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# Evaluation of Daytime High-Visibility Aids for Motorcyclists

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The results of a survey of consumer attitudes toward such conspicuity aids for motorcyclists as jackets, waistcoats, sleeves, and slippers are reported, and the results of laboratory and field trials conducted to determine the effectiveness of such conspicuity aids in facilitating the detection of motorcyclists are reported. These results are based on the first three years of a continuing research project. The user attitude survey indicates serious design problems with some types of conspicuity aids and, for most materials, a severe lack of fastness of both color and fluorescence. The laboratory trials indicated an inverse logarithmic relation between the projected area of fluorescent color and mean detection time.

To examine some of the problems associated with the design, use, and effectiveness of high-visibility aids and clothing for daytime use by motorcyclists, the U.K. Transport and Road Research Laboratory has sponsored a 3-year evaluation program that has been carried out by the Institute for Consumer Ergonomics and the Department of Transport Technology at Loughborough University. This paper briefly discusses the three principal research areas investigated in this project:

1. An evaluation of user attitudes to the types of clothing and other conspicuity aids currently in production and the subsequent design of more suitable clothing (1),
2. A laboratory simulation of the effectiveness of high-visibility aids in the daytime detection of motorcyclists (1), and
3. Field trials to determine the effect of such high-visibility aids on gap acceptance by drivers (2).

These research areas carried out over a period of 3 years form three parts of a continuing program of research into the conspicuity of two-wheeled vehicles that in the long term will embrace both motorized and nonmotorized vehicles under both daytime and nighttime conditions.

## USER SURVEY

### Study Design

There is strong evidence that, although motorcyclists can make themselves more visible by wearing such fluorescent clothing as slippers, waistcoats, or jackets, there is some consumer reticence toward using these conspicuity aids. Generally the number of riders wear-

ing fluorescent clothing is very small; in an observational survey carried out in conjunction with this work, only 1.5 percent of the sample ( $N = 2842$ ) were observed to be wearing any type of high-visibility clothing. To examine this problem in greater depth, a series of discussions on attitudes was carried out with groups of motorcyclists. This was followed by a survey of users' opinions on safety clothing. The survey attempted to

1. Establish the perceived effectiveness of different safety clothing,
2. Isolate particular problems of use,
3. Evaluate the acceptability of high-visibility clothing,
4. Determine users' willingness to purchase such garments, and
5. Evaluate the fastness of the fluorescence and color of the clothing.

A number of different styles of safety-related clothing were purchased and distributed free of charge to motorcyclists in four different areas in the United Kingdom. After three months of use, the motorcyclists were requested to complete an evaluation questionnaire. A large range of safety clothing was obtained, and from this range 19 items were selected for evaluation on the basis of the following five criteria:

1. Style—slipover, waistcoats, jackets, and sleeves;
2. Method of fastening—zip, Velcro, ties, buttons, elasticated sides, and press studs;
3. Material—Wavelock PVC, PVC-coated woven fabric, Webb-lite;
4. Color—red-orange to orange range plus Saturn yellow; and
5. Cost.

Altogether, 924 items of clothing were distributed in five population centers: Swindon (290), Peterborough (88), Nottingham (150), Manchester (113), and Loughborough (283). As the clothing was distributed, anthropometric measurements were taken from the users. Because sleeves were an unpopular option, 32 pairs of sleeves were given to respondents who were also given a slipover or a waistcoat. Therefore, only 892 volunteers received the 924 items. Three months after the date of distribution, the volunteers were each sent a copy of the evaluation questionnaire. Three reminders

were sent to nonrespondents. The response rate obtained from the participants was excellent; 93 percent replied to the questions in the areas indicated in the table below:

Area	Question
Details of machine	Type of machine
	Engine size
	Accessories fitted
Use of machine	Frequency of use for different activities
	Use for longer journeys
Views on safety clothing tested	Annual distance
	Frequency of use for different activities
	Whether or not clothing still being worn
	Reasons for no longer wearing clothing
	Perceived effectiveness
	Clothing worn under safety clothing
	Storage of safety clothing
	Type of fastening
	Ease of doing up and undoing
	Fastening damage
	Ease of putting on and taking off
	Effect of cold weather
	Adequacy of adjustment
	Satisfaction with length of safety clothing
	Maximum speed at which safety clothing worn
	Inconvenience caused at that speed
	Effect of wind stress
	Interference of safety clothing with riding
	Need for cleaning of safety clothing
	Frequency and ease of cleaning
Recent accident experience	Suitability for use throughout the year
	Embarrassment caused by wearing safety clothing
	Previous use of high-visibility clothing
	Value of safety clothing
	Value of other types of safety clothing
	Reference for different types of safety clothing
	Willingness to purchase types again
	General comments
	Incidence of recent multivehicle collisions
	Frequency
	Use of safety clothing at time of accident

## Results

A comparison was made between the distribution of motorcycle ownership by engine capacity for the study volunteers versus the known pattern of ownership for the general licensed population. The survey population was found to be underrepresentative of riders of small machines and overrepresentative of riders of large machines. It was felt that this was attributable to a high incidence of "enthusiasts" among the volunteers; it was not, however, considered to be an invalidating bias. The average distance traveled was approximately 5790 km (3600 miles), which indicated a normal level of use among the respondents.

After the 3-month trial period, 75.5 percent of the respondents indicated that they were still wearing their test clothing. Of the remainder, who no longer used the clothing, it was found that 50.3 percent had stopped wearing it in the first month of the trial. A variety of reasons were given for discontinuance: too troublesome and inconvenient (27.0 percent), no longer had a motorcycle (19.5 percent), considered it was for nighttime use only (8.8 percent), had purchased another item of safety clothing (6.5 percent), embarrassment (5.1 percent), and illness (1.4 percent).

The survey indicated that the overwhelming majority of motorcyclists wore either motorcycle jackets (45.5 percent), anoraks (24.1 percent), or three-quarter-length coats (18.9 percent) under the safety clothing. The incidence of motorcycle jackets was much higher than it had been in a complementary observational study conducted throughout the United Kingdom in which only 27.6 percent of all riders were seen to be wearing

motorcycle jackets. There is a strong positive correlation between the size of the rider's machine, expressed in terms of engine capacity, and the wearing of a motorcycle jacket. The high incidence of jackets in this study is mainly accounted for by the bias toward large machines.

A large proportion of those surveyed (81.9 percent) considered the clothing to be suitable for use throughout the year. Among the remainder, 42.4 percent considered that the clothing would cause sweating in summer, 26.5 percent did not feel it was necessary in the long daylight hours of summer, and 9.9 percent indicated that the clothing was too large to be used comfortably over summer clothing.

Failure to wear safety clothing is frequently imputed to the embarrassment caused by its color, material, and styling. Even among those who volunteered to participate in this work, 25.3 percent admitted to embarrassment. This was not sensitive to particular options. A number of reasons were given for embarrassment: initial self-consciousness or embarrassment caused by others' comments when the clothing was first worn (33.3 percent), a feeling that one was in a minority and consequently too conspicuous (17.4 percent), disquiet over the style of the clothing (10.9 percent), admission to particular embarrassment when the rider wearing the clothing was not riding the motorcycle (22.9 percent), or a feeling that fluorescent clothing was unnecessary in daylight conditions (4.5 percent).

