FINAL
CONTRACT REPORT

EVALUATION OF THE PRINCE WILLIAM COUNTY COLLISION COUNTERMEASURE SYSTEM

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16. Abstract

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This field evaluation, comprising a four-phase observational effort (before, acclimation, 4-month after, and 1-year after studies) assessed novelty and longer term CCS effects. Results reported herein are based on a 48-day, 109,000-vehicle data sample. In order to address CCS accident reduction potential, the study targeted 2,242 high-speed vehicles arriving at the intersection in close time proximity to cross traffic. This study also assessed the potential "familiarization" effect, i.e., driver response to the device in its non-activated condition, and conducted a benefit/cost analysis.

Vehicle behavioral measures of effectiveness (MOEs) were derived from CCS accident-avoidance objectives, i.e., specifically addressing intersection arrivals in close proximity to cross traffic. Applied MOEs were (1) drivers' CCS speed responses in the presence of cross traffic; (2) intersection approach speed reductions; and (3) projected times-to-collision (PTCs), i.e., the elapsed time to which an approaching vehicle would collide with a vehicle in its path in the absence of a timely avoidance response. Human factors (e.g., driver perception-reaction time) accident-avoidance requirements determined the critical PTC values that were used in the analysis.

The vehicle-behavioral field evaluation produced the following results: (1) lower intersection-approach speeds were observed following installation and 1-year operation of the CCS; (2) longer PTCs, indicating a safer condition in the presence of cross traffic, were observed following CCS installation; and (3) sampled high-speed vehicles, i.e., exceeding 72 km/h and 88 km/h, exhibited initial novelty-effect CCS speed reductions, which were not generally sustained during extended CCS operation. However, this sample nevertheless demonstrated reduced accident potential, i.e., longer PTCs, during extended CCS operation.

A "driver familiarization" study demonstrated that vehicles did not increase speeds during periods when the CCS was not activated.

A cost-effectiveness analysis produced a positive result. The average annual (1993 through 1997) accident property damage and injury cost for the studied intersection far exceeded the estimated annual CCS cost, i.e., sum of CCS capital recovery, manual monitoring, and operation/maintenance costs. In simplest terms, if the CCS prevents one side-impact accident per year, the device is cost-effective.

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ABSTRACT

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INTRODUCTION

The Collision Countermeasure System (CCS) is an ITS traffic control device used to warn drivers of conflicting cross traffic at rural, non-signalized intersections. The goal of the device is to reduce side-impact accidents at limited sight-distance intersections by enhancing driver awareness of vehicles approaching or entering the intersection. The CCS is particularly suited to rural highway applications where high intersection accident rates indicate the need for more than conventional signing and while low traffic volumes and high installation costs make conventional traffic signals inappropriate.

Actively illuminated, graphic signs, operating on input from vehicle-detection pavement loops, automatically warn through traffic (i.e., on the major roadway) of approaching vehicles on the minor roadway. Stop signs and activated signs are provided for traffic on the minor roadway. Drivers approaching the intersection from all directions are graphically advised of the presence and direction of approaching intersection traffic.

Figure 1 is a schematic diagram of the test intersection and sign installation. The diagram shows locations of signs (S1 through S6) and pavement loop detectors (D1 through D9) along with their distances from the center of the intersection. Figures 2 and 3 depict S4 on the major leg and S6 on the minor leg, respectively.

PURPOSE AND SCOPE

The purpose of this study was to evaluate the accident-reduction potential and to estimate the cost-effectiveness of the CCS. The study involved a series of field studies and analytic procedures.

A field study comprised a four-phase (before, acclimation, 4-month after, and 1-year after) CCS evaluation based on observed vehicle behaviors immediately before, immediately after, and 4-months following CCS installation. Results reported herein are based on a 48-day data sample, comprising approximately 109,000 vehicles traversing the Aden Road and

