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### **Publication Date**

2002-09-01

## Roadwise Signaling in the New Millennium

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### I. Introduction

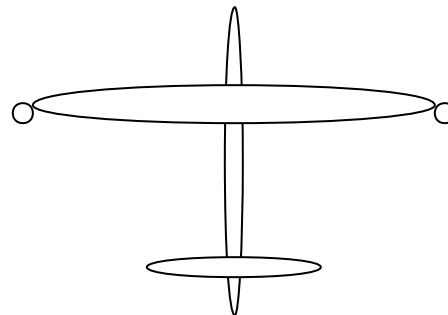
The initiatives known as the Intelligent Vehicle Highway System (IVHS) of the early 1990's, of the Automated Highway System and the Intelligent Transportation System of the middle 90's, and now USDOT's Intelligent Vehicle Initiative of 1998, have all created a climate for rapid advance in ground vehicle communication and control technology. An industry such as that of aerospace lighting, with its advanced technical prowess and experience regarding innovation, materials, sources, its facility with third party regulations and with standards, would be, in my view, in an ideal position to contribute to what appears to be an accelerating effort.

The purpose of this paper is to describe some areas of convergence of my interests in vision and in transportation with the reader's interest and experience in the development of devices and strategies for aerospace application. The common theme underlying these areas is that of safety plus the distinct possibility of significant interest on the part of cognizant federal agencies.

### II. An Example:

To illustrate the means by which these several areas of interest will be described, an example is presented. Consider the schematic of Figure 1 that is intended to show the general outline of the Piper Malibu Mirage, the aircraft operated by ALI Director Godfrey. The key piece of this figure is the wing-span of 41 Ft, as that approximates the separation of the wing-tip strobes. What I would like to analyze is the visibility of the pair of strobes from the perspective of an observer some distance removed.

Figure 1. Schematic of the Piper Malibu Mirage  
(Wing-tip anti-collision strobes magnified)

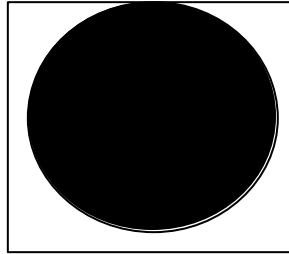


The eye does not integrate light over space: Visibility is usually referred to as the distance to which one can remove a light source until it is at its threshold [1]. Notice that such a definition tacitly assumes a monotonicity of visual effect with distance: the object should be easier to see at every intervening distance. Implicit here is the idea that photons are summed over space. Physical reasoning does indeed support such an assumption – the effect of media turbidity certainly is monotone with distance (provided the media are homogeneous). Moreover, the amount of light reaching the eye of an observer decreases (as the square) with distance from the observer. The problem is that physiological reality calls the monotonicity assumption into question. Consider what happens as the Piper leaves the ground and gradually increases its distance from an observer with normal vision. At a distance of about 35 Ft, the wing-tip strobes are imaged about 60 DEG apart on the observer's retinae. At that angular separation, their physiological effects are entirely independent. As the craft becomes further removed from an observer, the strobes come

closer together. At about 18,800 Ft, the strobes, separated by about 1/8 DEG and imaged entirely within the fovea of the eye fixed on them, fall to a relative minimum detectability and possibly become invisible. Yet, at about 30,000 Ft distance, visibility may reappear! If so, monotonicity is violated. It turns out that the problem actually derives from the implicit assumption of spatial integration usually expressed in terms of Ricco's Law of areal summation (threshold \* area = constant).

What is the visual basis for such a phenomenon? The simplest answer, though incomplete, rests on the properties of individual visual neurons. Consider the diagram of Figure 2 in which the part of the visible world 'seen' by a retinal ganglion cell is outlined.

Figure 2. The 'receptive field' of a visual neuron.  
(Strobes shown as O-----O)



The receptive field works as follows: when light lands in the center + zone, nervous activity increases. In the - zone, light causes activity to decline. Light falling simultaneously from two strobes would thus lead to mutually destructive responses. At closer separation (which might occur at larger distance), the two strobes are likely to fall in the same region, causing a summed response. Another way to describe this phenomenon can be seen in measured spatial contrast sensitivity functions which describes the ability of the entire visual nervous system to respond to stimuli of various spatial frequencies. The fovea of the eye is markedly bandpass, not low-pass, as the traditional conception of visibility presumes.