It was found that 18.6 percent of respondents had worn this type of clothing before. This is very much higher than the 1.5 percent who were observed to be wearing such clothing in the complementary study and reflects the level of interest and enthusiasm of those who chose to participate.

Table 1 summarizes general comments about the 19 options. Table 2 gives a summary of users' evaluations of the options and converts their comments into ratings.

The behavior of the fluorescent materials under prolonged exposure to light was tested for each of the 19 options by exposing five 7-cm squares taken from each garment. One set was designated "control," and the other patches were attached to a frame and exposed horizontally on a flat roof. The control samples were measured for International Commission on Illumination (CIE) chromaticity and luminance values. The illuminant approximated the D<sub>65</sub> light source, and measurements were taken on one thickness of material backed by a standard grey tile that had a luminance of 0.59. After 3 months and 6 months of exposure, further sets were sent for measurement. The patches were washed monthly and immediately before measurement. Those exposed for 9 months were not measured since all colors had faded and in some cases the fabric had disintegrated. The control set, having been kept in a light-proof place, was remeasured; it was found that there was no change in chromaticity coordinates in these control pieces.

Table 3 gives the readings for the three sets: control, 3 months of exposure, and 6 months of exposure. The very large changes in color are shown in Figure 1, in which a selection of large shifts in CIE chromaticity coordinates, shown approximately in the center of the chart, indicate a desaturation of color. (Only the measurements for the control and 6-month samples are shown in the figure. These are joined by straight lines only for clarity and not to represent the locus of fading. All samples desaturated during exposure, and their plotted points moved toward the measuring illuminant, D<sub>65</sub>.) PVC-coated materials performed relatively better, and option 8 performed best. The fading of nylon patches was rapid: After only 3 months they were almost transparent.

Table 1. General comments on 19 safety options from rider survey.

Number	Option	Comments
1	40-cm sleeves, PVC-coated woven fabric	Sleeves not a popular option, mainly wanted by those who wished to be more conspicuous when indicating turns; not easy to put on, especially when stiffened by cold weather; complaints of reduced circulation because of tightness around wrists and elbows
2	Slipover, PVC-coated woven fabric, lace, tie, and elasticated loop fastening	Main shortcoming a difficulty in fastening with elasticized loop; frequent breaking of stitching of fastening to fabric; although seldom used at high speeds, ballooning and flapping gave large problems
3	Slipover, embossed PVC, unattached lace ties through eyelets	Many complaints about short, easily lost laces, which were also difficult to do up in cold weather; flapping at speed; materials ripped easily around eyelets; head opening too small to pass helmet; option rode up motorcyclist's back
4	Slipover, Wavelock PVC, plastic strip fastening with buttons and buttonholes	Worst fastening failure of any option (50 percent in 3 months); buttonholes main failure but also strap and button failure; fastening task difficult in cold weather, especially with gloves; material curled; adjustment provided considered fairly good
5	Slipover, Webb-lite fastening by stitched lace ties	Ties again caused many complaints; knots became tight; difficult to undo with cold or gloved hands, especially when wet; difficult to clean, subject to billowing, and frequently considered too short
6	Slipover, acrylic nylon, fixed elastic sides	Difficulty with putting garment on with fixed elastic sides; damage to fastening frequently caused by strain of putting on and taking off; garment billowed and rode up; head opening too small to accommodate helmet
7	Slipover, embossed PVC, fastening with buckles and canvas straps, canvas shoulder straps	Tearing around stitching of straps to PVC buckle; fastening difficult, especially in cold weather; insufficient adjustment in canvas straps when worn over winter clothing
8	Slipover, PVC-coated woven fabric, press-stud fastening on elastic strip	Press-stud fastening easier to do up than many other types; head opening too small for helmet; longer back portion flapped when riding and doubled over
9	Slipover, Wavelock PVC, Velcro flap fastenings	Most satisfactory response of any slipover; easy tab fastening; billowing and flapping might have been more frequent with greater exposure to high speeds; head opening too small for helmet
10	Slipover, embossed PVC, small Velcro tab fastening	Fastening more difficult to use than those of option 9; damage at fixing of fastening to PVC; many complaints about billowing and flapping
11	Short waistcoat, PVC-coated woven fabric, Saturn yellow, Velcro flap fastening	68 percent of wearers complained of shortness; tight and uncomfortable over winter clothing; frontal high-visibility areas considered insufficient; equal number of comments for and against color
12	Waistcoat, PVC-coated woven fabric, front and side fastening by press stud, open sides	Fastening not difficult; subject to billowing and flapping; front area obscured by flapping up
13	Waistcoat, Wavelock PVC, front fastening by press studs	Generally well received; small press studs difficult in cold weather; without adjustment, could be tight over winter clothing
14	Waistcoat, woven nylon fabric, zip fastening	Most satisfactory of waistcoat options; easy and convenient to use, lightweight, easily stored; difficult to clean; zip tab difficult to grip
15	Waistcoat, Webb-lite, Velcro strip fastening, Saturn yellow	Velcro strip poorly attached, easily damaged, required difficult alignment; difficult to clean and heavy and difficult to store; material holds water; tight and nonadjustable over winter clothing
16	Waistcoat, PVC-coated woven fabric, fastening by four large plastic buttons	Stiff and not easy to store; fastening difficult in cold weather as material stiffens; considerable fastening damage observed with use
17	Overjacket, woven nylon, zip fastening, elasticized cuffs and waist	60 percent of wearers found option too short; zip tab found fiddly; difficult to accommodate bulky clothing; pocket found very desirable
18	Three-quarter-length coat, PVC-coated woven fabric, press-stud fastening	Difficult to put on over motorcycle clothing; fastening fiddly; ballooning and violent collar flapping at higher speeds found very disconcerting
19	Hooded Anorak, acrylic-proofed nylon, fastening by double-ended zip, inner storm cuffs fastened of Velcro, drawstrings around hood and bottom of garment	Generally highly acceptable and worn by many when not riding motorcycle; at speed, hood flapped violently; hood considered unnecessary by many; double-ended zip difficult to fasten

Table 2. User ratings, chromaticity coordinates, and unit cost of 19 options.