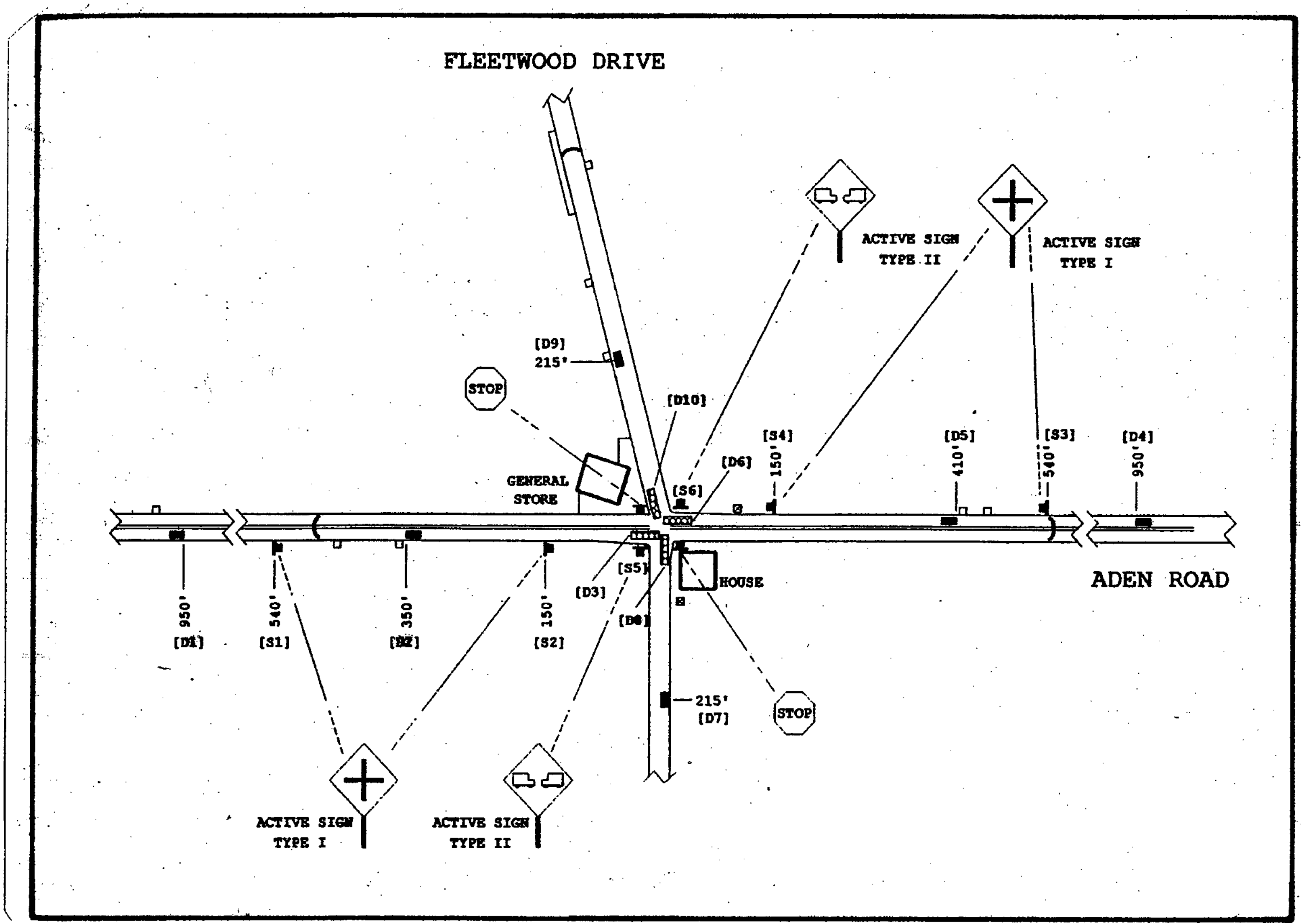

Figure 1 – Schematic Diagram of CCS Installation

Figure 2. Major Leg CCS Sign (S2 in Figure 1).

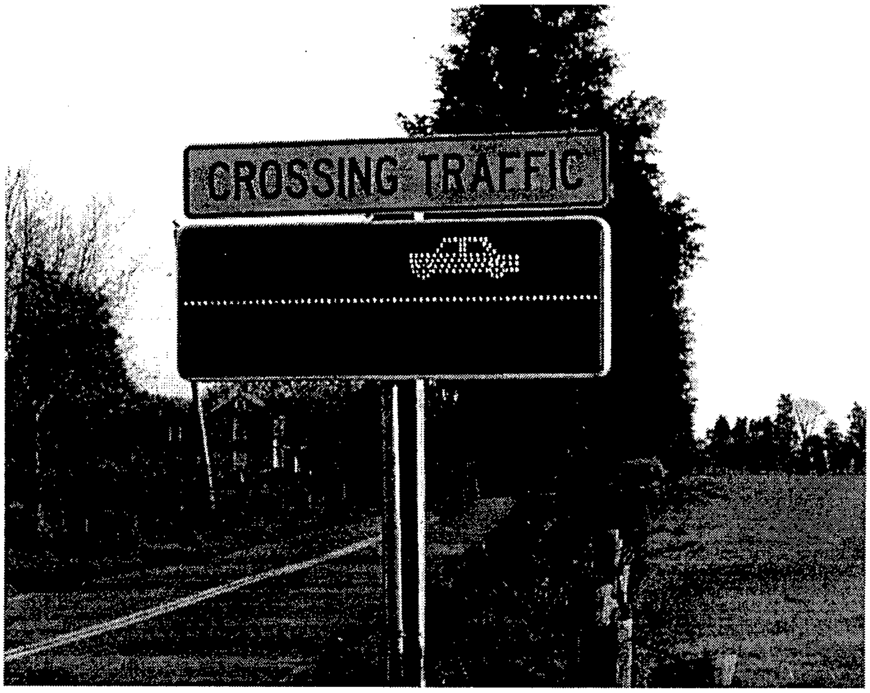

Figure 3. Minor Leg CCS Sign (S5 in Figure 1).

Fleetwood Drive intersection in Aden, Virginia. This site was selected because of its limited sight distance and accident history.

To address a concern that drivers might increase their speeds in the absence of CCS activation, e.g., possibly perceiving a false sense of security because of knowledge of no approaching cross traffic, this study analyzed speeds of vehicles that passed the intersection during periods of no CCS activation.

A cost-effectiveness study of the CCS was based on estimated annual accident costs and annualized CCS costs, i.e., capital recovery and operating costs.

STUDY METHODS

The CCS vehicle-behavioral evaluation began with a literature review, which developed a data-analysis approach capable of noting behavioral accident-potential. Data obtained from the CCS loop-detector system were then processed in a manner to analyze behavioral measures derived from the literature. A data analysis was then designed to target CCS effects on high-speed vehicles arriving at the intersection in sufficiently close time proximity to comprise real-world collision potential.

The cost-effectiveness study analyzed before-after intersection side-impact crash data. Side-impact data were selected, as they represent the accident type that the CCS was designed to prevent. Costs associated with the observed accident reduction were inferred from the literature on the basis of injury severity.

Vehicle Behavioral Study Approach

Vehicle behavioral accident-potential measures were derived from data obtained via the CCS system's in-pavement inductance loops. The CCS evaluation subcontractor, Transportation Research Corporation, developed software to track individual vehicles approaching the intersection from either direction on Aden Road and Fleetwood Drive. The first step in the applied software logic was to validate vehicle presence at each detector on the basis of specific flow criteria established by observed speeds/arrivals at the preceding detector. Vehicles (i.e., detector activations) not meeting the specified criteria were purged from the data set as a safeguard to ensure data quality. For example, vehicles crossing a detector in the wrong direction, or those that could not be confirmed on the basis of measured arrival at the succeeding detector, were omitted from the sample.

