Accident Reconstruction

at

Traffic Signal Intersections

A Manual for Law Enforcement Personnel, Accident Reconstruction Professionals, Traffic Engineers, and Forensic Engineers

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1. INTRODUCTION

An attorney once asked me if the process of reconstructing an accident at an intersection with a traffic signal was any different than reconstructing one at an intersection controlled by a stop sign. My answer was immediate — yes! While it is true that many of the typical accident reconstruction concepts and terms are the same for both signalized intersections and unsignalized intersections, there are just as many that are unique to signalized intersections.

Traffic signals are complex electrical devices that provide visual indications to drivers, thereby indicating who has to yield the right-of-way at an intersection. The decision-making processes that are needed at stop sign controlled intersections in order to proceed — such as paying attention to who arrived first, vehicles approaching on the other streets, or who is turning in which direction — are removed from the driver’s list of duties at a signalized intersection. It would seem that a traffic signal simplifies the decision making task.

Yet while the list of decisions may seem to be shorter on the surface, I would argue that the list actually becomes longer. Some of the decisions have even become more complex. For example, at stop signs the driver must stop. Period. At traffic signals, a driver can receive a yellow signal, forcing the driver to make a judgment call whether to stop or continue through the intersection. It is these judgment calls that often lead to collisions. And it is these collisions that need to be reconstructed to understand the actions at the scene.

This text is not intended to be an exhaustive book on the precise details that go into traffic engineering. It is intended to serve as a manual for reconstructing traffic accidents that occur at intersections controlled by traffic signals. Understanding how signals operate and the framework that likely was considered in their design is crucial for reconstructing collisions that occur at signalized intersections.

Chapter 2 leads the reader through an introductory discussion on roadway design with a focus on intersections. Traffic signals operate at roadway intersections, and thus roadway design and signal design share many common terms. Therefore, a basic
understanding of types of roadways and an explanation of key roadway design terms will be useful in later discussions about traffic signals.

Chapter 3 dives right into how traffic signals work. This section takes the reader through a quick course on applied traffic engineering for non-signal engineers. It provides definitions and descriptions of signal terminology and theory. Chapter 3 also discusses the standards by which traffic signals in the United States are designed.

Chapter 4 leads the reader into traffic signal timing. During an accident reconstruction it usually becomes necessary to create a timeline of pre-crash events. Traffic signal controllers often contain the base data needed to form such a timeline, provided the investigator understands how to use the data.

Chapters 5 through 9 present additional topics including traffic signal detection by traditional in-pavement methods and by video, as well as a discussion of signal preemption for emergency vehicles, transit, and railroads. Video monitoring at intersections is presented, and centralized computerized signal systems are discussed. As an aid to anyone not familiar with public engineering agencies, Chapter 9 also details how a typical agency might be staffed. This should guide you to the appropriate person who could assist with interpreting the operation of a traffic signal when an accident case needs to be investigated.

Chapter 10 presents the core of this manual. While Chapter 3 provides a solid foundation about signals, and chapters 4 through 9 present additional supporting materials, Chapter 10 applies this traffic engineering knowledge to reconstructing accidents. It is assumed that the reader has already completed basic accident reconstruction coursework and has some hands-on field experience. Chapter 10 takes a step-by-step approach to explaining the reconstruction process. The goal of this approach is to aid the reader when called to testify on his or her reconstruction by providing fast references to appropriate supporting material.

The methodologies used in Chapter 10 involve no computer simulations or animations. They make use of good, old-fashioned pencil and paper, and a simple calculator. People tend to understand concepts best when they aren’t required to stretch their imaginations too far outside their current circle of knowledge. Concepts
need to “feel” believable to them. If you can convince your audience that your opinions are based on principles and analysis that can be done on one or two sheets of paper and are in alignment with things they see in everyday life, the audience is more likely to understand and appreciate your opinions.

Chapter 11 puts into practice the ideas presented in Chapter 10. Learning new concepts and practices is helpful, but being able to actually apply the new knowledge is where the time you have invested in the learning process really begins to pay off. Case studies are an excellent transition from “book knowledge” to real life applications of the knowledge. The case study in this text often references materials in preceding chapters. This means that you as the investigator have a ready resource to support the methodologies you are using.

This is the first edition of this text. The reconstruction methods and traffic engineering explanations presented here are reliable and time-proven. As any experienced investigator knows, however, more than one way to solve any given case usually exists.

In this text, I have presented common “alternate” explanations for issues in the cases that are discussed. It would be foolhardy to think that I have been able to imagine and share with the reader every possible solution or explanation for every situation. It is here that I ask for your insight and help: if you discover something that has been missed, please let me know. I will consider it for inclusion in a subsequent edition of this text. My contact information is at the end of this book.

This text focuses on what takes place in the United States. International readers will need to take into account that this text may contain a few discrepancies from actual conditions in international locations.

Throughout the book, the reader will find italicized words. The first appearances of phrases, technical terms, and words with a special meaning in traffic engineering have been italicized for identification. These words and their meaning are listed in the Glossary at the back of the book. In addition these special words are indexed.
Finally, I would like to close this introduction with a word of caution. Many of us have encountered people who tell us “they may do it like that where you come from, but that’s not how we do it around here.” Traffic signal design concepts across the United States originate from one source: the Federal Highway Administration’s *Manual on Uniform Traffic Control Devices* (MUTCD). Sometimes state and local jurisdictions follow the federal Manual for every detail, or they might have additional specifications unique to their locale. It is important for the investigator to build a relationship with a local public agency traffic signals engineer or technician. Asking a few questions now about “how we do it around here” will lead to a very smooth investigation later on.

**Acknowledgements**

At this point it is appropriate to offer sincere thanks to those who did the real work on this book. Janet Doughty, my editor, is responsible for making my rambling lecture-style drafts into a readable text. Her talent and dedication have been very much appreciated. Thanks go to Mark Dunzo and Fred Burchett for believing that I could, and actually would, stop working on accident and signals projects long enough to write this book. Their support has been invaluable.

Ashley Odom deserves huge thanks for interpreting my many sketches and for then producing all the illustrations that fill this book. Her sense of ownership in this project has been wonderful. A silent partner in this book project has been Bruce Friedman. Bruce is a former Chair of the National Committee on Uniform Traffic Control Devices (NCUTCD) Signals Technical Committee, and graciously agreed to be my “does this make sense” editor.

In closing, I wish to thank my original partner in this book. Many years ago Al Williford, my mentor, and I searched in vain for an authoritative manual on reconstructing accidents at signalized intersections. Every year Al and I talked about putting time aside to write this book. Every year we became busier serving clients and growing the forensics business, and we never wrote the book. In May of 2005 Al died suddenly. Al may not be here to put the words on the paper, but rest assured that many of these words you are about to read are his thoughts as much as they are mine.
2. TRAFFIC ENGINEERING BASICS

Vehicular and pedestrian traffic throughout the world is controlled by “rules of the road.” In some locations these rules might be simple — for example, the driver of a smaller vehicle must yield to driver of a larger vehicle. In many communities, however, the rules of the road are more formal. These rules are usually legal in nature, and typically dictate expected and acceptable actions to be taken in specific traffic situations.

Law enforcement officers, attorneys, and the courts are intimately familiar with these rules. While this book is interested in the rules of the road, it focuses on the origin of these rules. The spotlight is not necessarily on which nation or territory had the first traffic laws on the books, but instead highlights the engineering principles that have evolved over the years to create our highway system and thus shaped the traffic laws by which so many of us not only live, but also rely upon as accident investigators to perform our jobs.

This chapter will focus on select traffic engineering principles with a focus on roadway features and codes. This builds a solid foundation that can help you explain the processes and formulas you use, and will be useful when putting into practice the concepts and formulas presented in subsequent chapters.

As you review this material, consider how you might apply traffic-engineering concepts to solving the questions surrounding a crash investigation. Armed with the basic information presented here, an investigator might be able to not only solve the question of what caused the crash, but also effectively communicate the findings to local officials so they can work on solutions to prevent future crashes.

2.1 Traffic Engineering Design Codes

In the early 20\textsuperscript{th} century, each state had its own design rules for traffic control devices. Not all yield signs were red, and the length of yellow signals varied in
each jurisdiction before the driver would see a red signal. Drivers operating in different jurisdictions had to pay attention to prevent facing penalties or causing a crash.

Eventually the Manual on Uniform Traffic Control Devices (MUTCD) was published. This federally published book sets forth the rules by which traffic engineers in all jurisdictions across the United States design, install, and maintain traffic control devices. The underlying concept is that, to the maximum extent possible, all traffic control devices are the same throughout the United States — this means the color and shape of a stop sign in Iowa and in South Carolina are the same.

Traffic control devices described in the MUTCD include signs, traffic signals, pavement markings (such as stripes, lines, and directional arrows), and channelizing devices (like barricades, cones, and barrels). Slow speed traffic on local streets and high-speed traffic on freeways are covered by the MUTCD. Also covered are work zone situations where conditions are dynamic.

