Journal of the National Academy of Forensic Engineers®

http://www.nafe.org
ISSN: 2379-3252

Vol. 36 No. 1 June 2019

Forensic Engineering Analysis of the Alleged Failure of an Emergency Vehicle Traffic Light Preemption System

By Robert O. Peruzzi, PhD, PE, DFE (NAFE 954M)

Abstract

This case involved a fatal collision between a police vehicle (operated by a police officer) and a non-police vehicle (operated by a civilian). With lights and sirens activated, the officer in pursuit ran a red light and crashed into the civilian's vehicle in an intersection whose traffic light controller included an emergency vehicle preemption system. The civilian driver was mortally injured, and died the next day. The estate of the deceased driver sued the police officer, municipal police department, and manufacturer of the emergency vehicle preemption system. The author was retained by counsel for the estate of the deceased to assist in the case against the manufacturer of the emergency vehicle preemption system and municipality. The evidence showed that the preemption system was working properly, but that the system's confirmation lights had been improperly programmed. A maximum speed was calculated at which a preempted green light for emergency drivers would be assured. Event logs in the police vehicle showed that the police officer was driving too fast for the traffic light controller to cycle through its sequence before the officer reached the intersection.

Keywords

Forensic engineering, traffic control system, infrared strobe transmission, infrared detection, traffic light preemption, emergency vehicle, traffic light controller, collision avoidance, traffic safety

Introduction

Of all the traffic control choices made by a municipality, installing traffic lights at an intersection is a last resort. Unless traffic signals enhance safety or efficiency, the preferred methods of traffic control are "no control," yield signs, or stop signs[1]. Traffic lights are installed when traffic is too heavy for drivers to assign right of way on their own. If engineering studies deem traffic lights are necessary, further choice is made between self-timed or actuated signals. Actuated signals may be controlled by vehicle sensors embedded in the roadway or by video camera sensors. In the interest of keeping a steady flow of traffic, multiple intersections may be controlled using sensor input from each intersection — either through distributed computation or from a remote central computer.

The purpose of traffic signal systems is to optimize safety and efficiency. Even so, traffic does back up at times, and collisions do occur. When responding to an emergency, responders may be delayed by backed up traffic approaching intersections. Sirens and flashing lights direct drivers to pull over and make way for the emergency vehicle, but pulling over is not always possible. Stopped drivers may not be able to move forward and pull over until allowed by a green traffic signal.

Preemption systems can open this bottleneck by turning traffic lights green or extending the duration of the green signal in favor of emergency vehicles[1]. When triggered by an approaching emergency vehicle, the system sends an interrupt signal to the traffic light controller and activates confirmation lights, which indicate that the approaching vehicle has been detected. The traffic light controller cycles through the sequence of signal states and presents the emergency vehicle with a green signal as soon as possible. The traffic light controller must follow specified minimum times for each state the signals pass through before presenting the green signal to the preempting vehicle[1].

Robert O. Peruzzi, PhD, PE, DFE, 719 Fourth Ave., Bethlehem, PA 18018, 610-462-3939; peruzzi@rperuzzi.com

This paper reports an analysis of the role played by emergency vehicle preemption system hardware and programming installed at an intersection where a fatal accident took place.

Background

According to his deposition, the defendant police officer was standing by, on duty, when he heard over the police radio an officer reporting that he had begun pursuit of a suspicious driver and vehicle and asked for support. According to the dispatcher's deposition, the police dispatcher assigned an officer other than the defendant officer to support the pursuing officer. According to his deposition, the defendant decided on his own, without informing the dispatcher, to join in the pursuit. The defendant officer turned on his emergency lights and siren, which automatically activated the emergency vehicle preemption emitter on his vehicle and activated his dashboard and rear-window video cameras (dash-cams).

Dash-cam recordings showed the defendant's vehicle traveling on a U.S. non-divided highway through intersections controlled by stop lights and traffic signals. His maximum speed reached 98 mph. Where traffic was light, other motorists pulled over. Where others could not pull over, the defendant detoured into oncoming traffic lanes, sometimes slowing down to less than 70 mph.

The dash-cam videos showed that traffic lights at preemption-controlled intersections, including the intersection of the crash, did not change to green in favor of the defendant's vehicle — nor did preemption confirmation lights activate at these intersections before the defendant crossed them. The crash happened within a preemption-controlled intersection. Records showed that the traffic light had turned red for the defendant about 5 seconds before the crash and had turned green for the victim about 3 seconds before the crash.

Witnesses testified at deposition that the victim apparently did not notice sirens or police emergency lights. Dash-cam records and anti-lock brake logs showed the defendant entered the intersection at about 89 mph and braked hard when he saw the victim's car directly in his path. Dashcam video also showed that he attempted to swerve but hit the driver's side of the victim's car broadside.

The police report stated the defendant was slightly injured. He was wearing a seatbelt, and his airbags deployed. The victim also wore a seatbelt, and her car's airbags deployed. Videos at the scene showed hydraulic rescue tools were used to extricate the victim. Medical report stated that she died the next day from head trauma.

Police investigators and municipal employees immediately accessed traffic controller records and preemption controller records. According to the controller log file, preemption occurred before the crash, indicating the preemption system did work properly.

Within the hour, they ran live, low-speed tests of the preemption controller at that intersection captured on video. During these tests, video recordings showed the lights consistently turning green in favor of the testing vehicles. However, flashing confirmation lights did not occur at the time of preemption but held off until the light turned green in favor of the testing vehicles.