Option	Actual Length (cm)	Questionnaire Rating						CIE Tristimulus Coordinates <sup>a</sup>			Unit Cost (£) <sup>b</sup>
		Satisfaction With Length	Speed Exposure	Inconvenience at Maximum Speed	Ripping Caused by Wind Stress	Interference With Riding	Ease of Cleaning	x	y	Y (%)	
1	38	Very good	Less than adequate	Fair	Very good	Less than adequate	Less than adequate	0.598	0.337	60.2	0.73 <sup>c</sup>
2	54.5	Fair	Poor	Poor	Good	Good	Fair	0.590	0.336	64.4	0.82 <sup>c</sup>
3	48	Less than adequate	Less than adequate	Fair	Good	Fair	Fair	0.610	0.338	59.1	0.81 <sup>c</sup>
4	61	Very good	Less than adequate	Fair	Poor	Good	Good	0.556	0.367	75.1	0.53 <sup>c</sup>
5	46	Poor	Less than adequate	Less than adequate	Good	Good	Poor	0.578	0.353	68.9	1.38 <sup>c</sup>
6	48	Poor	Less than adequate	Fair	Very good	Very good	Good	0.599	0.342	51.7	1.08 <sup>d</sup>
7	48	Less than adequate	Fair	Good	Fair	Good	Good	0.592	0.357	66.4	1.62 <sup>c</sup>
8	51 (front), 66 (back)	Very good	Less than adequate	Fair	Very good	Good	Very good	0.646	0.339	45.8	1.35 <sup>d</sup>
9	66	Good	Less than adequate	Good	Very good	Fair	Very good	0.595	0.365	72.1	2.00 <sup>c</sup>
10	58	Fair	Less than adequate	Fair	Good	Good	Fair	0.601	0.365	70.9	1.16 <sup>c</sup>
11	41	Poor	Very good	Good	Very good	Fair	Fair	0.402	0.552	116.0	1.15 <sup>c</sup>
12	59	Fair	Less than adequate	Poor	Very good	Very good	Fair	0.639	0.329	41.1	1.41 <sup>c</sup>
13	58	Fair	Good	Good	Good	Good	Fair	0.597	0.368	67.2	0.84 <sup>c</sup>
14	61	Good	Fair	Very good	Very good	Very good	Less than adequate	0.613	0.333	46.2	2.32 <sup>c</sup>
15	68.5	Very good	Good	Fair	Very good	Fair	Poor	0.385	0.520	93.3	4.09 <sup>c</sup>
16	68.5 (small), 70 (medium), 71 (large)	Good	Good	Very good	Very good	Fair	Good	0.614	0.335	37.7	2.02 <sup>c</sup>
17	53 (front), 58 (back)	Poor	Very good	Fair	Very good	Good	Less than adequate	0.584	0.375	52.7	3.25 <sup>c</sup>
18	85	Very good	Fair	Poor	Very good	Poor	Fair	0.596	0.332	63.3	3.96 <sup>c</sup>
19	76	Very good	Fair	Poor	Good	Good	Fair	0.611	0.330	43.7	3.90 <sup>c</sup>

Note: 1 cm = 0.39 in.

<sup>a</sup>Coordinates of International Commission on Illumination.<sup>b</sup>Approximate 1977 exchange rate of 1 £ = U.S. \$1.80.<sup>c</sup>Wholesale.<sup>d</sup>Retail.

# LABORATORY SIMULATION OF EFFECTIVENESS OF HIGH-VISIBILITY AIDS

One of the complementary studies to the survey of rider attitudes toward conspicuity aids was a controlled laboratory examination of the effectiveness of different aids. After a literature survey and extensive discussions with others working in the areas of conspicuity and visibility, it was decided that the most suitable laboratory technique was likely to be the tachistoscope.

The three principal factors that affect target recognition were considered to be the target itself, the background, and the method of presenting a stimulus. A number of methods of presenting the target were considered, tried, and eventually rejected. Among those rejected were (a) colored target stimuli on plain backgrounds, (b) colored target discs on photomontages of street scenes, (c) abstract backgrounds with targets added, and (d) artist's impressions of typical street scenes with superimposed figures of different sizes. The first two techniques were tested and abandoned because of the ease of target detection and the failure of the techniques to discriminate between target options; the latter two techniques were abandoned because of lack of realism.

Another problem that affected the first approaches to the laboratory work was the presence of fluorescent stimuli. When introduced into the tachistoscope, a small fluorescent patch of color did not give its true fluorescent color in the absence of the ultraviolet radiation of normal daylight. In the final test procedure, this problem was avoided by testing options of identical color in the tachistoscope so that the differences in detection times would not include the color effect.

## Experimental Stimuli Material

The options tested included clothing and machine-based items—namely, leg shields, headlamp covers, sleeves, waistcoats, jackets, and helmets. The control option was a motorcyclist wearing a black open-face helmet, a dark green Belstaff motorcycle jacket, black gloves, and blue denim jeans. Motorcycle and rider were photographed in nine urban road sites selected to give a range of backgrounds and traffic densities.

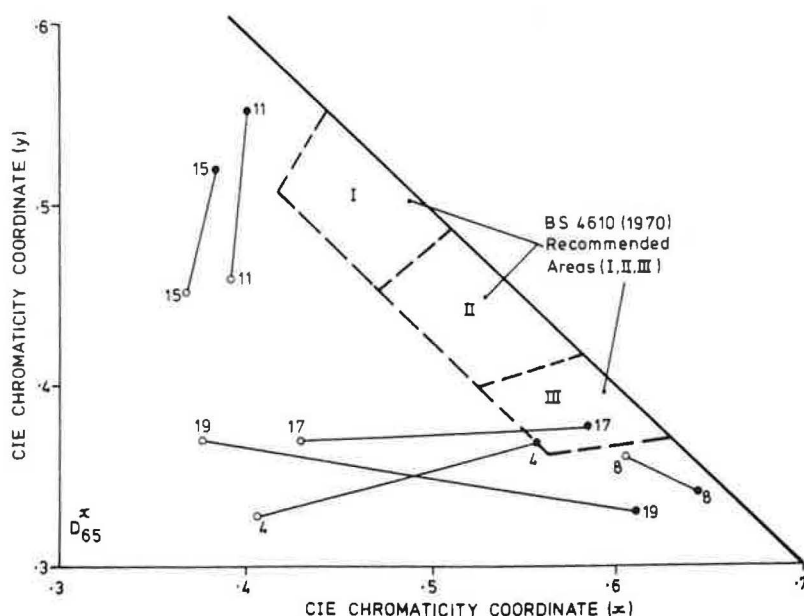
## Apparatus

Figure 2 shows the layout for the apparatus used in the laboratory trials. The technique used the back projec-

Table 3. Color changes on exposure for three sets of fluorescent materials.