Individual states are not required to adopt the guidelines presented in the MUTCD, but could lose federal funding for transportation projects if they do not do so. As a result, all states have adopted the federal MUTCD or have developed a state MUTCD that is in substantial conformance with the federal MUTCD. States are permitted to make their own MUTCD and/or their design standards more stringent than the federal MUTCD. Some have added state-specific rules that address conditions or situations unique to their area. For example, some southeastern coastal states might require that traffic signals be mounted horizontally on metal mast arms to minimize the impact of hurricanes. Wisconsin probably doesn’t need such a rule, but has adopted design details that address ice build-up on the mast arms.

It is important to remember that the MUTCD doesn’t govern the design of the actual roadway. Features such as the slope of the pavement to assure proper drainage to reduce the chance for hydroplaning are addressed in other publications. The MUTCD only provides guidelines for the devices that control the traffic.
2.2 Roadway Features

Roadways are typically defined in two broad general classifications — local or limited-access. Local roads include neighborhood streets, collector streets (which primarily provide access to property, carry some traffic between neighborhoods, and typically have two lanes), and thoroughfares (which usually cross the town or link one development center with another). Typically, the speed limits on local streets are low, and access to these local streets is pretty much unlimited. In other words, local streets have many commercial and residential driveway connections.

Limited-access roadways are Interstates, throughways, freeways, and other high-speed facilities. The term “limited-access” comes from the lack of directly connected private or commercial driveways to the roadway. By eliminating these connections and the resulting intersections, design engineers are able to provide a free-flowing express route, and eliminate conflict points. A conflict point is where vehicle paths cross and therefore create an opportunity for an accident. For example, a four-legged intersection where two opposing driveways connect to a road contains twenty conflict points. Many limited-access facilities also restrict connections with other roadways to grade-separated interchanges, or interchanges that require traveling to different elevations, such as an on-ramp from a local road to an interstate.

It is inevitable that roads will meet, either at intersections or interchanges. The difference between these often relates to grade — in engineering terms, grade usually refers to vertical height or elevation. Intersections are where two or more roadways intersect at the same elevation or grade — this is how local roads usually meet. Interchanges are where two or more roadways cross each other at different elevations or with a grade separation. Ramps that carry traffic up or down from one roadway to the other are features of grade-separated interchanges. If one of the roadways is a local street, we may see the ramp eventually intersect the local street at a traffic signal, yield sign, or stop sign.
Some common engineering terms are used to describe the traffic lanes leading into the intersection. As drivers move toward an intersection, they are said to be in the *approach lanes*. As they leave the intersection they are said to be in the *departure lanes*. Intersection approaches and departures may be single lane or multi-lane. The approach may have the same number of lanes as the departure, or these numbers may differ.

The approach lanes may be *dedicated lanes* or *shared lanes*. Dedicated lanes restrict traffic to one direction, while shared lanes provide traffic with more than one directional opportunity. Figure 2.1 shows a shared lane for through and left-turning traffic, and a dedicated lane for right-turning traffic.

### 2.3 Advance Lane Control Messages

As drivers near an intersection, they must maneuver into the appropriate approach lane for their intended direction of travel. Each lane’s designated use needs to be conveyed to the drivers through one or more means.

*Directional arrows* on the pavement may be sufficient at local intersections where many of the drivers are familiar with the intersection and the approach speeds are low. These pavement markings may be painted arrows or *thermoplastic* pavement markings.

Thermoplastic markings are thick plastic-like symbols that originated from a hot and melted mixture that was applied to the pavement and allowed to cool and...
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The surface of the thermoplastic may also contain tiny retroreflective beads that make the marking more visible at night under headlights. These markings are thick, dictated by local or state codes, but commonly they reach 60 to 120 mils of thickness. This thickness allows the thermoplastic pavement marking to project above collected or flowing water on a roadway during rain conditions. Although thermoplastic markings cost more initially than painted symbols, they provide an advantage of being visible under headlights even during rainy conditions. Painted markings are typically not as visible under water.

Engineering design codes control the placement of pavement markings and the number of markings shown approaching the actual intersection. As drivers near an intersection and begin to maneuver into the correct lane, they may need more than one reminder of each lane’s use since some markings may be covered by adjacent moving or stopped vehicles. An example of one design code for pavement markings is shown in Figure 2.2.

In addition to lane use markings on the pavement, we often see above-pavement messages to the approaching driver. Examples include ground-mounted signs like the one shown in Figure 2.3, and overhead lane use signs as shown in Figure 2.4.
Figure 2.3 – Ground mounted lane use sign

Figure 2.4 – Overhead lane use signs
The placement of advance warning signs is controlled by the MUTCD. Specifically, Table 2C-4, a portion of which is shown in Figure 2.5, provides guidelines regarding how far in advance of a hazard, such as the need to change lanes, a warning sign should be placed.

<table>
<thead>
<tr>
<th>Posted or 85th-Percentile Speed</th>
<th>Advance Placement Distance</th>
<th>Condition A: High judgment required&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Condition B: Stop condition&lt;sup&gt;3&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 mph</td>
<td>175 ft</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>25 mph</td>
<td>250 ft</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>30 mph</td>
<td>325 ft</td>
<td>100 ft</td>
<td></td>
</tr>
<tr>
<td>35 mph</td>
<td>400 ft</td>
<td>150 ft</td>
<td></td>
</tr>
<tr>
<td>40 mph</td>
<td>475 ft</td>
<td>225 ft</td>
<td></td>
</tr>
<tr>
<td>45 mph</td>
<td>550 ft</td>
<td>300 ft</td>
<td></td>
</tr>
<tr>
<td>50 mph</td>
<td>625 ft</td>
<td>375 ft</td>
<td></td>
</tr>
<tr>
<td>55 mph</td>
<td>700 ft</td>
<td>450 ft</td>
<td></td>
</tr>
<tr>
<td>60 mph</td>
<td>775 ft</td>
<td>550 ft</td>
<td></td>
</tr>
<tr>
<td>65 mph</td>
<td>850 ft</td>
<td>650 ft</td>
<td></td>
</tr>
</tbody>
</table>

<sup>2</sup> Typical conditions are locations where the road user must use extra time to adjust speed and change lanes in heavy traffic because of a complex driving situation. Typical signs are Merge, Right Lane Ends, etc. The distances are determined by providing the driver a perception-reaction-execution time of 6.7 to 10.0 seconds plus 4.5 seconds for vehicle maneuvers minus the legibility distance of 50m (175 ft) for the appropriate sign.

<sup>3</sup> Typical condition is the warning of a potential stop situation. Typical signs are Stop Ahead, Yield Ahead, or Signal Ahead. The distances are based on the 1990 AASHTO Policy for stopping sight distance (page 120) providing a perception-reaction-execution time of 2.5 seconds, friction factor of 0.30 to 0.40, minus the sign legibility distance of 50m (175 ft).

Figure 2.5 — Select portion of the MUTCD’s Table 2C-4 guidelines for advance placement of warning signs


There are other traffic control measures not covered in this text that are often used to inform and direct the highway user safely through a signalized intersection. An investigator should be familiar with the MUTCD, as well as state and local supplements, and should refer to these during the course of a crash investigation. The lack of or the improper installation or maintenance of traffic control devices or the use of non-standard devices may lead to driver confusion and may be a contributing factor to a crash. The MUTCD identifies standard devices, when to use them, and where to place them. The MUTCD also differentiates between required, recommended, and optional devices.
3. TRAFFIC SIGNALS

A law enforcement officer is an ideal traffic control device. The officer is able to accept visual and audible input from approaching intersection users, to determine which approaches are saturated with traffic or pedestrians, and to make real-time decisions as to who gets to go first and how many pedestrians or vehicles get to go while others wait. If an emergency vehicle approaches the intersection, the officer can immediately clear all traffic ahead of the approaching emergency vehicle, thus reducing response time and reducing the chance of a responder-involved crash. The officer provides visual signals to drivers with waving hands and also provides audible signals such as a whistle or verbal commands to pedestrians. An officer can communicate with another officer at the next intersection via radio or hand signals to work together to coordinate traffic flow through two or more adjacent intersections.

Staffing every intersection in town with rotating shifts of officers, however, is just not realistic. Therefore, most communities have relegated traffic control at major intersections to electrical devices that attempt to mimic the traffic control officer. Traffic signal controllers, actuation, preemption, video detection, and intelligent transportation systems are standard issue traffic control in many jurisdictions. These various components can help an investigator pinpoint vehicle and pedestrian locations at specific points in time before and after the crash. It is also important for you to be aware that signal components may sometimes go astray and lead to crashes. Of course, situations exist when the signal operates normally, but drivers or pedestrians do not respond correctly, and a crash results.

Traffic signals act in a predictable and repeatable manner — they can only do what they were designed and built to do. Timing parameters used by the signal controller, such as the yellow and red clearance times for main streets, don’t deviate from one hour to the next. The intersection movements allowed to receive the green signal simultaneously don’t deviate unpredictably. These
settings are established for safety and uniform message delivery to roadway users.

