Discussion

In the introductory and results sections we have presented four lines of evidence concerning the effectiveness of flashing lights at rural intersections; 1) Findings published in the literature, 2) The survey conducted as a part of this project, 3) The analysis of accident data before and after the installation of flashers and 4) The results from the field study at Eyota, MN.

Literature Review

In the part of the literature review pertaining there were few papers relating to the effectiveness of flashing lights at low volume intersections and the findings were mixed. Benioff [1] and [2] found that flashers did not provide effective control on major roads and only a slight degree on control on the minor road with a stop sign. By contrast Pant [7] found that flashers were not effective in reducing stop sign violations on the minor road but were effective in reducing accidents on the through road. Cribbins [5] found a significant reduction in property damage at low volume intersections based on the introduction of flashing lights. Cribbins [5] also noted that there were few data on the effects of flashers. In a survey of state highway departments Bonneson [3] found that 74 percent of them used flashing lights at some low volume intersections; effectiveness was not reported. Lyles [6] found that flashers at warning or stop signs reduced drivers' speeds by an average of three mph. Lyles [6] also found that flashers increased drivers' sign recall and recollection of a vehicle parked on the side road near the intersection. This was interpreted to mean that flashers increased drivers' awareness of the properties of the intersection.

Opinion Survey

The survey results yielded some surprises in the form of misconceptions about the meaning of flashing lights at a rural intersection and also in the finding that there were, in some cases, pronounced differences in the opinions of younger and older drivers.

When asked the meaning of a warning sign without flashing lights on a main road, the majority of respondents correctly stated that drivers should simply be especially careful when approaching the intersection, that cross traffic is not usually heavy and that they will not need to stop at a stop sign. More older than younger drivers stated that the warning sign means that drivers should reduce speed. In comparing the effectiveness of a warning sign with a flasher and a warning sign without a flasher the great majority stated that the meanings were the same; to reduce speed. However, many older but not younger drivers felt that the warning sign with a flasher implied that cross traffic did not stop (one in five older drivers). If the warning sign does not have a flasher, one in five drivers believed that cross traffic does not stop. Older drivers are much more convinced than younger drivers that cross traffic does not stop if the warning sign has a flasher but there is no overhead flasher. Very few of either age believe this if there are flashers at both the warning sign and overhead. When there are flashers at both the warning sign and overhead about one-half of the drivers believe that the intersection is especially dangerous. However, 50 percent more older drivers than younger drivers believe that flashers at both locations mean that the intersection is especially dangerous. For any of these conditions only one percent to four percent of the respondents believe that cross traffic must stop. For these three conditions, drivers have the correct general idea that flashers mean that they are approaching an intersection which could be hazardous. However, some drivers in both age groups entertain certain incorrect notions.

The comparisons for approaching the intersection from the side road are of respondents ideas about: 1) Stop signs only; 2) Stop signs with flashers; and 3) Stop signs with flashers and with overhead red flashers. A worrisome finding for all three conditions and both age groups was that from eight percent to 22 percent believed that a four-way stop was implied. For younger drivers the belief that the intersection is a four-way stop decreases as the number of flashing lights decreases from two flashers to one to none. Just the reverse was true for older drivers who believed that the intersection is a four way stop increased as the number of flashers increased. It is not clear why any drivers believe that the intersection is a four-way stop, however, the older drivers' misconception is easier to rationalize than that of the younger drivers.

In a separate question the majority of drivers correctly stated that the flashers indicated that the intersection was especially dangerous in that there was heavy cross traffic. This result did not agree with the findings just described. Why the responses to this question disagreed with the responses described in the preceding paragraph could not be determined.

In general, the survey respondents correctly identified the purpose of flashing lights at a rural intersection. There were some striking age-related differences in specific interpretations of the meaning of flashers. Some of these misinterpretations could well lead to accidents.

Accident Data

The accident data did not offer convincing support for a strongly positive effect following the introduction of either pedestal mounted or overhead flashing lights at rural intersections. One of the difficulties is using the occurrence of accidents as a dependent variable is the rarity. Accidents at the intersection studied occurred on the order of once in a million crossings. Thus, if over the course of three years the number of accidents decreased from say twelve to six, then while this is a 50 percent reduction it is still just a decrease of two accidents a year. Changes of this size are difficult to attribute to a single factor such as the installation of flashing lights.

Eyota Field Study

The results from the field study, while limited, show that on the main road, US 14, flashers had no effect in reducing speeds. Whether or not drivers were made more alert, as was suggested by Lyles [6], cannot be determined from the data collected at Eyota. The results show that the higher speed drivers, 55 mph or greater, were not differentially affected in terms of speed reduction. The overall changes in speed related to any flasher condition compared with baseline values were minuscule. The impending intersection alone (no flashers) resulted in substantial decreases in speed which could be attributed to either the warning sign or prior knowledge of the location of the intersection or both.

In summary, the field study results did not support hypothesis that flashing lights would reduce speeds on the main road approach to the intersection.

Conclusion And Recommendations

Neither the published reports, nor the opinion survey, nor the analysis of accident data, nor the field study unequivocally supported the effectiveness of flashers at rural intersections in promoting safety at rural intersections. While driver alertness or awareness to potential hazards at the intersection may have been enhanced by the installation of flashers, this project did not provide data which would demonstrate such enhanced alertness or awareness.

A recommendation for more research is customary. We recommend that if more research on the effectiveness of flashing lights at a rural intersection is contemplated it should be conducted in a situation such as that reported here at Eyota, MN. That is at a location permitting the phased installation of various configurations of flashing lights without any other changes occurring at the intersection or the roads approaching it. If sensors cannot be found which are highly reliable and proof against theft and vandalism, then the data collection should be done by people. High quality data for each conditions, even if limited in amount, would be preferable to large volumes of data for a few conditions and no data for other conditions.

We would also recommend that thought be given to the inclusion of a cost benefit analysis which would include such hard to estimate factors as the value to local citizens of having the highway department respond to their concerns about what they perceive as a dangerous intersection.

Finally we suggest that in drivers education courses and perhaps in *55 Alive* courses sufficient attention should be paid to explaining the meaning of flashers of different kinds placed at different locations sometimes in conjunction with signs.

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[9] **Bonneson, J.A., McCoy, P.T., and Truby, J.E. Jr. (1993).** "Safety improvements at intersections on rural expressways: a survey of state

departments of transportation." *Transportation Research Record* No. 1385, Intersection And Interchange Design, pp 1-47.

Appendix A

Literature Review for Flashers at Rural Intersections

Introduction

The following notes on the literature take the form of a categorized and annotated bibliography. All notes have been alphabetically entered by author into five categories where a category is based on similarities of the work performed.

We have made use of author abstracts or other author created material in addition to our own comments and summaries. We will use only this general attribution to the authors rather than using quotation marks or other means of showing which material was transcribed directly from the authors' work.

Background

Rural intersections in Minnesota generally do not warrant standard traffic light signal installations for two reasons. Firstly, economic limitations preclude putting full function traffic lights at every intersection. Secondly, putting a full function traffic light at every intersection would result in over-control with consequent loss of drivers' time and the promotion of scoff-law behavior. With this in mind we find that many rural intersections are equipped with flashers. Flashers are similar to regular traffic lights but they are meant to flash repeatedly in one state. This usually means they are constantly flashing yellow (to tell motorists to approach with caution on the major street) or red (the equivalent of a stop sign on minor streets). Rural roads have relatively light traffic flow and motorists approach intersections at high speeds. Confusion on what the current state of lights signify at these intersections has led to tragic results. This confusion has a number of causes including the lack of standardization of flashers and their use in different contexts. To illustrate the problem with varying contexts, consider that during power failures the regular traffic lights in most towns will automatically default to the red flasher mode. This means the intersections has a four-way stop. Urban motorists who are used to this, on leaving the town environment, might expect that the same situation exists when they see the red flashers in a rural setting, even though the rural red flashing light actually signifies a two-way stop. Such motorists on a minor road would operate under the false impression that approaching motorists from the major road will also stop at the intersection lights.

Previous flasher designs include overhead flashers (which can function in wig/wag mode or include other signs) and pedestal mounted flashers (may include various types of signs and be located at varying distances from the intersection).

The decision on what type of flasher to use is currently somewhat arbitrary and few design standards are available. The Manual on Uniform Traffic Control Devices for instance only gives very broad outlines, leaving much open to interpretation of the individual manufacturers. The proposed research intends to address these limitations by proposing standards for flashers on rural intersections based on video and simulator studies.

The following annotated bibliography is provided to establish a scope of not only the investigations and research regarding the inconsistencies in flasher design, placement, etc. at rural intersections but also to give an idea of current means of investigating rural intersection safety. A few studies may be regarded as rural intersection protocols and may serve as models for simulator studies.

Bibliography Categories

Five categories were selected from Lay, M. G. (1986). Handbook of Road Technology: Volume 2 - Traffic and Transport as independent measures of driver behavior and safety and are couched in the context of rural intersections. The handbook, prepared for use by professional transportation practitioners, postgraduate students, and academic persons working in the field, was selected as a reference based both upon its detailed theoretical and practical analysis of significant independent measures of driver behavior and its emphasis on driver safety measures. The handbook does not solely address issues pertaining to rural intersections but within each chapter pertinent issues relevant to rural intersections are discussed.

The five categories are:

- Lighting at Rural Intersections
- Pavement Markings and Rumble Strips at Rural Intersections
- Sight Distance and Visual Field at Rural Intersections
- Traffic Signals at Rural Intersections
- Traffic Signs at Rural Intersections

The following is intended to provide general information regarding the five categories presented in the annotated bibliography which follows:

1) Lighting

The general concept of road lighting design is that the road environment and objects in it need to be made sufficiently visible to enhance traffic and pedestrian flows, mainly through increased volumes and greater safety. Lighting must display the carriageway ahead for tracking and navigating, reveal its surrounds and permit the detection of the presence, position and movement of other road users. Objects to be detected include pedestrians, parked cars, traffic control devices, moving cars, pavement edges and changes in road conditions.

Many of the arguments for traffic route lighting relate to a reduction in both the rate and severity of night-time accidents. There is general belief that road lighting can reduce injury accidents by about 30 percent and that these savings more than offset the cost of the lighting. However, the relationship between increasing light levels and accident rates will follow a line of diminishing returns.

On an exposure basis, a disproportionate number of accidents occur at night and are, on the average, more severe than daytime accidents. This increased fatality rate can be attributed to the increased severity of multi-vehicle and pedestrian accidents, but not of single vehicle accidents. Multiple vehicle accidents are twice as likely to result in a fatality at night than by day and pedestrian accidents are four times more likely to be fatal at night.

Although part of this pattern can be attributed to the poorer visual conditions at night, we must also recognize that social habits mean that driver alcohol levels, for instance, will be high at night, thus making driving markedly more hazardous in a manner that cannot be aided by lighting levels. We also note that the lighting poles themselves constitute a significant traffic hazard.

The ideal design would start with an examination of the driving task, leading to a determination of its important visual components and an understanding of how visibility was influenced by road lighting. In practice, however, only simple visual components can be analyzed. Attempts made to relate lighting levels to car-following behavior as a performance measure have not been successful. It is therefore necessary to examine the role of lighting in a more pragmatic fashion.

2) Pavement Markings and Rumble Strips at Rural Intersections

Markings are applied to pavements to guide, warn or regulate traffic. They may be used to supplement traffic signs or signals or to act in a "stand-alone" mode. As with traffic signs, the basic requirement for pavement marking is that drivers should be able to interpret its meaning in sufficient time to properly react to its message.

The visibility of pavement markings in most cases is determined by the contrast between the marking and the adjacent portion of the road surface. Both of these areas will be equally illuminated. The luminance contrast is thus exclusively determined by the difference in the reflective properties of the road surface and the pavement marking. Color contrast may also improve the conspicuity of pavement markings.

Pavement markings suffer from the following limitations:

1) They may not be clearly visible, e.g. in the wet or in dusty or sonw or ice cover conditions or at night (unless reflectorized). At night the headlight beam of a vehicle will be incident on the pavement marking at a low angle to the pavement surface and so will provide relatively low illumination of the marking. In this respect rough surfaces will be better than smooth.

2) They wear under traffic and require frequent maintenance.

3) They can be obscured by traffic.

4) They may lower skid resistance.

5) They cannot be applied to unsurfaced roads.

6) They carry less informative messages than do signs.

However, pavement markings have the major advantage of conveying continuous information within the driver's direct field of vision. The need to make markings as large as possible to ensure adequate visibility can be seen to be counteracted by pressures under (2) and (4) above, and by cost pressures, to minimize their total area.

3) Sight Distance and Visual Field at Rural Intersections

Sight distance is defined as the distance at which an attentive driver can see a specified object ahead of him, given clear, well lit conditions, good visual acuity and the object centrally located in his field of vision. There are six main types of sight distance. Our concern is Intersection Sight Distance which provides vehicles stopped at an intersection with sufficient sight distance for them to cross the intersecting road safely. For detailed discussion see Chapter 19 "Road Geometry" and Chapter 20, "Intersections" in the handbook.