Option	Control			3 Months of Exposure			6 Months of Exposure		
	x	y	Y (%)	x	y	Y (%)	x	y	Y (%)
1	0.5980	0.3320	60.15	0.5842	0.3316	49.05	0.5402	0.3423	50.20
2	0.5900	0.3361	64.45	0.5759	0.3334	54.10	0.5141	0.3499	61.20
3	0.6095	0.3380	59.15	0.5924	0.3348	53.10	0.5065	0.3178	53.30
4	0.5560	0.3679	75.15	0.5261	0.3759	64.40	0.4051	0.3278	62.35
5	0.5785	0.3559	68.95	0.5640	0.3568	56.50	0.5221	0.3666	61.60
6	0.5991	0.3421	51.70	0.5548	0.3574	36.05	0.4189	0.3678	42.80
7	0.5923	0.3572	66.35	0.5675	0.3703	56.40	0.4219	0.3802	68.00
8	0.6457	0.3392	45.75	0.6373	0.3433	37.80	0.6057	0.3598	38.10
9	0.5953	0.3659	72.05	0.5550	0.3727	61.10	0.4328	0.3813	57.25
10	0.6011	0.3655	70.90	0.5673	0.3778	62.60	0.4074	0.3858	72.65
11	0.4022	0.5521	115.50	0.4155	0.5310	92.15	0.3937	0.4606	73.80
12	0.6385	0.3292	41.15	0.6210	0.3325	39.30	0.5606	0.3466	49.15
13	0.5965	0.3686	67.25	0.5754	0.3743	60.75	0.4948	0.3952	53.20
14	0.6128	0.3336	46.25	0.5582	0.3481	33.70	0.3740	0.3650	45.90
15	0.3850	0.5188	93.25	0.3869	0.4880	70.35	0.3699	0.4505	69.10
16	0.6136	0.3349	37.65	0.6044	0.3384	40.45	0.5165	0.3577	47.15
17	0.5844	0.3755	52.75	0.5510	0.3770	34.70	0.4288	0.3696	41.10
18	0.5959	0.3329	63.35	0.5841	0.3324	54.10	0.5278	0.3465	57.50
19	0.6110	0.3306	43.75	0.5531	0.3478	31.85	0.3791	0.3696	44.00

Figure 1. Section of CIE chromaticity chart showing readings for control materials and materials exposed for 6 months.





tion of slides. Because it was recognized that the color rendition of film is not perfect, single-color targets were used to eliminate any color effect. Color-reversal film (35-mm) was used and presented by means of a tachistoscopic slide projector controlled by the subject that back-projected the image onto a screen in front of

Figure 2. Layout of apparatus used in laboratory tests.

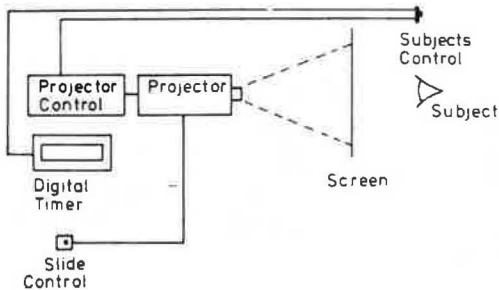


Figure 3. Mean detection and recognition times in pilot experiments.

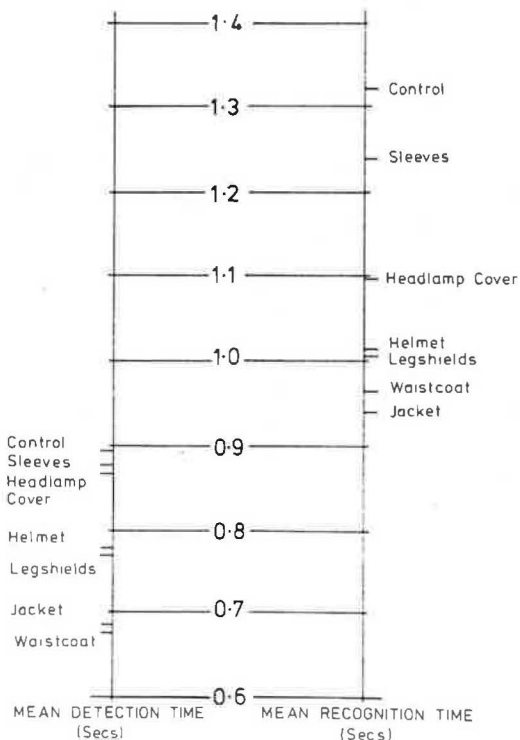
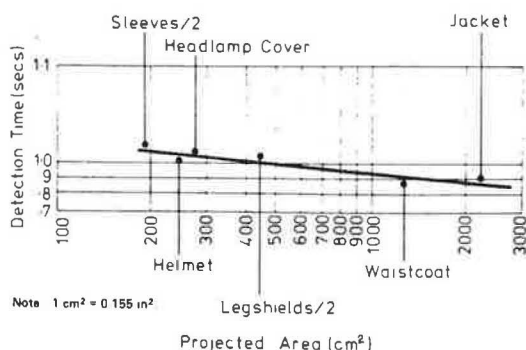


Figure 4. Relation between projected fluorescent area and detection time (log-log scale).



the subject for as long as the subject's control button was depressed. This time of presentation was recorded on an electronic digital timer. The experimenter was able to advance the slide magazine by use of the slide control button. The subject was seated 1 m (3.3 ft) from the screen, and the visual angle of the motorcycle image approximated a real-world viewing distance of 92 m (300 ft).

### Pilot Trials

Pilot experiments were carried out to validate the apparatus and to determine the best form of task to be given to the subjects. The two tasks set were detection and recognition. Subjects given the detection task were instructed to press their control button to project the traffic scene and then to release it on detecting a motorcyclist. If they could not see a motorcyclist in the scene, they were to release the button and inform the experimenter. Subjects given the recognition task were instructed in such a way that they could identify the control and the six high-visibility options and identify them by their associated names. The recognition task was similar to the detection task except that, after observing the motorcyclist in the scene and releasing the hand button, the subjects were required to state which option was shown in the photograph.

The 45 subjects (24 male and 21 female) were mainly students and university staff. All were given an Ishihara color vision test, and no defects were recorded.

The ordering and grouping of the mean recorded times for the two tasks are shown in Figure 3. The results are clearly of similar form although the range and value of the times vary. From these results, it was decided that the method of presentation permitted discrimination and presented options in an order that might be expected, i.e., in which the large areas of the waistcoat and jacket were perceived quickest and options with smaller areas took longer.

Of the two tasks used, the recognition task presented the most problems. Because many subjects did not release their hand button immediately on realizing which option was presented, recorded recognition times appeared to be artificially increased and unrepresentative of the true time. Frequently, the scene was retained while the subject checked with a reference set of photographs for the correct name of an option.

The validity of the results of the detection tests was confirmed by the inclusion of scenes that contained no motorcyclist. It was found that subjects given the detection task correctly reported no motorcycle present for all 10 blank slides presented. From this, it was concluded that the detection times were valid and not those times produced by subjects who released the hand button after a short period without actually perceiving the motorcyclist.

The form of the results of the pilot trials indicated that the experimental technique could be adopted for the main laboratory trials and that the detection task was most suitable for determining the conspicuity of motorcyclists.

### Main Laboratory Trials

The main laboratory trials conducted to measure the relative effectiveness of high-visibility fluorescent orange were conducted on the same equipment and with the same form of stimuli as those used in the pilot trials. The 72 experimental slides were presented in random order, and half of the slides were reversed to ensure balanced presentation on both the left and right sides of the screen.

The technique developed for the laboratory trials had proved to be satisfactory with respect to the ease with which experimental stimuli could be presented to the subjects. It was found that the method could be easily replicated and that new options for evaluation could be added for direct comparison with options already tested. It is important to emphasize that, because of limitations in the photographic reproduction of color, the technique can be used only to compare different options of the same color. The inability of film stock to reproduce fluorescent colors is particularly critical.