Once you understand how a particular signal controller assigns green, yellow, and red times to each intersection movement and what the specific timing values are, it is easy to investigate the timing of an accident. The signal controller creates a timeline by which all vehicle and pedestrian movements can be pinpointed. Also, by knowing how and when the traffic signal assigns right-of-way, it is possible to review witness, pedestrian, and driver statements to compare them with how traffic is allowed to flow at the intersection. This lends credibility to scrutinizing witness testimony.

This is the advantage to having a signal controller directing traffic rather than a traffic control officer. It would be impossible for an officer to recall how much “yellow” time he or she allowed a driver making a left turn last Tuesday at 3:12 PM. However, a signal controller can easily access this critical information.

3.1 What’s a Signal Controller?

The heart of the traffic signal is the controller. These devices, like the 2070L controller shown in Figure 3.1, turn signal indications on and off. They tell the signals when to show green, yellow, or red for each of the movements, either through predetermined programming or through information about conditions at the intersection. Because the information is assigned through traceable programming, it is fairly easy to retrieve many of the signal conditions at intersections at any given time.

Figure 3.2 shows a base mounted signal controller cabinet. Electrical cables connecting the cabinet to the signal as well as to a central control system enter the cabinet through the concrete foundation.
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The signal controller is housed in a signal controller cabinet like the ones shown in Figures 3.2 and 3.3.

Figure 3.1 – Modern 2070L Traffic Signal Controller

Figure 3.2 – Base Mounted Signal Controller Cabinet
Figure 3.3 shows a pole mounted signal controller cabinet. The pole mounted cabinet is typically smaller, holds less signal equipment, and is used at less complex intersections. The electrical conduits enter the underside of the cabinet through conduits attached to the pole. Historically, pole mounted cabinets were used in urban areas where sidewalks and pavement didn’t leave much room for larger base mounted cabinets. However, sight-impaired pedestrians, when using a cane to locate objects in front of them, will not detect the pole-mounted cabinet since it does not contact the ground and is not contacted by their cane. This puts a pedestrian on an unexpected collision course with the face or body-level signal cabinet.

3.2 Signal Controllers: Pretimed or Actuated

The traffic signal controller alternates the display of green, yellow, and red indications to each movement at the intersection. Controllers assign the green, yellow, and red indications to a movement one of two ways: pretimed or actuated. Most drivers have experienced the scenario where they are stopped at an intersection because of a red signal while no traffic on the side street ever
appears. This most often occurs at a pretimed traffic signal. The signal controller provides a predetermined green interval for the main street, and then a predetermined green interval for the side street, repeating the pattern regularly. The controller is unaware of actual traffic flow at the intersection, and is simply running in a pretimed mode.

Alternatively, most drivers also have experienced the scenario where they approach a red signal indication on a side street, only to have the signal turn to a green indication once they arrive at the intersection. These signals are most likely not pretimed, but are actuated. The signal controller is alerted to a vehicle’s presence upon arrival at the intersection, which actuates the signal and initiates a series of yellow and red clearance intervals for the main street. With an actuated signal, the main street, where most of the traffic is expected to flow, typically remains in green until a side street user is detected by the controller. This is typically more fuel-efficient because it allows a higher volume of vehicles to travel through the intersection on the main street without braking, idling, and restarting. From a public service viewpoint, the actuated signal often produces fewer complaint calls to the local traffic engineer from unhappy citizens who had to stop at a signal for no apparent reason.

3.3 Traffic Signals — What You Will See on the Street

Prior to the 1970s, the typical traffic signal controller was of the electro-mechanical type. A clock motor turned a dial, and pins protruding from the dial turned electrical switches on and off as they moved past the switch handles. The signal technician shifted the pins to one of many locations on the dial to create a predetermined number of seconds of green, yellow, and red time for each intersection movement. These electro-mechanical signal controllers were simple devices that worked well with little maintenance, yet were advanced enough to provide the ability to have multiple timing patterns.

These electro-mechanical signal controllers are still in use in many locations, particularly in downtown areas. Unable to detect traffic, they assign right-of-way to alternating movements all day and all night regardless of actual traffic flow conditions. They are pretimed controllers. The signal cabinets housing these
controllers are often small pole mounted cabinets with a short “T” pipe sticking out of the top of the cabinet for ventilation.

Using timing values from an electro-mechanical controller in accident reconstruction is no different than data from any other controller. A local traffic engineer or traffic signal technician can easily see the yellow, red, and green timing values on the dial and provide them to the investigator.

Actuated signal controllers come in a variety of models and brands. Signal technicians and engineers often refer to TS1, NEMA, TS2, Type 170, and 2070L. These actuated signal controllers all perform the same basic job: they assign green time to an intersection movement based on user demand. If you looked into a slightly older base mounted signal controller cabinet, such as the one in Figure 3.4, you might see a shelf-mounted signal controller (the large black box on the top shelf with three cables attached to the front panel). This older style of signal cabinet has many visible wires and all the components rest on shelves.

Newer signal controller cabinets might look like the one in Figure 3.5, using limited amounts of wiring and organized to keep all the components mounted in a rack similar to those in large computer installations. The signal controller is the larger box near the top of the cabinet with a 16-button keypad in its center.
The other components in the signal controller cabinet accept and monitor calls or actuations from bicycles, pedestrians, and motor vehicles, communicate with other signals, and control the signal indications that the intersection users see, and in the case of audible pedestrian signals, hear.

### 3.4 Traffic Signal Phasing

Each traffic signal controller assigns red, yellow, and green signal indications in *phases*. A left-turn movement that is assigned the right-of-way, or the green signal, separately from the adjacent through and right-turn movements, is a phase. In this instance, the through and right-turn movement is another phase. Each grouping of lanes that originates from the same common point and can operate independently of other lane groupings on that same approach is a separate phase. Figure 3.6 shows an intersection approach with two phases on one approach: a separate left-turn phase and a through/right phase. Right-turn and through movements, whether in dedicated or shared lanes, are considered to be one phase. Also note that the lanes leaving an intersection are known as the departure lanes.

![Figure 3.5 – Rack Mounted Signal Controller](image)

![Figure 3.6 – Intersection Approach with Two Phases](image)
Intersections are described by traffic engineers in terms of the number of phases they support. The simplest intersection is a two-phase intersection, as seen in Figure 3.7, called a phasing diagram. All of the north-south traffic — left turning, right turning, and through, in both directions — moves together as one phase. After this first phase is stopped, then all of the east-west traffic gets the green signal as the second phase. The arrows in the diagram within the circles describe which movements are allowed to move forward by the display of a green signal indication at any given time. It is understood that any intersection movement not shown with an arrow would be receiving a red signal indication during that phase. The arrows outside and between the circles describe how the two phases progress from one to another. In this two-phase design, the signal controller progresses from one phase to the other, and then back to the first phase, and then to the second, and continues in this process. In this simple two-phase design each intersection approach has two signal heads with three circular indications — red, yellow, and green — in each signal face as seen in Figure 3.8.

![Diagram of a simple two-phase intersection with single lanes for all approaches.](image-url)
A hypothetical situation with this intersection shows the challenges that can occur with signal timing. If the area surrounding this same intersection were to grow because of commercial and residential development, it is likely that the northbound left-turn volumes and the southbound through volumes would also grow. The northbound left-turning drivers would no longer be able to find a sufficient number of gaps in the oncoming southbound traffic to make left turns. Queues for the northbound lefts would routinely back up, while left-turn and angle collisions would increase as drivers tried to sneak northbound left turns into the red interval on insufficient gaps.

To address the problem, the town might pave a dedicated northbound left-turn lane, add a protected northbound left-turn phase, and add a three-section left-turn signal head with arrow indications. Figure 3.9 depicts how this new three-phase signal might operate, and Figure 3.10 shows how the signal faces might look.
Figure 3.9 – Three-Phase Diagram with Protected Northbound Left-Turn Phase

Figure 3.10 – Protected Left-Turn Signal Head & Two Signal Heads for Through and Right-Turn Movements
The phasing diagram shows that all northbound movements would receive a green concurrently in Phase 1. In Phase 2 the northbound through and right movements would operate concurrently with all southbound movements — notice that the protected only northbound left-turn movement is no longer depicted in this phase. In Phase 3, all northbound and southbound vehicles would be stopped and all eastbound and westbound vehicles would receive green signals at the same time.

The new northbound left-turn lane would provide a storage bay for northbound left turns and reduce the chances of a rear-end crash between left turning and through traffic. The separate left-turn phase for the signal would allow much safer passage for these drivers and a greatly reduced chance of a conflict with southbound vehicles.

While this scenario satisfied the rush hour drivers and improved safety, it might also draw complaints from a few drivers making a northbound left turn who would experience increased delay. Another option to allow northbound drivers to turn left would be a three-phase design with protected/permitted left-turn phasing.

Traffic laws assign hierarchy to opposing drivers both having a circular green signal indication, or in common terms, a green ball. Left-turning drivers must yield to oncoming through or right-turning drivers. The original design with only two phases allowed northbound drivers, in accordance with traffic laws, to turn left in a permitted only manner: they were permitted to turn left when gaps occurred in oncoming southbound traffic. The second design included a protected only left-turn phase that gave the northbound left-turning drivers a green arrow signal indication during which they could turn left while all southbound traffic was stopped. However, after the protected left-turn phase ended, they were required to remain stopped by the display of a red arrow until the green arrow appeared again.