Rumble strips are areas of coarse or grooved pavement surfacing, often intermittently spaced in the direction of vehicle travel. This technique relies for effectiveness mainly on the sound and vibration transmitted into the car and thus is less aggressive, and used for less critical trespassing, than a jiggle bar (which is louder and more jolting). Rumble strips must raise noise levels within a car by about 6 dB to be effective. They can be highly effective, both to warn straying vehicles as well as to slow down vehicles approaching potentially hazardous rural intersections.

One of the reasons for the effectiveness of rumble strips appears to be that drivers react more quickly to audible than visual signs. In addition, the device does not interfere with the motorist's visual functioning. For this reason, rumble strips are sometimes used to give advance warning of a visual signal.

4) Traffic Signals at Rural Intersections

Traffic signals are devices which, by means of changing colored lights, regulate the movement of traffic. They are appropriate control devices to alleviate:

1) excessive delays at Stop or Give Way signs

2) problems caused by turning traffic

3) angle collisions

4) pedestrian accidents, and

5) traffic entering into a road network.

Although traffic signals have beneficial effects, they will also have negative influences. For instance, signals may reduce the overall capacity of an intersection, increase some types of collisions and lead to the unwanted diversion of traffic to adjacent unsignalized routes.

Care must therefore be taken to avoid over-signalization, particularly in light traffic. One of the causes for over-signalization is the demand by people in residential areas for reasonable entry into or passage across the major arterial roads bounding their area.

Total and major accidents will drop (e.g., by 25 percent) as a result of signal installation, although accidents may rise at lightly-trafficked intersections. Right-angle accidents may be reduced by 90 percent, and rear-end collisions by 20 percent, whereas accidents between turners and on-coming vehicles may increase by 140 percent. In the lightly-trafficked intersections, only right-angle accidents will be reduced (by 30 percent). These data are a useful guide to the accident consequence of signalization and are consistent with the view that signals cannot be regarded as a universal accident panacea, mainly because they change the pattern of accidents rather than automatically causing an absolute reduction. In Australia about one percent of motorists appear to disobey the red signal at an intersection and are the cause of about 25 percent of intersection casualties.

Guidelines for traffic signal installation are listed in chapter 23 "Traffic Signals" on page 447 of the handbook.

There is no clear provision for indicating when signals are not operating nor do we understand how priority at the now uncontrolled rural intersection is treated. It is not treated as a four-way stop governed by the give way to the right rule as in urban areas and therefore an urban and rural uniformity is sought or at least an interpretable rural provision needs to be established.

5) Traffic Signs at Rural Intersections

Traffic signs are passive, visual traffic control devices. There is no world-wide uniformity of traffic signing, with the most widely followed document being an International (or Protocol) on Road Signs and Signals produced by the United Nations in Geneva in 1968. It uses symbolic codes and messages almost exclusively

Traffic sign theory states that the basic requirement for a traffic sign is that it must be capable of fulfilling an established need. The means of conveying information by signs consists of a combination of a legend (i.e., words), graphic symbols, shape and color. Symbols may be abstract (e.g., a crossroads sign). Hybrid signs contain both legend and symbolic elements, primarily as an interim step to educate users in the meaning of symbolic signs.

The effectiveness of a sign can be checked by considering that the potential user of a sign must go through four stages, often as the consequence of a single glance. The user must:

1) detect the sign (Is the sign visible? Is it conspicuous? Does it command attention?);

2) "read" the sign (Is the sign legible?);

3) understand the sign (Is the sign comprehensible? Does it convey a simple unambiguous meaning? Is the meaning clear?);

4) act on the sign in the intended fashion (Is the sign credible? Does it convey the intended meaning? Does its location give the motorist time to make an adequate or required response?).

Traffic signs can be classified into the following "Types":

- *Regulatory signs.* These signs indicate legal requirements and failure to comply with them is an offense. Prohibitory signs are usually white discs with a red annular border. Mandatory signs are usually colored discs with white symbols.

- *Warning signs.* These signs inform road users of an unexpected or hazardous situations on or adjacent to the road. They are often characterized by white triangles with a red border.

- *Guide or information signs.* These signs guide and inform road users of directions, distances, destinations, routes, points of interest, location of services, etc.

- *Temporary signs.* These signs warn of temporary hazardous or deleterious conditions.

Bibliography

Lighting at Rural Intersections

Anderson, K. A., Hoppe, W. J., McCoy, P. T., & Price, R. E. (1984). Cost-effectiveness evaluation of rural intersection levels of illumination. Transportation Research Record 996, pp. 44-47.

Lighting is often installed at rural intersections to improve the safety of night traffic operations at these locations. However, there are no generally accepted design criteria that define the levels of illumination required at rural intersections. The objective of this research was to evaluate the cost-effectiveness of rural intersection levels of illumination. Six lighting systems were installed at a rural, unchannelized intersection of two-lane highways. Speed profile and traffic-conflict studies were conducted on an uncontrolled approach to the intersection. The studies were conducted at night at each level of illumination as well as with no lighting. The data were analyzed to determine the safety- and cost-effectiveness of each level of illumination. The results of the research indicated that, for a given luminaire wattage, two-luminaire systems provided safer traffic operations than did one-luminaire systems; and the safest operations were observed under a two 200 watt high-pressure-sodium (HPS) luminaire system. The results of the cost-effectiveness analysis revealed that lighting was not warranted at rural intersections with main highway average daily traffic less than 3,250 vehicles per day. At higher volume intersections a two 200-watt HPS luminaire system was the most cost-effective.

Rockwell, T. H., Bala, K. N., & Hungerford, J. C. (1976). A comparison of lighting, signing, and pavement marking methods for detecting rural intersections at night. (Report No. OHIO-DOT-08-76 Final Rpt). Columbus, OH: Ohio State University, Department of Industrial and Systems Engineering.

Six test drivers were tested over four nights each for their responses to different lighting, signing, and pavement marking configurations at rural intersections. There were 168 approaches made at the test sites under different treatment combinations. Performance measures included driver visual behavior measures and driver control and vehicular state measures. The major results were that when compared to a baseline, no-treatment condition, the use of lighting significantly improved driver performance resulting in earlier detection of the intersection and smoother velocity profiles. Signing had only marginal effects and new pavement markings showed no effect. The study suggested that additional research should be performed with larger sample sizes for the purposes of validation and to develop information that would aid in design-warrants for rural intersection lighting and signing. Such field studies would examine the effects of intersection treatment on driver performance according type of maneuver performed at the intersection, e.g., left-turn drivers (as in this study), right-turn drivers, and through drivers. Future research should also examine the effect of driver anticipation of treatment at the intersections such as used in this study could be treated as follows with a positive effect on motorist safety: (1) use of reflectorized name markers on the crossroad on both sides of the road, (2) use of two signs similar to the SR-SR (state route-state route) junction sign, one sign 900 feet and a second sign at 500 feet, (3) use of one mercury luminaire, or (4) use of one sodium luminaire. Accident data and driver velocity profiles could be studied in a subsequent two-year test period.

Wortman, R. H. & Lipinski, M. E. (1974). Rural at-grade intersection illumination. Urbana, IL: University of Illinois. (NTIS No. PB-234993/AS).

Rural intersections in Illinois were examined as the basis for determining the effectiveness of fixed illumination. Safety was the primary design concern. Accidents at the existing intersections were evaluated, and a predictor of accident reductions due to illumination were developed which are based on the ratio of night accidents to total accidents. For a comprehensive intersection lighting program, priorities for lighting may be established by ranking the intersections based on the greatest probable or overall accident reduction.

Pavement Markings and Rumble Strips at Rural Intersections

Carstens, R. L. (1983). Safety effects of rumble strips on secondary roads. Transportation Research Record 926, pp. 12-15.

The use of rumble strips on paved rural secondary roads has often been suggested as a means of enhancing safety. *Rumble strips are used widely in some jurisdictions in advance of intersections controlled by stop signs.* A few jurisdictions also make use of rumble strips in advance of railroad grade crossings or at other locations thought to require supplemental warning devices.

No definitive guidelines or warrants have been developed to suggest locations at which rumble strips should be installed. Some of the research reported in the literature indicates that they can be effective in reducing accidents at some locations. On the other hand, several studies of rumble strip use have shown that the number of accidents does not change following the installation of rumble strips, although the number of certain types of accidents was reduced.

Research was undertaken to identify specific locations where rumble strips could improve safety on *rural secondary roads.* Factors that were considered include intersection sight distances, approach gradients, accident experience, and distance from the last stop. These factors were quantified through a field inventory of selected locations in Iowa where rumble strips had been installed. Analysis of the correlation of these factors with safety made use of the accident records available in Iowa through the accident location and analysis system (ALAS).

The goal of the research was to improve safety on rural secondary roads by recommending guidelines or warrants for the use of rumble strips. To accomplish this goal those factors were to be identified and quantified that could be used to distinguish between locations where rumble strips could be shown to be effective in reducing accidents and those locations where no beneficial effect on accident frequency was expected. The effect of each factor was to be quantified so that numerical warrants could be developed.

Of the 685 rumble strip installations on secondary roads in Iowa, 207 were selected for detailed study. At 88 locations a before-and-after comparison of accident experience was made because accident records were available for at least one full year both preceding and following the installation of rumble strips. (Accident records were available only for 1977-1980.) The accident experience at the 119 locations that have rumble strips installed before 1978 was compared with a sample of comparable locations that do not have rumble strips. No difference was found in the accident experience at secondary road locations between the periods before and after the installation of rumble strips. Secondary road locations that have rumble strips for longer periods experienced slightly more accidents than did comparable control locations that did not have rumble strips. Comparisons were made on both the total number of accidents and the number of accidents attributed to running a stop sign. Furthermore, no correlation could be demonstrated between the occurrence of accidents at the locations in the sample and the factors such as traffic volume, sight distance, and distance from the last stop.

The general conclusions reported were that the frequency of accidents at rural locations on secondary roads was independent of the presence or absence of rumble strips. No factors were identified that characterize locations where a reduction in accident frequency could be expected to result from the installation of rumble strips. Although secondary road intersections that have accident rates higher than 2.5 accidents per million entering vehicles (MEV) always showed a reduction in accident rate following the installation of rumble strips, this reduction would be expected by chance given the low traffic volumes and infrequent occurrence of accidents at these locations.

Hostetter, R. S. & Crowley, K. W. (1987). Information deficiencies on low-volume rural roads. Transportation Research Record 1106 (2), pp. 217-225.

The objectives of the study were to identify driver information needs on two-lane rural highways; identify potential driver problems that can be alleviated by way of low-cost information treatments; and develop a simple procedure that can be used by state and local personnel to identify information deficiencies on low-volume roadways for which adequate accident data are not available.

A vehicle equipped with sensors collected data that included information related to distance, steering wheel position, accelerator position, and brake pressure. This vehicle traveled strictly on two-lane rural roads for a total of 5000 miles, accumulated across 15 states.

Research efforts and discussion focused only on environmental features. Driver information was conspicuously absent from analysis. The analysis looked at:

1) terrain: flat, rolling, or mountainous

2) surface: paved or unpaved

3) road width: <20 ft, 20 ft, or >20 ft

4) curves: 6-10 degrees or >10 degrees; isolated and non-isolated

5) road signs: warning, speed, speed reduction, and stop/yield

6) bridges: narrow and sight-restricted

7) intersections: signal and sign controlled

Close attention was placed in examining what warning information through road signs or pavement markers were present in situations deemed as potentially hazardous by the authors. As an example in discussing rural intersections, the authors data base identified approximately 5600 intersections, out of which only 321 stop-controlled intersections and 64 signal-controlled intersections were present. This was broken down further into whether or not these specific intersections were sight-restricted and whether warning information, if any, was present at these sight-restricted areas.

Jarvis, J. R. (1990). Yellow bar markings: Their design and effect on driver behavior. 15th ARRB conference, Darwin, Northern Territory, 26-31 August, 1990. Proceedings. 1990. 15(7) pp. 1-22.

This paper examines the braking behavior of drivers on approach to isolated rural intersections in order to determine the effectiveness of yellow bar markings as a speed reducing device. Approach speed profiles were measured over some 450 m to examine in detail the effect of the markings. It was found that the markings do reduce approach speeds, including the speeds of these drivers identified as approaching in the highest speed ranges. The markings do not appear to reduce speed through manipulation of the driver's visual field as was thought; rather the effect of the markings is that of a very large hazard warning device which it is virtually impossible for the driver to disregard. On the basis of the study findings it is possible to propose an installation design which maximizes the effect of the device, given the better awareness of their method of operation that has been obtained.

Rockwell, T. H., Bala, K. N., & Hungerford, J. C. (1976). A comparison of lighting, signing, and pavement marking methods for detecting rural intersections at night. (Report No. OHIO-DOT-08-76 Final Rpt). Columbus, OH: Ohio State University, Department of Industrial and Systems Engineering.

-See "Lighting at Rural Intersections"

Taylor, W. C. (1967). Colored pavement materials. Ohio Department of Highways, (Report No. Hps-hpr-1/33).