According to manufacturer's literature and department of transportation regulations, the confirmation lights should be programmed to activate as soon as the preemption is triggered[2].

Preemption System Overview

A preemption system is an optional enhancement to a traffic signal controller and does not operate on its own[3]. Preemption system components include infrared (IR) emitter assemblies mounted on emergency vehicles, IR detector assemblies mounted on traffic signal supporting structures, phase selectors (sometimes called discriminators) located in the traffic controller cabinets, confirmation lights mounted with the detector assemblies on traffic signal supporting structures, and various connectors, cables, chassis and mounting hardware.

A block diagram of the preemption system is shown in **Figure 1**[3] (on page 3). Items 14 -16 are components of the emergency vehicle emitters. Item 17 is the control box mounted inside the emergency vehicle. Item 33 corresponds to the IR detector. Items 34 and 35 correspond to the phase controller assembly. Item 11b corresponds to the traffic signal controller, which the preemption system augments.

The preemption system used in this municipality at the time of the crash is described as follows[4]. Infrared strobe-light emitters mounted on emergency vehicles are activated whenever sirens and/or emergency lights are enabled. The activated emitter generates infrared optical pulses directed forward from the vehicle.

Infrared detectors are mounted on or near the traffic

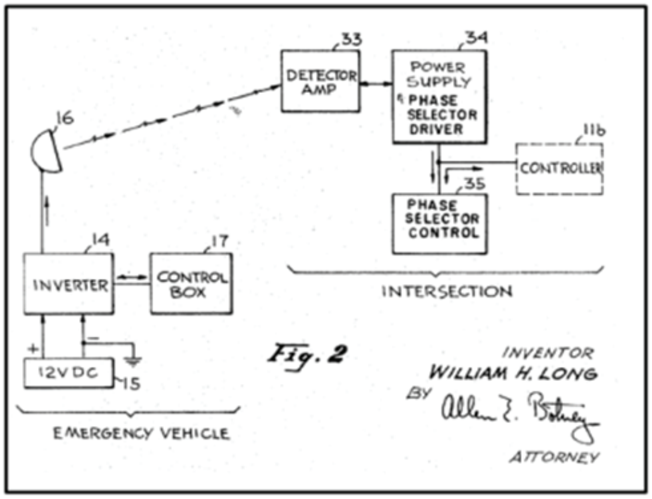

Figure 1
Block diagram of preemption system from `078 patent.

light supporting structure at the intersection. Detectors convert the infrared pulses into electrical pulses that are conducted through cable to a "phase selector" signal processing unit, which decodes the pulse sequence to determine whether or not it originated from a registered emitter. Sources of optical energy other than a registered preemption emitter are rejected. The phase selector may also arbitrate between emitter-mounted vehicles approaching from different directions according to "first-come first-served" or assigned precedence, such as ambulance over police vehicle.

When the phase selector logic has made the decision to preempt normal traffic signal sequencing, it delivers a preemption signal to the traffic controller. Older electromechanical traffic light controllers (still in use) utilize an electro-mechanical interface module to couple to their dial-and-cam mechanism. More recent electronic traffic light controllers have input ports for preemption trigger signals.

The received preemption trigger signal is latched as an interrupt to the traffic light controller. The controller's program defines the timing of its response according to an official intersection permit and state laws. The permit and laws specify minimum times for green, yellow, and pedestrian walk signals that may not be violated during a preemption event. At the earliest allowable time, the traffic light turns green in favor of the preempting vehicle. When the detectors stop receiving IR emitter pulses, the phase selector waits a programmable time interval and then releases the preemption trigger. After trigger release, the traffic light controller resumes its usual progression.

Figure 2 illustrates a typical confirmation light

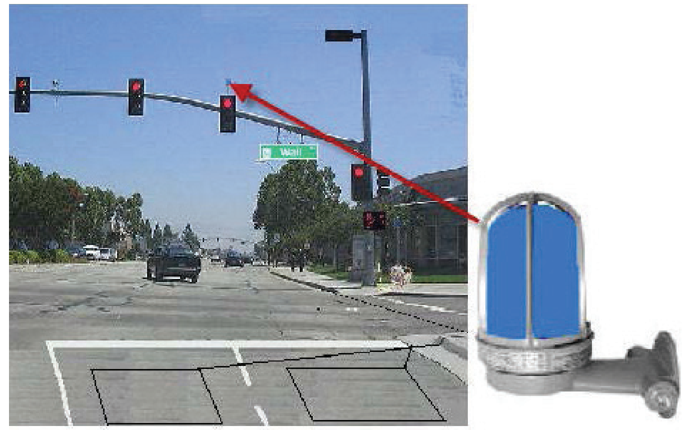

Figure 2
Mounting and close-up of a typical confirmation light.

mounted along with three signal heads over a roadway, unrelated to the roadways involved in this case. To the right of the photo is a close-up of the confirmation light.

Intersection and Equipment

The collision happened at a four-way intersection. The major roadway is a substantially four-lane East/West U.S. "business route" non-divided highway, with a posted speed limit of 35 mph in both directions through the intersection. The intersecting roadway to the south of the intersection is a two-lane road leading to/from a shopping mall. The intersecting roadway to the north is an unnamed access to a strip mall, consisting of one entrance lane and three exit lanes.