In many jurisdictions, the protected/permitted design, or the third design option, would use a five-section signal head with red, green, and yellow balls and green and yellow left arrows. When traffic conditions are heavy, and the signal
controller senses that the northbound left turners are waiting longer than a predetermined delay time, the controller would stop all conflicting movements and provide a northbound protected left-turn arrow. Alternately when traffic is light and the northbound left turners can proceed without delay, the signal controller senses no delays and just displays the green and yellow ball signal indications.

With this protected/permittted scenario, safety would likely be improved over the first design and drivers would only wait in heavy traffic to be able to make a left turn. Figure 3.11 shows how a five-section signal head might be used in such a situation. The phasing diagram for this signal is shown in Figure 3.12. Notice that the northbound left turn is shown in the diagram as a short permitted left-turn arrow symbol when running concurrently with southbound traffic in Phase 2. The northbound left is shown as a longer 90 degree left-turn arrow symbol when it is in the protected mode in Phase 1.

Figure 3.11 – Five-Section Signal Head (“Doghouse” Style) for Protected/Permitted Left-Turn Phase
3.5 Jurisdictional Differences in Signal Design Details

It is important to be aware of jurisdictional differences with phasing diagrams and signal heads and faces, or indications. The MUTCD clearly describes what a left arrow means and what a ball (or circular signal indication) means, and what motorists may do when faced with each one. The MUTCD also describes what combinations of arrows and balls may be shown to a motorist at the same time. The MUTCD leaves it up to individual jurisdictions, however, as to exactly which signal faces are used to describe a protected/permitted left turn. Some areas prefer the five-section “doghouse” style head shown in Figure 3.11. Others may use a horizontal five-section head like the one in Figure 3.13.
Figure 3.13 – Horizontal Five-Section Signal Head for Protected/Permitted Left Turns

Regardless of which signal faces are used, the meanings are the same to the left-turning driver – a green left arrow indicates a protected left turn and a green ball indicates a permitted left turn. This is accepted in all jurisdictions.

It has been recognized that some left-turning drivers don’t understand that they need to yield when assigned a green ball. Without this understanding of the difference between permitted and protected left turns, some crashes occur when drivers think they can turn left in front of oncoming traffic during the display of a circular green signal indication.

To address this confusion, some jurisdictions have installed flashing yellow left-turn arrows for permitted left turns. While not prevalent, it is important to be aware of these permitted left-turn signals, even though they do not impact the process of reconstructing crashes.

Also worth noting is that signal phasing diagrams vary from area to area. Some agencies show stopped movements with a small “T” as shown in Figure 3.14.
Other agencies omit the stopped movements and just show the ones having a green signal.

![Phasing Diagram with Stopped Movements Shown](image)

Some agencies depict protected and permitted left turns with the same arrow symbol, while other agencies use a dashed arrow for permitted left turns. It would be helpful to contact the local traffic engineer’s office to have them demonstrate how they use phasing diagrams.

Up until this point we have used the term “phase” to designate all the movements that take place during a green interval, such as the north and southbound movements receiving a green signal simultaneously in Figure 3.14. There is another use of the word “phase” which is used to designate individual movements for each approach. This is discussed in Section 3.6.

### 3.6 Typical NEMA Phasing

Because traffic signals are electrical devices, they are monitored under the general oversight of the National Electrical Manufacturers Association, or NEMA. All traffic signals employ standard NEMA phasing designations in terms of using even and odd numbers for certain phases. As shown in Figure 3.15, a four-legged intersection may have eight phases where phases 2 and 6 are the main/major street through (and right) movements, and phases 4 and 8 are the
side street through (and right) movements. Notice that the through movements for all four approaches have even numbers, and the left-turn movements have odd number designations of 1, 3, 5, and 7. NEMA establishes this use of even and odd numbers.

This phasing nomenclature is going to be critical during reconstruction of an accident in order to understand what signal programming would permit.
**ACCIDENT SCENARIO**
Consider the scenario that an accident has occurred at the three-phase signalized intersection in Figure 3.16. A northbound left-turning driver (Vehicle 1) claims that he had waited to turn left on a circular green for some time, and then received a green arrow. The southbound through driver (Vehicle 2) that crashed into the passenger side of the northbound car claims she had a green circular indication.

![Crash Drawing at Three-Phase Signal](image)

Witness statements provide additional information. A westbound driver (Vehicle 3) reports being stopped at a red signal for some time, looking down, hearing a crash, and looking up to view the accident. Another statement is obtained from a
northbound driver (Vehicle 4) who turned right and reported seeing the left turner sitting and waiting to turn left as the Vehicle 4 driver slowed to make the right turn. The Vehicle 4 driver further reported that after seeing the circular green for the right and through northbound traffic, he turned right and saw the crash in the rearview mirror.

The local traffic engineer reviews a copy of the signal design plans for this intersection, which include the phasing diagram in Figure 3.12. After reviewing the phasing diagram and the witness statements the traffic engineer explains that (the reader is encouraged to sketch their own phasing diagram based on the following descriptions):

- Phase 2 includes a circular green for permitted left turns for north and southbound traffic — three drivers indicated a circular green for northbound and southbound, which means Phase 2 was in effect at that time.
- Phase 5 is the protected northbound left-turn phase and can run concurrently with Phase 2
- Phase 6 is the southbound phase and can run concurrently with Phase 2, but not with Phase 5
- The signal is designed, as shown in the phasing diagram, to never transition from Phases 2 and 6 to Phases 2 and 5 [see the arrows between the phase combination circles]. The diagram shows that Phases 2 and 6 must transition to Phases 4 and 8 (which assign circular greens for the side streets), and only then can the signal controller proceed to Phases 2 and 5 — the condition cited by one of the drivers.
- Because the side street driver indicated that a circular green was never shown for the westbound traffic, the signal never went into Phases 4 and 8, and the signal could not have progressed from Phases 2 and 6 to Phases 2 and 5 without going through 4 and 8.

All statements indicate that the northbound left-turning driver did not receive a green arrow and pulled out in front of an oncoming car when only the circular green was still being displayed to northbound traffic. The seemingly meaningless statements from other drivers that contained no other typical pre-crash observations like speed, direction, or evasive skidding proved to be very valuable when combined with the proper knowledge of signal operations.
3.7 Side Street Options

The intersection described in the preceding Accident Scenario was programmed to have the eastbound and westbound side street approaches receive a green indication *concurrently*. In some cases this may not be desirable. Consider an intersection where the main street runs along a ridge. The side streets come up inclines toward this ridge so each side approach is uphill. The Phase 4 driver, as defined in the NEMA standard phasing diagram in Figure 3.15, approaches the intersection they cannot see the oncoming Phase 3 driver who is initiating a left turn. The top of the hill, or *vertical crest*, blocks both drivers’ views of each other. If controlled by a signal that allows both side street phases to run concurrently, this intersection might be a prime site for accidents. An example of this is seen in Figure 3.17. Although difficult to see in this picture (isn’t that the point!), there is an opposing leg to this side street approach.

Traffic engineers often treat this situation by using *split side street phasing*. Each of the side phases, 4 plus 7 and 3 plus 8, run independently. Phases 4 and 7 runs and then Phases 3 and 8 gets the green after all Phase 4 plus 7 vehicles come to a stop. This is a much safer treatment than concurrent side street phases when *vertical sight distance* is limited. While it is true that drivers have a legal duty to yield to oncoming cars when turning left, if drivers don’t see oncoming cars, they are unable to prevent crashes. Split side streets are a traffic signal solution to this common crash scenario.

An example of split side street phasing is seen in Figure 3.18 in the three-phase diagram where Phase 2 plus 6 is the main street phase and Phase 4 is one side street phase and 8 is the other side phase.
With split side street phasing, a protected left-turn message needs to be conveyed to the Phase 4 or Phase 8 drivers. In many jurisdictions, a four-section signal head with the typical three circular indications plus a green arrow is used. The circular green and green arrow illuminate simultaneously and thus provide a message to left-turning drivers that opposing traffic is being controlled by a red indication. An example is seen in Figure 3.19.
3.8 A Little More on Protected Left Turns

The use of protected left turns with a green arrow to allow drivers to turn left across heavy volumes of oncoming traffic already has been discussed. Other cases also exist when protected left turns are commonly used for safety concerns or for other reasons.

For example, a four-lane divided highway with a planted median has grass, small trees, and shrubs to make the landscaping in the wide median appealing. The roadway design engineer included left-turn bays. As drivers pull into the bay to make a northbound left turn, as seen in Figure 3.20, their view of oncoming through or right-turning traffic is blocked by opposing left-turning vehicles also sitting in their respective southbound left-turn bay. Using protected left turns for the main street can prevent this dangerous situation.

In Figure 3.20, the view of through and right-turning vehicles from the opposite approach is completely obscured by the minivan. This scenario forces a driver to make a decision regarding how to proceed even as oncoming traffic is obscured. A circular green signal, if used in this situation, may be asking left-turning drivers to make decisions when they do not have sufficient information.