The eye doesn't always integrate over time either: Now, to pursue the matter, consider the effect of the attempt to make the strobes more visible, as for example by flashing them twice in succession. The Blondel-Rey law rests on the assumption that the eye integrates over time [cf. 1]. Suppose the Piper strobes were fitted to flash twice in succession during their roughly 1 Hz beacon cycle. In the dark, such flashes are presumed to sum if delivered within about 200 MSEC. Under light adapted conditions the empirical interval for integration is considerably shorter [2]. But the Blondel-Rey conceptualization is based upon single flashes of varying duration. Testing paired homogeneous flashes reveals a very different pattern of perception, and integration is a poor approximation. Two flashes delivered 28 MSEC apart, well within the presumed 'integrating time' of the eye, lead to mutually destructive inhibitory effects [3]. The results of this inhibition can be so devastating, that paired flashes separated by about 40 MSEC may be invisible when either one alone is above its threshold. The physiological basis for this phenomenon is presumably the bi-phasic impulse response of retinal neurons which arises as early in the system as at the photoreceptors. As in the spatial domain, the temporal processing of the eye is not low pass, but bandpass under most viewing conditions.

One might think that the destructive effects of improper spatial separation and of improper temporal separation, would lead to an especially disadvantageous situation if both strategies were employed. In act, the opposite happens. Consider a near-threshold pair of light flashes that are separated by both time and space. Such a stimulus can be called an 'apparent motion' stimulus if its parameters are appropriately selected. The apparent motion version of two separated spots can become twice as detectable as when separated only by time or by space. The physiological basis for this surprising finding is that the most sensitive of the parallel pathways in the visual nervous system is actually optimized to see motion [4], and there is considerable motion energy in this particular paired flash. For that reason, the strategy of delaying one of the wing-tip strobes by an appropriate amount, say 40 MSEC, would lead to a superb improvement in detectability, would look to the eye like a light that shoots across the breadth of the wing.

In what follows, I will outline a number of problems that arise closer to the ground. Each is characterized by a non-trivial visual problem or phenomenon, and each represents, in my view, an arena of opportunity.

**III. Variable Message Signs (VMS):**

**Problem:** A regional Caltrans office has the problem of developing a VMS that advises motorists to tune to a particular AM frequency for traffic information. Most of the time the information will be benign and of only general interest. But on occasion, the information will be important. Under those circumstances, they want the sign to attract attention. The sign should be seen at 300 Ft in a modest rain. The problem is how to specify the sign. The designer had chosen the following parameters: a relatively long flash cycle of 3.5 SEC including a ½ SEC 'off' phase, standard 4 Ft high by 8 Ft wide size, 8 In high 590 nm self-luminous letters.

**Visual problem:** The problem here is how to alert a motorist to attend to the sign when an alert is in progress. Flashing the sign in its entirety is one choice.

**Analysis:** 8 in. high (4 in. wide) letters subtend 10 (5) ARCMIN at 230 ft. This is the minimum visible height for licensed driver with 20/40 acuity (the usual acuity limit for licensure). This means that at 300 ft., the letters won't be visible, and that in the rain, the problem is worse. For the average driver with 20/20 acuity, the letters should be visible at 300 ft. From the discussion above one can see that letters of 4 in. width and a typical separation of 2 in. are going to be mutually inhibitory whether or not they are flashed. Recent work [5] suggests that this effect, termed 'crowding' in the realm of visual acuity, is worse in the periphery where signals are first likely to be seen. The flash strategy itself is an area of opportunity. If the sign stays on for 2.5 SEC and then goes off for ½ SEC, the result is a full half second of useless signaling time. In that time, the motorist who enters the visible zone of some 300 ft distance can move as much as 50 ft. It would be better to use what had been designed as the 'off' phase to be the alerting phase.

**Solution:** It might be best to flash the sign rapidly (say at 6 Hz) during the ½ SEC 'off' phase. 6 Hz is a very readily seen frequency and will have maximum alerting quality. Even beyond 300 ft distance, the flashing will alert the motorist to be ready to read the sign when it becomes intelligible at about 300 ft. It may be appreciated that the specifications not mentioned here, of portability, weather-proofness, immunity to sun glare, and those that have been mentioned, are very demanding and would require attention by a vendor with superior experience in demanding applications.