This study was designed to evaluate the use of colored pavements as a control and guidance device through intersections with left-turn slots. Three rural intersections were selected for this study. In each of them at least one left-turn lane was covered with green asphalt and a painted channelizing island, forming the slot, was covered with yellow asphalt. Data on spot speeds, lateral placement of vehicles and flow patterns were collected before the installation of the colored asphalt, during the first month following the installation and 6 months after the installation. The only significant effect of the colored pavement was to discourage some drivers from crossing the channelizing island when entering the left-turn lane during the day. No significant influence was observed on the velocity of the vehicles in the through lane. No change could be detected on the drivers pattern of entry into the left-turn lane. It was also found that the colored asphalt had little effect on traffic flow patterns at night.

Zaidel, D., Hakkert, A. S., & Barkan, R. (1986). Rumble strips and paint stripes at a rural intersection. Transportation Research Record 1069, pp. 7-13.

A common cause of traffic accidents at low-volume rural intersections is failure by drivers on the minor approaches to stop or slow down sufficiently, as warranted. The current experimental field study compared the effectiveness of transverse paint stripes, such as those developed by the UK Transport and Road Research Laboratory, and similarly placed rumble strips in inducing drivers to reduce speed and stop at intersections. The experiment was conducted on the two minor approaches to the same four-way rural low-volume intersection. A geometrically converging pattern of 38 paint stripes, each 60 cm (2 ft) wide, were laid out over a distance of 270 m (886 ft) of one leg, and a similar pattern of rumble strips, 12 to 15 mm (1/2 to 5/8 in.) high, was laid on the opposite leg. A before-and-after and a crossover (after a year) experimental design were used. Speeds were monitored at eight point on each leg along 420 m leading to the intersection for a total of over 2,500 lead vehicles. The main results and conclusions are as follows: (a) paint stripes have only minor influence on driver behavior; (b) rumble strips lowered speeds by an average of 40 percent; (c) both treatments had a small positive effect on compliance rate; (d) with no pavement treatment, deceleration began at 150 m (492 ft) and peaked within the last 60 m (197 ft); (e) with rumble strips, most of the deceleration took place before the vehicle passed the first strip, followed by an additional deceleration within the last 60 m (197 ft); (f) rumble-strip effects remained stable after a year; and (g) a 150-m (492 ft) treatment of 12-mm strips is long enough to produce the positive effects of rumble strips.

Sight Distance and Visual Field at Rural Intersections

Cielecki, A., & Wieckowski, M. (1993). Selected factors influencing vehicle speeds as observed on two-lane rural roads in Poland. Highways. Proceedings of seminar B held at the PTRC European Transport, Highways, and Planning 21st Summer Annual Meeting (September 13-17, 1993), UMIST. Volume P364. 1993. pp. 217-232.

Research conducted on vehicle travel speeds on long road sections was carried out in 1987-91 by a team at the Warsaw University of Technology. The research which was sponsored by the General Directorate of Public Roads focused on two-lane roads which form the majority (92.5%) of rural national roads in Poland. *The aim of the research was the confirmation of an assumption that vehicle speeds depended not only upon road factors and vehicle stream factors but on road environment factors as well.* Development of equations expressing the influence of the above factors was a practical goal of the research. A data base for the development of those equations consisted of results of field observations conducted on 81 road stretches around Poland, each of them 2 to 20 km long. In total, speeds of 150,000 vehicles were recorded during 216 measurement periods lasting from 1.5 to 5 hours each. The paper deals in general with the speed/flow relationship as found during the research mentioned above. In particular, variability of that relationship is reported and an attempt to explain the variability with the influence of selected factors is made. Three groups of factors were considered in the research and part of them are included in the paper: traffic flow factors (e.g., directional split of traffic and flow composition), road factors (e.g., functional class, horizontal and vertical alignment characteristics, cross section type), and road environment factors (e.g., percentage of built-up areas, intersection density, severity of speed limits, degree of surrounding area urbanization and its tourist attractiveness). Many of the factors listed above are key factors taken into account by road network planners and designers during the decision making process. Knowledge of magnitude and the relative importance of separate factor effects seems very important for the economics of projects and safety of traffic.

Fambro, D. B., Urbanik, T. II, Hinshaw, W. M., Hanks, J. W. Jr., Ross, M. S., Tan, C. H., & Pretorius, C. J. (1989). Stopping sight distance considerations at crest vertical curves on rural two-lane highways in Texas. Final report. (Report No. TX-90/1125-1F). Texas State Department of Highways & Public Transportation, Transportation Planning Division.

Rehabilitating or upgrading existing two-lane roadways sometimes involves design decisions concerning improved vertical alignment and roadway cross section. These decisions are especially critical whenever the existing alignment does not meet current standards. In order to make these decisions in a cost-effective manner, the safety and operational effects of alternative crest vertical curve designs must be known. This study attempted to quantify those effects. In summary, the study concluded that the relationship between available sight distance on crest vertical curves and accidents is difficult to quantify; that the AASHTO stopping sight distance model is not a good indicator of accidents on two-lane roads; and that when there are intersections within the limited sight distance portions of crest vertical curves, there is a marked increase in accident rates. There was also no definitive relationship between available sight distance and operating speed on crest vertical curves.

Gattis, J. L. (1992). Sight-distance design for curved highways and tangential intersections. Transportation Research Record 1356, pp. 20-27.

The intersections created by the projection of a minor road from the tangent of a major road at a curve allow drivers to make an unusual form of left-turn movement and engender some operational patterns that may lead to difficulties in assigning right-of-way. These curved-tangential intersections appear to be more common on secondary or local rural roads, but they are not confined to those settings. Special design issues may arise at these skewed intersections at the beginning or end of the curve. Horizontal sight restrictions and middle ordinate values that would define an adequate line of sight through a curve are considered. At locations where curved roadways intersect with tangential roadways, using stopping sight distance alone to evaluate the adequacy of sight distance around the curve does not appear to be sufficient; a sight distance adequate for stopping may not satisfy intersection sight needs. Current intersection sight-distance design criteria may not fully address the operational behaviors found at these curved intersections. After relevant issues and special needs are considered, conceptual design criteria for intersections of curved roadways with projecting tangential roadways are developed. An example application of the method indicated that this intersection type needs a much larger roadside area clear of sight obstructions than that required solely by criteria for stopping sight distance. These intersections with projecting tangential roads at curves will require more attention when new projects are designed and when old roads are retrofitted.

Hoban, C. J. (1988). Selecting appropriate geometric standards for rural road improvements. Compendium of Technical Papers: ITE 58th Annual Meeting, September 25-29, 1988, Vancouver, British Columbia, 1988, pp. 332-40.

This paper reviews the types of improvements which are routinely considered for rural roads, and the issues which need to be assessed in evaluating options and developing standards. This leads to a consideration of what types of information are required, and what progress is being made in providing that information. Based on the evaluation parameters of "performance measures" and "road characteristics," we will consider "accidents" and "sight distances," (evaluation parameters are outlined in Table 1).

Regarding the performance measure of "accident rate," many road improvement proposals and the majority of road standards are largely concerned with road safety. This section considers how available knowledge can be used to assess the safety effects of various road geometry changes.

Sharp curves are associated with a higher accident rate, but research indicates that the effect is strongly influenced by alignment consistency. In other words, curves present a hazard to drivers when their design speed is more than 10-15 km/h below the 85th percentile traffic speed on the approach. This has two implications for road safety: 1) a series of low-standard curves will not present traffic safety problems as long as they are consistent, and 2) the estimation of approach speed is clearly important. This may be well above the notional design speed of the road, and may arise where two curves are separated by a long straight stretch.

Sight distances on curves and crests may not meet the design requirements for stopping in an emergency. This does not appear to be a major cause of road accidents, except where specific hazards exist, for example at *intersections* and driveways near a crest. As with horizontal curvature, moderate departures from standards do not appear to create safety problems. Again, a correct estimation of approach speed is important in this analysis.

Steep grades at above about 6 percent are also associated with a higher accident rate.

Because of the low traffic flows and long distances on rural roads, accidents at any one location are rare, and upgrading the alignment for safety reasons is often not economically justifiable. However there are a number of lower-cost treatments which greatly improve traffic safety: 1) delineation of curves, advisory speed signs and additional hazard warnings for curves well below the approach speed, 2) road widening on sharp curves and crests where *sight distance* is a problem, to provide more room for drivers to maintain control and maneuver around obstacles, and 3) improving the conspicuity of hazards such as *intersections,* and providing turn lanes to separate fast and slow vehicles.

These treatments are often cheaper and more effective than alignment changes designed to improve safety on rural roads.

Hostetter, R. S. & Crowley, K. W. (1987). Information deficiencies on low-volume rural roads. Transportation Research Record 1106 (2), pp. 217-225.

-See "Pavement Markings and Rumble Strips at Rural Intersections"

Lassarre, S., Lejeune, P., & Decret, J. C. (1991). Gap acceptance and risk analysis at unsignalized intersections. Intersections without traffic signals II. Proceedings of an international workshop, 18-19 July 1991, Bochum, Germany, 1991, pp. 258-69.

In order to explore the possibility to use the critical gap acceptance as an intermediate variable related to accident risk, an exploratory study has been designed including eight intersections on rural roads in the south of France. Traffic data are collected by video, and gaps on the principal roads are calculated by computer. Lag and gap distributions are estimated by a probit model. The median gap acceptance for the three maneuvers: crossing, right and left turn, is a significant discriminant factor between junctions, related to the *visibility distance.* Its variability according to different factors such as the age and the sex of the drivers, the speed of the approaching vehicle, the time of the day makes difficult a statistical accident analysis.

Leonard, J. D. II, Bilse, D. P., & Recker, W. W. (1994). Superelevation rates at rural highway intersections. (Report No. UCI-ITS-RR-94-1). Irvine, CA: California University, Irvine, Institute of Transportation Studies.

Standard superelevation rates on rural highways may be as high as 12% depending on the curve radius and design speed. One common design situation in rural areas occurs when a cross street intersects the main highway at a curved, superelevation section. In these cases, the highway designer may reduce mainline superelevation to facilitate vehicles turning onto the mainline from the intersecting cross street. This research investigated the relative impact of these reduced superelevation rates on large vehicles (e.g., trucks, tractor semi-trailer combinations, etc.), and includes 1) a review of accident records at similar sites in California, and 2) a dynamic analysis of large vehicle dynamics at alternate section curve designs. Results suggest that the practice of nominal reductions of superelevation rates on section curves accomplishes the desired goal of increasing the margins of safety on the cross street while producing only minor reductions to the failure speeds of vehicles traversing the rural highway.

Mounce, J. M. (1981). Driver compliance with stop-sign control at low-volume intersections. Transportation Research Record 808, pp. 30-37.

The objective of the research was to determine whether stop-sign control under designated conditions was fulfilling the requirements for application as specified by the Manual of Uniform Traffic Control Devices. This was to be demonstrated by the percentage of observed motorist violations and compliance, assuming that these measures reflect confirmation of need and respect afforded the public. The dependent variables of violation and compliance rate, conflicts, and accidents were compared in a factorial experimental design with the independent variables of major-roadway volume, minor-roadway sight distance, rural or urban traffic condition, and type of intersection geometry. Minor-roadway volume, signing control, roadway cross section, geography, and weather were all controlled variables. The results from 2830 observations at 66 intersections indicated that the violation rate decreased with increasing major-roadway volume and was significantly high ($p<0.001$) up to the average-daily-traffic (ADT) level of 2000 and significantly low ($p<0.001$) above the ADT level of 5000-6000. An interaction effect between major-roadway volume and minor-roadway sight distance results in a violation rate that was significantly higher ($P<0.05$) when sight was unrestricted than it was when sight was restricted. No conclusive relationships could be established between violations at low-volume intersections either in the rural-urban traffic environment or in the intersection geometry type that had three to four legs. No correlation was established between violation rate and accidents across all study variables; however, conflict rate was reduced at the upper and lower major-roadway volume levels. Mounce concluded that the operational effectiveness of low-volume intersections could be enhanced with no observed safety detriment by the application of no sign control below major-roadway volume of 2000 ADT, yield-sign control at major-roadway volume between 2000 and 5000 ADT, and, depending on minor-roadway volume, stop-sign control or signalization above 5000 ADT. These recommendations should be modified based on adequate sight distance; yet the determination procedure used in this study seemed insufficient and requires further revision. (Author)

Neuman, T. R., Glennon, J. C., & Leisch, J. E. (1983). Functional analysis of stopping-sight-distance requirements. Transportation Research Record 923, pp. 57-64.

The following may also apply to rural intersection research:

A basic highway design concept is that the driver should be provided sufficient visible length of highway to enable collision avoidance. Translating this concept to appropriate standards and criteria is an important design consideration. Given that the traffic engineering and design profession has focused on the traditional parameters associated with safe stopping-sight-distance (SSD) of eye height, object height, and perception-reaction time, it is believed that a broader perspective is now necessary when considering SSD requirements in order to accommodate such interests as the effects of small passenger cars on eye heights and SSD. A framework for evaluating such requirements is presented that is based on the functional aspects of SSD. SSD is described in terms of a) the types and frequencies of conflicts or events that occur on the highway, b) the geometry of the highway, c) the environmental conditions, and d) the variable performance capabilities of drivers and vehicles.

