Abstract

With an ever increasing number of nighttime work zones due to growing urban congestion, researchers are exploring the use of various technologies to help improve nighttime safety at work zones. Sequential warning lights are wireless lights that flash in a sequence to clearly delineate the taper at work zones. In theory, they help to improve driver recognition of lane closures and work zone tapers. But could these lights make nighttime work zones safer in practice? Are there any unintended consequences to using such lights? The University of Missouri set out to answer the aforementioned questions with the support of the FHWA Smart Work Zone Deployment Initiative program. The effectiveness of sequential lights was investigated using controlled field studies where the same sites were investigated with and without these lights. Because many work zones are relatively short term, crash analysis is not possible. Therefore, surrogate safety performance measures were used. These measures were speeds of approaching vehicles, number of late taper merges and locations where vehicles merged into the open lane from the closed lane. The results of this study indicate that sequential warning lights had a net positive effect in shifting the overall merge behavior upstream (6.74% overall increase and 19% increase for trucks), enhancing driver compliance (overall speed pattern lowered) and reducing the speeds of approaching vehicles (2.21 mph mean speed decrease). However, a possible concern was that a small proportion of drivers merged more aggressively near the taper because the taper became more visible.

Introduction to Sequential Lights in Work Zones

Sequential warning lights are designed to improve driver lane discipline by providing a directional guide. They use LED and wireless communications technology to dynamically enhance the visibility of work zone entrances. Some models that are currently available in the market include Dorman-Dicke Safety Products SynchroGUIDE (tested in this study) and Empco-Lite LWCS. The flash rate of the lights is around 60 flashes per minute and each lamp uses two 6V batteries. Flashing refers to an increase in light intensity. Once synchronized wirelessly and placed in a line as seen in Figure 1, they appear as a single light source traveling along the lamps from front to back of a work zone area. These sequential lights were included as an option in the latest Manual on Uniform Traffic Control Devices (FHWA, 2009).
We are the ITS industry leader in innovation and education for Surge Protective Devices. Our products are designed and manufactured in the USA and will protect sensitive electronics in traffic systems from damaging surges caused by lightning and utility switching and load switching.

The AC Power DIN Rail Series utilizes large block 50kA Thermally Protected MOVs with surge current levels of 50kA per mode. These devices are designed to mount onto DIN Rail. The small compact design and DIN Rail mounting capabilities make it ideal for point of use protection.

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Although nighttime work zones help to alleviate congestion encountered during the day time and during peak periods, they could result in some potential safety concerns. There is some evidence of problems with lighting and illumination of channelizing devices at nighttime work zones (Garber and Zhao, 2002) and a potential for higher fatality rates (Bushman et al., 2005). There are some potential drawbacks to using sequential lights that were not investigated in this study. One is the possibility of photo-sensitive seizure with a wrong flashing rate. Another is the synchronization of driving speeds to sequential warning lights leading to vehicles speeding up in work zones.

This article is one of the first documented field experiences in the United States. The Texas Transportation Institute (TTI) had investigated an earlier wired model in 2001 (Finley et al., 2001), and the British Highway Agency trial had concluded that wireless sequential lights did improve safety (HA, 2005). As driver behavior and road design differ between the United Kingdom and the United States, it was interesting to see if the results would be similar on both sides of the ocean.

Description of Field Studies
Sequential lights were deployed on three short-term maintenance work zones on the same interstate freeway, I-70. All three work zones were in close proximity and had similar geometrics and traffic conditions. Each work zone was evaluated after 9:30 p.m. or after the sun had fully set. All locations involved a two-to-one lane closure on the right lane. The speed limit on this urban freeway was 60 mph. At each location, both the “with” and “without” lights conditions were investigated using multiple video cameras, traffic detectors and a speed radar. With the instrumentation, the researchers could see the entire area from around 700 feet upstream from the taper. Since the taper is where a lane is closed off, this 700 foot area which includes the taper was the focus of the instrumentation. Figure 2 shows how the approach to the taper was divided into equal length zones separated by delineators (DEL) visible in the video field-of-view. Using these zones, it was easy to determine where a vehicle merged upstream from the taper. Since the taper is where a lane is closed off, this 700 foot area which includes the taper was the focus of the instrumentation. Figure 2 shows how the approach to the taper was divided into equal length zones separated by delineators (DEL) visible in the video field-of-view. Using these zones, it was easy to determine where a vehicle merged upstream from the taper. Figure 3, on page 52, shows a picture of the area where the instrumentation was monitoring traffic. The traffic flow at those sites was fairly low at night being around 200 vehicles per hour per lane.