**IV. Inter-Vehicle Signaling:**

**Problem:** Urban transit properties have experienced a surprisingly large number of incidents in which their busses are rear-ended during normal operations. These collisions generally occur when all vehicles are operating at the slow speeds and with the short headways common in urban settings. Designers are weighing the possible benefits of either a rear-facing 'following vehicle detector' that could signal to the following driver in the instance of a too-fast closing rate, or of a front-facing incident-predictor that could be used to ignite a warning alert to the effect that the vehicle may soon be stopping.

**Visual Problem:** How should the information from these detectors be signaled to the following driver? One wants the information to be readily perceived and to be more useful than existing information (the ignition of the brake lights on the bus).

**Analysis:** Brake lights on transit vehicles appear to have been chosen with no thought given as to their importance. They are generally small, (as little as 3 in diameter -- smaller even than those on 'light' vehicles) and the center high-mounted stop light (CHMSL), present also in passenger vehicles, is very high and well away from the usual line of sight of the following driver.

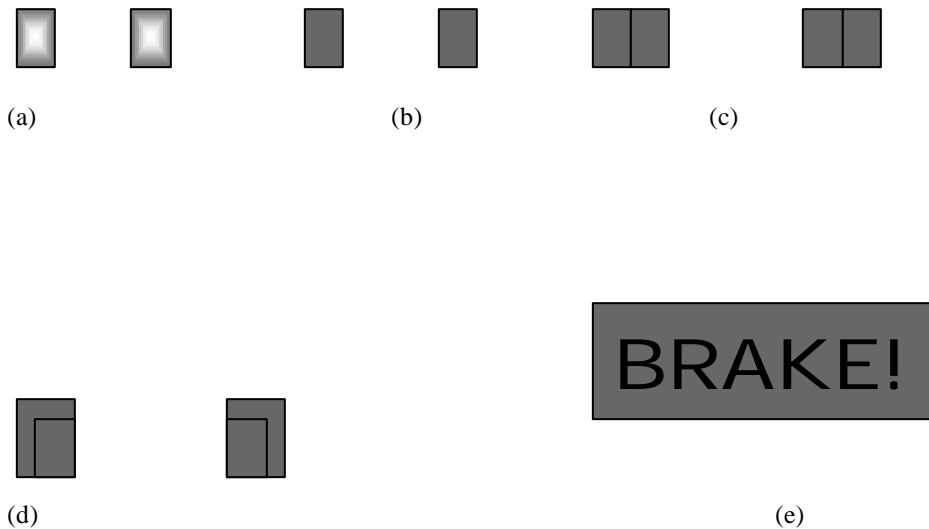
**Solution:** If nothing else is done, it would be advantageous to retrofit brake light indicators with LED lamps (as some manufacturers are already doing on new vehicles) as illustrated in Fig. 3b. Such indicators turn on with greater rapidity, and by itself, this strategy would be expected to enhance time to react for the following driver. The next refinement would be to change the spatio-temporal configuration of the brake lights themselves. Brake-lights that utilized movement would be seen more readily and more quickly than simple 'on' lamps (see discussion above in II.) If the movement included the percept of looming, as might be caused by a signal fixture which appeared to expand over time, the following driver might perceive the bus as coming closer more quickly and be alerted to slow or stop. Finally, one might want to ignite a sign

(e) that clearly instructs the maneuver that other indicators haven't. If these signals are coupled to look ahead or to rear facing detectors, additional improvements in time to react are possible.

Of course, the look-ahead and/or rear-facing detectors can lead to a considerably improved warning. Presumably the former can by-pass the delay introduced by the bus driver while the latter can react to dangerous pre-conditions presented by the following vehicle. A system in which detection and visual signaling were thus integrated poses additional challenges in terms of complexity and sophistication. Nonetheless, the elements underlying such designs will soon exist as prototypes that emerge from federally-sponsored development projects.

This arena is rich in future possibility as well. Interverhicle signaling is actively being researched in a number of ITS and IVI applications. It may someday allow in-vehicle warnings to the following driver as for example in a head-up display. Vehicle identification could then allow specific visual, haptic or even auditory warnings (e.g. Tim! Slow down. The bus ahead is about to stop.”).