The mean detection times for the seven options across all nine sites are as follows: control, 1.090 s; sleeves, 1.116 s; leg shields, 1.048 s; jacket, 0.896 s; headlamp cover, 1.070 s; helmet, 1.008 s; and waistcoat, 0.880 s. Dunnett's statistic at the 0.05 level indicated that the jacket and waistcoat produced detection times faster than the control whereas all other options did not. A less stringent test using the *t*-statistic for individual comparisons showed that the jacket, waistcoat, and helmet produced times faster than the control. Although the jacket had an area almost twice that of the waistcoat—2260 versus 1270 cm<sup>2</sup> (350 versus 197 in<sup>2</sup>)—no significant difference could be found in their mean detection times. This result is likely to arise from two effects that act either separately or in concert:

1. There is a cut-off point in the detection time-area relation beyond which an increase in the size of the area does not result in a decrease in detection time.
2. The smaller area of the waistcoat is compensated for by a contrast with the areas of the arms and shoulders in dark motorcycle clothing. Contrast in this case, and consequently visibility, are therefore not so dependent on background as they are for the jacket option.

These trials indicated the following inverse logarithmic relation between the projected area of fluorescent color and mean detection time (Figure 4):

$$y = 1.7526/x^{0.0902} \quad (1)$$

where

- y = detection time (s) and
- x = project fluorescent area (cm<sup>2</sup>).

It is interesting to note that the helmet produced significantly faster detection times than many options with larger areas of fluorescent color. The reason for this is not known, but it could be surmised that the helmet shape is more easily associated with motorcyclists and hence reduces the detection time. There was strong evidence that detection times varied greatly depending on the nature of the site. Sites with large areas of unbroken color and low variations of light and shade resulted in relatively fast mean detection times. Slow mean detection times were found at busy sites where the amount of traffic produced a broken background pattern for visual search with numerous gaps and variations of color and shading, giving a patterned effect in which the motorcycle could be placed.

#### EFFECT OF HIGH-VISIBILITY AIDS ON DRIVER GAP ACCEPTANCE

It was felt that studying gap acceptance might prove fruitful as a field test of the effectiveness of conspicuity aids. It was hoped that the relative effectiveness of an aid could be related to changes in the observed distribution of gaps that motorists were prepared to accept in front of a motorcycle.

#### Study Design

It was decided to measure the gap-acceptance behavior of motorists toward a motorcycle in three conditions—control, dipped headlight, and fluorescent jacket. It was therefore necessary to introduce the experimental motorcycle into a traffic stream. It was apparent that to achieve an adequate rate of data collection the motorcycle would have to make repeated circuits past the junction in question. A rapid circuit was achieved by conducting the trials at a large roundabout, the Cock Pitt in Derby. The roundabout had a circumference of approximately 530 m (0.3 mile) with four access points; at the two junctions being studied, the path taken by the motorcycle was in the left-hand lane. A short pilot trial was conducted in which an experimental automobile preceded the motorcycle around the roundabout. The trials showed that gaps between 1.5 and 5.0 s would have to be used in the main trials to cover the range of accepted gaps, as suggested by Ashworth.

In the main series of trials, two videotape recorders were secured on a 3.6-m (12-ft) platform in the center of the roundabout. The trials were conducted by a team of six over a period of 4 d at the end of March 1977. The three options tested on the 250-cc motorcycle were

1. Control—The riders wore blue trousers; dark green jackets; black, open-face helmets; and black gloves.
2. Headlight—Conditions were the same as above except that the motorcycle headlight was switched on in the dipped condition (the lamp was 6 V and 24 W).
3. Fluorescent jacket—Conditions were the same as for item 1 but for the addition of a nylon fluorescent orange jacket.

The options were changed at half-hour intervals, and the order of presentation was varied between days to ensure even exposure to varying traffic conditions. In all, a total of 1854 passes were recorded on 10 half-hour tapes.

#### Video Analysis

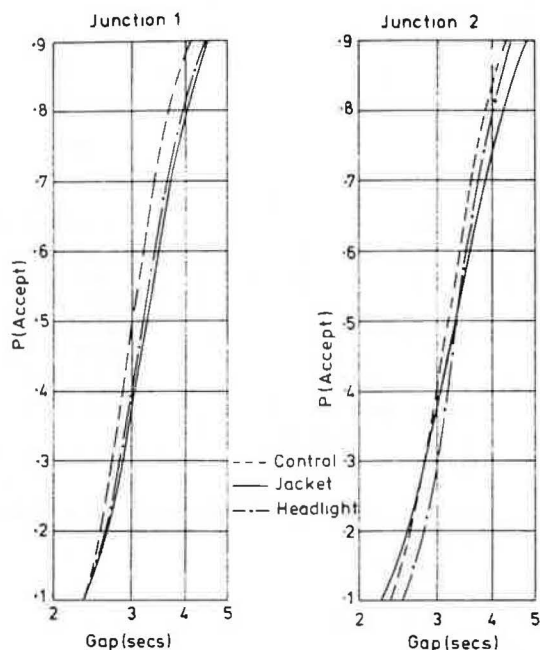
The video tapes were replayed on a Sanyo 1100 SL recorder and a Shibaden monitor at one-fifth real speed to permit tape analysis. Replaying at slow speed reduced errors in judgment when a vehicle passed a reference point and also reduced errors in reaction time in the analysis. The information taken directly from the tapes was the size of gap in seconds and, if the pass was valid, whether it was accepted or rejected.

Gaps were measured with a Colne electronic digital timer to the nearest hundredth of a second. The timer was started as the rear of the automobile passed a reference line and stopped as the front wheel of the motorcycle passed the line. A gap was included in the data only if it was a valid presentation, subject to the following criteria:

1. One or more automobiles or light vans had to be stationary at the junction as the lead experimental automobile passed by.
2. There was no interference from other traffic already on the island (i.e., passing the motorcycle and effectively shortening or filling the gap).

Sometimes a vehicle other than the experimental automobile preceded the motorcycle across the intersection. These gaps were measured and used in the analysis if the other vehicle kept to an acceptable line around the round-

Figure 5. Fitted curves for probability of gap acceptance at junctions 1 and 2.



about and the above criteria were satisfied. After all data had been taken from the tapes at one-fifth speed, they were all replayed at real time to check the accuracy of decisions concerning acceptance and rejection. At one-fifth speed it was sometimes difficult to judge whether some vehicles had come to a standstill at the junction before accepting a gap or if they had merely slowed down and then driven into the traffic stream. It was easier to make this classification when viewing at real speed. From the 1854 passes taped, a total of 352 acceptances and 922 rejections were recorded.

#### Data Analysis

The analysis of gap-acceptance data has been the subject of many papers (3, 4). The technique used here to analyze these data was the fitting of lognormal curves by probit analysis (5). Curves were also derived without the logarithmic transform, but the fit to the experimental data was poorer and the estimation errors on the median accepted gaps were much larger.