Once the software "built" the valid-vehicle array, the next step was to reconstruct Fleetwood Drive (the minor road) vehicle intrusions onto Aden Road (the major road). Minor road crossing vehicles were detected to pull into the intersection, i.e., as determined by their arrival at a loop placed sufficiently within the intersection to ensure a commitment to cross. Locations/speeds of all approaching Aden Road vehicles were concurrently calculated via interpolation with respect to their arrivals/speeds at the appropriate detectors. A separate data sub-file was created to store information (i.e., distance from intersection, speed, projected time to collision [PTC]) on this select set of "potentially conflicting" vehicles, i.e., associated with specific vehicle arrivals from Fleetwood Drive.

Selection of the appropriate CCS evaluation vehicle sample involved the application of specific intersection-arrival criteria. First, potentially conflicting vehicles, i.e., driven by motorists to which the CCS was intended to apply, had to be within sight distance of the intersection when vehicles were crossing. Therefore, based on intersection sight-distance characteristics, any vehicle further than 800 ft (244 m) from the intersection at the time of a Fleetwood Drive "intrusion" was precluded from the sample. Second, vehicles that could have been influenced by turning movements or lead vehicles within a queue were also precluded. Consequently, the ensuing analysis is based on a targeted 2,242 vehicle sample from the observed 109,000-vehicle database.

On-site videotaping was conducted during the before, acclimation and after study phases. The purpose of this activity was to record visual observations of conflict behaviors and to provide a basis for limited confirmation of detector-based behavioral observations.

To the extent possible, this field evaluation was based on dry-pavement observations. Weather data at a nearby airport were monitored throughout the evaluation period, and rainy days were precluded from the database. Although no systematic wet-pavement evaluation was conducted, a preliminary analysis indicated favorable CCS response during wet-pavement conditions.

Measures of Effectiveness

The evaluation procedure first developed appropriate measures of effectiveness (MOEs). Designation of these measures considered CCS operational objectives, i.e., targeting vehicle behaviors that the CCS intends to affect. The MOE set and their definitions are as follows:

1. *Sign response speed:* measured vehicle-specific speeds at the intermediate loop detectors, measuring speeds after vehicles have passed the first sign and are in clear view of the second sign. These loops are shown in Figure 1 as Loop D2 and Loop D5 for eastbound and westbound traffic, respectively.

2. *Intersection arrival speed:* measured vehicle-specific speeds at the intersection loop detectors, i.e., Loop D3 and Loop D6 for eastbound and westbound traffic, respectively. These loops were placed within the intersection approaches and reflect intersection arrival speeds.

3. *First speed reduction:* measured vehicle-specific speed differences between the advance and intermediate loops, i.e., Loop D1 speed minus Loop D2 speed for eastbound and Loop D4 speed minus Loop D5 speed westbound traffic, respectively.

4. *Second speed reduction: m*easured vehicle-specific speed differences between the intermediate and intersection loop detectors, i.e., Loop D2 speed minus Loop D3 speed for eastbound and Loop D5 speed minus Loop D6 speed westbound traffic, respectively.

5. *Overall speed reduction:* measured vehicle-specific speed differences between advance and intersection loop detectors, i.e., Loop D1 speed minus Loop D3 speed for eastbound and Loop D4 speed minus Loop D6 speed westbound traffic, respectively.

6. *Projected times to collision:* theoretically elapsed times to which an approaching major-leg vehicle would collide with an intersecting vehicle in the absence of a timely avoidance response. This measure was derived by the detection of an intersecting minor-leg vehicle's encroachment into the intersection and the simultaneous determination of an approaching major-leg vehicle's speed and position. The calculated PTC is simply the times to collision in the absence of an avoidance response.

The PTC is also the amount of time available for potentially colliding motorists to take an accident-avoidance action. Based on reviewed literature the two applied PTC values for avoidance-maneuver time and actual stopping time were 3.0 and 4.6 seconds, respectively.

RESULTS

Literature Review

The literature review addressed three objectives. First, in order to preliminarily assess accident-reduction potential associated with the CCS, the review examined the rural intersection accident problem and relevant traffic-control accident countermeasure implications. Second, selected human factors literature was reviewed to determine advance warning requirements for prevention of rural intersection accidents. Third, results of the review were applied to develop the primary CCS MOE.

CCS Accident-Countermeasure Potential

A number of studies have addressed accident occurrence at rural intersections. Hanna et al. (1976) in a study of more 300 Virginia locations observed that rural intersections with poor driver sight distance on one or more approaches have higher-than-normal accident rates. An examination of accident experience at 885 rural low-volume intersections (Lum and Parker, 1982) revealed that stop signs were generally used at intersections with adequate sight distance. However, accident experience did not statistically differ between stop-controlled and uncontrolled intersections. This finding is consistent with another study finding (Stockton et al., 1981) that stop signs do not reduce accidents at low-volume rural intersections.

Passive signing applied to limited sight distance situations was found to be ineffective. A 1981 study (Christian et al.) evaluated a standard limited sight distance sign at sight-restricted locations. Speed data collected at critical accident-potential locations indicated that the warning sign, even though supplemented with advisory speed plates, had no effect at slowing vehicles.

Lyles (1980) evaluated activated signing to warn of potentially conflicting vehicles at a rural stop-controlled intersection. Activated signing was designated for rural locations where stopping sight distances were inadequate for prevailing speeds. Tested signs included the lighted "Vehicles Entering When Flashing" message. Applied MOEs included observed speed reductions and driver sign recall. Results indicated that activated signs produced speed reductions and superior recall by comparison with non-activated signs. Driver familiarity did not affect sign responses.