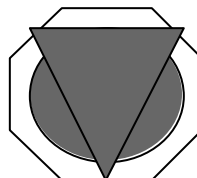
Figure 3. Possible Brake light Configurations. (a) Traditional incandescent lamp brake lights. (b) LED replacement. (c) LED motion-based signal: sections toward the center of the vehicle are ignited first for about 100 MSEC. These are extinguished and followed immediately by ignition of the outer lamps. (d) A variant of (c) in which the inner lamps are smaller so that the whole gives the perception of motion and 'looming'. These configurations can include a CHMSL. (e) Ignited signage to instruct the following motorist.



**V. Alternative Traffic Signals**

Problem: Traffic signals are so mundane that they are often taken for granted. Nonetheless they constitute an important element in traffic control systems and they present an enduring operating and maintenance cost. Intersections, which they guard, are the site of the greatest collision frequency. The question is, can traffic signals be improved. One inventor thinks so. He has proposed an integrated signal which codes its advisory in terms of color (in the usual way) but also in terms of shape. The 'stop' signal is a large octagon, the amber caution an inverted triangle, and the 'go' signal is a green disc. All are implemented with LEDs that are housed in a single compact unit in such a way that the geographic centers of each coincide. A sketch of this is shown in Figure 4 and a simulation may be found at [www.unilight2000.com](http://www.unilight2000.com).

Figure 4. An integrated traffic signal configuration.



Visual Problem: It will be apparent that the key question here, as it was in the context of simple LED retrofit fixtures for otherwise incandescent traffic signals [7], is whether drivers will stop with the same (or better) certainty with the new fixture as they do now. This problem can be restated as: “Is the paired cue of shape and color as useful as the traditional cue of color and location in leading to correct identification?”

Solution: This problem can be approached, first in the laboratory and then in the field. The investigation would have to devise a means of presenting such signals, chosen randomly, to the eye under computer control and to record observer decisions (and the times of their occurrence) as to which had been presented.

Analysis: If such a fixture proves to be as visually useful as the traditional fixture, or more useful, then a whole new set of possibilities can be entertained. LED intensity can be modulated in time at very fast speeds, so fast that the human eye cannot follow the alternation. If so the device can become a transmitter of information to oncoming vehicles which could ‘read’ the transmitted signal. The signal sent could be as prosaic as “stop” (with in-vehicle enunciation) or as informative as “Detour left this intersection to avoid tie-up three blocks ahead”.

## **VI. Crosswalk Signaling:**

Problem: Over 7,000 pedestrians die each year when hit by motor vehicles. The number of recorded injuries is an order of magnitude higher [8]. A significantly large fraction of these occur at intersections with marked cross-walks. The burden to society of this circumstance is quite large. The questions are: “Can one find factors that cause such events (the CDC urges that these events not be labeled ‘accidents’)”? And having found causative factors, “Can interventions be developed?” One inventor feels that the problem is that pedestrians are, in many circumstances, only marginally visible as are crosswalks themselves. He has developed a cross-walk marking system, that employs LED fixtures embedded in pavement at the leading edge of the cross-walk and distributed across the intersection [9]. These fixtures are ignited when a pedestrian is in the cross-walk.

Visual problem: We have here a problem analogous to the variable message sign problem. What should the signal be that alerts a driver as to the presence of one or more pedestrians in the cross-walk? As in many other similar problem areas, inventors must cope with prevailing or newly developed strictures enforced by government agencies. In this instance, the Caltrans Traffic Operations Program, the cognizant state body, developed interim guidelines. They adopted the NEMA standard for flashers which requires a near 1 Hz flash rate (beacon rate) with balanced duty cycle and specified, in addition, that all lamps in the system be ignited simultaneously and that fixtures be equally spaced across the road.

Analysis: The specifications enforced in the interim guidelines are not optimal from the perspective of visual signaling. Here are the problems: First, the beacon rate of 1 Hz with an enforced off-time of ½ SEC effectively cuts the value of the signal by ½. Next, the requirement that fixtures be ignited simultaneously has the same unfortunate inhibitory effect that was described above in the context of the VMS and the wing-tip strobes. Finally, the requirement of equal spacing of lamps is short-sighted (unless staged ignition is adopted). The result of this strategy, coupled with simultaneous ignition will lead to a spatially periodic pattern in the field of view. Such a pattern can cause the eyes to adopt an inappropriate angle of convergence with the result that the brain will inaccurately estimate the distance to the signals [10].