Figure 3 is a diagram of the intersection (not to scale). Based upon police reports, eyewitness depositions

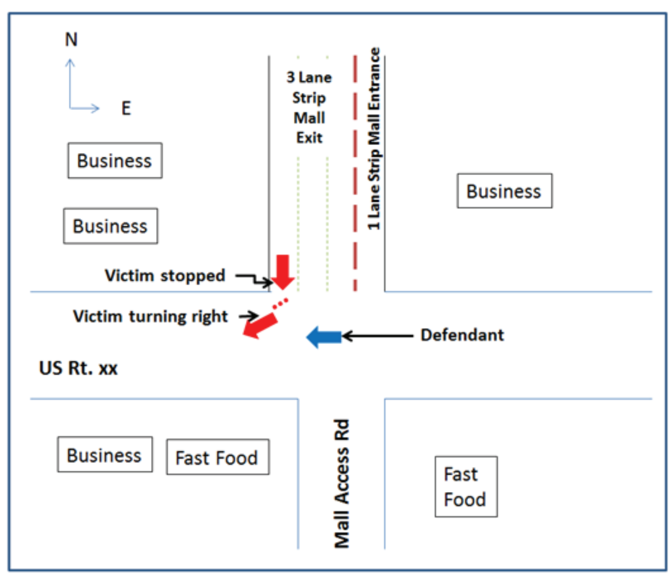

Figure 3
Intersection diagram.

and dash-cam videos, the diagram indicates the victim's vehicle (red arrow) stopped at the strip mall exit's right turn lane and then turned right (westbound) onto the highway. The victim did not turn right-on-red as allowed but waited for a green light. The defendant officer's vehicle (blue arrow) is shown heading west on the highway.

Figure 4 is an aerial photo of the intersection[5], with street name identifiers obscured. **Figure 5** indicates the position and numbering of the 12 vehicular signal heads (traffic lights) controlling the intersection. **Figure 6** photographically shows the 12 vehicular signal heads controlling the intersection, from a driver's eye point of view outward

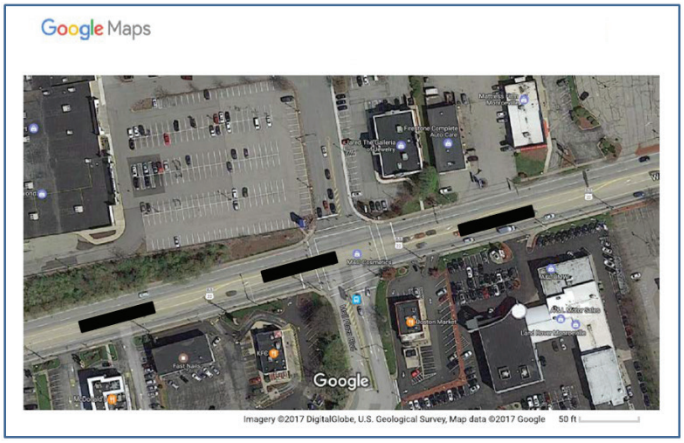

Figure 4
Intersection aerial photo.

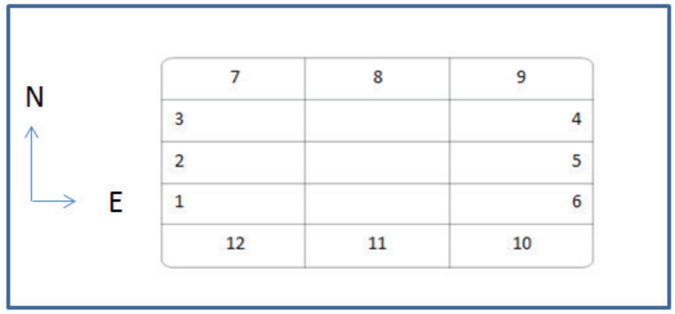

Figure 5
Signal head positions and numbers.