This brief literature review indicates that stop signs and other passive signing may be ineffective at reducing the accident problem at limited sight-distance rural intersections. Although activated signs have shown promise, applied speed data obtained from the pavement loop-detector system in the Lyles study did not measure interactions with potentially conflicting vehicles. Therefore, the literature was void of data that directly measured driver response to crossing vehicles at limited sight-distance rural intersections.

Accident-Avoidance Time Requirement

For a traffic control device to produce a safe response at an intersection, it must provide the driver with sufficient time to detect, recognize, decide, and initiate an appropriate avoidance response. Thus, the current CCS evaluation considered the need to provide the driver with the appropriate advance warning time for accident avoidance at a rural intersection.

A number of viable approaches are available to assess accident-avoidance requirements in the context of the CCS application. Two scenarios were addressed in the literature review. In the first situation, the intersecting driver (i.e., confronting cross traffic) must perform a slowing or swerving maneuver but does not have to come to a complete stop. In the second, the driver is required to stop completely. Accident-avoidance time requirements were separately derived from the literature for each scenario as follows.

First, given that an approaching driver needs only to perform an avoidance maneuver (such as slight slowing), the issue is what amount of perception-reaction time is appropriate for a rural intersection. The decision sight distance (DSD) concept is based on the requirement for a driver to detect an unexpected hazard, recognize it, and execute the appropriate maneuver. Much literature has addressed DSD perception-reaction time requirement, e.g., considering factors such as (1) type of required avoidance decision, (2) visual scene complexity, (3) driver factors such as age and fatigue, and (4) mean versus 85th percentile value application. Neuman (1989) addressed such factors and developed varying perception-reaction times for specific types of roadways. His assigned perception-reaction time for the two-lane primary rural roadway was 3.0 seconds. Therefore, the applicable accident-avoidance time for the first scenario in the current study was determined to be 3.0 seconds.

Second, given the necessity for a driver to execute an emergency stop, wheel lock-up and skidding time requirements were also taken into account. Although DSD perception-reaction times (allowing for difficult-to-perceive hazards) require extended duration, much shorter perception-reaction times (0.75 to 1.0 seconds) are well documented as applicable in an emergency-stop situation. Thus, the second accident-avoidance scenario time was based on less-theoretical empirical brake response times, which have been documented in actual field experiments.

Documented mean brake response times (i.e., from perception to brake activation) pertaining to an unexpected hazard have ranged from 1.21 seconds (Sivak et al., 1982) to 1.50 seconds (Lerner, 1995). The Lerner study further evaluated perception-reaction time for the specific geometric and maneuver condition represented in the current study, i.e., a through-maneuver at a two-lane undivided roadway. For this condition, mean response times ranged from 0.99 to 1.38 seconds, depending upon the age of the driver. The weighted mean perception-reaction time derived from the Lerner study, and applicable to the two-lane undivided highway intersection, is 1.15 seconds.

In addition to the specific perception-reaction time requirement, the current scenario accounts for time consumed by wheel lock-up and skidding to a stop. Wheel lock-up time is estimated to be 0.3 second (Knipling et al., 1993); assuming a typically traveled asphalt surface friction coefficient of 0.65, 3.2 seconds would be consumed during the skid to a stop from the posted intersection 72 km/h approach speed.

Therefore, the estimated accident-avoidance time requirement, applicable to the intersection of Aden Road and Fleetwood Drive, is the sum of these values, i.e.,

1.15 seconds, perception-reaction time
0.30 seconds, wheel lock-up
3.16 seconds, skidding to a stop

totaling 4.61 seconds. Therefore, the applicable accident-avoidance time for the accident-avoidance second scenario was determined to be 4.6 seconds.

Based on the results of this literature review, it was concluded that 3.0 to 4.6 seconds advance warning time would be required for the CCS to reduce accidents effectively. Application of this finding was applied to develop a CCS MOE with demonstrated sensitivity to rural intersection accident potential.

Projected Time to Collision

The application of real accident data in traffic control device evaluations is hampered by the (admittedly fortuitous) circumstance that traffic accidents are relatively infrequent events. Thus, the accumulation of a statistically valid accident data set does not comprise a viable study approach. Moreover, a frequently applied accident surrogate, the traffic-conflict technique, has been validly challenged in the literature (Glennon et al. 1977) on the basis of its non-sustained reliability. In the current study, application of the traffic conflicts technique was not feasible because of the relatively low traffic volume and the absence of suitable observation locations at the test intersection.

Although virtually undocumented as an observable safety measure because of the infrequent nature of accidents, PTC does comprise a valid behavioral CCS evaluation approach. This measure was validated during the course of one FHWA study (Hanscom, 1981), which applied activated roadway instrumentation and involved active data gathering at a time coincident with an accident in close proximity to the pavement loops.

Thus, reviewed literature supports the application of PTC as a primary MOE in a behavioral accident countermeasure evaluation. Applicable values for this measure given the CCS test environment comprise the 3.0-second to 4.6-second range. A major advantage of this measure is its sensitivity to in-situ rural intersection vehicle responses to cross traffic, which have not been applied in previous activated signing field studies.

Before-After Vehicle Behavioral Effects

Before-after results were based on a 28-day data sample of observed vehicle behaviors immediately before and 4 months following CCS installation. The sample comprised approximately 63,000 vehicles traversing the Aden Road and Fleetwood Drive intersection. This section first summarizes CCS effects in terms of observed overall MOE differences. Following this summary, specific CCS effects are illustrated by more detailed discussions of critical PTC effects and observed critical speed differences.

MOE Effects

Table 1 indicates observed MOE mean and percentile values for the before and acclimation study periods. The before study period was the few weeks prior to commencement of CCS operation on April 16, 1998. The after period consisted of the corresponding period in mid-April 1999.

Data shown in the table are based on the 28-day sample of potentially affected vehicles, i.e., approaching cross traffic at a distance of 800 ft (244 m) or less. The sample was limited to throughput Aden Road traffic; i.e., turning vehicles were purged from the database.