Another example of needing protected left turns is when the minor street runs along a ridge and the main street approaches will both be uphill coming into the intersection, as described previously. Protected left turns are a common engineering solution to reduce potential conflicts between left turning and opposing through vehicles in this situation. An example is shown in Figure 3.21.
If this left turn was a permitted left the stopped driver, upon receiving a circular green, might be partway through her left turn when an oncoming through vehicle crests the hill and a collision occurs. With the protected only left-turn signal as shown, all-oncoming traffic must stop before this driver receives a green arrow for a protected left turn.

A final example of requiring a protected left turn involves the case of a high-speed multi-lane highway where a left-turning main street driver must navigate across several lanes of oncoming traffic during the turn. The left-turning driver’s ability to see through and past oncoming traffic is complicated and often leads to crashes. Again, protected left-turn phasing is a typical safety treatment for this situation.

3.9 Traffic Flow and Interruptions

When traffic flowing from one signalized intersection to the next along a main highway needs to stop for red lights, rear end crashes can occur. Also, every time cars decelerate, stop, and restart their forward motion there is lost time and increased air pollution. Delays also cause driver frustration and thus complaints to the traffic engineer, as well as erratic driving.

To minimize delays, traffic engineers seek ways to keep all main street traffic flowing as delay-free as possible. While protected left turns do promote safety, they also force all oncoming traffic to stop. This may cause many southbound vehicles to stop and restart just so one northbound driver can turn left. As much as traffic engineers are concerned about safety, they also report to elected officials who face many pressures from business owners and citizens who want to move freely along the main street without stopping excessively at signals. It is possible that you will encounter scenarios where traffic flow on main streets has preempted the use of protected left turns.

3.10 Overlaps

When two normally conflicting phases are run concurrently under special conditions — for example, a right-turn movement from a side street that doesn’t
conflict with a protected left turn—this is called an overlap. Consider the intersection shown in Figure 3.22 where the side street has a dedicated right-turn lane. Also note that the main street has a protected left turn for southbound traffic. This protected left turn is shown with a longer left arrow symbol for Phase 1.

In an effort to maximize vehicle and pedestrian flow through an intersection, a traffic engineer will design a signal to allow as many movements to run concurrently as possible. In the intersection shown in Figure 3.22, the engineer sees that the Phase 4 right turn can safely operate when Phase 1 left turns are moving. Phase 1, a main street phase, and Phase 4, a side street phase, are typically conflicting phases and would not run together. By programming the signal controller, or by wiring the cabinet in a special manner, the traffic engineer can allow these movements to run together as an overlap.
Most signal controllers handle up to four overlaps and NEMA designates them as Overlaps A, B, C, and D. For example, the overlap in Figure 3.22 involves Phases 1 and 4. This means that every time that either Phase 1 or Phase 4 is showing green, the signal indications for the Phase 4 right-turn movement are showing green. As seen in Figure 3.23, the signal uses a three-section, all-arrow face for the side street right-turn movement.

![Figure 3.23 – Three-Section All Arrow Face Used for Right-Turn Overlap](image)

In this figure, Phase 4 operates the signal, and the face with circular indications; all-arrow signal face is operated by Overlap A. When the signal controller gives green to the side street, both the ball and arrowheads are illuminated. When the controller gives a green arrow to Phase 1 for the main street protected left turn, the right-turn green arrow is also illuminated. The main street lefts and the side street rights run concurrently.

It is worth noting that many jurisdictions use a modified form of a signal overlap. When an intersection has the same approach laneage as in the previous example in Figure 3.22, there may be a desire to not use an all arrow face head for the side...
street. In this case the traffic engineer might use a five-section face for the right-turn indication. Figure 3.24 depicts such a situation.

![Figure 3.24 – Five-Section Signal Face Used for Right-Turn Overlap; Circular Green Displayed](image)

In this example, during normal side street (Phase 4) operation the motorist sees only circular greens. The Phase 4 right-turning drivers can turn right on the circular green signal. When the main street Phase 1 is on and the protected main street left turn is operating, both the Phase 4 signal heads would have circular reds displayed. In this example, the five-section head for Phase 4 would also have a right-turn green arrow displayed as seen in Figure 3.25.
Right-turn overlaps are used in many locations. Investigators need to be aware of their presence at an intersection and of how they operate. Overlaps are probably more common on side streets, but can also be seen on main streets, as well.

**ACCIDENT SCENARIO**

Consider the scenario that a crash has occurred at a T-type intersection. The driver of a southbound left-turning main street vehicle (Vehicle 1) ran into the passenger side of a left-turning side-street car (Vehicle 2). The main street southbound driver claims to have had a left-turn green arrow, having waited for some time on a red arrow and then received the green left arrow and started forward. The driver then saw a car coming across his path from the left, and then hit the other car. The scene is depicted in Figure 3.26.
Driver 2 reports approaching the intersection on a circular green that stayed green the whole time she traveled through the intersection. The driver of Vehicle 2 also reports being adjacent to a vehicle that was on the right side of her car (Vehicle 3). The other vehicle turned right while Vehicle 2 turned left.

A witness who was walking along the main street across from the side street approach reports seeing several cars move through the intersection from the side
street. Following a long gap after the group of cars went through the intersection, the witness reports a southbound car was stopped with its left-turn signal flashing. The witness claims that the cars moving toward her on the northbound main street approach came to a sudden stop — the witness saw one car skidded a little and almost rear-ended a stopped truck. Also, the other cars that were stopped next to the witness in the southbound through lanes were also stopped, and then started forward at the same time the southbound left-turning driver also started forward.

The engineer provides you with the traffic signal plan. Upon examination of the plan, you identify the following:

- The side street driver claims to have approached the intersection on a circular green that is consistent with the signal being in Phase 4.
- The pedestrian reports seeing other vehicles on Phase 4 going through the intersection, which supports the side street driver’s claim of having a circular green.
- The pedestrian reports seeing the main street left-turning driver stopped, which supports this driver’s claim of initially having a red arrow and coming to a stop.
- The pedestrian further reports seeing the main street traffic stopped, which supports the side street driver’s claim.
- The witness also reports seeing the southbound through traffic start moving forward at the same time as the southbound left-turning driver starts moving forward.

As you review the signal-phasing diagram, shown in Figure 3.27, you see that the signal progresses from Phase 4 to Phases 2 and 6 unless a vehicle is waiting on Phase 1, the main street left turn. If a driver is waiting on Phase 1, the signal will progress from Phase 4 to Phases 1 and 6. The engineer tells you that the signal will terminate the green for Phase 4 after two seconds of inactivity — in other words, after the group of cars ahead of Vehicle 2 went through the intersection on this approach.
You question the pedestrian witness, who states that approximately 10 to 15 seconds passed between when the group of side street cars traveled through the light and when the side street driver in the crash approached the signal. This information, combined with the engineer’s report that after two seconds of inactivity on the Phase 4 approach the signal controller will terminate the Phase 4 green and go to the next phase combination, is key to understanding what happened to cause the crash. This indicates the long gap between the previous group of vehicles on Phase 4 and Vehicles 2 and 3 occurred when the signal changed from Phase 4 to Phases 1 and 6.

This scenario presents a challenge in terms of overlap analysis. The right-turn arrows for Phase 4 are overlapped with Phase 1: when Phases 1 and 6 are on, so is the Phase 4 right-turn green arrow. So the errant side street driver, although still at fault, most likely saw two things happen which, in an apparent state of
inattention, caused her to make an incorrect assumption that she had a circular green for a left turn:

- She saw the car to her right proceed through the intersection on a green arrow intended for Phase 4 right turns.
- Not seeing the driver to her right stop supported her last observation of seeing green indications for Phase 4 although the observation was made many seconds earlier.

The key points to take away from this accident analysis are the following:

- Interview questions lead to more questions. Don’t be afraid to go back and ask a second or third round of questions as more information becomes available.
- While overlaps are great for maximizing traffic flow, they can also sometimes lead to motorist confusion since red and green signal indications are displayed for the same intersection approach. Certainly, a trained driver should be able to interpret circular from arrow and red from green. But with the many distractions drivers face, a correct interpretation may not always take place.
- You now have a whole different set of questions to ask witnesses to gain a complete picture of traffic conditions. What used to seem like meaningless witness observations are starting to become the important keys for solving crash investigations.

### 3.11 Timed Overlaps

Overlaps have *parent phases*, or phases that are associated with overlaps. For example, in Figure 3.22, Phase 1 and Phase 4 are the parent phases for Overlap A. Every time the controller provides right-of-way to either Phase 1 or Phase 4, it concurrently provides right-of-way to signal indications tied to Overlap A. In Figure 3.28 we see how this could be sketched.
Overlap A acts like a relay: when the signal controller activates Phase 1 and turns on a green, yellow, or red Phase 1 signal indication, an electrical current simultaneously engages Overlap A. In turn, Overlap A will time green, yellow, and red signal indications concurrently with Phase 1. This same chain of events will also transpire if Phase 4 is the active parent phase.