The concept of safe stopping-sight-distance as developed by AASHTO is reviewed and discussed. A functional SSD model is offered as a means of demonstrating shortcomings and inconsistencies in AASHTO design policy. In addition, the geometry of SSD is evaluated through the use of sight-distance profiles. Significant conclusions are presented that relate to SSD design values on horizontal curves and special problems with trucks on horizontal curves. The functional SSD model is helpful in understanding accidents at locations that have inadequate SSD.

Pant, P. D., Park, Y., & Neti, S. V. (1992). Development of guidelines for installation of intersection control beacons. Final report. Cincinnati, OH: Cincinnati University, Department of Civil and Environmental Engineering. (NTIS Report Number: PB93-216794).

-see "Traffic Signs at Rural Intersections"

Traffic Signals at Rural Intersections

Benioff, B., Carson, C., & Dock, F. C. (1980). A study of clearance intervals, flashing operation, and left-turn phasing at traffic signals. Volume 3. Flashing operation. Washington, D.C.: Federal Highway Administration. (NTIS No. FHWA-A-RD-78-48 Final Rpt).

This volume describes a study to develop recommendations for putting traffic signals on flashing operation during low volume periods. The study procedures included a literature review, a review of state laws, questionnaires to public officials and to drivers, analytical models of traffic flow, and field studies of accidents, conflicts, violations, speed and delay. Flashing yellow/red operation was found to be desirable for only a limited number of traffic and signal conditions. Flashing red/red operation was not found to be a desirable form of low volume traffic control, but it might be used for emergency operation of traffic signals.

Benioff, B., & Rorabaugh, T. K. (1980). A study of clearance intervals, flashing operation, and left-turn phasing at traffic signals, Volume 1. Summary report. Washington, D.C.: Federal Highway Administration. (NTIS No. FHWA-RD-78-48 Final Rpt).

This volume is a summary of three research studies on several aspects of traffic control to improve traffic operations and reduce accidents. The first study dealt with clearance intervals and more specifically with the effectiveness of a uniform yellow interval and all-red intervals. The second study addressed the question of whether traffic signals should be put on flashing operation during low volume periods. The third study considered signal phasing that allows vehicles to make left turns during both a protected (green arrow) interval and an unprotected (green ball) interval. Each study used a literature review, a review of state laws, questionnaires to public officials and to drivers, analytical models of traffic flow, and field studies to arrive at the recommendations.

Bonneson, J.A., McCoy, P.T., and Truby, J.E. Jr. (1993). Safety improvements at intersections on rural expressways: a survey of state departments of transportation. Transportation Research Record No. 1385, Intersection And Interchange Design, pp 1-47.

The current state of the practice of measures used to improve traffic safety at intersectons on rural expressways is described. This survey is based on the results of a survey of 49 state highway departments. In general, highway departments use their access control policy and variety of safety improvement measures at locations with poor safety records to minimize accident potential. The bulk of this document deals with the control of median openings that bridge between the two travel directions. Traffic signal control and flashing beacons are considered by 74% of the states for use at high accident rate locations. These results do not apply well to the type of rural intersections envisioned for study by this project.

Box, P. C. (1970). Intersections. Hwy Users Fdn for Safety & Mobility, Chapter 4.

Statistics show that intersectional accidents are a national problem in highway safety. About 24 percent of fatal accidents listed in a national tabulation were classified as occurring at intersections. In urban areas, approximately 41 percent of total accidents, and 39 percent of fatal accidents, were reported as intersectional. *In rural areas, the data showed that 27 percent of total accidents, but only 17 percent of fatal accidents, were at intersections.* Intersection elements which can be related to intersection accident rates include geometric layout and traffic controls. The basic intersection configurations include the L, Y, T, offset (jog), and cross-type. In a comparison of uncontrolled intersections in limited-access subdivisions, the cross-type was found to have 14 times the accident frequency as the T-type. Accident frequency for cross-type intersections in gridiron subdivisions was 41 times that of T-type. *The intersection shape was also found to be an important element in rural locations.* Cross-type intersection of Indiana County roads were found to experience an accident frequency four times that of T and Y-types. *Accidents were studied at low-volume rural intersections along Minnesota highways.* Traffic volume was found to have the greatest effect on accident frequency at cross-type intersections. These studies point strongly to the desirability of using T-type intersections for local streets in both urban and rural areas. An important design element involves provision for vehicles to make left turns off major routes. Left-turn channelization was installed at 40 unsignalized urban and rural intersections along California highways and accidents were found to be reduced significantly. *The types of intersectional controls included in the discussion are yield, two-way stop, four-way stop, and the traffic signal.* The yield sign is used to regulate traffic flow at low-volume intersections and at intersections where the accident rate is above the average of other intersections of the same type. Yield signs were found to be an effective measure at previously uncontrolled, isolated, urban, low-volume intersections in Berkeley, California, where accidents were reduced 44 percent at a total of 13 intersections, and in Seattle, Washington, where a 52 percent reduction at a total of 30 intersections was achieved. The findings of various researchers indicate that yield signs can be an effective control under many low-volume conditions. Several studies are reported on two-way stop control. The studies indicate for two-way stops that: 1) accident rates increased as cross-street volume increased, and 2) accident rate decreased as main street volume increased. For four-way stops, St. Paul and California studies support a conclusion that accident reduction can be effective if the installation is warranted by accident frequency and the volumes are moderate and balanced. Many studies are reported on the effect of traffic signals on traffic operations. *Studies on flashing beacons and directional signing are described.*

Bruede, U. & Larsson, J. (1988). Staggered 3-way junctions on rural roads: Effects on traffic safety. Linkoeping, Sweden: National Swedish Road & Traffic Research Institute. (NTIS No. PB88-167135/WTS).

The purpose of the investigation was to obtain deeper knowledge of the effect on traffic safety achieved through replacing 4-way junctions on rural roads by two staggered 3-way junctions. 253 pairs of existing staggered 3-way junctions have been studied. The data consisted of accidents reported to the police during the period 1977-1983. From the results obtained, the number of standardized accidents (taking into account both the number accidents and their seriousness) is reduced by 0-40% when a 4-way junction is replaced by two staggered 3-way junctions.

Cribbins, P. D. & Walton, C. M. (1970). Traffic signals and overhead flashers at rural intersections: Their effectiveness in reducing accidents. Highway Research Record, Hwy Res Board, 325, pp. 1-14.

-See "Traffic Signs at Rural Intersections"

Janssen, S. T. M. C. (1992). Safety of multi-level junctions on one-lane roads. Leidschendam, Netherlands: Institute for Road Safety Research SWOV. (NTIS No. PB94-202355-WTS).

The study tests the following hypotheses concerning the study of junctions on one-lane roads outside built-up areas in the Netherlands: 1) Level road junctions without traffic signals are less safe, as far as the ratio of daily intensities of motor vehicles on the side road and main road (IZ/IH) increases; this hypotheses is affirmed; 2) Multi-level junctions are safer than level road junctions; this hypotheses is affirmed, when: a) the ratio of IZ/IH is greater than 1/10; and b) there is an average use of the junction by 5,000-11,000 motor vehicles each day; 3) Level road junctions with traffic signals are safer than those without these signals; the results of this study show that this hypothesis should be rejected in general; and 4) Level road junctions are less safe, when they are located between multi-level junctions; it was not possible to test this hypothesis due to errors made during the inventory of data. It is concluded that multi-level junctions are safer than level road junctions with traffic signals.

Luyanda, F., Smith, R. W., Padron, M., Resto, P., & Gutierrez, J. (1983). Multivariate statistical analysis of highway accident and highway conditions. Mayaguez, PR: Puerto Rico University, Mayaguez. (NTIS No. PB84-165760).

The purpose of this study was to investigate statistical relationships between the major factors of rural highway conditions and the accident experience. The objective was to use multivariate statistical techniques including cluster, factor, discriminant, and regression analysis to relate traffic accidents to the traffic and roadway design characteristics of rural intersections and rural segments. The end result of the statistical analysis was a set of discriminant analysis models which provide the best linear combination of variables to distinguish between high accident frequency and low accident frequency locations for three different intersection types and three segment types.

Peterson, A. (1993). Experience with the LHORVA strategy for traffic signal control of isolated intersections. Expert workshop on congestion management, Barcelona, March 29-31, 1993 at the Jefatura Provincial De Trafico, Vol 1, 1993.

This paper outlines the LHORVA technique, developed in Sweden for traffic signal control of isolated intersections, and discusses its traffic safety and priority functions. LHORVA's basic principle is to solve traffic safety and service level problems at rural intersections by inexpensive urban traffic control measures like traffic signals and roundabouts. A development project was set up, aiming to: 1) use the advantages of signal control, especially its reduction of accidents at intersections; 2) reduce the risks of rear-end collisions and red-light infringements; 3) create a signal control technique that is similar to control by yield regulations during off-peak periods; 4) promote a technique for differentiated priority for traffic on primary roads. Rear-end collisions and red-light infringements comprise 2/3 of all accidents at Swedish signal-controlled intersections. LHORVA has three components to reduce these risks: 1) traffic signal conspicuity; 2) incident reduction; 3) control of red-light infringements. LHORVA's "truck priority" function assigns priority to trucks or buses when required. It can operate on a passive level, mainly at low traffic flows, or at an active level, with a cyclic or acyclic signal sequence. The LHORVA project has been very successful.

Pline, J. L. (1988). Traffic control devices for low-volume, two lane roads. Compendium of Technical Papers: ITE 58th Annual Meeting, September 25-29, 1988, Vancouver, British Columbia, 1988, pp. 326-29.

A review of the U.S. Manual on Uniform Traffic Control Devices (MUTCD) relative to traffic control devices for low volume residential streets or local and rural roadways is of concern since the MUTCD does not directly address these types of roadways. The MUTCD does cover expressways, freeways, motorist service signing, civil defense, traffic signals and islands, all of which usually have no applicability to the local or rural road systems. However, the MUTCD does state it is applicable to

all streets and highways open to public travel regardless of type or class or jurisdiction. A menu of traffic control devices is provided in the MUTCD to be used if they are deemed necessary. Additionally, the MUTCD-General Provisions indicates that it provides standards for installation but does not create a legal requirement for installation. Accordingly, it might be safe to assume that traffic control device installation is not legally required on some low volume roads.

The motorist needs must be considered although they have not been adequately delineated for low volume roads. Frequently, the occurrence of an accident signifies that there should have been additional traffic control to advise, warn or regulate the drivers so they could have avoided the accident. The problem confronting local jurisdictions is how much signing and striping is needed to fulfill the MUTCD requirements, satisfy the motorist needs, avoid liability lawsuits and still be within the practical economic constraints of local government.

A number of states have addressed this problem by developing traffic control handbooks for low volume roads (see article for listings). However, these publications are only guidelines and have no legal adoption in that particular state or nationally. The states by law must adopt a manual on traffic control devices and they have substantially adopted the MUTCD. This leaves some question on the legality of the handbooks and their application as standards of practice.

The Institute of Transportation Engineers (ITE) did establish a technical committee titled 4A-27, "Traffic Control Devices on Low Volume Roads," in 1986 to address the problems noted above. Their objective was to critique existing state handbooks and develop recommended practices or an ITE handbook for low volume roads. The committee concluded to develop a short guide manual which complies with the MUTCD and discusses the application of traffic control devices on low volume roads. Based upon liability concerns, motorist needs and lack of direction for local jurisdictions, a four-stage process is recommended to undertake the problem. The topics briefly discussed are: 1) Criteria for low volume roads, 2) MUTCD revisions, 3) Application guidelines, and 4) Low volume road (LVR) handbook on traffic control devices.

Troutbeck, R. & Akcelik, R. (1994). Capacity research and applications in Australia. Traffic engineering and control, 1994/11, 35 (11), pp. 624-8.

This report presents a summary of recent capacity research undertaken at Australian universities, state road and transport authorities, and the Australian Road Research Board. The subjects covered include *signalized intersections*, roundabouts, other *unsignalized intersections*, vehicle-actuated signals, dynamic control of *traffic signals*, saturation flows, pedestrian-vehicle interaction, paired intersections, arterial road performance, network analysis, shopping center design, *rural roads* and freeways, fuel consumption and emissions, accidents at roundabouts, *intersection design* packages and software integration.

Zhang, X. (1988). The influence of partial constraint on delay at priority junctions. *Intersections without traffic signals,* 1988, pp. 180-196. Springer-Verlag, Berlin New York, U.S.A.

