A ten-point tool kit for effective warning lights

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This is the third article in a series looking at emergency vehicle markings and warning lights. An extended version of the first and second articles can be downloaded from the Ambulance Visibility website CLICK HERE. These articles are provided to ensure all members of the Colorado EMSAC community have access to the up-to-date information presented at the 3rd Annual EMS Safety Summit held in October 2010.

I realised very quickly that I should listen to my own advice!

The Intensive Care ambulance was on its way to an urgent case, weaving though heavy traffic under lights and sirens. It approached my car, swiftly closing the gap and soon passed by. It now became glaringly obvious to me that the new flash pattern we had programmed into the light-bar was utterly confusing. As I continued on my thoughts turned to the many times I had spoken at conferences and presentations, each time emphasising the importance of undertaking careful testing of new warning lights or vehicle markings before committing the vehicles to the road. The sinking feeling in the pit of my stomach soon began to shift to the mental arithmetic of how much it was going to cost to fix this problem with the light-bar.

Hindsight can be so frustrating

So what happened? Our ambulance service, just like so many other EMS agencies around the world has been progressively changing to LED lighting. LED technology provides numerous benefits and delivers proven advantages like flexible flash patterns, long lamp life along and low current draw. Over past years our agency has used LED lamps supplemented with white halogen intersection lights at either end of our light-bars. The old-style halogen lamps oscillate back and forth through an arc of 90 degrees and the lamps can also be manually switched to shine sideways at the incident scene as alley lights.

The decision to replace the halogen lamps had already been made. Two separate sets of white LED's would be installed in an arc at each end of the new bar. The new lamps would illuminate in a cyclic sweeping pattern to emulate the previous moving lamps. This was a great idea on paper and was clearly described in the brochure but the new arrangement still had to be trialled before production started. Several days after confirming the LED decision the vehicle builder advised that the build-slots would be available in ten days time - three months earlier than expected. Our build specification was quickly finalized to meet the deadline. We never had a chance to trial the sample light-bar before moving forward into production. It goes without saying that almost everybody in EMS has experienced a short-call on a project at some time or another.

Redesigning a good light-bar may unintentionally make it worse!
Several months later and our brand new ambulance is rapidly approaching my car. The six brilliant white lamps are clearly overwhelming the synchronized red and blue lamps positioned on each side of the light-bar. There is now no doubt that the dazzling display of (no less than) seven uncoordinated flash patterns will definitely amplify the confusion felt by drivers as they strain to decode the crazy light show. The new lamp configuration seems to lock the bewildered drivers into a visual hiatus and subsequent hesitation. They appear to stare at the warning lights in a drawn out period of indecision, well overstaying typical observation times. This illuminated chaos packed into our light-bar seems to fog the perception of drivers.
The postscript to this story is good news - the light-bar manufacturer cheerfully assisted by changing the lamps and reprogramming the lightbar sequence at very little extra cost.

Five important objectives for emergency vehicle warning lights

The protection provided by a combination of vehicle markings, sirens and warning lights are the tools-of-trade for emergency operations on the road. It is crucial that all three work together to maximise warning times, however siren limitations in the real world environment loads extra emphasis onto the visual warning elements. If your warning lights are to be fully effective, then carefully consider the following points:

1. Warning lights must be conspicuous and readily seen by other drivers
This is not usually an issue at night but during daylight hours or inclement weather other drivers may not see some types of warning lights clearly, especially if those lights are fitted discretely to an unmarked emergency vehicle. All light-bars fitted with blue lamps may also suffer a substantial dilution of color and diminished intensity when viewed under bright skylight during the day. Just to complicate the issue excessive warning light output should be controlled at night to prevent temporarily blinding people nearby. Warning lights on emergency vehicles should not only command attention but also swiftly release the viewer's concentration so they can rapidly attend to the avoidance task.

2. Be quickly recognizable as an emergency vehicle – the use of standardized colors and lamp combinations facilitates rapid recognition and indicates a vehicle with special status. The chosen or legislated colors for all emergency vehicles operating around your region should be markedly different from any lighting fitted to local general service vehicles. There is a definite advantage if fire, police and EMS are able to regionalize the use of identical warning light colour combinations on their vehicles.