Solution: It would be far better to use the ‘off’ phase to flash the signal, for the joint purposes of attention-getting and continued marking. A flash rate near the best seen temporal frequency would be desirable from the perspective of visibility. This would be in the range of 6 to 10 Hz. A lower rate would be useful, however, and less likely to engender epileptic seizures in the sub-population that is susceptible. The manufacturer has advocated the strategy and has approached the National Uniform Traffic Control Devices Committee to urge that the Manual of Uniform Traffic Control Devices (MUTCD) reflect such a standard. Simultaneous ignition is simply less sensitively seen by the visual nervous system than would be a staged

or sequential ignition. If the latter were deployed with appropriate selection of parameters, the entire system could be arranged to give the appearance of a ball of light moving across the intersection. This would improve sensitivity and would decrease the time to react. The disorientation caused by the periodic structure would then also be eliminated. If staged ignition cannot be allowed, then steps must be taken to place lamps at intervals that differ across the array.

Figure 5a. Fixtures embedded in the road  
Mark the location of a cross-walk when a  
pedestrian is present (perspective view).

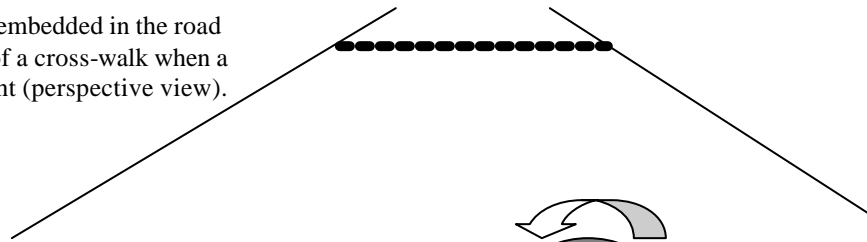
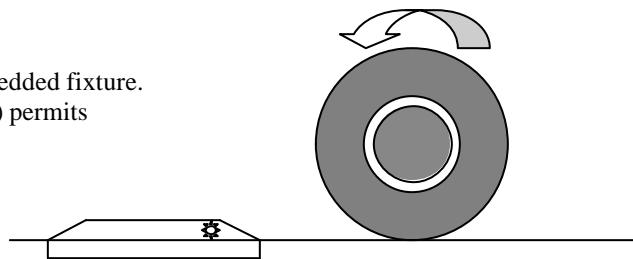


Figure 5b. Cross-section of the embedded fixture.  
Low height above roadway (~3/4 in.) permits  
Smooth vehicle tire passage.



## VII. Signals for Railroad Crossings:

**Problem:** Railroad and highway authorities record, with great concern, around 4,000 fatalities that result from collisions between trains and vehicles. Similar numbers accord pedestrians struck by trains, and the vast majority of these occur at railroad crossings. It is important to record, in this regard, that grade crossings exhibit quite a wide range of protective signals and devices. These are designed to warn vehicle operators and pedestrians [11]. ‘Passive crossings’ have signage (e.g. “Railroad Crossing Ahead”). ‘Active crossings’ have train-triggered lights and bells and sometimes gates that are lowered to block the roadway. It develops that relatively well-protected crossings still experience collisions and deaths, and the question is “Why?”

**Visual Problem:** A variety of theories exist as to the cause of these fatalities. To some degree, they touch on the possibility that the train is simply not seen, or not seen well enough. Some are quite straightforward (e.g. crossing geometry) and admit to simple fixes. Others are more interesting from a vision science perspective. One of these is that active signals, so inexactly tied to train arrival, begin to be treated as ‘false alarms’ by motorists. On that interpretation, a suitable fix would be to tie the signal more exactly to train arrival. ITS innovations on the horizon appear to be able to handle this. GPS techniques can be used to find the location and speed of a train and thereby ignite the crossing signal at the optimal point.