This paper presents a simulation model, in which delays at priority junctions can be determined under conditions of partially constrained, non-stationary traffic of varying intensity. Traffic is "partially constrained" if not all drivers can maintain their desired speeds, due to the presence of other vehicles, and "nonstationary" if its intensity varies with time. Within this context, any possible traffic streams at intersections of two-lane roads can be considered. *The method developed here will contribute to the decision whether to introduce traffic signals at an intersection.* Simulation has been used to evaluate the influence of partial constraint on delay; some example simulation results are discussed in order to provide a first impression of the traffic intersection, for the example of a priority junction of two two-lane rural roads. The following conclusions were reached: 1) under partially constrained traffic conditions in the major road, the average delay decreases significantly in comparison to free-flow major stream traffic, whereas partial constraint on minor streams has insignificant effects on average delay; 2) a rapid increase in average delay compared to free-flow traffic occurs only under conditions of higher minor road traffic volume for partially constrained nonstationary traffic; 3) for constant total traffic volume on the major road, delay is reduced as the difference of directional traffic volume decreases.

Traffic Signs at Rural Intersections

Bandyopadhyay, A. K. (1976). Evaluation of traffic control devices at intersections of low-volume roads and streets. (Report No. CE-TRA-76-2 Intrm Rpt). Lafayette, Indiana: Purdue University, Transportation and Urban Engineering.

The purpose of this study was to evaluate the performance of two-way STOP, YIELD and no control intersections at low volume roads in Indiana. The evaluation parameters included travel time through intersection, number of stops and conflict as well as occurrence of accidents at intersections. In addition, operating costs of vehicles for traveling through different types of controls were also estimated. A total of 53 intersections from different low volume roads were studied. It was observed that the mean travel time through STOP controlled intersections was significantly higher than that through YIELD controlled intersections. Mean travel time through unsigned intersections was significantly less than that through YIELD controlled intersections. It was further observed that on an average 31.4 percent of vehicles failed to stop at STOP controlled intersections. The operating cost through STOP controlled intersections was considerably higher than that through YIELD controlled intersections. However, the difference in operating costs between YIELD and uncontrolled intersections was not significant. On the basis of accident records for the last three years, the author determined that there was no significant difference in the occurrence of accidents in the STOP, YIELD, and no control intersections. It appears that much improvement on the productivity of the highway system of Indiana can be achieved by

removing STOP signs or changing them to YIELD signs on those low volume intersections where sight distances are adequate. In this way, a considerable reduction in unnecessary time loss, stopping and slowing at intersections can be achieved without affecting intersection safety.

Botha, J. L., McKean, P., & Cheng, W. (1994). Acceleration lanes for turning vehicles at rural intersections. Washington, D.C.: Federal Highway Administration. (Report No. FWHA/CA/TO-95/08).

Guidelines for the implementation and design of acceleration lanes for right- and left-turning traffic, *at stop-controlled intersections on rural high-speed highways*, are presented. The guidelines are based on a review of existing practice and an operational as well as a safety analysis at intersections with and without acceleration lanes.

Bruede, U., & Larsson, J. (1992). Conversion from stop to yield. Effect on the number of personal injury accidents. Linkoeping, Sweden: National Swedish Road & Traffic Research Institute. (NTIS Report Number: VTI/MEDDELANDE-695).

The before-and-after study comprises 257 junctions, most of which are in rural areas. Only personal injury accidents with simultaneously involved motor vehicles from both the major and minor roads have been analyzed. After a change from stop to yield, the above type of personal injury accidents increased by approximately 30%. The increase is not different from zero at a level of significance close to 10%.

Corder, L. (1948). Means of evaluating intersection improvement. Highway Research Abstracts, Hwy Res Board, Vol. 18, No. 3, pp. 15-22.

In rural areas intersections below the stop-and-go signal level have generally been treated haphazardly, and with a startling lack of uniformity. The object of this study, therefore, is to evaluate various methods of control for low-volume intersections, and to express graphically empirical warrants for their use.

A number of generally used intersection treatments have been selected and placed, in what seemed to be their proper order of importance. These treatments involve the use of *2-way and 4-way stop sign installations*, overhead suspension type *flashing beacons* and part time stop-and-go signals. They are intended for use singly or in combination, and comprise a group of proposed traffic controls.

In evaluating these controls two major warrants have been considered: "vehicular volume" and "interruption of continuous traffic". Additional consideration has been given to the relative percentages of vehicular traffic volume originating on each of the two intersecting routes.

Graphically represented warrants for each of the proposed traffic control treatments have been drawn, in chart form, for quick reference. Since the bases for establishing and limiting such warrants

have been determined from somewhat limited factual and scientific data, they should be considered merely as suggestions and not as ultimate answers. Nevertheless, results from such installations have been promising.

The method outlined is presented to further stimulate thought and effort in the low volume intersection field.

Cribbins, P. D. & Walton, C. M. (1970). Traffic signals and overhead flashers at rural intersections: Their effectiveness in reducing accidents. Highway Research Record, Hwy Res Board, Vol. 325, pp. 1-14.

A large percentage of vehicular traffic travels over rural roadways. As a whole, rural roadways, highways, and intersections have been overlooked. Unfortunately, records show that accident experience at rural intersections of low-volume highways is disproportionately high for the volume accommodated and the need to devote attention to this problem is long overdue. There are several conventional traffic control measures that can be used in an attempt to reduce the accident cost at these locations; however, there is no guarantee that the treatment will have a positive effective on the accident experience. A need exists to determine which treatment optimizes accident reduction so that the best treatment for specific conditions can be implemented. It is a well-documented fact that certain traffic control measures actually cause an increase in specific types of accidents or in the severity of the accident. Therefore, it appears that the impact of various traffic control treatments in use at high-accident locations should be evaluated prior to their installation.

Few factual data are available regarding the relative merits of specific minor improvements, such as flashing beacons and traffic signals at rural intersections. The expenditures required to install such devices are normally relatively small, but the benefits that can be derived in the form of increased safety for the road user can be very significant. Many traffic engineering departments with highway agencies in the various states are installing traffic control devices at high-accident locations on rural highways without being able to predict subsequent accident reduction, if any, that can be expected. Traffic control measures should, of course, not be accepted as a panacea for all types of traffic intersection problems; indeed, improper or indiscriminate installation can sometimes create a less efficient and more dangerous condition than previously existed.

The warrants presently cited in the Manual on Uniform Traffic Control Devices (for 1961) for flashing beacons and traffic signals are general and are, at best, only a guide in relation to installation at high-accident locations on rural intersections. To avoid unwarranted use of the devices and a resulting reduction in efficiency, there is a real need for more specific guidelines that will assist the practicing engineer in evaluating the intersection and in selecting corrective measures that can be applied with reasonable promise of success. It is the primary objective of this study to measure the effectiveness of traffic signals and overhead flashers in reducing traffic accidents on low-volume, high-speed rural highway intersections.

Initially, all flashers and signal devices installed in North Carolina since 1965 were considered, but subsequent investigation and a more restrictive definition of a test site reduced the original inventory from 72 flashers and 153 signals to 14 flashers and 19 signals. A before-and-after study was made encompassing minimum time frames of 1 year prior to and immediately after installation of the device. Accident exposure during the two periods was compared on the basis of exposure rates, severity indexes, and equivalent property damage only accidents and rates. It was determined that the equivalent property damage only rates, rather than the normally used accident rate, was the most reliable and significant indicator of accident consequences. If all other factors were constant, any significant change in rate after installation of the control device could be attributed to the presence of the device. The relationship between the installation of signals and equivalent property only rate reduction was not statistically significant except for undivided highway intersections. The relationship between the relationship of a flashing beacon and rate reduction was found to be statistically significant at the one percent confidence level.

Hostetter, R. S. & Crowley, K. W. (1987). Information deficiencies on low-volume rural roads. Transportation Research Record 1106 (2), pp. 217-225.

-See "Pavement Markings and Rumble Strips at Rural Intersections"

Lassarre, S., Lejeune, P., & Decret, J. C. (1991). Gap acceptance and risk analysis at unsignalized intersections. Intersections without traffic signals II. Proceedings of an international workshop, 18-19 July 1991, Bochum, Germany, 1991, pp. 258-69.

- See "Traffic Signs at Rural Intersections"

Lum, H. S., and Parker, Jr., M. R. (1983). Intersection control and accident experience in rural Michigan. ITE Journal, 53 (5), pp. 27-29.

The basic purpose for Stop sign control of an intersection is to provide orderly and safe movement of traffic through the intersection. Stop signs provide orderly movement by assigning the right-of-way and safe movement by warning motorists of a hazardous situation. In most cases, low-volume intersections are Stop controlled rather than uncontrolled or Yield controlled. It is estimated that 95 percent of nonsignalized low-volume intersections in Texas are Stop controlled. Data extracted from an ongoing Federal Highway Administration (FHWA) contract "Geometric Treatments for Reducing Passing Accidents at Rural Intersections on Two-Lane Highways" showed that 96 percent of 885 randomly sampled nonsignalized intersections were Stop controlled. It is hard to believe that such a high percentage of low-volume intersections are unduly hazardous or that most motorists approaching such intersections do not know who has the right-of-way. Regardless of the type of control, the driver on the minor road must not enter the intersection when a vehicle on the major road is close enough such that entry by the driver on the minor road would "constitute an immediate hazard."

A study has been conducted in selected counties of Texas, New York, and Florida to investigate the use and need for Stop control at low-volume intersections. The findings of the study were as follows: 1) Stop signs do not reduce accident experience at low-volume intersections, and 2) Stop signs are being used even where there is adequate sight distance. However, the sample size in this study was rather small - only 140 intersections.

This article reports on a similar, but more extensive, study conducted in rural Michigan. In the Michigan study almost 900 intersections were examined based on type of control and related accident experience.

Lyles, R. W. (1980A). An evaluation of signs for sight-restricted rural intersections. Orono, Maine: Maine University, Social Science Research Institute. (NTIS Order No. PB80-203755).

The report reviews an experiment undertaken to examine the effectiveness of six signs and sign sequences for warning motorists of a hazardous or sight-restricted intersection ahead in a rural two-lane situation. Signs examined ranged from the standard intersection symbol warning sign (cross) to vehicle actuated signs with flashing warning lights. Data collected during the experiment included: speeds of motorists as they approached and passed through test intersections (sometimes with a vehicle stopped on the side road); vehicle classification and registration information; and, for selected sign/site combinations, survey information for some motorists regarding their recollection of and reaction to the tested signs. The principal findings were that emphatic type signs (warning sign with flashers or a regulatory sign) caused drivers to reduce their speed by about 5 k.p.h. (3 m.p.h.) more than standard warning signs, and to increase driver awareness (as measured by sign recall and noticing of a side road vehicle) by a factor of approximately two. Familiarity with a test site, type of vehicle being driven, and sex did not have a significant effect on drivers' reactions to the various sign/site conditions.

Lyles, L. W. (1980B). Evaluation of signs for sight-restricted rural intersections. Executive summary. Orono, Maine: Maine University, Social Science Research Institute. (NTIS Order Number: PB81-153553).

The report summarizes the results of an experiment sponsored by the Federal Highway Administration and carried out at the Maine facility, which examined the effectiveness of several alternative sign configurations (traditional warning, warning signs with lighted beacons, and regulatory signs) for warning motorists of a hazardous intersection ahead in rural two-lane situations. The principal findings were that enhanced warning signs (i.e., with flashing beacons) and the regulatory speed zone configuration were consistently more effective than basic non-enhanced warning signs relative to making motorists aware of the situation and slowing them down. The conclusions were based on both actual speed decreases at the intersection and motorists perception (from a survey) of the situation.

Lyles, L. W. (1980C). Evaluation of signs for hazardous rural intersections. Transportation Research Record 782, pp. 22-30.

An experiment to evaluate the effectiveness of several different signs (or sign sequences) in informing motorists of an intersection on the road ahead in rural two-lane situations is described. Typically, intersections that would require these treatments would be those where stopping sight distances for prevailing speeds are inadequate. As random motorists approached and passed through two test intersections, they were "tracked" by means of a data-collection system that collected time intercepts of motorists at 60-m (200-ft) intervals in the vicinity of the intersection. These data were supplemented by manually collected vehicle registration and classification data and, in selected instances, survey data collected from motorists who passed through the intersections. The results essentially showed that a regulatory speed-zone configuration and lighted warning signs were more effective than more traditional unlighted warning signs in reducing motorists' speeds in the vicinity of the intersection and increasing their awareness of both the signs and conditions at the intersection

McCoy, P. T., & Hoppe, W. J. (1986). Traffic operations study of the turning lanes on uncontrolled approaches of rural intersections. Transportation Research Record 1100, pp. 1-9.

A time-lapse film study of the traffic operations on 14 intersection approaches on rural two-lane highways in Nebraska was conducted. The purpose of the study was to evaluate the safety effects of turning lanes on the uncontrolled approaches of intersections on rural two-lane highways. The turning lanes evaluated were left-turn, right-turn, and fly-by lanes. Traffic operations on the approaches with turning lanes to determine the safety effects of the turning lanes. The measures of safety effectiveness used in the study were (a) standard deviation of mean approach speed, (b) traffic conflict rate, (c) frequency of abnormal turning maneuvers, and (d) improper lane utilization. Lower values of these measures were assumed to be indicative of safer traffic operations. The results of the study indicated that the provision of turning lanes on uncontrolled approaches of intersections on rural two-lane highways improved the safety of traffic operations on these approaches, especially those without paved shoulders. It was also apparent from the results of the study that consideration must be given to the adequate design of these lanes, particularly left-turn and fly-by lanes, in order to eliminate their improper use and encroachments by turning vehicles on adjacent through lanes, which negate the safety benefits provided by such lanes.