Having two parent phases on an overlap makes sense for many overlap uses, such as the right-turn overlap discussed in Section 3.10. Traffic engineers occasionally use overlaps with only one parent phase to handle unique signal display situations. For example, a signalized intersection adjacent to a railroad crossing is shown on Figure 3.29.
In this example, a school is located to the south of this intersection. Ninety school buses loaded with children travel northbound through this signalized intersection five days a week. For safety reasons, it is highly desirable to never have buses stop on the railroad tracks. Also, state law prohibits school bus drivers from making a right turn on a red traffic signal. While most buses will eventually turn right at this particular intersection, many will become stranded on the tracks because of their inability to turn right on red.
A common solution would involve installing two sets of signal heads for northbound traffic: one on the north side of the tracks and one on the south side of the tracks. In normal operation for Phase 2 (the northbound vehicular phase), both sets of signal heads would display the exact same color and would time the same intervals. At this intersection, however, only the southernmost Phase 2 signal heads, heads 23 and 24, are controlled by Phase 2. The northernmost signal heads, heads 21 and 22, would be operated by Overlap A. Phase 2 is the single parent phase to Overlap A.

Overlap A is programmed, as may be done in many modern signal controllers, to time a *green extension* when the parent phase’s green interval expires. In this example the *timed overlap* would run as follows:

- Phase 2 provides a green signal indication to northbound traffic with signal heads 23 and 24.
- Phase 2 green triggers Overlap A green which provides a green signal indication to signal heads 21 and 22.
- Phase 2 green (signal heads 23 and 24) is terminated in response to a need for service on Phase 4; Phase 2 green expires and Phase 2 yellow starts.
- When Phase 2 green ends and Phase 2 yellow starts, a programmed timer starts to run on Overlap A. This timer extends the Overlap A green (signal heads 21 and 22) for a predetermined time beyond the expiration of the parent phase (Phase 2) green.
- Phase 2 yellow expires and Phase 2 red starts for signal heads 23 and 24.
- Eventually the Overlap A green expires, and Overlap A yellow and red are displayed for signal heads 21 and 22.

This timed overlap sequence provides a sequential progression for stopping traffic at the southern side of the tracks before stopping traffic on the northern side of the tracks. The messages conveyed to drivers by this timed overlap are to not enter the area on the tracks or between the tracks and the east-west roadway while also providing a clear message to drivers near the intersection that they can still move northward. This simple timed overlap is considered to be effective for clearing traffic from select areas, such as near dangerous rail crossings.
3.12 How a Signal Controller Thinks

Modern traffic signal controllers operate on a common conceptual approach to organizing phases and thus assigning green time to the intersection phases. This method is known as the \textit{dual-ring} structure. As shown in Figure 3.30, the eight vehicle phases are organized in two rows. Phases 1 through 4 are on the top and Phases 5 through 8 are on the bottom. These phases correspond to the NEMA standard phases shown in Figure 3.31.

Notice that there is a vertical \textit{barrier} in the middle of the dual-ring controller layout in Figure 3.30. Phases 1, 2, 5, and 6 are on the left side of the barrier and are the main street phases. Phases 3, 4, 7, and 8 are the side street phases and are on the right side of the barrier. Also notice there is a barrier on the far right side of the diagram in Figure 3.30. Barriers will be discussed in detail later.

A signal controller that is capable of handling all eight phases is called an eight-phase controller. There are also two-phase controllers. An eight-phase controller can also handle fewer phases. Keep in mind that a discussion with a traffic engineer might include talk of an intersection having an eight-phase controller; however, there may be
fewer than eight phases actually in use. Be sure to review a phasing diagram for the particular intersection to better understand which phases are in use, regardless of the capacity of the controller.

The signal controller’s computer is programmed to allow the assignment of a green signal indication to phases in numerical order along the top row and along the bottom row. Phase 1 gets a green, then Phase 2, and so on in the top row. In the bottom row, Phase 5 is served with a green indication first, then Phase 6, then Phase 7, and finally Phase 8. In traffic engineering terms, these rows are sometimes called *rings*.

A signal controller is programmed to allow certain phase combinations to run concurrently, or simultaneously. As we see in the NEMA phasing designation diagram in Figure 3.31, Phase 1 can safely operate at the same time as Phase 5. We commonly see opposing main-street left turns running concurrently. Phase 1 also can operate concurrently with Phase 6, which is the adjacent through movement. This is often used in situations where the left-turn volume for Phase 1 is heavy and it might be advisable to allow some of these vehicles to clear out before letting Phases 2 and 6 operate together. When Phase 2 plus 6 operates, the Phase 1 drivers might not find gaps in Phase 2 traffic through which they could turn left. Keep in mind that under Phases 2 and 6 operations, the vehicles turning from Phase 1 are operating under a permitted green ball from Phase 6.

Returning to the dual-ring controller diagram in Figure 3.30, if connecting lines were drawn between all the phases that could safely run concurrently, the diagram would look like the one in Figure 3.32.

![Figure 3.32 – Dual-Ring Controller Showing Concurrent Phase Combinations](image-url)
This shows that concurrent phase combinations will permit safe travel for phases that are on a diagonal from each other like Phases 1 and 6. Also, vertically aligned phases, like 3 and 7, will travel safely concurrently. Horizontally aligned phases, like 5 and 6, or like 3 and 4, however, are not able to run concurrently. These are referred to as conflicting phases, or are phases that would be in conflict with each other, as shown in the NEMA phasing diagram in Figure 3.31.

Now that you can see how a signal controller organizes the eight vehicle phases, it is time to review how the controller systematically assigns green time to each phase or to phase combinations.

When a signal controller is started by the flow of electric power, the controller defaults to a flash mode for a specified number of seconds. This flash mode gives motorists and pedestrians a warning that the traffic signal is powering up and will be operating soon. (Flash mode will be discussed in more detail in Section 3.15.) The signal controller progresses from start up flash to green for whatever phase is programmed to start in green. Typically, the green start up phases are the main street through phases (Phases 2 and 6) since drivers on the main street would typically have been proceeding on a flashing yellow indication during the flash mode. In this scenario, the side street drivers would receive a red signal upon start up, which means that the flashing red indication becomes a steady red.

While the signal is providing the start up green phases — assumed in this example to be Phases 2 and 6 — the controller is looking for other phases with vehicle or pedestrian actuations. Detection of pedestrians and vehicles, or actuations, will be discussed more in Chapter 5. For now, assume that the signal controller can detect pedestrians and vehicles waiting to receive a green or WALK signal. The controller progressively scans, in numerical order, all the main street phases and looks for phases with waiting actuations, or as signal engineers sometimes say, calls, on that phase. In our example, the controller looks at Phase 5 since it follows the current green phase, Phase 2. The controller sees no calls on Phase 5, and now the controller looks to the side streets and find vehicles waiting on Phase 4.
As the Phase 2 and 6 start up green time expires, the controller progresses to Phase 4 to serve the queue of cars waiting on the side street. Notice that to progress from the main street phases on the left side of the diagram to the side street phases on the right side, the controller must pass through the barrier. In terms of a traffic signal controller, the barrier is a safety feature: any time that a controller passes through a barrier the entire intersection has red signals.

For example, when Phases 2 and 6 are green, all other phases are red. As the greens for Phases 2 and 6 expire and Phases 2 and 6 go into yellow and then red, they join the other phases already signaling red. For a short time, the entire intersection has red signals.

This *all-red* makes sense from a safety standpoint. The main street traffic needs to come to a standstill before allowing conflicting minor street phases to begin moving.

Going back to Figure 3.30, the right edge of the dual-ring diagram indicates another barrier. As each of the rings finish serving all waiting vehicles — that is, when Phases 4 and/or 8 are finally served — each of the rings progresses back to the start and the whole process runs again. When each ring progresses from the side street phases back around to the main street phases, the controller once again crosses the rightmost barrier and goes through an all-red interval. Again, this makes sense to bring all the minor street movements to a complete stop before allowing the main street phases to receive a green signal indication.

To help illustrate this process, below is an example of how the controller senses waiting traffic and provides a green signal to each waiting phase:

- Calls are waiting for response on Phases 1, 2, 5, 4, and 7.
- The controller starts in Phase 1 and looks to see if any traffic is currently on Phase 1. A vehicle has put a call on Phase 1, so Phase 1 will be given a green.
- The controller also looks to see if any phases that are compatible with Phase 1 also have a queue of waiting vehicles. Phase 5 meets these criteria, having a call for the signal and presenting a non-conflicting phase.
- Phases 1 and 5, the main street lefts, are given green indications.
The controller now polls the remaining phases in order of the ring, and considers the same two criteria. Phase 2 has traffic waiting and is compatible with Phase 5, which is already running in green.

Assuming that the Phase 1 queue dissipates, Phase 1 will turn from green to yellow to red. Phase 2 will then turn green, so Phase 2 plus 5 is now operating.

The controller then reviews the subsequent ring phases for waiting traffic, and sees that Phases 4 and 7 have calls, and that cars have started to accumulate on Phase 1 again.