Before-versus-after condition differences for four of the six MOE values were statistically significant at the 0.05 confidence level, as indicated in the table. An overview of average MOE before-after differences indicates that, although drivers did not slow down at the first loop detector, they did have greater speed reductions approaching the intersection and lower speeds at the intersection. On average, there was no difference in PTC between the before and after conditions; however, PTCs for specific vehicle samples are subsequently examined in this report.

TABLE 1. Before Versus 1-Year After MOE Differences

Measure of Effectiveness	Before Period (N = 561)			After Period (N = 727)		
	5th Percentile	Mean	95th Percentile	5th Percentile	Mean	95th Percentile
1. Sign Response Speed	58	72.1	87	55	71.5	85
2. Intersection Arrival Speed	50	66.6	82	47	64.4*	79
3. First Speed Reduction	-4.8	5.2	16	-3.2	7.1*	19
4. Second Speed Reduction	-4.8	5.5	16	-4.8	7.1*	16
5. Overall Speed Reduction	0	10.8	27	3	14.0*	27
6. Projected Times to Collision	3.4	7.8	12.1	3.4	7.7	12.1

Note: Speed is given in kilometers per hour and time in seconds.

*Indicates significant difference, $\alpha < 0.05$.

The strongest effect was shown for MOE 5 (the overall speed reduction between the intersection and the 290-m advance locations). During the after condition, the average speed reduction increased to 14.0 km/h from the before condition level of 10.8 km/h. The second strongest effect was observed for MOE 3, the initial speed reduction as drivers see the CCS, indicating a greater average speed reduction from 5.2 to 7.1 km/h.

An examination of observed 5th and 95th percentile MOE values, i.e., responses of slower versus faster drivers, shown in the table is insightful with regard to CCS effects. Percentile MOE values for speed-based measures confirm the improved condition elicited by the CCS during the after condition. Most critical are 95th percentile values, which indicated that faster vehicles in the sample either slowed or did not increase their speeds during the after condition.

PTC percentile values showed non-significant decreases during the after condition, which are consistent with the observed average difference. Because of its significance as an MOE, PTC measure differences were examined in more detail.

PTC Effects

As noted above, PTC is the theoretically elapsed time to which an approaching main roadway vehicle would collide with a vehicle entering the intersection from the minor road in the absence of a timely avoidance response. This measure can also be considered as the amount of time available for potentially colliding motorists to take an accident-avoidance action. In view of differing sight distances between east and west bound approaches, each direction was separately analyzed.

The PTC effects analysis examined the proportion of vehicles that were associated with critically short PTCs, i.e., designating a vehicle sub-sample considered to be at risk of a side-impact accident at the intersection. Among this sub-sample, the analysis targeted high-speed motorists and those associated with short PTCs. In order to identify a sufficient sample of such vehicles (with which to associate a statistically viable speed sample), the analysis targeted the vehicle group with the shortest 10% of the overall PTC distribution (eastbound and westbound, combined). Table 2 indicates an average PTC increase during the after period from 2.54 to 3.50 seconds and an associated average speed reduction from 80.0 to 76.1 km/h. Results shown in the table are statistically significant ($\alpha < 0.01$).

TABLE 2. PTCs and Associated Speeds for 10% Shortest PTC Vehicle Sub-Sample

Measure	**Before (N = 56)**		**1-Year After (N = 73)**	
	Mean	**Std Deviation**	**Mean**	**Std Deviation**
PTC (seconds)	2.5	0.61	3.5	0.70
Speed (km/h)	80.0	9.3	75.4	9.8

Target Vehicle Speed Effects

Given that the CCS was intended to target higher speed motorists who comprised the greater accident threat, a detailed examination was undertaken to isolate high-speed vehicles. The first step isolated the fastest 10% group from the overall observed vehicle sample and determined their speeds along with their associated PTC values. These values, shown in Table 3, demonstrate that 4 months following installation of the CCS, the mean speed of the fastest 10% vehicle group decreased from 89.4 to 88.4 km/h. Although this speed-related finding is not statistically significant, the associated sub-sample of these vehicles (e.g. approaching the intersection within 400 ft (122 m) of traffic crossed) had a highly significant increase ($\alpha < 0.001$), i.e., PTC of 6.4 seconds. Moreover, it is significant that the average PTC of this high-speed subsample is considerably longer than the critical 4.6-second accident-avoidance time requirement.

TABLE 3. Intersection Approach Speeds and Associated PTCs for 10% Highest Speed Vehicle Sub-Sample

Measure	Before (N = 56)		1-Year After (N = 73)	
	Mean	Std Deviation	Mean	Std Deviation
Speed (km/h)	89.4	3.96	88.4	4.28
PTC (seconds)	3.2	1.6	6.4	2.0

A second analysis addressed two categories of speed violators. This effort isolated vehicles exceeding the site-specific posted speed limit of 72 km/h and vehicles that exceeded 88 km/h. Table 4 indicates percentages of speed violators and the associated number of critical PTCs (i.e., < 3.0 second, and < 4.6 seconds) in the before and after periods for each speed-violator category. A higher percentage of 88-km/h violators was observed in the after period (possibly resulting from increased speeds because of re-paving); nevertheless, a reduced proportion of 88-km/h violators were associated with hazardous PTCs in the presence of cross traffic following installation of the CCS. Moreover, there was a significant reduction ($\alpha < 0.001$) in the proportion of vehicles violating the intersection's 72 km/h speed limit during the after condition. Furthermore, proportions of both the 72 km/h and 88 km/h violator groups associated with 3.0-second and 4.6-second PTCs were significantly reduced ($\alpha < 0.001$), thus indicating more careful behaviors for those motorists in close proximity to cross traffic.