3. Define the size and shape of the vehicle – The warning lights and ancillary lighting should clearly demarcate the shape and size of your vehicle. The lighting design becomes a key element after dark or during adverse weather conditions such as heavy rain, fog or snow. It can be easy for some common light-bar and lamp configurations to confuse other drivers, especially if programmed to display random or uncoordinated flash patterns. Lights that illuminate in alternating or motion patterns often draw attention away from the key landmarks on the vehicle that visually convey the dimensions of the emergency vehicle to other drivers. If all the lights flash simultaneously across the entire length of a light-bar they provide accurate visual information about height, width and vehicle orientation.

4. Clearly indicate to other drivers the course & speed of the emergency vehicle – this follows on from point 3 where the individual warning lights should work together to clearly reveal your speed and direction of travel (or any subsequent change in course). Warning light patterns that flash randomly, alternate or are not synchronized tend to disguise changes in vehicle speed or orientation. An example of this issue would be best described by a person standing on the ground at night looking skywards. After seeing just one initial flash of the white anti-collision lights on an overflying jet they immediately attempt to predict the flight path of the aircraft. Each time the next wingtip flash illuminates, the jet is never at the expected point in the sky where the person is gazing. On the other hand, if the steady-burn red and green navigation lights are visible on the wingtips, the person on the ground is able to calculate the plane's direction and speed almost instantaneously. More about the benefits of steady-burn lights later on.

5. Lighting should guide and generate an appropriate response from drivers
If the warning lights do not convey clear, visible and easily understood information then the reactions of the surrounding drivers may become confused. The risk of something untoward occurring increases as it takes a longer time for other drivers to accurately interpret and mentally choose an appropriate response,. The whole see and avoid process must be successfully completed in just a few seconds.

Visual effects that influence our perception of warning lights

Flashing lights are not perceived as quickly as steady-burn lights, but once seen, they attract and hold the attention of the viewer. Flashing lights require higher levels of light output to compete with similar steady-burn lighting. It is also much easier to track a steady-burn lamp than a flashing lamp when the vehicle is in motion and more difficult if the flash-pattern has a changing flash rate or pattern. Flashing lights produce slower reaction times. Stephen Solomon often stated that *"Fewer lights, flashing slower & less brightly"* are more effective. Here are some other issues:

Glare

Uncontrolled glare from emergency vehicle warning lamps can affect the crew during response, other drivers (especially older drivers) as well as the personnel working around the vehicle at an incident. Glare from poorly designed warning lights is not limited to use at night and may occur at any time of the day. Here are the four different types:

- **Distraction glare** - caused by car headlights or streetlights, causing eye fatigue, annoyance and distraction.
- **Discomfort glare** - can be caused by everyday light conditions and may be uncomfortable regardless of the weather or time of day. It can be present at any level or intensity of light, or when moving from one lighting condition to another. It often causes squinting and eye fatigue.
- **Disabling glare** - comes from excessive, intense light. Disabling glare can impede vision as the intense light causes significantly reduced contrast of the retinal image. The effects can last well beyond the time of exposure.
- **Blinding or reflected glare**
  This comes from light reflected off smooth or shiny surfaces such as water, snow or as the halation or overglow from reflective vehicle markings. It can be strong enough to block vision.

It is recommended that your organization should, at the very least, subjectively test your warning lights for glare. Mount your sample lamps in position on a vehicle and stand back with a few people to assess the characteristics of the lights. While not a highly technical method, testing lamps this way for output and glare is effective. If you are lucky enough to have access to scientific testing facilities, then knock yourself out!

The Wake Effect

In general, any collisions or accidents caused by the passage of an emergency vehicle that does not actually involve the emergency vehicle are called Wake Effect accidents. The Wake Effect has proven difficult to quantify in research despite the accumulation of large amounts of anecdotal evidence. At night, in terms of glare and brightness from flashing warning lights, the Wake Effect can cause a rapid loss of night adapted vision, followed by temporary night-blindness in other drivers. This can also occur around large accident scenes, more so if the excessive glare from any number of uncoordinated flashing lights is not controlled. Despite the difficulty in proving the Wake Effect, the existence of the problem is widely accepted.