#### Results

The median accepted gaps and their 95 percent fiducial limits are given below:

Junction	Option	Median Accepted Gap (s)	95 Percent Fiducial Limits (s)
1	Jacket	3.25	2.96, 3.64
	Headlight	3.23	3.00, 3.50
	Control	3.07	2.87, 3.33
2	Jacket	3.31	2.79, 3.98
	Headlight	3.36	3.06, 3.76
	Control	3.21	2.87, 3.64

Figure 5 shows the cumulative distribution curves computed from the data. Clearly, the largest difference for the median accepted gap at either junction is only 0.18 s (between jacket and control conditions at junction 1), and there is considerable overlap of the limits

on the medians. The median accepted gaps were compared for each junction. The largest difference was between the jacket and control conditions at junction 1, but this was not significant at the 0.05 level. Significant differences were not detected between any other medians. The slopes of the fitted lines corresponding to the standard deviations of the lognormal distributions did not differ significantly. The proportions of gaps of a particular size that were accepted in the noncontrol conditions were compared with the corresponding data for the control condition. No significant differences were obtained at either junction.

The analysis of the data from this series of field trials showed that the use of fluorescent clothing or a dipped headlight on the experimental motorcycle had no significant effect on the sizes of gaps accepted in front of it. The absence of any detectable change in the gap-acceptance behavior of motorists joining the traffic stream suggests that, if the motorcycle is perceived at the junction, the use of high-visibility aids has no effect on drivers' gap-acceptance behavior.

Although the presence of these high-visibility aids has not produced a detectable change in gap-acceptance behavior, it cannot be concluded that the use of such aids will have no benefit in the accident situation. The most important reason for the use of high-visibility aids is not to improve the drivers' perception of a motorcycle already detected but to ensure that the motorcycle is seen in the first place. On reflection, it seems unlikely that effects of this kind could be observed in an experiment studying gap-acceptance behavior.

The method in which the motorcycle followed the automobile around the traffic island was successful. It allowed rapid data collection in a natural traffic environment under controlled conditions. In addition, since it was unlikely that an observed gap was presented more than once to a vehicle waiting to enter the traffic stream, only one data point—an acceptance or a rejection—was recorded for each vehicle. Thus, the gap-acceptance functions obtained provide an essentially unbiased estimate of the population gap-acceptance response (6).

#### CONCLUSIONS

Several significant findings have come out of the work described in this paper:

1. Many pieces of high-visibility clothing have severe design problems and are strongly criticized by motorcyclists.
2. Most fluorescent materials show a strong tendency to lose both color and fluorescence in a relatively short time.
3. The time taken to detect a motorcyclist wearing a conspicuous color was shown to be inversely related to the projected area of color.
4. Neither the wearing of high-visibility clothing nor the daytime use of headlights affected motorist gap-acceptance behavior.

#### ACKNOWLEDGMENTS

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## Discussion

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Ashford, Stroud, Kirkby, and Kirk have presented an extensive analysis of several important issues concerning the potential acceptability and effectiveness of methods for enhancing the daytime visibility of motorcyclists. They have found that a very small proportion of motorcyclists currently take the initiative of increasing their conspicuity by wearing high-visibility safety-related clothing. They have further found in a laboratory simulation that garments such as jackets and waistcoats of high-visibility colors can significantly decrease the time required for detection of a motorcyclist in an urban road environment.

It must be assumed that the observed reluctance of motorcyclists to wear high-visibility clothing stems from a belief that reported inconveniences associated with the clothing outweigh its possible usefulness in preventing accidents. A very important question that must be addressed from the standpoint of the motorcyclist then is, What is the role of conspicuity or lack of conspicuity in motorcycle accidents? This question is also of considerable importance to those who are concerned with evaluating the potential effectiveness of techniques for enhancing conspicuity.

Unfortunately, no direct answer to this question is available. However, an accident study conducted by Reiss, Berger, and Vallette (7) on a sample of motorcycle accidents that occurred in Maryland in 1973 does allow some inferences to be made. That study found that approximately 61 percent of motorcycle accidents involved collisions with other vehicles and that of these accidents 62 percent occurred at intersections. Reiss, Berger, and Vallette used a randomly selected sample of 200 such accidents, assigned culpability on the basis of accident descriptions by police, and found that the greatest single contributing cause was the failure on the part of the "other" driver to yield the right-of-way. This occurred in about 64 percent of the cases. Together, these percentages indicate that intersection accidents in which the other driver failed to yield ac-

counted for approximately 24 percent of all (single and multivehicle) accidents studied. Reiss, Berger, and Vallette further found that, in the multivehicle intersection accidents, the motorcycle was most often proceeding straight ahead (86 percent of the cases) while the other vehicle was either turning left (49 percent), moving straight ahead (39 percent), or turning right (5 percent). The most common collision orientation involved the motorcycle striking the other vehicle at an angle (54 percent), and the next most common involved the other vehicle striking the motorcycle at an angle (21 percent).

Waller's 1972 analysis of the 630 multivehicle motorcycle accidents reported in North Carolina in 1968 (8) similarly concluded that culpability was attributable to the other driver in 62 percent of the cases. Waller further indicates that the predominant contributing circumstances in the multivehicle accidents studied were (a) the other vehicle turned in front of the motorcycle, (b) the other vehicle pulled out into the motorcycle, and (c) the other vehicle maneuvered without seeing the motorcycle. These categories accounted for 29, 20, and 10 percent of the accidents studied respectively.

Clearly, these studies indicate that drivers of other vehicles occasionally either do not perceive motorcycles, misperceive the location or speed of motorcycles, or intentionally fail to yield the right-of-way to motorcycles. It is not particularly surprising that these types of accidents occur at intersections since in many cases drivers entering an intersection must make very rapid decisions concerning the speed and location of vehicles approaching from several different directions. In addition, based on the relative number of motorcycle and other vehicle registrations in the United States, the probability of encountering a motorcycle rather than a larger vehicle on the road is relatively small. Thus, roadway encounters of automobile drivers with motorcycles are relatively rare events and as such are events that automobile drivers may not expect or specifically look for.

The implications of these findings for motorcyclists are quite clear: One should attempt to be as visible as possible and drive as defensively as possible, expecting occasionally not to receive the right-of-way when it is due.

These findings may also explain to some extent why greater differences were not found in the gap-acceptance study described by Ashford, Stroud, Kirkby, and Kirk in which drivers presented with a gap between an automobile and a motorcycle had only to contend with traffic approaching the intersections in question from one direction. As the authors point out, the primary purpose of high-visibility aids is to ensure that the motorcycle is seen in the first place. If the given detection task is too simple, one would probably not expect to find substantial differences in distributions of accepted or rejected gaps unless the sample sizes were extremely large. This may not be the case, however, in a more complex intersection situation where drivers are faced with traffic approaching from a number of directions.

Overall, the research presented is of considerable value to those concerned with the issue of motorcycle safety. It has shown that very few motorcyclists currently attempt to increase their conspicuity by wearing high-visibility clothing, that the styling and durability of many high-visibility garments is less than optimal, and that the use of high-visibility clothing can, at least in simulated conditions, significantly decrease the time required to detect a motorcyclist. Although the study did not find that the use of visibility-enhancing techniques had a measurable effect on the gap-acceptance behavior of drivers under the condition studied, it did



show that the technique was procedurally workable and of potential value in future research on conspicuity.