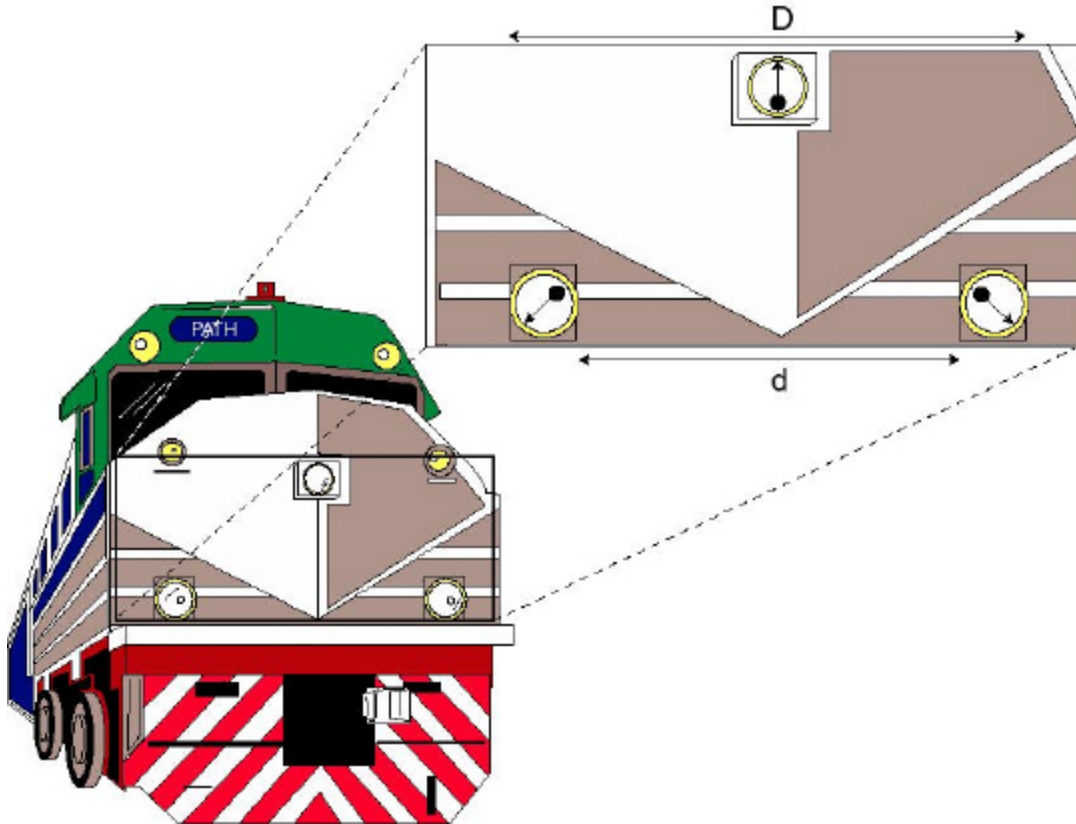
**Analysis:** Let’s look at two other theories that are more closely related to visual phenomena. One is due to Hershel Leibowitz at the Penn State University. Leibowitz examined the crossing problem closely and took the unique step of riding in the locomotive to observe motorist behavior. He observed what others have previously described as a seemingly unwarranted risk-taking on the part of motorists. Some even skirted the lowered crossing gate (and collision statistics bear this out as a key contributory factor) and crossed in front of the oncoming train. Leibowitz chose to analyze this from two perspectives. First, he noted, that crossing signals are so unreliable as to often be false alarms. Interpreted in that way, it is not surprising that a motorist would proceed. Next, he observed that the oncoming locomotive, when close enough to be a threat, is a quite large moving object. He pointed out that the human visual system does not accurately code motion for large objects, routinely underestimating speed (the reader will have experienced this when watching large airplanes land – their movement appears to be slow and halting).

Another visual theory is that the locomotive, particularly at night, is simply not visible enough.

**Solutions:** A traditional solution to the second of these theories is to mark the locomotive or illuminate it. One common technique is to add two ultra-bright reflectorized (and thus nearly collimated) headlights placed so that they form a triangle (upright or inverted is satisfactory). The triangle of sources thus produced is indeed highly visible. But, it would not be interpretable. An observer would simply be unable to look at it for any length of time, owing to its brightness. In fact, in Great Britain, such lights must be dimmed when an oncoming train encounters another.

A better solution would use the concept of a visibility triangle in a different way.

Figure 6. The illuminated triangle of the locomotive – modified. The triangle is developed using LED matrices. Small round areas ignite first followed by increasingly large areas radiating outward from the initial areas (top one is drawn upside-down).