Moth effect

Sometimes called phototaxis, this effect gains its name from nature where a moth is drawn towards the light of a flame. On the road it is the tendency for a driver to fixate on warning lights or another object and drive toward it. The driver may be further influenced by alcohol, fatigue or drugs. Perceptual narrowing may also play a part at night or during adverse weather conditions. An affected driver may not necessarily collide with an emergency vehicle but could run over emergency personnel moving around the scene. Solomon and several other researchers have demonstrated that using amber lights on-scene may decrease the incidence of collision or injuries.

The blue advancing – red receding illusion

Research by Berkhout in 1979 showed that a stationary vehicle displaying red and blue warning lights could induce an illusion of vehicle motion in the viewer. The flashing red lamp led to more than 50% of the test subjects believing the vehicle in front of them was actually moving away. Red lamps increase the chance of a rear-end collision occurring in a real situation if the viewer was in another vehicle approaching the stationary car. Alternatively, 26% to 31% of the test subjects believed the stationary vehicle was approaching toward them when a blue flashing light was illuminated.

This research shows why alternating red and blue warning lights appear to jump backwards and forwards with this apparent motion slowing reaction times and increasing the possibility of a collision with the stationary vehicle on the roadside. At any one time it is possible for between 26% and over 50% of approaching drivers to think that a stationary emergency vehicle with flashing lights is actually moving. Synchronizing the warning lights so they flash together or using amber lighting on-scene mitigates the some of these problems.

A ten-point plan for effective warning lights

1. Standardise the colours of your warning lights

All States and Territories in Australia legislate that the red and blue lamp combination is exclusively reserved for use by Police, Fire, EMS and rescue agencies. A green beacon is set aside for stationary incident command vehicles.
A national standard ensures that emergency vehicles are immediately recognisable anywhere in the country, regardless of region of origin or agency type. The red and blue colours were chosen to minimise differences in human eye sensitivity between day and night. The United Kingdom and some European countries specify all blue lighting for emergency vehicles. Legislation must ensure that an emergency vehicle of any type or state of origin is quickly recognisable as soon as the lamps are seen.

Emergency vehicles in the US tend to carry a plethora of warning light colours in diverse combinations. Where a state has not legislated for the use of a particular warning light colour there may be many lighting variations fitted to emergency vehicles working the roads throughout the state. Ambulances or police vehicles operated by different agencies across regional or county lines that are adjacent to each other will often use different color combinations. The variations in lighting colors may cause confusion as the vehicles travel between the adjoining areas. Wherever possible, local agencies should get together and attempt to reach agreement on warning light colors. Unlike Australia and Europe, the US government has no draft federal recommendation specifying colors for a nationwide emergency vehicle code that would steer future change.

2. Effective and controlled warning light output for both day & night

It is not technically difficult to mount high-output lamps on a vehicle and achieve maximum light output, except the vehicle will blind everyone around it at night (including your crew). Recent developments in lamp technology allow for optimal light output during the day and a selectable reduction in output for night operation. Reducing the output does not necessarily lessen inbuilt glare so all lamp and lens combinations should be tested insitu on a vehicle. The ACT Ambulance Service in Australia conducted outdoor assessments on forty different lamps and only a few of the test lamps stood out for their control of brightness and reduced glare. The chosen lamps that demonstrated constrained output with low levels of glare are now fitted to their ambulances. Crews can also work anywhere around the vehicle without being affected by residual glare from the warning lamps.

As explained earlier it is important not to underestimate the effect of skylight dilution on blue colored lamps at medium to long distances when they are viewed under bright daylight conditions. Blue remains very effective at close range but as the distance increases, the blue fades and eventually disappears completely, whereas a red lamp mounted alongside the blue would still be visible at the same distance. This is not an issue at night when blue lamps become visually superior to red.

3. Choose lamps with larger lenses that control glare

Surprisingly, the main offenders for excessive intensity and glare are the smaller light-heads with a condensed optical surface area. Small lights use miniature lenses that are incapable of controlling glare effectively. They also need a very high light

output to simulate the apparent size of the larger lamps that possess a greater surface area with their optically engineered lenses. Unfortunately it is becoming more difficult to find space on vehicles to mount lamps and as a result the smaller sizes are becoming more popular. Medium to large slamps should be used wherever possible and always mounted high on the vehicle, well above eye level. This mounting height can be seen over traffic and allows the crews to work around the vehicles at night without visual interference from any overly bright or glaring lights.