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In a large proportion of collisions between motorcycles and other motor vehicles, drivers of the other vehicles reported that they did not see the motorcyclist. This may or may not be the fact depending on the extent to which one is willing to accept reports of drivers who have been involved in such accidents. However, the geometric aspect posed by a motorcycle in many daytime driving situations and perhaps even more at night suggests that motorcycle and rider provide a target that is difficult to see.

Until the actual reason for these accidents is better understood, it is worthwhile to consider means of increasing the conspicuity of motorcycles and their riders. The study that is being discussed here was concerned with such an evaluation of the effectiveness of various aids to visibility in daytime conditions.

## USER EVALUATION SURVEY

Apparently, 75.5 percent of the respondents to the opinion survey on safety-related clothing indicated that they were still wearing the clothing issued to them. This would suggest a generally high degree of satisfaction. That much of this clothing had an odd appearance was demonstrated by the fact that 25.3 percent of those participating in the study admitted to some degree of embarrassment in wearing it. This points out the need for good styling of clothing and integration of proper reflective materials into normal clothing worn by motorcyclists. Relatively few of the items that were evaluated in this study could be considered to be in the category of acceptably styled clothing that motorcyclists would willingly purchase.

Measurements of the degree to which the colors faded showed that the effectiveness of the clothing could not be assumed to be retained over very long periods of time, which indicates the need for improved materials.

This study should provide an impetus to the manufacturers of motorcyclists' clothing to make it better suited and more acceptable to motorcyclists and to provide improved visibility in daytime. Parenthetically, it would seem that an even greater effort needs to be made to ensure that clothing that is effective at night (9) should be more readily available.

## LABORATORY SIMULATION OF EFFECTIVENESS OF HIGH-VISIBILITY AIDS

The tachistoscopic study of detection and recognition

times of motorcyclists in a visual scene revealed that there appeared to be certain differences according to the types of clothing being worn. Primarily, the jacket and waistcoat produced significantly lower detection times than the control condition. In addition, the authors reported that the helmet produced shorter detection times than the control condition, but this finding was based on the dubious use of multiple t-tests. Although it was not stated by the authors, it is assumed that the sleeves, helmet, headlamp cover, and leg shields did not differ in their effect on detection time or differ from the control condition. However, I am also assuming that, since the mean detection times for these items of clothing were approximately the same as those for the control condition, they would as a group have had longer detection times than those for the motorcyclist wearing the waistcoat or jacket.

One might, therefore, argue with the use of these data in terms of a nonlinear equation that relates the area of clothing to detection time. Basically, Figure 4 could be indicated by two points that represent the central tendency of the detection times for the group consisting of the sleeves, headlamp cover, helmet, and leg shields and the central tendency of the other group consisting of the waistcoat and jacket.

This experiment was worthwhile and indicated that there were differences that were probably attributable to the various visibility aids that were evaluated by the 892 motorcyclists.

## EFFECT OF HIGH-VISIBILITY AIDS ON GAP ACCEPTANCE BY DRIVERS

In the field test, three configurations were evaluated in daytime: the control condition, the dipped headlight, and the fluorescent jacket. The use of a roundabout (traffic circle) was ingenious in that it allowed very frequent gap-acceptance measures to be taken dependent only on the extent of the traffic flow on the roundabout. There were 352 gaps accepted and 922 rejected out of a total of 1854 passes; this indicates that in 69 percent of the passes traffic that involved some decision on the part of other drivers was present. The authors reported that there were no differences in the median accepted gap times that were attributable to the three motorcycle-and-rider display configurations.

It might be questioned whether median gap times are the most appropriate basis for comparison. Clearly, there is an increased likelihood of accidents if short gap times are accepted. Thus, an evaluation of, for example, the 10th percentile values of accepted gap times might be more relevant to an analysis of a potential hazard in the gap-acceptance judgments of other drivers. In Figure 5 it can be seen that the 10th percentile values of the three configurations at junction 1 are the same, whereas at junction 2 there is a spread in the gap times accepted for the three configurations that is greater than the spread between the medians. Thus, it appears that the headlight was somewhat more effective than the other two configurations in increasing the gap times accepted at the low end of the distribution. Whether such differences are significant has not been evaluated.

Although the authors conclude that it is quite likely that this type of experiment could not demonstrate any effect on the effectiveness of high-visibility aids whose function is to improve the detection of a vehicle, I do not feel this to be entirely the case. However, there might be another effect besides an effect on detection of using either the headlight or the fluorescent jacket. These aids may have increased the apparent image size of the motorcycle and its rider. If so, they could have

had an effect not just on detection but also on the perception of distance and velocity. In that case, an effect on gap acceptance attributable to perceptual factors rather than increased likelihood of detection might have been noted.

It would also be interesting to evaluate whether the gaps accepted were discriminatory against the motorcyclist by using an automobile to make a comparison in the same situation of gap acceptance. This would help to answer questions such as whether or not the gaps that are accepted with respect to motorcycles are different from those accepted with respect to other vehicles for any number of reasons including perceptual as well as risk-taking factors.

In conclusion, it is felt that this research was most worthwhile, was carried out in a logical progression of studies concerned with various facets of the problem of motorcycle visibility, and used well-devised techniques to obtain the data. Obviously, more work needs to be done to improve detectability and provide other vehicle drivers with better information concerning the movements of motorcyclists.

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The authors are to be complimented for a high-quality, comprehensive piece of research. I would only like to comment on the problem to which the paper is addressed—motorcycle conspicuity.

The Highway Safety Research Institute (HSRI) is currently under contract to the National Highway Traffic Safety Administration (NHTSA) to investigate ways of improving the conspicuity of motorcycles. Thus, our program has aims quite similar to those described in the paper by Ashford, Stroud, Kirkby, and Kirk. Specifically, our charge was to conduct an analysis of motorcycle accidents, select promising conspicuity treatments, and carry out a field test program. Interestingly, the field test methodology we are using involves measures of gap acceptance.

Our analysis of the accident literature, based on about 10 000 accidents involving automobiles and motorcycles in the state of Texas in 1975, indicated that the precrash geometric relations were somewhat different than they were for accidents involving two automobiles. Notably, motorcycles tend to be involved in accidents when an automobile attempts to maneuver across their path. Specifically, the two situations that seem to be most significant in this respect are (a) what we have come to call a right cross or left turn and (b) a center-left turn. The former is a situation where the automobile is initially stopped on the right of the motorcyclist and is attempting to enter the roadway, either to cross completely or to perform a left merge maneuver. In the second situation, the automobile is initially facing toward the motorcycle and attempting to make a left turn across its path.

The overrepresentation of these two kinds of collisions in the motorcycle accident picture suggests that there is a problem with motorcycle conspicuity. We

cannot be certain at this time what the exact problem is. It may be, for example, that the motorcycle is simply more difficult to see because it is considerably smaller than the bulk of the vehicles on the road. On the other hand, it may be that the motorcycle is seen but tends to be classified with pedestrians and bicycles whose mass it more nearly approximates. Whatever the reason, it appears that motorcycles would benefit from improved conspicuity and means of identification.

A variety of candidate conspicuity treatments were developed by using available materials. The various treatments were evaluated subjectively by a committee composed of NHTSA and HSRI personnel. Several of these were selected for initial field testing.