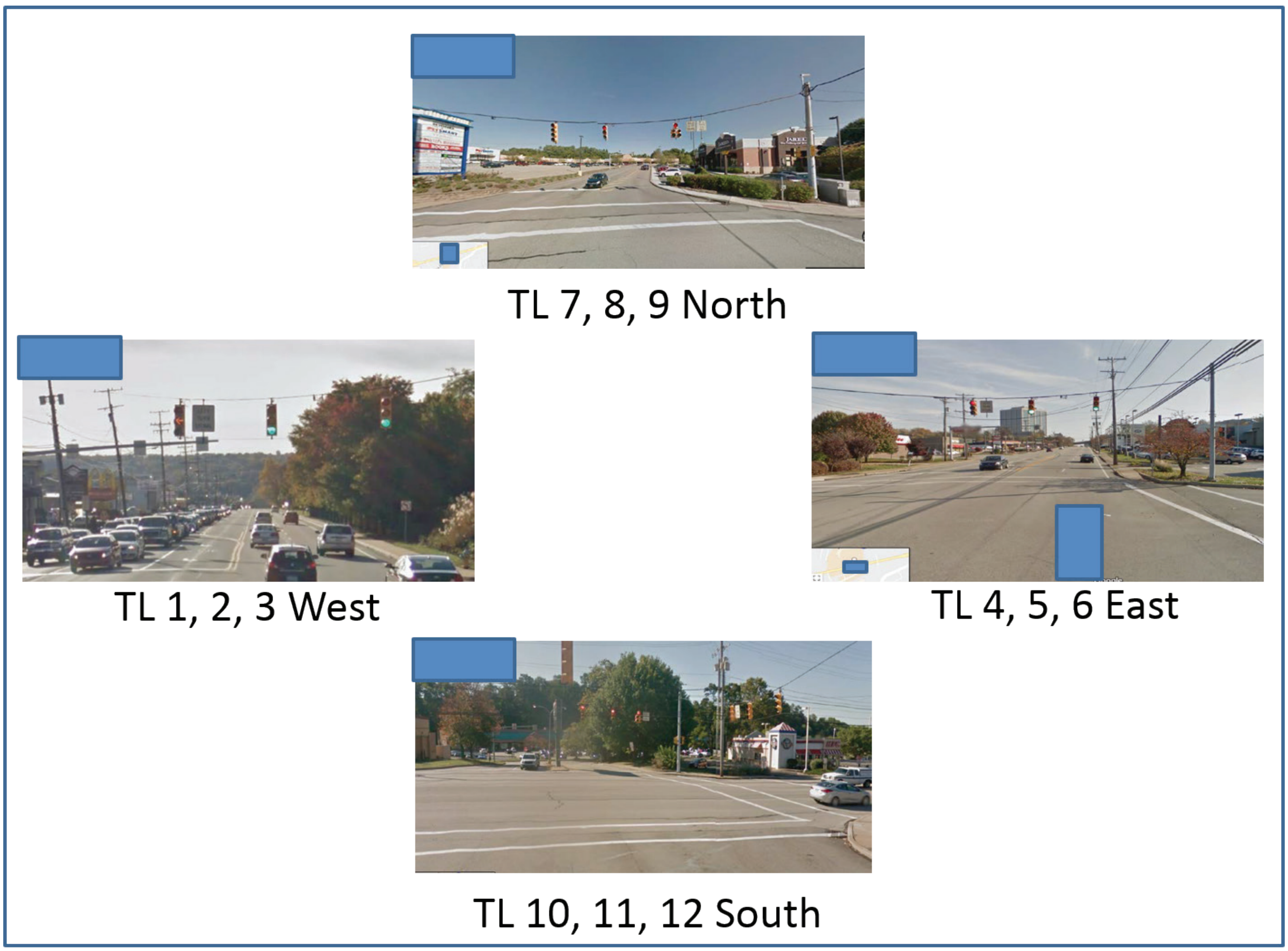

Figure 6
Traffic light photos facing out from intersection.

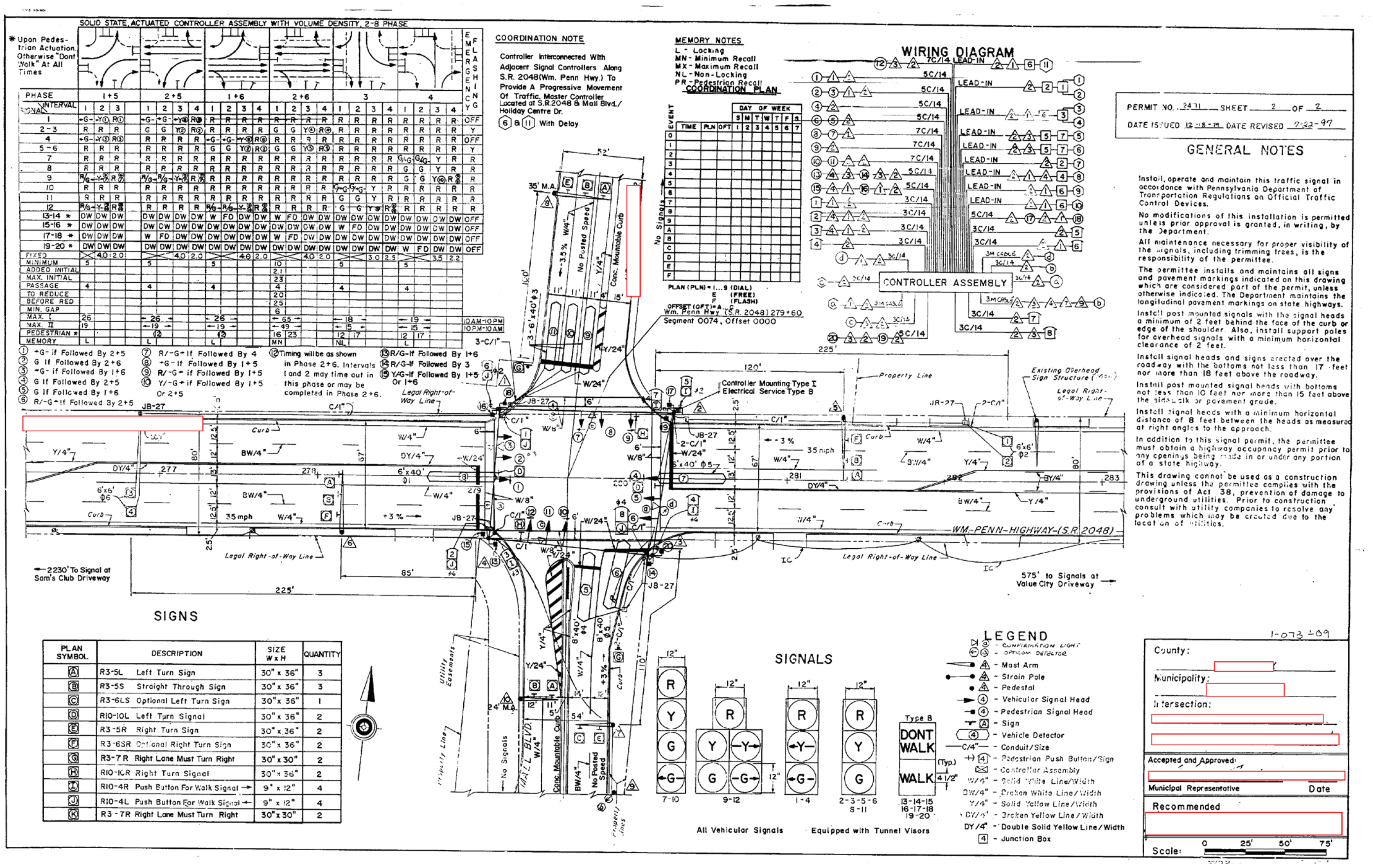

Figure 7
Traffic signal permit.