Figure 2 Layout of Instrumentation.
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The researchers examined various aspects of driver behavior in order to assess the safety impacts of sequential lights. One aspect is vehicle speed characteristics such as the mean speed, 85% speed, speed compliance and speed standard deviation. Another aspect is merging behavior at the taper such as the vehicle’s lateral position near the taper area. And one last aspect is the use of the closed lane, and the location where a vehicle changed lanes in relationship to the taper. A comparison was made between the behavior of trucks and passenger vehicles, since the two vehicle types have different safety concerns, driver training, regulations and vehicle performance. Special attention was also focused on vehicle platoons, because of the complexity of multi-vehicle interactions.

So Was There Any Difference With and Without Lights?

Vehicle Merge Location
During nighttime and uncongested conditions, it is desirable for vehicles to merge to the open lane early to avoid a forced merge at the taper. Figure 4 shows the percentage of vehicles merging into the open lane at different zones with and without sequential lights. Zone 8 is closest to the work zone taper. After deploying sequential lights, the percentage of total vehicles and passenger vehicles merging into the open lane shifted away from the taper. Vehicles merged earlier in anticipation of the lane closure in the with lights scenario. Thus there were fewer vehicles in Zones 5-8 and more vehicles in Zone 1-4. Comparing trucks versus passenger cars, the percentage of passenger cars merging in the first five zones increased from 58.62% to 65.36% (or 6.74% increase) while the percentage of trucks merging increased from 46.51% to 65.52% (or 19% increase). Sequential lights may have had a more pronounced effect on trucks, because commercial trucking is heavily regulated, truckers have a greater sight distance from a higher vantage point, and trucks have more limited performance characteristics so drivers exhibit a greater reaction to visible warnings.

As shown in Table 1, on page 53, sequential lights use resulted in a statistically significant mean speed reduction of 2.2 mph for all vehicles and 2.5 mph for trucks. The 85% speeds with sequentially lights were lower than those without sequential lights. And the speed limit compliance increased by 6.7% with sequential lights. But the standard deviation also increased by 0.91 mph. One possible explanation as evidenced by the video footage is that a small portion of aggressive drivers made last minute merges or even passed at merge location.

Vehicle Speeds
Several different speed measures were analyzed because they each tell a slightly different story. The mean speed represents the central tendency of drivers. The 85% speed is a speed that is commonly used for setting speed limits, thus it a measure associated with driver compliance of the speed limit. The speed standard deviation is important because variation in speeds is a factor in crashes and crash severity. The speed limit compliance rate represents the percentage of vehicles that are under the speed limit. For a thoughtful discussion on these speed measures please see TRB (1998).

In addition to looking at where the vehicles merged, the average merge distance from the taper was calculated for the vehicles that merged within the eight zones. The average merge distance from taper of all vehicles with sequential lights was 20 feet longer than without sequential lights. The average merge distance of passenger cars and trucks with sequential lights are 13 and 49 feet longer than without sequential lights.

Figure 3 Monitoring of driver behavior near the work zone taper.

Figure 4 Percentage of vehicles merging at different zones.

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Vehicle Lateral Position at Taper
The percentage of vehicle occupancy in open, middle, and closed lanes near the taper gives an indication of aggressive driving behavior at the taper. Figure 5 shows 7.8% of vehicles were in the closed lane with sequential lights in contrast to 6.2% without sequential lights, and 8.0% of vehicles were in the middle with sequential lights in contrast to 6.0% without sequential lights. These lateral position percentages are undesirable, because there were a higher percentage of vehicles in the closed or middle lane near the taper when sequential lights were deployed. One possible reason for the increase in the number of late mergers with sequential lights was again that a small portion of aggressive drivers waited longer to merge as they were better able to estimate the location of the taper illuminated by sequential lights.

<table>
<thead>
<tr>
<th></th>
<th>With lights</th>
<th>Without lights</th>
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<tbody>
<tr>
<td>Mean (mph)</td>
<td>55.55</td>
<td>57.76</td>
</tr>
<tr>
<td>85th Percentile (mph)</td>
<td>62</td>
<td>63</td>
</tr>
<tr>
<td>Standard Deviation (mph)</td>
<td>6.66</td>
<td>5.73</td>
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<tr>
<td>Speed Limit Compliance Rate</td>
<td>78.1%</td>
<td>71.4%</td>
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</tbody>
</table>

Conclusion
So the answer to the question, “Does sequential warning lights make nighttime work zone tapers safer?” is likely a yes. Although sequential lights caused an increase in speed standard deviation and a decrease in the open lane usage at the taper, the decrease in average vehicle speeds, decrease in 85% speeds, increase in driver speed compliance rate, increase in early merging and increase in average merging distance point to an overall increase in safety. Evidence suggests that an unintended consequence of better illumination at the taper is a small percentage of drivers who become more aggressive with overtaking at the taper.

Acknowledgements
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References


Figure 5 Vehicle lateral position at taper with and without lights