Phases 2 and 5 will receive a yellow and a red signal, and the intersection is now all red as the middle barrier is crossed. Phases 4 and 7 are compatible, so they run together.

When Phases 4 and 7 have expired, the end barrier is crossed, and the rings both circle back to the major streets.

Phase 1 is now served, and the controller’s cycle begins again.

It is important to note that the all-red situation discussed above is not used in every jurisdiction. Some agencies allow, for example, the main street signals to turn red at the same instant that the side street signals turn green. Specific signal timing issues are discussed in Chapter 4.

### 3.13 Special Controller Sequence Situations

Traffic engineers sometimes program a signal controller to accommodate unique situations. Many of these programming efforts focus on maximizing traffic efficiency and minimizing motorist and pedestrian delays.

Consider an example where a car is sitting on Phase 8 (westbound) waiting — or calling — for a green signal. No other side street calls (Phases 3, 4, or 7) are waiting. At typical intersections, the through phases receive more traffic than left-turn phases. If all main street movements are stopped for Phase 8 to run in green, and then a car arrives on Phase 4 (eastbound), the controller must
sequence back through the main street phases before it can answer the call of the Phase 4 car. The situation is not optimal, since the Phase 4 driver must wait a significant amount of time, and the main street phases will be interrupted a second time just to serve the lone Phase 4 car.

To provide a more effective controller sequence, traffic engineers can program the controller for dual entry on Phases 4 and 8, since they are the most likely pair of side street phases to receive compatible calls. A dual call controller setting places a call without an actual car being on a particular phase. In this example, when Phase 8 is called, the controller sees that Phase 4 has been flagged as a dual call phase, and it is compatible with Phase 8. Phases 8 and 4 will run in green concurrently despite no actual traffic on Phase 4. Should a vehicle arrive on Phase 4, the driver will already see a green and will just proceed through the intersection without delay.

In terms of accident reconstruction, this type of special controller sequence means that you might encounter a case where a phase is mysteriously called and receives a green signal when no vehicle is present to actuate that particular phase. Witness statements describing traffic conditions might not match what one or both drivers claim to have seen the signals do. It is important to always have a signal technician check for phases assigned for the dual call.

It is important to keep the major approaches that are most likely to receive an approaching vehicle in green as much as possible to maximize traffic flow. To accommodate the resting of prominent phases in green, signal controllers are able to recall any selected phase. Signals design engineers often place the main street phases (for example, Phases 2 and 6) on recall. In the absence of conflicting calls on other phases, this means the controller will default to a green signal for the main street, even if the phase does not currently have a call. While any phases could be used for recall, typically the main-street through-phases have a recall associated with them.

Recall can be a useful feature when used in the proper context. As with the dual call, however, it is important to be aware of the recall option during accident investigation. Again, witness statements describing traffic conditions might not
match what one or both drivers claim to have seen the signals do, so it is critical to ask a signal technician to check for phases on recall.

### 3.14 Pedestrian Signals

Pedestrian movements at a signalized intersection may be controlled by the traffic signal. Two typical situations exist:

- **Special pedestrian signal heads** convey WALK (walking person) and DON’T WALK (upraised hand) messages at the intersection, as shown in Figure 3.33.

- **No pedestrian signals at the intersection**, which forces pedestrians to receive their visual message from the vehicular signal heads

When pedestrian signal heads are present, the signal controller has typically been programmed to accept input from *pedestrian pushbuttons* located near the *wheelchair ramps* at the intersection corners. Design codes usually require ramps to be built at intersections that will have pedestrian traffic in order to allow accessibility to the sidewalk from the crosswalk and visa-versa. Codes also usually call for the pushbuttons to be located at a height and a horizontal location such that it is accessible to a wheelchair user.

When a pedestrian pushes the button in order to cross, the signal controller receives an actuation, or a call, to a special pedestrian phase. Each of the typical NEMA through phases — 2, 4, 6, and 8 — has an associated pedestrian phase:
2P, 4P, 6P, and 8P. After a call for the pedestrian, or ped, phase is received, the controller provides a yellow and red display to conflicting vehicular phases, and then provides a WALK signal to the appropriate ped phase. Any vehicular phases that are non-conflicting with the ped phase may also be set up to run concurrently at this time. This facilitates keeping at least some of the intersection’s vehicular traffic moving while the pedestrians are given a WALK signal.

In the example-phasing diagram shown in Figure 3.39, the Phase 2 peds will operate concurrently with the Phases 2 and 6 vehicles when called. Keep in mind that most jurisdictions have laws requiring drivers to yield to a pedestrian, who is inside a crosswalk. In this example, the left-turning Phase 6 vehicles and the right-turning Phase 2 drivers would have to yield to Phase 2 peds.

In the second pedestrian scenario where no pedestrian signal heads or pushbuttons are available, the pedestrian must watch the vehicular signal heads and walk on a parallel green. A pedestrian waiting to cross the eastern leg of the intersection from the southeast corner would watch for the northbound vehicular signal heads to turn green, and would then start a crossing movement.
Timing for pedestrian phases is accomplished in several ways, as discussed in Chapter 4.

Section 3.13 discussed recall and how vehicular phases may be placed on recall to ensure green is received for that phase on every signal controller cycle. Similarly, ped recall can be used with any pedestrian phase. This is often used in urban areas where large numbers of pedestrians are expected on almost every signal cycle. The traffic engineer will place the signal controller on, for example, Ped 2 recall and Ped 6 recall for accommodating the large number of north-south pedestrians. In this instance, the controller will provide walk time for Ped 2 and Ped 6 phases on every single cycle. The controller also will provide green time for vehicular Phases 2 and 6 concurrently with the Ped 2 and Ped 6 walk intervals.

In addition to the upraised hand and walking person symbols typically displayed by the pedestrian signal heads shown in Figure 3.33, older pedestrian heads sometimes use the words WALK and DON’T WALK to communicate right-of-way status to pedestrians. Figure 3.35 shows a newer LED (light emitting diode) pedestrian signal where the walking person and upraised hand symbols are alternately displayed in the same area.
Drivers see green for go, yellow to symbolize the end of the green interval and the approach of the red interval, and red that prohibits entry into the intersection. Pedestrians also receive three visual indications:

- **WALK** – indicated by a steady display of the word WALK or the walking person, meaning that pedestrians may enter the roadway to start the crossing movement
- **Flashing DON’T WALK** – indicated by a flashing display of the words DON’T WALK or the upraised hand, meaning that pedestrians should continue to the other side if already in the crosswalk, but should not begin crossing the street
- **Steady DON’T WALK** – indicated by a steady display of the words DON’T WALK or the upraised hand, meaning that pedestrians should not be in the crosswalk

Some intersections use signs near the ped pushbuttons to explain the ped signals, as shown in Figure 3.36.

Some jurisdictions use the *countdown pedestrian signal heads*, as shown in Figure 3.37. The typical walking person symbol is displayed with the WALK interval, and then during the flashing DON’T WALK portion of the ped time, the numerical counter displays descending numbers. This countdown feature provides the pedestrian arriving at the intersection during the flashing DON’T WALK portion of the ped phase a chance to make an informed decision regarding his or her ability to cross. For example, if the arriving...
pedestrian sees 17 seconds remaining, he or she might cross, knowing enough
time is allotted for the crossing. If the pedestrian were to see only 3 seconds
remaining for the pedestrian phase, he or she might wait to cross until the next
permissible cycle.

Depending upon local circumstances, jurisdictions will allow different
relationships to exist between vehicle phase and ped phases with respect to the
yellow interval. Two patterns are used most typically. The first one follows this
basic process:

- Vehicle phase begins green display at the same time the ped phase begins
  WALK display
- Ped phase terminates WALK display and begins flashing DON’T WALK
display; vehicle phase remains green
- Flashing DON’T WALK display terminates and steady DON’T WALK
display begins; vehicle yellow display begins
- Vehicle yellow display ends and vehicle red display starts

The second commonly used pattern between pedestrian and vehicles follows a
different process:

- Vehicle phase begins green display at the same time the ped phase begins
  WALK display
- Ped phase terminates WALK display and begins flashing DON’T WALK
display; vehicle phase remains green
- Flashing DON’T WALK display terminates and steady DON’T WALK
display begins; vehicle phase remains green
- Vehicle green display ends, moves through yellow display to red; ped phase
  remains in steady DON’T WALK

The second process provides a little more time for the pedestrian to clear the
intersection before releasing the conflicting vehicles on green since the
concurrent vehicular yellow doesn’t begin until after the flashing DON’T WALK
ends.
It is important for an accident investigator to understand not only how the ped signals at an intersection work, but also how their changing messages relate to the vehicular phase signal changes. Direct observation and conversations with the local traffic engineer can help make the most of this knowledge during accident reconstruction. Also, during an investigation it is key to remember that some drivers still see ped heads even though efforts are made to shield pedestrian signals from drivers’ view. This sometimes causes drivers to start or stop their vehicles in an incorrect response to seeing ped heads.