The first step in the field testing program was to determine whether the criterion selected was capable of discriminating among the various treatments. To do this, the first testing compared a control condition with several treatments that were very conspicuous; minimum regard was given to their appeal to the people who would have to use them.

As I mentioned earlier, a gap-acceptance methodology was employed in our study as well. It seemed clear to us as it apparently did to the authors of the paper being discussed that, if one can measure actual changes in the behavior of drivers maneuvering in front of a motorcycle, it is far more meaningful evidence of the effectiveness of a treatment than are the types of data provided in previous investigations. Obviously, if gap-acceptance measures show any changes, they imply that crashes arise from a fairly general response on the part of drivers and not, for example, from rare instances of poor judgment. Thus, negative results do not necessarily mean the treatments are ineffective.

I was impressed by the experimental method used in the gap-acceptance study described by Ashford, Stroud, Kirkby, and Kirk. It was a model of simplicity and good control. Unfortunately, if I understood it correctly, only one type of maneuver was possible for the automobiles. That maneuver would correspond (when corrected for the fact that Americans drive on the wrong side of the road) to what we call a right-right turn. This is not one of the maneuvers that our accident analysis suggests is particularly dangerous. For this reason we wanted to carry out our study in a way that allowed us to collect data on the two maneuvers described earlier (right cross or left turn and center-left turn). We did, however, collect data on the right-right turn maneuver as well.

Briefly, the data are collected in the following way. The motorcycle is driven along a busy thoroughfare in a city near Ann Arbor, Michigan. It is a very busy street with a great deal of cross traffic from shopping centers, restaurants, and so on. The speed limit is 72.5 km/h (45 mph). The motorcyclist is instructed to position the motorcycle behind a cluster of other traffic and to open a gap of about 100 m (a few hundred feet). As the experimenter rides along under this condition, he or she monitors traffic on the right and the left. If the motorcyclist sees a vehicle in position to make one of the three maneuvers of interest, he or she turns on the recording equipment with which the motorcycle is equipped and prepares to take data. The motorcycle is provided with equipment to measure distance traveled and an array of buttons to code various things. By pressing the appropriate buttons at the appropriate times, the experimenter can measure the size of the gap presented, report whether it was accepted or rejected, and what kind of maneuver was involved. These data are stored on magnetic tape and analyzed by computer.

We currently have data on five daytime conditions: (a) control motorcycle, (b) control automobile, (c) motorcycle equipped with a fluorescent fairing, (d)

motorcyclist wearing a fluorescent jacket and helmet cover, and (e) motorcycle with low-beam headlight on. Not all of the conditions have as much data as we would like to see or will ultimately collect. The data we have at this time suggest that it may be possible to measure changes in driver behavior by the method described. It must be remembered that the study is in progress and conclusions at this time are tentative. We are encouraged by trends that show changes in the probability of acceptance of short gaps (less than 5 s) as a function of the treatment conditions investigated. However,

these trends are only found in the right cross or left turn and center-left turn maneuvers. The maneuver that is most similar to that measured by Ashford, Strond, Kirkby, and Kirk seems to show no differences.

Again, I think this is an excellent paper. It is regrettable that the gap-acceptance methodology provided negative results, but it may be that an expansion of the technique will still prove meaningful.

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## Signalization of High-Speed, Isolated Intersections

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At signalized intersections where approach speeds are 56 km/h (35 mph) or higher, drivers face a "dilemma zone." If the yellow signal comes on while the driver is in this zone, a decision to stop may result in a rear-end collision or a sideswipe. The opposite decision, to go through the intersection, might produce a right-angle accident. For such an intersection, the traffic engineer needs to select a detector-controller configuration that will (a) detect an approaching vehicle before it enters the dilemma zone and either (b) extend the green signal to provide safe passage through the zone or else (c) end the green signal when the vehicle is still upstream of the dilemma zone and thereby provide adequate stopping distance. A major research project examined in detail a number of advanced detector-controller designs. The resulting design manual has systematically integrated into a single publication the available knowledge on the subject. This paper condenses the author's contribution to the design manual, elaborates on certain points incompletely treated by it, and proposes a new configuration. Current knowledge of dilemma-zone boundaries is reviewed, a classification of controllers and detectors and a taxonomy of detector-controller configurations are provided, and research data on the effectiveness of green-extension systems are summarized. The proposed new configuration uses a basic, actuated, nonlocking controller; 25-m (85-ft) long, delayed-call loop detector at the stopline; and two extended-call detectors upstream to give protection to the dilemma zone.

For over a decade, it has been known that at signalized intersections where approach speeds are 56 km/h (35 mph) or higher drivers face a "dilemma zone" or "zone of indecision." If the yellow signal comes on while the driver is in this zone, the decision whether to stop or go through may be difficult. A decision to stop abruptly may result in a rear-end collision. The opposite decision, to go through the intersection, might produce a right-angle accident. If the traffic-signal controller is vehicle-actuated rather than pretimed, the traffic engineer can attempt to design the installation to minimize the problem of the dilemma zone.

The goal of the traffic engineer in tackling this problem is to ensure, if possible, that no vehicle is in the dilemma zone on the display of the yellow interval. The key to the solution is the selection of a cost-effective detector-controller configuration that will (a) detect an approaching vehicle before it enters the dilemma zone and either (b) provide safe passage through the zone or (c) provide adequate stopping distance. Thus, the solution focuses on the placement of vehicle detectors and

the coordination of that placement with the timing functions of the controller.

It bears emphasizing that the dilemma zone can be protected only if the green signal is terminated by "gap-out." If the green is extended by heavy traffic (or an overlong unit extension) to the maximum interval, there can be no protection. A vehicle may well be caught in the dilemma zone.

A major research project examined in detail a number of advanced detector-controller designs for use at high-speed, isolated intersections. The resulting design manual (1) systematically integrated into a single publication the available knowledge on this subject. This paper condenses my contribution to the design manual and elaborates on certain points incompletely treated by it. A new configuration is proposed.

The dilemma caused by indecision on the display of the yellow interval is the subject of this paper but is only one of three separate difficulties associated with the termination of the green interval. A second and different dilemma faces the motorist if the length of the yellow interval (plus any all-red clearance interval) is not enough to permit him or her either to clear the intersection or to stop safely (2). A third type of dilemma is the "short green" problem in high-speed signalization (3). A green interval of only 2 to 4 s in length may so conflict with a driver's expectations that he or she may panic and not react to the yellow change interval although there is ample opportunity to stop.

### BOUNDARIES OF THE DILEMMA ZONE

Once it has been determined from analysis of accidents or conflicts that the problem of a dilemma zone exists on an approach, despite a rational timing of the yellow-plus-all-red clearance period, an advanced detector-controller configuration is warranted. The first step in the selection of this configuration is the identification of the extent, or boundaries, of the dilemma zone. This can be obtained from the literature and adjusted for gradients (4).

In 1974, Parsonson and others (5) examined research on the probability of stopping from various speeds (6, 7, 8). They characterized the dilemma zone as that ap-