from the intersection[6]. **Figure 7** is a copy of the traffic signal permit for the intersection[7]. The author received this drawing as an 8-inch by 11-inch photocopy, which was slightly more readable than what is reproduced here. The retaining attorney subpoenaed a 2-foot by 3-foot full-size copy from the Department of Transportation that was fully readable but too large to be reproduced in this paper.

Traffic signal permits carry all of the information about the intersection in compressed form, including the default, minimum, and maximum timing for each signal duration or "phase," the sequence of phases, the modified sequences when preemption occurs, and more. It is a compressed version of all of the narrative, diagrammed, and tabulated information present in a traffic signal permit application. The permit application was subpoenaed as well, but the Department of Transportation claimed it no longer existed.

The traffic signal permit authorizes that the intersection be equipped with a solid-state, actuated controller assembly with volume density, 2-8 phase. Following is a partial list of the equipment comprising the intersection's controller assembly:

- 12 vehicular signal head assemblies (red, yellow, and green traffic lights, some with arrows) suspended over the roadway.
- Eight pedestrian signal head assemblies (walk/don't walk) mounted near each crosswalk.
- Four IR laser pulse detectors mounted alongside vehicular signal head assemblies.
- Four preemption confirmation lights mounted alongside the detectors.
- Solid-state traffic light controller mounted inside traffic controller cabinet.
- Conflict monitor mounted inside traffic controller cabinet.
- Phase selector (sometimes referred to as discriminator) mounted inside traffic controller cabinet.

According to discovered purchase orders, the intersection's controller assembly components from various manufacturers and sellers are integrated by the purchaser into a system intended to control traffic in normal situations and to respond to emergency vehicle preemption requests.

As specified in discovered documents, an emitter assembly was mounted on each police vehicle in the municipality, including the vehicle operated by the defendant. This type of emitter assembly emits timed and encoded pulses of infrared light when activated, which occurs whenever vehicle emergency lights and sirens are activated. The emitted pulses of infrared light are detected by the detectors mounted alongside vehicular signal head assemblies.

According to manufacturer's datasheets, detectors have an 8-degree field of view and must be mounted so they have an unobstructed view of the approaching roadway for at least their programmed reception distance. The detector assembly uses photodetectors and electronic circuitry to convert light pulses to a voltage waveform. The voltage pulses are transmitted through cables from the detectors mounted near the traffic lights to the phase selector mounted in the traffic controller cabinet.

According to the manufacturer's datasheet, the phase selector's detection range is adjustable. According to documents produced during discovery, the detection range was programmed to 1,800 feet.

The voltage waveform the phase selector receives from the detector is amplified and electronically processed to isolate and select signal content resulting from 14 Hertz infrared sources, such as from the vehicle-mounted emitters. Waveform content due to anything else is ignored by the phase selector. Upon identification of an electrical signal corresponding to a 14 Hertz sequence of infrared pulses (of amplitude greater than or equal to the amplitude corresponding to the programmed detection range), the phase selector transmits a preemption trigger signal to the solid state controller mounted in the traffic controller cabinet.

Using basic electronics theory and the author's experience, the time-interval from an activated emitter entering the detection range to the phase selector transmitting a preemption trigger to the controller is composed of three time-intervals:

1. The time it takes the infrared pulses to travel 1,800 feet at the speed of light (about 1 foot per nanosecond) or 1.8 microseconds.

2. The response time of the photodiodes and associated electronics comprising the detector assembly and transmission time from the detector to the phase selector. This is not specified in any of the manufacturers' documents provided, but can be approximated to be on the order of 100 nanoseconds[8].

3. The response time of the phase selector to filter, amplify, and process a 14-Hz square pulse signal. This is not specified in any of the provided manufacturer's documents. However, according to the manufacturer's operation manual, the phase selector has a programmable delay that defaults to 0 seconds (not 0.0, but 0), and may be incremented by 1 second steps (not 1.0, but 1). The implication by elementary rules of measurement precision is that the delay through the phase selector is less