Mounce, J. M. (1981). Driver compliance with stop-sign control at low-volume intersections. Transportation Research Record 808, pp. 30-37.

-See "Sight Distance at Rural Intersections"

No author given. (1983). Four-way stop signs cut accident rate 58% at rural intersections. ITE Journal, Vol. 54, No. 11, pp. 23-24. Reprinted from *Better Roads*.

Accident rates declined by an average of 50% at 10 rural Michigan intersections following a replacement of 2-way stop signs with 4-way stop signs. This article reports the results of a study which compared data for each of these intersections prior to and following the switch to 4-way stop signs. The data included: accident experience (accident rates and costs), vehicle operating costs, travel time, fuel consumption, and vehicle emissions.

Pant, P. D., Park, Y., & Neti, S. V. (1992). Development of guidelines for installation of intersection control beacons. Final report. Cincinnati, OH: Cincinnati University, Department of Civil and Environmental Engineering. (NTIS Report Number: PB93-216794).

The characteristics of traffic flow at rural, low-volume intersections controlled by stop signs and by intersection control beacons in conjunction with stop signs were examined. The measures of effectiveness included vehicular speeds, stop sign violations, service delay, gap acceptance, and accidents. In addition, the effects of sight distance and traffic volume were considered. The study found that intersection control beacons generally reduced speeds in the major directions, particularly at intersections with inadequate sight distance. The intersection control beacons had, in general, little or no impact on accepted or rejected gaps. A large portion of drivers (40 to 90%) violated stop sign laws by not completely stopping at the intersections. The intersection control beacons were not necessarily effective in reducing stop sign violations or accidents. Guidelines for installation of intersection control beacons have been recommended.

Rockwell, T. H., Bala, K. N., & Hungerford, J. C. (1976). A comparison of lighting, signing, and pavement marking methods for detecting rural intersections at night. (Report No. OHIO-DOT-08-76 Final Rpt). Columbus, Ohio: Ohio State University, Department of Industrial and Systems Engineering.

-See "Lighting at Rural Intersections"

Stammer, R. E. (1994). Highway capacity implications as the U.S. driving population ages. Proceedings of the second international symposium on highway capacity, Vol 2, 1994, pp. 555-65.

The purpose of this research is to investigate collectively both the highway capacity and analysis implications resulting from an older driving population in the U.S. Highway capacity considerations and the importance of a micro-level understanding of increasing numbers of older drivers are discussed first. A demographic analysis concludes that at least a 6.7 percent increase in drivers 65 or older by the second or third decade of the 21st century is likely. A brief synopsis of why an increase in older drivers will cause certain highway capacity impacts and how increased delays occur is presented next. The major portion of this paper reviews highway capacity analysis considerations from both theoretical and applied example perspectives. Highway capacity analyses and resulting implications are studied for general roadway segments, two-lane and multi-lane rural roads, weaving areas, ramps, for both *unsignalized and signalized intersections*, and when incidents/accidents occur. The major contributions of this research are increased awareness of highway capacity analysis issues, data needs, examples of highway capacity implications, and consideration of system modifications that may be required to accommodate increasing numbers of older drivers.

Stockton, W. R., Brackett, R. Q, & Mounce, J. M. (1981). Stop, yield, and no control at intersections. College Station, TX: Texas A&M University, Texas Transportation Institute. (NTIS No. PB82-117649).

Observations and measurements were made at 140 low volume intersections in three regions of the United States. Control type, region, location (urban/rural), geometry (3-leg/4-leg), major roadway volume and sight distances were examined to determine their individual and interactive effects on driver behavior, accident experience and travel time. Region, location and geometry had an essentially negligible effect on safety and operations at low volume intersections. Increasingly restrictive control did not result in reductions in accident experience. STOP control produced the highest travel times and thus the highest total road user costs; YIELD control resulted in the lowest road user costs of the three control types considered.

Appendix B

Survey of Opinions on Traffic Control Signals for Rural Intersections

Introduction to Appendix B

This appendix contains a copy of survey questionnaire followed by the results of the survey.

Survey of Opinions on Traffic Control Signals for Rural Intersections

The Minnesota Department of Transportation and the University of Minnesota are studying the use of flashing lights at rural intersections. We hope to find a design for the use of flashing lights which improves safety. Please help us by answering the following questions.

Definition of a Rural Intersection

A rural intersection is characterized by low traffic volumes in an area that could not be described as urban. There are no red-yellow-green traffic control signals. One of the roads, the main road is a through road. The intersecting side road has a stop sign. The roads meet at approximately right angles to each other. We have all driven through many such intersections and we are probably more familiar with some than with others. The following questions are about you and your experience with such intersections.

Information about Participants

Age in years _____.

Gender _____. (M or F)

I have lived in the United States for _____ years.

I drive about _____ times per week.

I drive about _____miles per week.

I have difficulty driving at night. _____(Y or N).

Glare from approaching headlights is a troublesome part of night driving. _____(Y or N).

My general familiarity with rural intersections is _____(High, Medium, Low)

I have seen flashing lights at or near rural intersections _____(Often, Occasionally, Seldom)

Intersection Descriptions and Photograph Presentation

The following intersections described and illustrated with pictures (pictures were not included in this appendix) will form the basis for the next group of questions:

Main Road (No Stop Sign)	Side Road (Stop Sign)
No Flashing lights	No Flashing lights
Flashing yellow light at the Warning Sign	Flashing red light at Stop Sign
Overhead light flashing yellow	Overhead light flashing red
Both Warning Sign and Overhead flashers	Both Stop Sign and Overhead Flashers

We will now show you pictures of each of the above approaches to rural intersections.

Driver Behavior

Please check all answers that apply.

1. How do you respond when approaching an intersection marked by a flashing yellow light located over the intersection?

a)____I slow by about 10-15 mph.
b)____I prepare to stop.
c)____I do not reduce speed but I am more cautious.
d)____I look for possible construction or other hazards.

2. How do you respond when approaching an intersection marked by a flashing red light located over the intersection?

a)____I slow by about 10-15 mph.
b)____I prepare to stop.
c)____I do not reduce speed but I am more cautious.
d)____I look for possible construction or other hazards.

3. How do you respond to the yellow flashing light at the Warning Sign when approaching the intersection on the Main road?

a)____I slow by about 10-15 mph.
b)____I prepare to stop.
c)____I do not reduce speed but I am more cautious.
d)____I look for possible construction or other hazards.

4. What influence do any of these flashing lights have on your behavior?

a)____No behavior change.
b)____I become more cautious.
c)____I reduce my speed.
d)____I look for possible construction or other hazards.

5. How often does a flashing red light above the stop sign increase the likelihood that you will come to a full stop at the stop sign?

a)____Always
b)____Hardly ever
c)____It depends on conditions.
d)____The flashing red light never influences me.

6. How does an overhead flashing red light compare to the flashing red light just above the stop sign in causing you to come to a full stop?

a)____Overhead is better
b)____Above stop sign is better
c)____About equal
d)____It doesn't matter

7. Do you think that familiarity with the intersection makes a person:

a)____More cautious
b)____Less cautious
c)____Has no effect
d)____Depends on conditions

8. Compared to the warning sign without a flashing light, does a flashing light at the warning sign cause you to:

a)____Reduce speed
b)____Stop
c)____Be more alert
d)____No effect

9. Compared with an intersection without a flashing light does a yellow overhead flashing light at an intersection cause you to:

a)____Reduce speed
b)____Stop
c)____Be more alert
d)____No effect

10. Do the flashing lights associated with intersections have a greater effect on your driving behavior at night?

a)____Night and day effects are the same
b)____Daytime effects are greater than nighttime
c)____Nighttime effects are great than daytime
d)____Flashing lights never have an effect

11. How often do the flashing lights associated with rural intersections confuse you?

a)____Never
b)____Always
c)____Only at night
d)____Depends on conditions

12. When you are approaching the intersection and the overhead light is flashing red, how often did you think that this light would also be flashing red for the traffic on the intersecting road and that this was a four-way stop intersection?

a)____Most of the time
b)____Some of the time
c)____Never
d)____Depends on conditions

Specific Questions about Rural Intersection Safety

For the following multiple choice questions, **please check all choices that apply.**

13. When approaching an intersection when driving on a main road one should:

a)____Slow before entering the intersection.
b)____Stop and wait for traffic at the intersecting road to clear.
c)____Continue through the intersection without slowing.
d)____Other, please explain.

14. As you approach the intersection when driving on the side road you should:

a)____Slow before entering the intersection.
b)____Stop and wait for traffic on the main road to clear.
c)____Continue through the intersection without slowing.
d)____Other, please explain.

15. As you approach an intersection when driving on a main road, you notice a diamond-shaped, yellow sign with a large black cross on it:

a)____This sign only warns that there is an intersecting road a short distance ahead.

b)____This sign means that you should reduce your speed as you approach the intersection.

c)____This sign warns that traffic at the intersecting road ahead does not stop, so you should be careful.

d)____This sign means that traffic at the intersecting road must stop so that you need not reduce your speed.

16. As you approach an intersection when driving on a main road you notice a diamond shaped, yellow sign with a large black cross on it. Just above this sign is a flashing yellow light:

a)____This sign with a flashing yellow light warns that there is an intersecting road a short distance ahead. The flashing light only adds emphasis.

b)____This sign with a yellow flashing light means that you should reduce your speed as you approach the intersection.
c)____This sign with a flashing yellow light warns that traffic at the intersecting road ahead does not stop, so you should be careful.
d)____This sign with a flashing yellow light means that traffic at the intersecting road must stop so that you need not reduce your speed.

17. As you approach an intersection when driving on a main road you notice a diamond shaped, yellow sign with a large black cross on it. There is no flashing yellow light above this sign but hanging over the intersection ahead there is a flashing yellow light:

a)____This overhead flashing yellow light only warns that there is an intersecting road at this location.
b)____This overhead flashing yellow light means that you should reduce your speed as you approach the intersection.
c)____This overhead flashing yellow light warns that traffic at the intersecting road ahead does not stop, so you should be careful.
d)____This overhead flashing yellow light means that traffic at the intersecting road must stop so that you need not reduce your speed.

18. As you approach an intersection when driving on a main road you notice a diamond shaped, yellow sign with a large black cross on it. There is a flashing yellow light above this sign and hanging over the intersection ahead there is also a flashing yellow light:

a)____The warning sign and the flashing yellow lights at both locations mean that there is an intersection ahead that is especially dangerous and that you should reduce speed and be especially careful.
b)____When flashing yellow lights are at both the warning sign and overhead at the intersection this means that cross traffic does not stop and you should be especially careful.
c)____When flashing yellow lights are at both the warning sign and overhead at the intersection this means that cross traffic must stop and you need not reduce your speed.
d)____When flashing yellow lights are at both the warning sign and overhead at the intersection this is just to make sure that you know that there is an intersection ahead.

19. As you approach an intersection when driving on a main road you notice that there are no flashing lights to be seen, only the warning sign:

a)____This lack of flashing lights means that there is rarely traffic on the side road and you need not reduce speed.
b)____This lack of flashing lights means that neither main nor side roads have stop signs.

c)____This lack of flashing lights means that you need only heed the warning sign and exert normal caution.
d)____ This lack of flashing lights means that side road traffic must stop.

20. As you approach an intersection when driving on a side road you see the stop sign in the distance. There is a flashing red light above this sign and hanging over the intersection there is a flashing red light:

a)____The flashing red lights at both the stop sign and overhead locations mean that there is an intersection ahead that is especially dangerous and that you should be sure to stop and look both ways before proceeding.

b)____When flashing red lights are at both the stop sign and overhead at the intersection this means that cross traffic also has a stop sign and you should behave as you would at any 4-way stop.

c)____When flashing red lights are at both the stop sign and overhead at the intersection this means that cross traffic does not stop.

d)____When flashing red lights are at both the stop sign and overhead at the intersection this is just to make sure that you know that there is an intersection ahead at which you must stop.

21. As you approach an intersection on a side road you notice a stop sign. There are no flashing lights visible at this intersection.

a)____This means that the intersection ahead has a 4-way stop.

b)____This means that there are no stop signs on the main road.

c)____The absence of flashing lights means that it is unlikely that there will be traffic coming on the main road.

22. As you approach an intersection on a side road you see flashing red lights above the stop sign but no flashing lights overhead at the intersection.

a)____The flashing red light above the stop sign warns you to stop before proceeding into the intersection.

b)____Because of the flashing red light over the stop sign, you know that there is a 4-way stop at this intersection.

c)____Since there is no overhead flashing light, you know that this is not a dangerous intersection and you do not need to come to a full stop but only look both ways.

d)____When flashing red lights are only at the stop sign this means that cross traffic does not stop.

General Questions

23. Do you behave differently when passing through a familiar rural intersection, on either the main road or the side road, than when passing through a similar intersection that is new to you?
___YES ____NO

If YES, explain the difference in your behavior.