The significance of this finding is that the CCS was apparently effective at modifying behaviors of the intended target drivers, i.e., those experiencing conflicts or accident potential with cross traffic. The elimination of critically short 3.0-second PTCs for 88-km/h violators during the after condition is indicative of a safer intersection being associated with the CCS presence.

TABLE 4. Observed Reduction in High-Speed Traffic and Associated Critical PTCs

Measure	Before (N = 561)	1 Year After (N = 772)
Proportion of vehicles exceeding 72 km/h.	343 (61.1%)	314 (40.7%)
Proportion of vehicles exceeding 88 km/h.	16 (2.8%)	35 (4.5%)
72-km/h violator PTCs less than 4.6 seconds	68 (12.1%)	48 (6.2%)
72-km/h violator PTCs less than 3.0 seconds	17 (3.0%)	7 (0.9%)
88-km/h violator PTCs less than 4.6 seconds	12 (2.1%)	6 (0.8%)
88-km/h violator PTCs less than 3.0 seconds	4 (0.7%)	0 (0.0%)

Novelty Versus Longer-Term Behavioral Effects

CCS novelty effects, observed between the before and acclimation periods, produced a generally greater behavioral impact on the overall intersecting-vehicle sample than were found to be sustained during the 4-month after and 1-year after periods. For example, all six MOEs noted in Table 1 were significantly reduced between the before and acclimation study periods. However, before-acclimation effects, observed for the overall sample, revealed neither sustained CCS-response speed reductions nor improved PTC responses. In certain other instances, demonstrated CCS before-after effects (although statistically significant) were weaker than comparably observed before-acclimation differences, because of the apparent novelty impact. However, as will be subsequently demonstrated, the CCS nevertheless did produce sustained beneficial safety effects for vehicle groups at the highest accident risk.

The key to determining CCS effectiveness was to target vehicle groups that the CCS was intended to affect, i.e., higher speed vehicles in closest proximity to cross traffic. These designated vehicle groups had less susceptibility to mere novelty effects of the CCS than did the overall vehicle sample. Given samples of the fastest vehicles (e.g., highest 10th percentile speeds) and those in closest proximity to cross traffic (i.e., accident-indicative PTCs), before-after results were consistent with before-acclimation results.

In order to maximize the sensitivity of the data to actual accident potential, the analysis isolated groups of speed-limit violators and examined their associated PTC differences. Examination of observed effects across the before, acclimation, and after study periods were conducted to determine novelty versus sustained CCS impacts. Separate analyses were conducted for groups of 72 km/h intersection-advisory speed-limit violators and 88 km/h route-specific speed-limit violators. Separate analyses were also conducted for two PTC levels: the 3.0-second intersection-hazard perception-response time, and the 4.6 intersection accident-avoidance requirement. These analyses revealed significant CCS effects, as shown in Table 5.

TABLE 5. CCS Effects Over Time with Regard to High-Speed Traffic and Associated Critical PTCs

Measure	Before Period N = 561	Acclimation Period N = 667	4 Months After N = 424	1 Year After N = 772
Proportion of vehicles exceeding 72 km/h.	343 (61.1%)	124 (18.6%)	171 (40.3%)	314 (40.7%)
Proportion of vehicles exceeding 88 km/h.	16 (2.8%)	4 (0.6%)	11 (2.6%)	35 (4.5%)
72-km/h violator PTCs less than 4.6 seconds	68 (12.1%)	20 (3.0%)	32 (7.6%)	48 (6.2%)
72-km/h violator PTCs less than 3.0 seconds	17 (3.0%)	6 (0.9%)	11 (2.6%)	7 (0.9%)
88-km/h violator PTCs less than 4.6 seconds	12 (2.1%)	2 (0.3%)	3 (0.7%)	6 (0.8%)
88-km/h violator PTCs less than 3.0 seconds	4 (0.7%)	1 (0.2%)	0 (0.0%)	0 (0.0%)

Reading from top-to-bottom in this table describes CCS effects results for increasing categories of accident potential. Logically, intersection-accident potential increases with increased violator speeds and shorter PTC times. Reading from left to right in this table describes CCS effects over time, progressing through the before, acclimation, and after study phases. A number of interesting and significant trends are evident from the table. The initial (or novelty) response was an apparent acclimation-effect speed reduction for groups of general 72 km/h and 88 km/h speed violators. However, this initial speed reduction was seen to considerably diminish over time. Speed increases between the 4-month after and 1-year after periods were attributed to a re-paving of Aden Road. Nevertheless, as evident in the bottom four table rows, speed violators in both groups apparently exercised greater caution in the presence of cross traffic following CCS activation, and this effect was sustained over time.

This finding was evident in two respects. First, reading from left to right in the table for all violator/PTC categories reveals that the apparent risk of side-impact accidents decreased over time. Generally uniform trends were evident in that smaller numbers and proportions of high-speed vehicles were associated with predominately shorter PTCs in all of the accident-potential categories during the progression through the before, acclimation, and 4-month after and 1-year after periods. Second, reading from top to bottom in the table (i.e., along increased levels of accident potential) also indicates that smaller numbers and proportions of high-speed vehicles were uniformly observed in the acclimation and 4-month after and 1-year after periods to be associated with shorter PTCs.

Various statistical applications confirmed the significance with regard to reduced PTC occurrences over time. Sufficient sample sizes permitted application of the z test of proportions to establish confidence regarding before versus acclimation results ($\alpha < 0.01$). The small sample of PTCs in the after condition was determined via application of the chi-squared test to represent a significant decrease between the acclimation and after conditions ($\alpha < 0.01$).

Familiarization Effect

An expressed VDOT concern was that drivers increase their speeds in the absence of CCS activation, possibly perceiving a false sense of security attributable to knowledge of no approaching cross traffic. This concept is referred to as the familiarization effect.