4. Warning lamp ON time should be greater than or equal to the OFF time
Wherever possible choose a flash pattern with long ON times. A very short duration flash, a rapidly changing pulse length or light sequences that cycle through several different patterns all delay reaction times and escalate confusion by increasing the mental load. Random or rapid types of flash pattern may cause the viewer to psychologically hesitate, or pause while they attempt to decode and interpret the continuously changing warning signals.

5. The ideal flash pattern is a double flash or a similar quad flash
Simple flash patterns do not overwhelm the senses of the viewer and should remain predictable throughout the flash sequence. A double flash allows thinking time so drivers can identify the emergency vehicle, accurately interpret direction/speed and then calculate avoiding action. The frequency of the double flash provides an efficient number of consecutive light bursts to present a repetitive and continuous flow of information to the viewer so that any directional changes made by the emergency vehicle are quickly noticed and recognised. Rapid or random flash patterns usually lead to sensory overload and this can delay a driver's reaction.

6. Synchronise all flashing warning lights
Recent research by the University of Michigan demonstrated that the synchronization of warning lights (all lamps flash on & off together) is superior to flash sequences that are random or alternating. As already stated, synchronization increases the recognition of the vehicle size and shape, as well as improving the viewer's perception of the vehicle's orientation, course and speed. Lights that flash simultaneously can be seen further away than lights that alternate. Synchronizing the warning lights also reduces the effect of any motion illusions induced by random or alternating red and blue warning lights.

In addition, synchronization enhances the ability of passing drivers to visualize people working around the ambulance. This occurs during the dark time when the warning lamps are in the OFF period and is a very positive advantage. Another benefit is the improved ability of motorists to detect and differentiate a single vehicle located within a group of emergency vehicles parked around an incident scene. When the warning lights on all the emergency vehicles flash out of sync with others nearby at night, it becomes almost impossible to visually separate any one individual vehicle located within the large pack of parked vehicles.

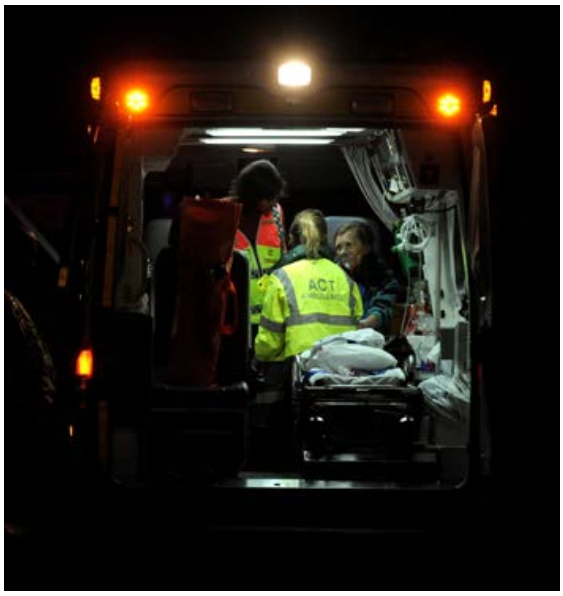
7. Try not to mix the different types of flashing lamps
Even though LED lamps are the flavor-of-the-month these days, there is still a place on the roads for older halogen and strobe lamps, as well as the traditional rotating beacon. Each type of lamp projects light in a different way depending on the age of the technology, lens type, reliability, current draw and efficiency. It is however almost

impossible to synchronize an LED, strobe, halogen lamp or beacon so they flash together in a programmed sequence.

The flash characteristics of all the lamps are diverse with each type having distinct advantages in different situations. Rotating beacons can provide 360^{o} visibility on very large vehicles where it would take many more LED light-heads to achieve the same result. Strobe technology suits the compact warning lamps needed to fit the tight spaces on response motorcycles, but controlling glare from strobes can be very difficult. As a general rule try not to mix different lamp types; if you cannot avoid it then make sure to take extra care when you mix & match.