24. Have you ever noticed anything which you consider dangerous or confusing about rural intersections? ____YES ____NO

If YES, list the dangerous or confusing conditions.

25. What suggestions do you have to improve safety at rural intersections?

Please list them.

Thank you very much for your help.

Results from

Opinion Survey on The Effectiveness of Flashers at Rural Intersections

Introduction

Over the summer of 1996, 144 Minnesota drivers were surveyed by mail by the University of Minnesota's Human Factors Research Laboratory (HFRL). Their opinions were sought about the use of flashing lights at rural intersections currently used statewide by the Minnesota Department of Transportation (MN/DOT). The survey questions addressed drivers' behavioral issues as well as interpretive issues of the various contexts and settings in which rural flashers are installed. Specifically, the survey topics were: general driver behavior, rural intersection safety, and side road driving. Main road driving questions were asked within the topic of general driver behavior.

The demographic information collected for our survey population of 144 was grouped into four categories: age, either young (18-35) or old (65 and above); gender, male or female; whether or not glare from approaching vehicles caused trouble driving ("Glare" or "No Glare"); and a rating of frequency of having seen flashers at rural intersections ("Often," "Occasionally," or "Seldom"). The total survey group consisted of 42% young drivers and 58 % older drivers. Of the young respondents, 52% were male and 48% female. The older group consisted of 57% male and 43% female respondents. The following tables present the complete demographic data and the results for each of the 22 survey questions. A discussion of the results follows. The survey form is Appendix A.

Results

Characteristics of the Survey Population

The characteristics of the population are summarized in Table 1.

Table B1. Characteristics of the Survey Population

Age Group	Total	Male	Female	Glare	No Glare	Have Seen Flashing Lights: Often	Occasionally	Seldom
Young	61	32	29	39	22	19	34	8
(18-35)	(42%)	(52%)	(48%)	(64%)	(36%)	(31%)	(56%)	(13%)
Old	83	47	36	44	39	11	30	42

(65+)	(58%)	(57%)	(43%)	(53%)	(47%)	(13%)	(36%)	(51%)
Total	144	79	65	83	61	30	64	50

Tables 2 - 4 show the results for each of the survey questions. For each question, respondents were asked to choose all answers that applied. Thus, percentages did not usually add to 100%.

Survey Responses

Table B2. Survey Responses to General Driver's Behavioral Questions

Question 1 Response to Overhead Yellow Flasher	Question 2 Response to Overhead Red Flasher	Question 3 Response to Yellow Flasher on Warning Sign
Young	Young	Young
62% Slow 10-15 mph	5% Slow 10-15 mph	61% Slow 10-15 mph
21% Prepare to stop	97% Prepare to stop	26% Prepare to stop
25% No reduction but caution	2% No reduction but caution	25% No reduction but caution
23% Look for hazards	8% Look for hazards	15% Look for hazards

Table B2 Continued

Old	Old	Old
61% Slow 10-15 mph	27% Slow 10-15 mph	59% Slow 10-15 mph
59% Prepare to stop	98% Prepare to stop	60% Prepare to stop
10% No reduction but caution	0% No reduction but caution	7% No reduction but caution
34% Look for hazards	20% Look for hazards	27% Look for hazards
Question 4	Question 5	Question 6
General Behavioral Influence of Flashing Lights	Red Flasher on Stop Sign Increases Likelihood of Full Stop	Overhead vs. Pedestal: Which Best Causes Full Stop?
Young	Young	Young
0% No behavioral change	67% Always	36% Overhead
75% More cautious	2% Hardly ever	18% Pedestal
46% Reduce speed	16% Depends	23% Equal
23% Look for Hazards	13% Never	21% No Difference
Old	Old	Old
1% No behavioral change	81% Always	49% Overhead
78% More cautious	6% Hardly ever	11% Pedestal
78% Reduce speed	13% Depends	39% Equal
41% Look for Hazards	1% Never	7% No Difference
Question 7	Question 8	Question 9
Rural Intersection Familiarity Makes a Person:	Yellow Flasher on a Warning Sign Causes:	Overhead Yellow Flashers Cause Drivers to:
Young	Young	Young
28% More cautious	31% Speed reduction	48% Reduce speed
59% Less cautious	2% Driver to Stop	3% Stop
3% No effect	79% Increased alertness	64% Be more alert
16% Depends	8% No effect	5% No effect

Table B2 Continued

Old	Old	Old
24% More cautious	61% Speed reduction	64% Reduce speed
36% Less cautious	12% Driver to Stop	7% Stop
6% No effect	73% Increased alertness	73% Increased alertness
41% Depend	5% No effect	2% No effect
Question 10	Question 11	Question 12
Do Flashers Help Night Driving More Than Day?	Do Rural Flashers Confuse You?	At minor road, how often have thought main traffic also has an overhead red flasher?
Young	Young	Young
34% No - same	59% Never	38% Most of the time
0% Day more	7% Always	41% Sometimes
59% Night more	5% Only at night	15% Never
5% No effect	30% Depends	10% Depends
Old	Old	Old
41% No - same	49% Never	46% Most of the time
0% Day more	5% Always	31% Sometimes
59% Night more	4% Only at night	17% Never
0% No effect	45% Depends	11% Depends

Table B3. Survey Responses to Specific Questions about Rural Intersection Safety

Question 13	Question 14	Question 15
When Approaching Intersection On Main Road You Should:	As You Approach Intersection From Side Road, You Should:	Yellow Diamond-Shaped Sign With Black Cross Means:
Young	**Young**	**Young**
51% Slow before entering	46% Slow before entering	61% Intersection ahead
11% Stop and wait for clear	59% Stop and wait for clear	25% Reduce speed
30% Continue without slowing	3% Continue without slowing	15% Cross-traffic does not stop
11% Other	2% Other	0% Cross-traffic must stop
Old	**Old**	**Old**
67% Slow before entering	45% Slow before entering	71% Intersection ahead
16% Stop and wait for clear	83% Stop and wait for clear	41% Reduce speed
28% Continue without slowing	1% Continue without slowing	19% Cross-traffic does not stop
4% Other	1% Other	2% Cross-traffic must stop

Question 16	Question 17	Question 18
Yellow Diamond Sign With Black Cross And Flasher Means:	Warning Sign And Overhead Flasher Means:	Warning Sign With Pedestal And Overhead Flashers Means:
Young	**Young**	**Young**
51% Same as without flasher	34% Intersection ahead	49% Especially dangerous intersection ahead
43% Reduce speed	51% Reduce speed	30% Cross-traffic doesn't stop
8% Cross-traffic does not stop	23% Cross-traffic does not stop	5% Cross-traffic does stop
5% Cross-traffic must stop (no speed reduction necessary)	3% Cross-traffic must stop (no speed reduction necessary)	25% Only adds emphasis
Old	**Old**	**Old**
45% Same as without flasher	36% Intersection ahead Table 3 Continued	87% Especially dangerous intersection ahead
64% Reduce speed	80% Reduce speed	27% Cross-traffic does not stop
20% Cross-traffic does not stop	18% Cross-traffic does not stop	4% Cross-traffic does stop
1% Cross-traffic must stop (no speed reduction necessary)	2% Cross-traffic must stop (no speed reduction necessary)	13% Only adds emphasis

Table B3 Continued

Question 19

No flashers anywhere, just a warning sign, means:

Young		Old	
15%	Rarely any cross-traffic - don't slow	5%	Rarely any cross-traffic - don't slow
10%	No stop signs either side	18%	No stop signs either side
59%	Just be careful approaching	82%	Just be careful approaching
15%	Side road traffic stops	8%	Side road traffic stops

Table B4. Survey Responses to Specific Questions about Side Road Driving

Question 20 Stop sign with pedestal and overhead flashers means:		Question 21 Stop sign with pedestal flasher alone means:		Question 22 Stop sign alone (no flashers) means:	
Young		Young		Young	
64%	Especially dangerous intersection ahead	62%	Especially dangerous intersection ahead	21%	Intersection is 4-way stop
8%	Intersection is 4 -way stop	18%	Intersection is 4 -way stop	62%	No stop sign on main rd
3%	Cross-traffic does not stop	18%	Cross-traffic does not stop	10%	No flashers means little traffic
33%	Intersection ahead				
Old		Old		Old	
82%	Especially dangerous intersection ahead	87%	Especially dangerous intersection ahead	12%	Intersection is 4-way stop
22%	Intersection is 4-way stop	14%	Intersection is 4 -way stop	73%	No stop sign on main roa(
16%	Cross-traffic does not stop	18%	Cross-traffic does not stop	5%	No flashers means little traffic
33%	Intersection ahead				

Discussion And Conclusions

This discussion serves to summarize, highlight and correlate the findings tabulated in the preceding section. Conclusions are drawn from the responses for each of the questions. The reasons why respondents responded as they did were not sought and thus cannot be a part of this discussion.

General Driving Behavior (Questions 1-12)

Response to flashing light color and location.

We would anticipate that drivers respond with greater caution to red than to yellow flashers and indeed this was the case. Both older and younger respondents stated that they slowed about 50% more to red flashing lights than they did to either yellow flashers on warning signs or yellow overhead flashers. Also all drivers stated that they were much more likely to prepare to stop in the presence of a red flasher compared to a yellow flasher. Interestingly, younger drivers were about three times more likely to reduce their speed in the presence of yellow flashers than were older drivers.

Comparison of overhead versus pedestal mounted flasher at a stop sign.

We asked whether the pedestal-mounted red flashers at stop signs increased the likelihood that drivers would come to a full stop. Only two-thirds of the respondents said that this was always the case. When asked to compare the effectiveness in causing a full stop of red overhead flashers with pedestal-mounted red flashers at the stop sign, overhead flashers were thought to be more effective by two to one by younger drivers and four to one by older drivers. However, one-half of the respondents said that flasher location made no difference in their behavior.

Comparison of effects of flashers at warning signs with overhead flashers.

In comparing yellow flashers at warning signs with overhead yellow flashers, respondents found little difference in effectiveness in reducing speed and increasing alertness between the two yellow flasher locations. Older respondents stated that yellow flashers in both locations were about twice as effective compared to younger respondents. Only one respondent in 20 felt that the flashers were without effect.

Effect of intersection familiarity.

Both younger and older drivers stated that familiarity with the intersection made drivers less cautious. Older drivers stated that mitigating circumstances played a significant role compared to younger drivers by more than two to one.

Comparison of flasher effectiveness at night versus during the day.

More than one-half of both younger and older drivers felt that flashing lights were more effective at night. However, nearly one-third of respondents felt they were equally as effective at night as during the day.

Potential confusion by flashers.

About one-half of respondents were never confused by the meaning of flashing lights. About one-third stated that under some conditions they could be or had been confused by flashing lights.

We were concerned that drivers on the minor road approaching an intersection with an overhead light flashing red might believe that the light was similarly flashing red for the through, main road drivers. For young drivers 38% and for old drivers 46% thought if the overhead flashed red for the minor road it also flashed red for the major road. About 40% of young and 30% of older drivers thought that this was sometimes but not always the case. Only about 15% of the drivers thought that this was never the case. This finding is a cause for some concern. There has been some speculation that drivers may developed this mistaken belief from observing urban traffic control signals occasionally flashing red for all four directions during emergency conditions.

Overall behavioral effects due to flashers.

Overall, all respondents stated that flashing lights modified their behavior in the direction of greater caution resulting in speed reductions and awareness of the possibility of hazards. This is precisely the effect sought and anticipated by traffic engineers. It would seem from this survey that beneficial effects of flashing lights at rural intersections on drivers' behavior may outweigh undesirable effects.

Rural Intersection Safety (Questions 13-19)

Correct behavior when approaching an intersection.

Respondents were asked to compare approaching an intersection on a main road with approaching an intersection on a side road. Most stated that one should slow before entering the intersection. Surprisingly, about one driver in seven stated that drivers should stop and wait for traffic to clear when approaching the intersection on the main road. This contrasts with nearly one-third of the drivers who felt that there was no need to slow when approaching from the main road. Not so surprisingly, drivers on the minor road would stop and wait for traffic to clear compared to drivers on the main road by a ratio of about five to one. There was little difference between young and old respondents.

Meaning of flashers

Main Road Approach to The Intersection

The discussion which follows refers to approaching the intersection on the main road. When asked what a warning sign without flashing lights means, the majority of respondents correctly stated that drivers should simply be especially careful when approaching the intersection, that cross traffic is not usually heavy and that they will not need to stop at a stop sign. More older than younger drivers stated that the warning sign means that drivers should reduce speed.