In order to address the existence of a possible familiarization effect, this study analyzed speeds of approximately 24,600 Aden Road vehicles that passed the intersection during periods of no CCS activation, e.g., when there was no approaching cross traffic following 1 year of operation. Weekday observation periods, matched by season of year, were (1) shortly prior to CCS installation, and (2) 1 year following installation. The primary speed measures of interest were mean and 85th percentile speeds. In addition, regarding concern because of higher-speed vehicles in the sample, the analysis also cited 95th percentile speeds. Separate analyses were conducted for eastbound and westbound directions.

Results (shown in Tables 6 and 7) indicated no speed differences between before and after conditions. It was, therefore, concluded that drivers did not increase speeds following installation of the CCS during periods when the CCS was not activated. The data demonstrate that no familiarization effect exists.

**TABLE 6. Eastbound Speed Observations (km/h)
During Periods When the CCS Was Not Activated**

	Before Installation	**One Year After**
Sample Size	6,736	6,512
Mean Speed	67.8	67.6
Std Deviation	10.5	11.4
85th Percentile	77	77
95th Percentile	85	85

**TABLE 7. Westbound Speed Observations (km/h)
During Periods When the CCS Was Not Activated**

	Before Installation	**One Year After**
Sample Size	5,595	5,639
Mean Speed	72.3	72.1
Std Deviation	10.3	11.1
85th Percentile	82	84
95th Percentile	88	88

Benefit-Cost Study

Estimated Side-Impact Accident Injury Cost

Because the CCS was designed to prevent angle, i.e., side impact, accidents, a cost estimation was derived for this accident type. Motor vehicle accident injury costs were estimated on the basis of severity as determined from Abbreviated Injury Scale (AIS) ratings. Specific costs have been associated (Federal Highway Administration, 1994) with specific AIS ratings, as shown in Table 8.

**TABLE 8. Comprehensive Costs in Police-Reported Crashes by
Abbreviated Injury Scale Severity (1994 Dollars)**

Severity	**Descriptor**	**Cost Per Injury (Dollars)**
AIS 1	Minor	5,000
AIS 2	Moderate	40,000
AIS 3	Serious	150,000
AIS 4	Severe	490,000
AIS 5	Critical	1,980,000
AIS 6	Fatal	2,600,000

Source: Federal Highway Administration, 1994.

A literature review was conducted to estimate the level and cost of injuries typically associated with side-impact accidents. A comprehensive study of 5,578 side-impact accidents with known injury levels, based on National Automotive Sampling System (NASS) data files, was undertaken at the University of Michigan (Huelke and Compton, 1992). The resulting distribution of injuries for side-impact accidents, as a function of seat-belt use, is shown in Table 9. It is noteworthy that seat belt usage demonstrated a minimal benefit with regard to reduction of injury severity in side-impact accidents.

TABLE 9. Injury Frequency and Associated Severity of Side-Impact Accidents

	Lap-Shoulder Seatbelts	Unrestrained
No Injury (AIS 0)	54.6 %	54.4 %
Minor-Moderate (AIS 1-2)	40.9 %	41.3 %
Serious-Fatal (AIS 3-6)	4.5 %	4.3 %

The NASS data set applied by Huelke and Compton indicated that approximately 45% of side-impact accidents result in injuries. By contrast, a considerably larger proportion, i.e., 64% (9 of 14), of the reported accidents occurring at the Aden Road and Fleetwood Drive intersection in the 6 years prior to the CCS installation resulted in injuries. Of these, more than half were multiple-injury accidents. Although this sample is too small to establish statistical validity, there is a measurable tendency for higher than normal accident injury and severity rate at this intersection.

Two additional studies, assessing injury severity resulting from side-impact accidents, tended to confirm the general nature of injury severity that was shown in the Huelke and Compton study. First, an estimation of fatalities and disabilities in car-to-car side impacts (Haland, 1990) documented that 10% of all side-impact injuries were in the AIS 3-6 (serious to fatal) range. This finding closely corresponds to the proportion of serious-fatal accidents noted in the Huelke study. Second, a study of non-minor head injuries, i.e., AIS 2 or more severe, in lateral-impact collisions (Morris, 1995) indicated that 48% were moderately severe, i.e., AIS 2. Although no single study directly addressed the relative proportions of AIS 1 versus AIS 2 side-impact occurrences, the overall literature base suggested an AIS-severity distribution characterized by a geometric progression. That is, successive injury levels (in the AIS 1-to-2 range) were approximately 52% as prevalent as the preceding level.

Literature review results were applied to estimate side-impact injury costs. Injury severity (and associated cost) was estimated on the basis of reported intersection accident/injury data in combination with results of the literature review. Accordingly, the following logic was applied to develop the estimation. Ten percent of the accident base was assumed to be in the AIS 3-to-6 range based on the Haland study and generally confirmed in the work by Huelke and Compton. It follows that the remaining 90% were distributed between AIS 1 and AIS 2 severity accidents based on the above-noted geometric progression. That is, AIS 2 severity accidents were 52% as prevalent as AIS 1 accidents. These derived distributions, in combination with the associated AIS-severity injury costs from Table 7, produced the weighting scheme for estimating side-impact injury costs shown in Table 10.

The weighted mean injury cost (in 1994 dollars) derived from Table 10 is $30,350. The equivalent cost in 1998 dollars is $34,159. The likelihood of accidents more severe than AIS 3 were not considered because of their relative infrequency.

TABLE 10. Applied Scheme for Estimated Study Injury Costs

Injury Likelihood	Injury Cost
10%	$150,000, i.e., AIS 3
31%	$40,000, i.e., AIS 2
59%	$5,000, i.e., AIS 1

Weighted mean injury cost (1994 dollars) = $30,350.