8. Consider adding steady-burn lights

The take-up of steady-burn lamps continues to increase as more agencies realise that ultra-bright or exaggerated displays of flashing lights on vehicles do not necessarily increase scene safety. Excessive lighting may in fact actively contribute to increasing the accident rate around incident scenes. Vehicles like the Mercedes Sprinter have an extra advantage with a number of small amber running lights fitted along their baseline which can be paired with roof level steady-burn lamps. Roof mounted steady-burn lamps effectively encircle the vehicle whenever the flashing lamps are extinguished. If there are multiple vehicles at an accident scene it is becoming more common to see only one or two dominant vehicles displaying flashing warning lights while the remainder of the vehicles switch down to steady-burn only.



Steady-burn lights not only increase crew and vehicle safety at the scene, but also reduce the likelihood of Moth and Wake effect accidents occurring by reducing the clutter and glare of multiple bright flashing lights; lights that appear to dance around in the dark. Drivers approaching or negotiating the scene can rapidly identify an individual emergency vehicle. The conspicuity of individual emergency personnel walking around the scene is also enhanced when the number of flashing light are reduced.

Steady-burn lights can be used day and night to establish an effective warning zone around vehicles parked at the kerbside without illuminating the entire roadway with high-intensity flashing lights. Over the last few years new cruise lighting technology has become available. This allows flashing lamps to be set at several levels of steady-burn brightness. Cruise light capability reduces the number of extra light-heads required on the vehicle and also allows the steady-burn lamp output to be

tailored to the time of day and changing weather conditions. There is also evidence that selectively used amber-only lighting reduces Moth Effect accidents by reducing the number of flashing lights. This makes amber lighting popular with Paramedics who are working around the vehicles.

9. Switch off any flashing white lights at night

It has become common practice worldwide to flash the front headlamps and fit a white warning lamp to the light-bar. A white flashing lamp is a very bright, effective and powerful “attention-getter” that can be visible at long range, even in daylight. At night just a short exposure to bright flashing white lamps can obliterate night adaptation in nearby drivers within seconds, thus producing temporary night blindness. Those same white lamps can also affect the crew as they respond by producing strobing and stop-motion effects that are visible through the windscreen. The onset of night-blindness can have catastrophic consequences for other drivers if they continue to attempt driving in traffic or try to navigate around an accident scene (the Wake Effect). It is crucial that all flashing white lights are programmed to illuminate only during daylight hours.

10. Avoid fitting side flashing lamps at the eye level of other drivers

A popular and increasing practise is the fitting of flashing lamps to the waistline or the wing mirrors of emergency vehicles. This trend accelerated after the NFPA 1901 Standard for Automotive Fire Apparatus was published in 2009. Similar recommendations for waistline lighting have been cut & pasted into the NFPA 1917 Standard for Automotive Ambulances (due for release in 2013). Information has been submitted to the NFPA suggesting that placing an “optical warning device ....between 18 in. and 62 in. (460 mm and 1600 mm) above level ground” may cause temporary blindness in nearby drivers. The latest recommendation in the draft standard places waist-height lamps exactly at the eye-level of seated drivers in an average sedan.

At night a flashing side lamp may pass alongside a vehicle and then be less than 3 feet away from the eyes of the other car driver. Any driver glancing sideways at the lamp while stationary or being overtaken will have his night vision adaptation eliminated in less than a second - followed by secondary after-flash effects. It may take up to 20 minutes for the driver to regain their night vision. Older drivers are particularly susceptible to bright light sensitivity and loss of night-vision. Promoting eye-level lights along the vehicle waistline may well be a magnet for future litigation following any Wake Effect type accidents. In fact, most warning lamps are delivered with a written warning stating that eye damage will occur if the lamp is viewed at close range. The maximum height for these low-level lamps should be no more than 30 inches above ground level to ensure the effect on other drivers is limited.

The final word

Warning lights on emergency vehicles have always been heavily promoted by suppliers who follow the “bigger-brighter is better” strategy. Research into warning lights has begun to influence and change the “old school thinking”. As the desire to increase personnel safety gains impetus, emergency service organisations are taking more interest in their fleet warning systems. This ten step lighting tool-kit provides simple and commonsense recommendations that if followed, will greatly enhance your safety on the move and at the roadside.