In comparing the effectiveness of a warning sign with a flasher and a warning sign without a flasher the great majority stated that the meanings were the same; to reduce speed. However, many older but not younger drivers felt that the warning sign with a flasher implied that cross traffic did not stop (one in five older drivers). In comparing the effectiveness of: 1) a warning sign with a flasher and no overhead flasher at the intersection, 2) to a warning sign without a flasher but with an overhead flasher at the intersection, 3) to a warning sign with a flasher and an overhead flasher there was a great deal of equivalence among the responses. If the warning sign does not have a flasher, one in five drivers believes that cross traffic does not stop. Older drivers are much more convinced than younger drivers that cross traffic does not stop if the warning sign has a flasher but there is no overhead flasher. Very few of either age believe this if there are flashers at both the warning sign and overhead. When there are flashers at both the warning sign and overhead about one-half of the drivers believe that the intersection is especially dangerous. However, 50% more older drivers than younger drivers believe that flashers at both locations mean that the intersection is especially dangerous. For any of these conditions only 1% to 4% of the respondents believe that cross traffic must stop. For these three conditions, drivers have the correct general idea that flashers mean that they are approaching an intersection which could be hazardous. However, some drivers in both age groups entertain certain incorrect notions.

Side Road Driving

This section deals with approaching the intersection on the side road. The comparisons are of respondents ideas about: 1) Stop signs only; 2) Stop signs with flashers; and 3) Stop signs with flashers and with overhead red flashers. A worrisome finding for all three conditions and both age groups is that from 8% to 22% believe that a four-way stop is implied. For younger drivers the belief that the intersection is a four-way stop decreases as the number of flashing lights decreases from two flashers to one to none. Just the reverse was true for older drivers who believed that the intersection is a four way stop increased as the number of flashers increased. It is not clear why any drivers believe that the intersection is a four-way stop, however, the older drivers misconception is easier to rationalize than that of the younger drivers.

The majority of drivers correctly believed that the flashers indicated that the intersection was especially dangerous in that there was heavy cross traffic. This result did not agree with the finding described in the previous paragraph. Why the responses to this question disagreed with the responses described in the preceding paragraph cannot be determined from this data.

Appendix C

Accident Data from Rural Intersections Before And After The

Installation of Flashers

Introduction

An analysis of accident data was done comparing accident rates and total accidents at rural Minnesota intersections. The analysis was based on accident experience three years before and three years after the installation of flashing lights. Twelve intersections were examined. Each met the MnDOT Technical Advisory Panel definition of rural intersection. The definition established was: 1) All intersections must be four-way and intersect perpendicularly, 2) Average Daily Traffic (ADT) less than 12,000 vehicles, and 3) Only two-way stop intersections - no four-way stops.

Methods

Two comparisons were investigated. Condition I was no flashers versus overhead flashers and Condition II was no flashers versus pedestal mounted flashers (flashing lights on both stop signs and intersection ahead signs). A third condition of overhead flashers versus pedestal-mounted flashers was sought but was reported as either rare or not existing in Minnesota.

Results

For the first condition, no flashers versus overhead flashers, eight intersections were analyzed. Overall, there was a 39% reduction in accidents after the installation of overhead flashers with intersections varying from a 4% increase in accidents to a 63% decrease in accidents. For all eight intersections there was a total traffic volume of over 64 million vehicles before the installation of flashing lights compared to over 69 million vehicles following installation. The number of accidents before installations was adjusted to permit direct comparison with after installation values. Both the actual and adjusted values are shown in the tables. There were 83 accidents for all eight intersections for the three year period before the installation of overhead flashers. This value was adjusted to 89 accidents to permit comparison with the 54 accidents occurring after installation of flashers. In terms of mean accident rates per 1,000,000 cars for the eight intersections, the adjusted before flasher installation rate was 1.29 and the after rate was 0.78.

Seven of the eight intersections showed overall reductions in accidents. The largest reduction in accident rate occurred at T.H. 169 x CR 60 near Kelly Lake in District 2. The accident total fell from 16 to 6. The accident rate for this intersection was reduced from 1.64 per million to 0.61 per million. The intersections that had an increase in accidents were T.H. 5 x C.S.A.H. 13 in Victoria, West Metro District, and T.H. 71 x C.S.A.H. 30 near Blackduck in District 2. The total accidents for the former intersection was slightly less than ten before flashing light installation and ten after installation. The District 2 intersection's accidents increased slightly from four to five.

The second condition, no flashers versus pedestal mounted flashers, resulted in an overall accident reduction of 40% for the four intersections studied. The total number of accidents occurring at the three reported intersections before installation, 31 (adjusted by 1.19% from 26), fell after installation to 18. The mean accident rate for the four intersections fell from 1.66 per million to 1.01 per million. Although there was an overall reduction in accidents of 40% for Condition II, only two of the four intersections resulted in an accident reduction. Two of the intersections showed accident increases of 67% and 10% while the other two showed decreases of 32% and 79%.

Discussion

In the data discussed above the accident rates are on the order of one per million. We are focusing on the one accident and not the 999,999 cases in which no accident occurred. If the data showed that accident rates either doubled or halved following the installation of flashing lights we would still be looking at small numbers of changes in the number of accidents following the introduction of flashers relative to the total number of opportunities for accidents to occur. A halving of the rate would mean that following the installation of flashers there would be approximately one accident per two million opportunities instead of the observed rate of about one accident per one million. That is, even halving or doubling of already low accident rates does not necessarily imply a strong effect from the introduction of flashing lights. Nevertheless, any reduction in accidents is desirable, even though the exact reasons for even slight reductions cannot be proven.

Given the small changes and changes in both directions shown in the data we do not feel comfortable recommending flashing light as a panacea for reducing accidents at rural intersections. Since the impact of overhead flashers was nearly the same as that for pedestal mounted flashers, there is no justification in this data for preferring one type of flasher to another.

Appendix D

Vehicle Speed Histograms

The following histograms show the distributions of speeds for drivers approaching the Eyota intersection. U.S.14 is the through highway.

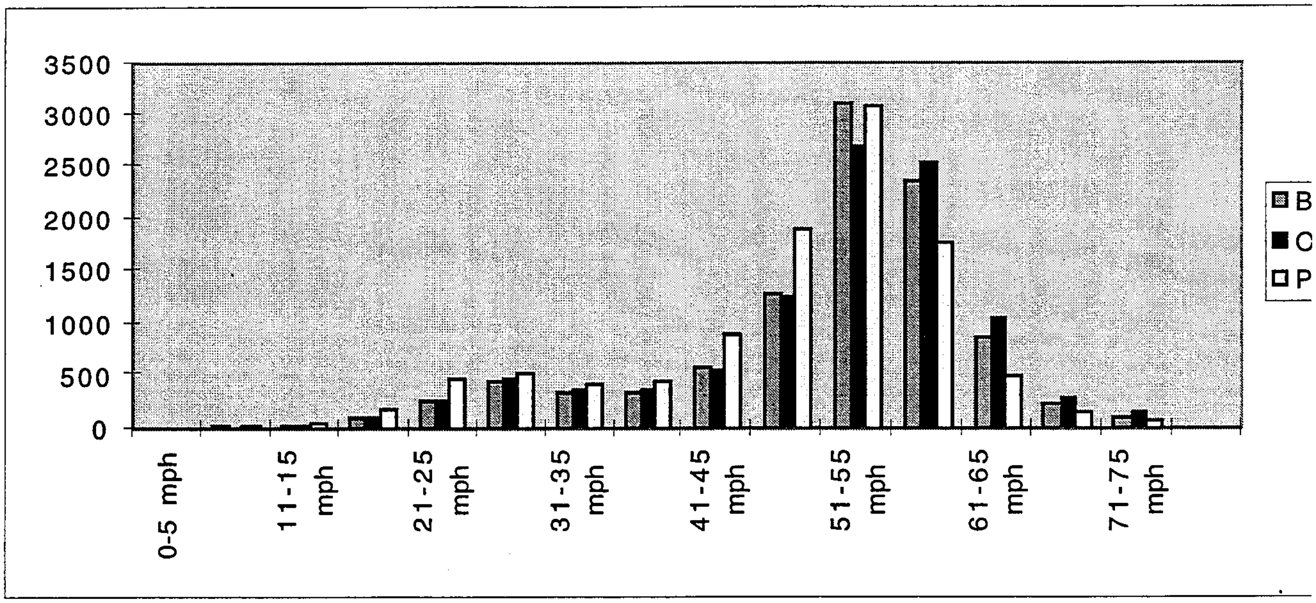

Figure D1. Speed Frequency Histogram for The 100 Foot Sensor on Eastbound U.S. 14

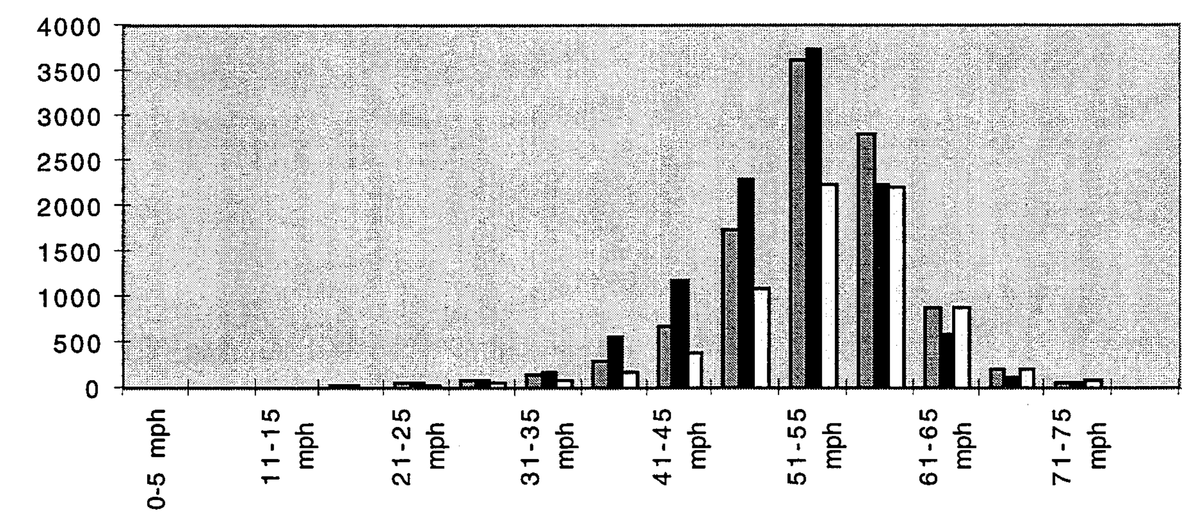

Figure D2. Speed Frequency Histogram for The 600 Foot Sensor on Eastbound U.S. 14

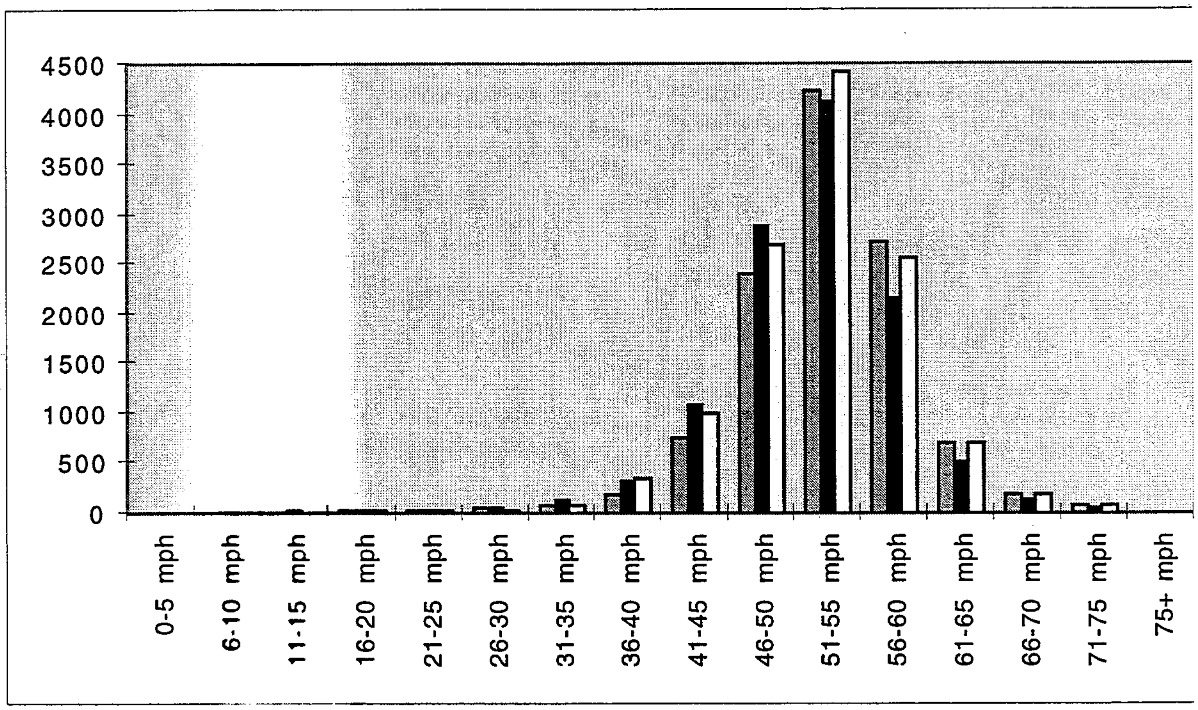

Figure D3. Speed Frequency Histogram for The 1100 Foot Sensor on Eastbound U.S. 14

There was insufficient data to permit comparisons such as the above for the Minnesota Highway 42 data