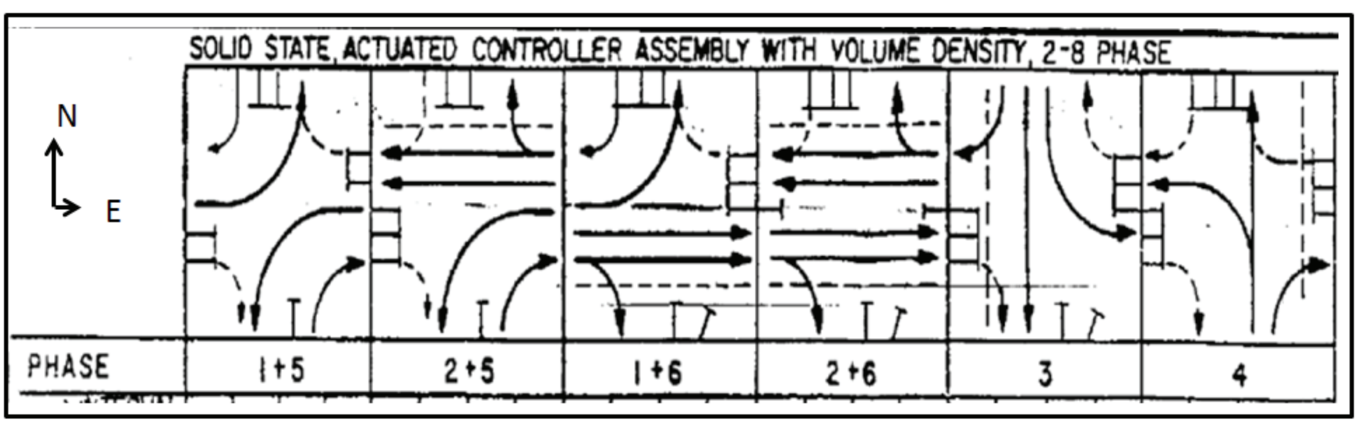

Figure 8
Permit detail — six states of traffic lights.

than 0.5 seconds.

A conservative analysis approach is to assume the sum of the three time intervals is just over 0.5, and round it up to 1 second.

Moving on to the traffic light controller components, **Figure 8** shows the six possible states of the 12 traffic lights at the intersection[7]. Normal progression through the phases is from left to right. Progression is from phase 1+5 to 2+5, to 1+6, to 2+6, to 3, to 4, and then back to 1+5. Refer to **Figure 5** on page 4 for the positions of traffic lights 1 to 12 and **Figure 7** on page 5 for more perspective.

In **Figure 7**, note that Phase 1 (PH1), controlled by traffic light 4 (TL4), is the left turn lane from eastbound on the highway to northbound on the strip mall entrance: phase 1+5 and phase 1+6.

PH2, controlled by TL2, is the straight through lane, westbound on the highway: phase 2+5 and 2+6.

PH3, controlled by TL10, is the left-turn-arrow lane from southbound on the strip mall exit to eastbound on the highway: phase 3.

PH4, controlled by TL8, is the straight through lane, northbound from the mall access road to the strip mall entrance: phase 4.

PH5, controlled by TL1, is the left-turn-arrow lane from westbound on the highway, onto southbound on the mall access road: phase 1+5 and phase 2+5.

PH6, controlled by TL5, is the straight through lane, eastbound on the highway: phase 1+6 and 2+6.

PH7, controlled by TL7, is the left-turn-arrow lane from northbound on the mall access rode to westbound onto the highway: phase 4.

PH8, controlled by TL11, is the southbound exit lane from the strip mall to the southbound mall access road: phase 3.

PH8, controlled by TL12, is also the right-turn exit lane from the southbound strip mall exit to westbound on the highway: phase 1+5, phase 1+6, and phase 3.

PH8, as a permitted right-turn-on-red, is seen as a dashed line: phase 2+5, phase 2+6 and phase 4.

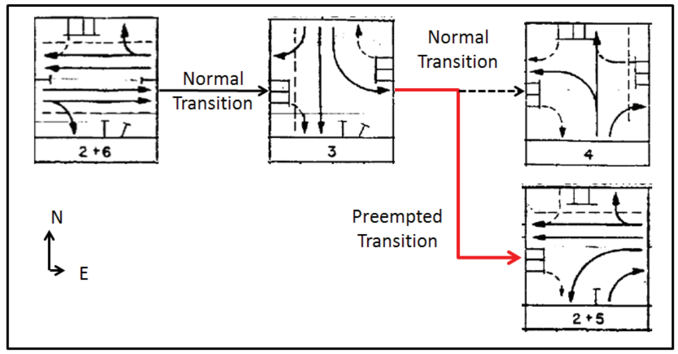

Figure 9
Normal transition followed by preemption transition.

The Collision and Preemption System Behavior

According to depositions and interviews, traffic lights 10, 11, and 12 all turned green just before the crash: phase 3. The normal phase progression is from phase 2+6 to phase 3. An emergency vehicle with lights, sirens, and emitter activated, westbound on the highway would generate a preemption trigger to the controller, causing the controller to cycle from phase 3 back to phase 2+5, allowing the emergency vehicle to continue straight westbound, turn right northbound, or turn left southbound. This phase transition is diagrammed in **Figure 9**.

In PH 2+6, traffic eastbound and westbound on the highway has green signals, allowing straight-through and right turns from west to north and from east to south. A right-turn-on-red from south to west is signified by a dotted line.

After the interval specified in the traffic light permit, the intersection transitions in the normal way to PH 3. In PH 3, traffic southbound from the strip mall exit has green signals, allowing straight through to the mall access road, left onto the eastbound highway, or right onto the westbound highway. A right-turn-on-red from eastbound on the highway to southbound on the mall access road is signified by a dotted line.

During PH 3, the victim made a right turn from southbound on the strip mall exit to westbound on the highway. Meanwhile, during PH 3, the defendant's police vehicle approached and entered the 1,800 feet detection zone. As the police vehicle entered the detection zone, the preemption system was expected to detect and process the IR pulses emitted from the police vehicle, and, in due course, transition to PH 2+5. In PH 2+5, westbound vehicles have green lights, allowing straight through, right turn to the north or left turn to the south.