Estimated Accident Costs at Study Intersection

Table 11 summarizes side-impact accident occurrences and costs, applicable to Aden Road/Fleetwood Drive for the 5-year period preceding CCS installation and the 2-year period of its operation. Property damage costs shown in the table are the reported dollar value at the time of the accident. The annualized accident is the sum of injury property damage costs for the number of accidents shown, corrected for inflation (GDP = 3.0%) to 1998 dollars. Only the first 3 months of the year 2000 are shown in the table, as the CCS was removed at the end of March 2000. The CCS was operated from mid-April 1998 through March 2000, during which time there were no side-impact accidents while the device was functioning.

Table 12 compares side-impact accident/injury rates and associated costs for the 5-year period before its installation with the 2-year period of its operation.

TABLE 11. Accident History (with Estimated Costs) for Study Intersection

Year	Accidents	Injuries	Property Damage ($)	Annualized Cost ($)
1993	3	5	32,175	235,298
1994	3	3	9,410	125,930
1995	2	4	13,000	163,511
1996	2	1	5,400	41,968
1997	3	1	13,250	48,831
1998	0	0	0	0
1999	0	0	0	0
2000	0	0	0	0

TABLE 12. Side-Impact Accident Rates and Estimated Associated Costs

	Before	After
Average Annual Accidents	2.6	0
Average Annual Injuries	2.8	0
Average Annualized Cost	$123,108	0

Accident cost savings considered only side-impact accidents, and the after study was limited to periods when the CCS was operational. The side-impact accident type was selected as it is the accident type that the CCS was designed to prevent, i.e., by advising drivers of cross traffic. Head-on and rear-end accidents, unaffected by cross traffic, were not considered in the analysis.

One side-impact accident did occur on August 10, 1999, during a time when the CCS was not functioning. FHWA on-line monitoring of the CCS had terminated in April 1999 and no alternate arrangement was implemented until after the August 1999 accident. This accident tends to validate the previous operational finding that attests to the CCS's accident-reduction capability. Nevertheless, the accident was minor, i.e., property damage in the amount of $2,200 and a minor injury. The estimated cost of this accident is approximately $8,000. In the event this accident had been included in the CCS benefit/cost analysis, it would not change the overall CCS benefit/cost conclusion subsequently discussed in this report.

CCS Costs

The computation of CCS costs (see Table 13) was based on Raytheon's 1998 incurred equipment (custom and off-the-shelf hardware) and estimated installation costs. In addition to those costs noted in the table, the FHWA spent $6,900 on software. However, the software was retained on disks, and the user license was included in the initial cost. Therefore, this software is available for future CCS installations at no cost.

TABLE 13. Itemized CCS Costs

Cost Item	Cost ($)
Initial Investment	
Custom Hardware	23,391
Off-the-shelf Hardware	69,288
Installation Labor	15,000
Initial Capital Investment	$107,679
Annualized Cost	
Assumed Service Life	8 Years
Assumed Interest Rate	3%
Annual Capital Recovery Cost	15,340
Manual Monitoring	8,400
Power	240
Telephone	600
Maintenance	1,000
Total Annual Cost	25,580

A benefit/cost study must consider the annualized cost, which was computed using a conservative service life of 8 years. The applied interest rate was derived from economic growth data for 1998 and 1999.

CCS Benefit/Cost Results

Cost analyses consider initial installation, (i.e., materials and manpower), subsequent maintenance requirements, and overall service life. A relative cost-effectiveness computation is then based on the annualized present worth of the device under study. The benefit analysis likewise considers the annualized cost savings associated with the device under study. In this case, the annualized CCS cost was compared with the estimated annual accident reduction cost savings.

The estimated annual accident property damage and injury cost for the studied intersection, i.e., $123,108, far exceeds the estimated $25,580 annual CCS cost, i.e., sum of CCS capital recovery, manual monitoring, and operation/maintenance costs. In simplest terms, if the CCS precludes one side-impact accident per year, the device is cost-effective.

SUMMARY AND CONCLUSIONS

Vehicle Behavioral Study

The data analysis demonstrated that the CCS had a greater impact on driver behavior on the shorter sight-distance approach. Specific findings were as follows.

- Lower intersection approach speeds and safer PTCs occurred in the presence of the CCS.
- Vehicle groups with the shortest 10th percentile PTCs in the before condition averaged longer PTCs and lower average speeds during the acclimation and after periods.
- Certain high-speed vehicle groups (i.e., fastest 10th percentile, 72 km/h and 88 km/h speed violators) exhibited apparent novelty-effect CCS speed reduction. Although the speed reduction was not sustained in the after study, these vehicle groups nevertheless were associated with safer PTCs.
- Targeted high-speed vehicle groups, i.e., 72 km/h and 88 km/h violators, were associated with sustained progressively safer PTC behaviors throughout the before, acclimation, and after study periods.

The data and analysis reported herein support the conclusion that safer traffic operations resulted from installation and continued operation of the CCS.

Potential Driver Familiarization Effect

Drivers did not increase speeds following installation of the CCS during periods when the CCS was not activated; therefore, no familiarization effect was evident.

Cost-Effectiveness Result

The average annual (1993 through 1997) accident property damage and injury cost for the studied intersection far exceeded the estimated annual CCS cost, i.e., sum of CCS capital recovery, manual monitoring, and operation/maintenance costs. In simplest terms, if the CCS prevents one side-impact accident per year, the device is cost-effective.

RECOMMENDATIONS

The CCS was demonstrated to be an effective device for reducing accident-prone vehicle behaviors at a limited sight-distance rural intersection. The reduction of side-impact accidents validated the findings of the behavioral study. Therefore, future application of the device is recommended.

Although there is concern with regard to the "failure mode," i.e., device display in the event of a power failure, the manual monitoring procedure has been effective thus far with respect to accident prevention. Nevertheless, further research is needed with regard to possible device modification in terms of a fail-safe operation.

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