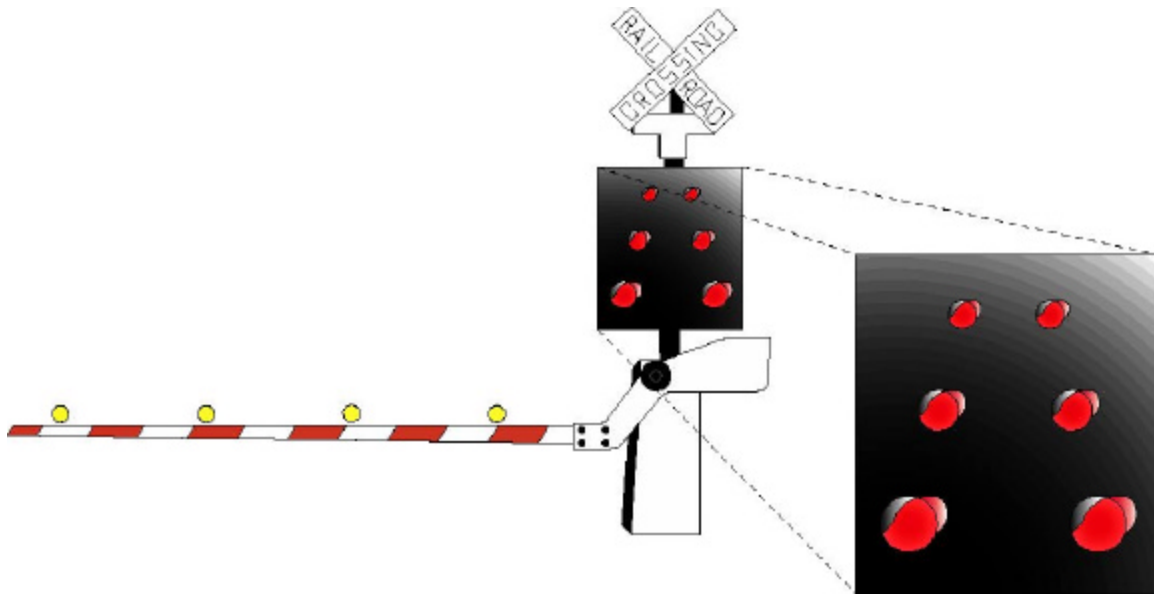


Figure 6. illustrates this notion. The triangle becomes one which expands, giving the eye-brain the erroneous percept of something coming towards the observer with greater than actual rapidity.

Another strategy could be used to increase the visibility of the crossing lights. The modified lights are illustrated in Figure 6. These are present on several spatial scales and the timing and spacing are chosen to optimally stimulate motion-sensitive neurons when seen at different distances. Such a device is more sophisticated than the one it replaces and thus would require special expertise to develop.

### VIII. Conclusion:

I have described above a few of the many areas of roadside signaling that will be considered for future deployment on our roads. None of the new ideas described above are proven as yet, and indeed, for each, other alternatives might prove more useful. But what appears inescapable to the author, is that increasingly sophisticated innovation will be needed, and indeed will be welcome, on the highway of the future.

Next Steps: It may prove to be the case that the foregoing descriptions merely echo thinking that the reader has already been engaged in. If so, the exercise will not have been especially useful. On the other hand, this discussion may prove of such interest and novelty that the reader will be motivated to seek additional information. If so the following suggested sites/organizations for gaining further information may prove of some use:

The annual meeting (April 19-22, 1999) of the Intelligent Transportation Society of America: [www.itsa.org](http://www.itsa.org)

Organizations sponsoring other such meetings:

ERTICO (European counterpart of ITSA at [www.ertico.com](http://www.ertico.com))

Transportation Research Board of the National Academy of Sciences ([www.nas.edu/trb/](http://www.nas.edu/trb/))

ITS World Congress (biennial)

Research and development:

Department of Transportation: [www.dot.gov](http://www.dot.gov)

Turner Fairbanks Highway Research Center: [www.tfhrc.gov](http://www.tfhrc.gov)

National Highway Traffic Safety Administration: [www-nrd.nhtsa.dot.gov/crashavoid/](http://www-nrd.nhtsa.dot.gov/crashavoid/)

**IX. Acknowledgements:**

We thank staff at California PATH for the cover illustration which also appears in the text. The work was supported in part by a PATH project (MOU 323)

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