However, during PH 3, the defendant's police vehicle entered the intersection heading westbound on the highway, facing red lights, and crashed into the victim's vehicle.

The preempted transition from Phase 3 to Phase 2+5 adhered to the timing specifications shown in **Figure 7**, which are as follows:

For Phase 3, the minimum green time is 5 seconds. That is, if the southbound traffic lights TL 10, 11, 12 have turned green, they must stay green for at least 5 seconds before turning yellow. For Phase 3, the fixed yellow time is 3.0 seconds before turning red. Following that, there is a fixed all-red interval of 2.5 seconds, during which all 12 of the traffic signal heads at the intersection must be red.

To calculate the worst-case delay from emitter activation during Phase 3 through preemption to controller activation of Phase 2+5, the pedestrian signal head timing requirements must also be considered. According to **Figure 7**, the fixed WALK time is 12 seconds, followed by 17 seconds fixed pedestrian clearance time (FLASHING DON'T WALK), followed by solid DON'T WALK.

According to the *Manual on Uniform Traffic Control Devices* (MUTCD)[9], during the transition into preemption control:

A. The yellow change interval, and any red clearance interval that follows, shall not be shortened, or omitted.

B. The shortening/omission of any pedestrian walk interval and/or pedestrian change interval shall be permitted.

So, according to part B, as soon as the traffic light controller receives a preemption signal from the preemption system phase selector, it may be programmed to immediately change the pedestrian signal from WALK to FLASHING DON'T-WALK (pedestrian clearance time). An upper bound can be calculated for the time-interval for transition from Phase 3 to Phase 2+5, taking pedestrian signals into account:

- If TL 10, 11 and 12 have been green/green-arrow-right, green, and green for less than 5 seconds, they continue green/green-arrow-right, green, and green until 5 seconds, then turn yellow for 3 seconds, then red.

- Simultaneously,

  - If pedestrian crossing signal heads 15 and 16 are in the solid Walk state, they may immediately change to FLASHING DON'T WALK state for 17 seconds, then change to solid DON'T WALK.

  - Else if pedestrian crossing signal heads 15 and 16 are in the FLASHING DON'T WALK state, they continue in the FLASHING DON'T WALK state until 17 seconds, then change to solid DON'T WALK.

- When TL 10, 11, and 12 reach red, and pedestrian crossing signal heads 15 and 16 are in solid DON'T WALK, the following events occur simultaneously:

  - TL 1 continues red for 2.5 seconds, then turns green-arrow-left.

  - TL 2 and 3 continue red for 2.5 seconds, then turn green.

  - TL9 continues red for 2.5 seconds, then turns red/green-arrow right.

At which point, Phase 2+5 is in effect.

Time interval between preemption of Phase 3 to Phase 2+5 with pedestrian signals 15, 16 on solid Don't Walk is 10.5 seconds.

- 1 second from emitter entering the zone until phase selector preemption.
- 5 seconds for TL 10, 11, and 12 to cycle from "new" greens to yellows.
- 3 seconds for TL 10, 11, and 12 to cycle from yellows to reds.
- 2.5 seconds clearance time for "All Red."
- TOTAL = 11.5 seconds

However, the worst-case delay, 19.5 seconds, between preemption of Phase 3 to establishment of Phase 2+5, occurs when pedestrian signals 15, 16 are in solid "Walk" state:

- 1 second from emitter entering the zone until phase selector preemption.

- Instantaneous change of signal heads 15 and 16 from “Walk” to “Flashing Don’t Walk.”
- 17 seconds for signal heads 15 and 16 from “Flashing Don’t Walk” to “Solid Don't Walk.”
- 2.5 seconds clearance time for “All Red.”
- TOTAL = 20.5 seconds

The calculated 20.5 seconds delay presumes that:

1. Emitter is functional, properly mounted, calibrated within specification, and clean.
2. Detectors are functional, correctly aligned with approaching roadway, calibrated within specification, and clean.
3. Phase detector is functional and calibrated within specification.
4. The vehicle is heading such that the emitter’s infrared light beam is directed within the detector’s 8-degree cone.
5. The vehicle’s heading remains substantially straight in its approach to the intersection.

The first three conditions are likely to be met if the municipality adheres to the preventive maintenance schedule set forth in various documents provided by the manufacturer of the preemption system.

According to various discovery documents provided to the author, the phase detector’s range was programmed to 1,800 feet. The calculation of maximum speed for assured phase transition from Phase 3 to Phase 2+5 before a westbound vehicle approaching the intersection is straightforward:

$$\frac{Detection\ Range\ (feet)}{Worst\ Case\ Delay\ (seconds)} * \frac{1\ mile}{5280\ feet} * \frac{60\ seconds}{1\ minute} * \frac{60\ minutes}{1\ hour} = maximum\ speed\ (MPH)$$

Plugging the values 1800 feet and 20.5 seconds into this formula:

$$\frac{1800\ feet}{20.5\ seconds} * \frac{1\ mile}{5280\ feet} * \frac{60\ seconds}{1\ minute} * \frac{60\ minutes}{1\ hour} = about\ 60\ MPH$$

Furthermore, it would be straightforward to use the methods of this basis to calculate the maximum speed for every approach direction at the intersection, and for every approach to any intersection with equipment and timing documented by a traffic light permit.

Findings and Their Significance

The traffic light controller’s data log indicated preemption occurred properly before the crash. Documents and videos of post-crash tests showed that the controller and preemption system worked for low-speed approaches.

Did the preemption system operate properly before the crash? Yes.

Could the system have been overrun by the driver of the emergency vehicle? System operating manuals and training literature show that a fast-enough vehicle can travel the distance between the detection point and the intersection before the traffic light controller can cycle through states to present a green light to the emergency vehicle. Municipal customers and emergency drivers are informed of this limitation by the system vendor. However, it is the traffic light controller — not the preemption system — that limits the speed of approach.

The municipality traffic engineer, who designed the integration of the preemption and controller systems, could have calculated the maximum speed for the intersection using the timing information found in **Figure 7**.

What is the maximum speed at which an emergency vehicle could approach the intersection where the crash occurred and be assured of receiving a green light upon reaching the intersection? About 60 mph, constant from 1,800 feet to the intersection (worst case).

Is it feasible to calculate a maximum speed for every approach to every equipped intersection? Yes — directly from the information documented in the equipped intersection’s traffic light permit.

Videos of the post-collision tests of the intersection show the confirmation light activating as the traffic light turns green — and not at the moment of preemption.

The author considered the usefulness of the information, given this behavior of the confirmation light conveys. The emergency vehicle driver can already see the light is green; does it matter whether that green came about normally or through preemption? Does simultaneous light-change and confirmation light activation provide useful information to drivers from other directions?

Activating the confirmation light immediately on preemption would convey to the emergency vehicle driver that detection and preemption have occurred and that a green signal is forthcoming. Even without a public information campaign, other drivers would know that a non-normal event is occurring, and the flashing confirmation light might draw their attention to approaching sirens and lights[10]. As such, the author followed up on this aspect.

The default setting of the phase selector activates the confirmation light immediately upon preemption. A programmable parameter of the phase selector had been changed from the default in order to delay the confirmation until the green signal state was reached. Leaving this parameter at its default is suggested in the manufacturer's manual and training literature. Furthermore, it is specified by regulation in the state department of transportation signal design handbook[2].

Was the confirmation lights behavior consistent with the requirements and specifications for the preemption system? No.

Conclusion

An emergency vehicle entering the 1,800-foot range of the detector is assured of receiving a green light upon reaching the intersection if the vehicle's speed remains less than 60 mph over the distance to the intersection, and if all the traffic light control equipment is functioning correctly. This presumes: the vehicle's emitter is properly mounted, functioning, and actuated; the vehicle is heading such that the emitter's infrared light beam is directed within the detector's 8-degree cone; and the vehicle's heading remains substantially straight toward the intersection.

Since it is feasible to calculate a maximum speed for every approach to every equipped intersection, it is technically possible for the equipped intersection to communicate that maximum speed information to incoming emergency vehicles.

For this incident, preemption did occur but the emergency vehicle overran the system. It was found that confirmation lights were not activated coincident with preemption as they ought to have been. Configuring or programming the traffic light control system to activate the confirmation lights coincident with receiving a preemption request was possible. In fact, it was the default behavior of the system as installed. Configuring and programming the traffic light control system other than to activate the confirmation lights upon receiving a preemption request from the system is a lack of an easily implemented safety element required by PennDOT[2].

Configuring or programming the traffic light control system to activate the Confirmation Lights upon receiving a preemption request communicates feedback to the emergency vehicle driver that preemption has occurred, and conversely, confirmation lights not flashing communicates that preemption has not yet occurred.

Although the purpose of confirmation lights is not public knowledge, their bright flashing can alert other drivers, interrupting their pattern expectation and interrupting their first impulse "to go" upon seeing a green light[10].

References

1. Department Federal Highway Administration (FHWA), "Advanced Transportation Management Technologies," 8 February 2017. [Online]. Available: https://www.scribd.com/doc/47702578/Advance-Transportation-Management-Technologies-Abridged. [Accessed 20 November 2017].

2. Pennsylvania Department of Transportation, "Traffic Signal Design Handbook," 14 October 2010. [Online]. Available: https://www.dot.state.pa.us/public/PubsForms/Publications/PUB%20149.pdf. [Accessed 14 April 2017].

3. W. H. Long, "Traffic Signal Remote Control System." USA Patent 3,550,078, 22 December 1970.

4. U.S. Department of Transportation, "Traffic Signal Preemption for Emergency Vehicles," 1 January 2006. [Online]. Available: https://ntl.bts.gov/lib/jpodocs/repts_te/14097_files/14097.pdf. [Accessed 21 November 2017].

5. DigitalGlobe, "Google Maps," 2017. [Online]. Available: https://www.google.com/maps/. [Accessed 17 November 2017].

6. Google, "Google Maps Streetview," 2017. [Online]. Available: https://www.streetviewonline.com. [Accessed 17 November 2017].

7. S. o. T. Bradley L. Mallory, Traffic Signal Permit, Harrisburg, PA: Pennsylvania Department of

Transportation, 1997.

8. J.-m. Liu, Ch. 14 in Photonic Devices, Cambridge University Press, January 2010.

9. US Department of Transportation, Federal Highway Administration, "Preemption and Priority Control of Traffic Control Signals," in Manual on Uniform Traffic Control Devices for Streets and Highways, US Department of Transportation, 2009, p. 489.

10. P. L. O. David A. Krauss, Forensic Aspects of Driver Perception and Response, Tucson, AZ: Lawyers & Judges Publishing Company, Inc., 2015.