Mid-block signalized pedestrian crossings are sometimes used in urban or commercial settings. These do not involve street intersections, but simply consist of a main street with a pedestrian crossing. The signal rests in green for the street until the controller receives a call from a ped pushbutton indicating the presence of a pedestrian wishing to cross the street. The vehicle signals will provide a yellow and red interval and then the pedestrian signal will time pedestrian intervals. Then the vehicle signal will return to green on the street until another pedestrian actuates it some time later.

3.15 Flashing Operation

Traffic signals typically operate in the traditional sequence moving from green to yellow to red. In these normal operational intervals, the signal indications are displayed in a steady-state mode. Special flashing operations can be used under certain circumstances, however.

When a traffic signal is first turned on, the signal is typically programmed to begin in flashing mode. The start-up flash mode typically lasts approximately ten seconds. The signal then transitions to normal operation with the main street typically receiving the green signal first.

The start-up flash mode usually involves signals flashing yellow indications on the Primary Street and red indications on the minor streets. The flashing yellow signals direct drivers to proceed with caution. The flashing red signal indicates drivers should stop, see if the path to cross is clear, and then proceed through the
intersection. A flashing yellow on the major street meets the motorist’s expectations of having side street drivers yield the right-of-way to them. Flashing red on the side streets meets expectations of minor street drivers of being required to stop at the intersection.

Some jurisdictions have signals programmed to flash yellow on all main street phases except for protected main-street left turns. This forces the primary street’s left-turning drivers to proceed through the intersection only after stopping to see if the path is clear.

Responding to fuel shortages and growing pressure to conserve fuel in the mid-1970s, many traffic agencies programmed traffic signals to flash during low-volume traffic periods. Common flash hours ran from around 11:00 PM to about 6:00 AM. This was intended to allow vehicles on the major street to proceed unimpeded along that route and save fuel by not stopping, idling, and restarting. In addition, minor street drivers could come to a stop and proceed as if they were at a stop sign rather than having to wait through a full cycle. Some agencies continue this program to this day, and others have abandoned late night flash in favor of full signal control 24 hours each day.

Some locations make it necessary to flash all intersection approaches on red — for instance, at an intersection with poor sight distance. In this case, the traffic engineer will program an all-red flash in order to reduce the chance of potential crashes by requiring all drivers to stop before proceeding through the intersection.

The scenarios explained above are the result of a programmed flash, which is flashing in an intentional and planned manner. Traffic signals also can flash in conflict flash. Most signal cabinets contain a separate electrical device called the conflict monitor, signal sequence monitor, or malfunction management unit that monitors several critical functions. If any monitored functions are considered to be erroneous, the monitor will send the intersection into flashing operation. When a signal goes into conflict flash it will remain in flashing mode until a technician manually resets the monitor and allows the signal to resume normal operation.
Common faults that send a signal into conflict flash include detection of the following scenarios:

- **Green indication is displayed simultaneously to two conflicting phases.**

- **Absence of red.** If the controller sends a signal out to turn on Phase 4 red and no red bulb is illuminated, the signal will go into flash.

- **Less than minimum yellow time.** The monitor is programmed to consider any yellow interval less than some predetermined value to be a fault, and to send the intersection into flash. For example, if 4 seconds is the allowable minimum yellow time for any phase, and a field technician accidentally programs 3 seconds into the controller for Phase 7, the monitor will revert to conflict flash the first time a 3-second yellow is shown to a Phase 7.

An important point for the accident investigator who is investigating a crash where both drivers claim to have had conflicting green indications to consider is that because of the presence of a properly operating conflict monitor it is virtually impossible that both drivers did in fact both have green signals. Some other explanation of what occurred must exist.

### 3.16 Yellow Traps

Section 3.12 discussed how a controller decides in what order it serves phases. A matter that can complicate the reconstruction of accidents when looking at phasing is the **yellow trap**. This occurs when a signal *backs up* from a permitted left to a protected left by stopping opposing traffic.

An example of a yellow trap in action involves an intersection with 6 phases: the main street has Phases 2 and 6 for northbound and southbound through traffic, right turns, and permitted left turns. The main street also has Phase 5 for northbound protected left turns and Phase 1 for southbound left turns, using a protected/permitted signal head arrangement for the main street lefts. The side streets operate as Phase 4 for eastbound traffic and Phase 8 for westbound traffic.
No separate left-turn phases are programmed for eastbound or westbound traffic. A partially drawn phasing diagram for this intersection is shown in Figure 3.38.

Consider that traffic is flowing in Phase 2 plus 6 and northbound left-turning drivers (Phase 5) have been waiting to turn left. Eventually the signal controller recognizes the waiting vehicles and simultaneously scans for vehicles waiting on other phases. No other phases have calls waiting to be served by the controller, which is programmed to provide a yellow signal to Phase 6 traffic while retaining the green signal for Phase 2 traffic. The controller in this case would change from Phase 2 plus 6 to Phase 2 plus 5, thus providing a protected left turn for northbound drivers. This is called a lagging left turn since the protected movement lags behind the permitted movement.

As the Phase 6 signal heads turn yellow, a southbound left-turning driver arrives at the intersection with the intent to turn during the yellow signal. This driver assumes that the yellow signal for his phase means the oncoming traffic is also receiving a yellow signal. Because Phase 2 is remaining in green, and is not
progressing through a yellow and red interval like Phase 6, the southbound left-turning driver would be mistaken to assume he could safely turn left.

Although most traffic engineers do not intentionally allow signals to back-up into yellow trap situations because of the increased potential for crashes, accident investigators need to be aware of the potential for yellow traps in signal phasing. Not only is it important to observe the signal operation, but it also is key to ask a traffic engineer or technician to check the controller’s settings or cabinet wiring. He or she will be able to tell if programming or wiring which protects against left-turn traps has been installed at the signal. Assigning true responsibility to the left-turning driver in yellow trap crashes becomes difficult since the driver might have acted in good faith based on the available information. It is important to check if this is actually what happened at a crash scene, rather than assuming that because yellow traps typically do not occur at signals then it must not have happened here.

For the traffic engineer to design a signal that prevents back-ups from permitted lefts to protected lefts and therefore protects against yellow traps, a special programming command is used in the controller to omit selected phases. In the previous example intersection, the controller could be programmed to “omit Phase 1 during Phase 2 on” and to “omit Phase 5 during Phase 6 on.” This means when the northbound Phase 2 is green, or on, the controller will omit or ignore all calls placed by a car waiting on the southbound Phase 1 left turn. And the controller will omit all calls placed by waiting northbound cars on Phase 5 so long as Phase 6, the southbound phase, is green.

This solution, however, creates a problem for any drivers waiting on Phase 5 to make a left turn. While the controller is programmed to ignore calls to Phase 5 when Phase 6 is on, it still accepts calls to phases other than 5 while 6 is on. By programming the controller to call Phase 4 every time a call comes in from the detector for Phase 5, the Phase 5 vehicles will be accommodated. There is no problem with the controller progressing from Phase 6 to Phase 4. Phase 6 is on the major street, and Phase 4 is on a side street. The signal will cross a barrier when going from main to side streets, and an all-red will be displayed. Once in
Phase 4 green, the controller will recognize the waiting call on Phase 5 since there are no prohibitions to omit Phase 5 when Phase 4 is on.

Once in Phase 4 green, and assuming that there really were no vehicles waiting for Phase 4 green, the signal will hold the green display for the minimum green interval for Phase 4, and will then progress to a protected Phase 5 left-turn signal. This phasing sequence provided a safe haven for the permitted left to clear to all red before allowing a protected left-turn arrow to be displayed. When the Phase 5 protected left turn occurs before the permitted left turn in Phase 2 plus 6 it is called a leading left turn.

With all of the options available for signal phasing, it will be important to use the knowledge of a traffic engineer or technician to determine what is really going on in the cabinet.
4. TRAFFIC SIGNAL TIMING

Previous chapters have discussed the green, yellow, and red times, or intervals, for traffic signals. Discussion of how long those times are or how traffic engineers determine how long they should be is the subject of Chapter 4.

4.1 General Timing Considerations

The total time that a traffic signal controller takes to provide green, yellow, and red signal indications to all phases is called a cycle. In a pretimed signal controller, the cycle length is always the same from one cycle to the next since the controller only uses predetermined green, yellow, and red times. In an actuated controller, the cycle length can vary since the time spent on each phase is dependent upon traffic demands for more or less time.

Each cycle is further broken down into phases. A complete signal cycle for a simple two-phase intersection is shown in Figure 4.1.

Each phase is further broken down into intervals, the smallest denomination of signal timing. Intervals are designated as green, yellow, and red and indicate the time that each color is displayed. At some intersections the amount of green time is arbitrary, while at others the amount is determined by the traffic engineer using computer models and extensive traffic data collected and processed by standardized methods.

Figure 4.1 – Traffic Signal Cycle With Intervals
(Next Page)
Yellow and red interval values are calculated within specific design guidelines. Red and yellow times are often given much thought and debate. Not only do they involve lost time and thus lost efficiency, but they also dictate how long a driver has to change forward speed or risk a crash or citation.

4.2 Green Interval Timing

Traffic signals are typically installed because of a defined need for a new signal. As part of the pre-design study performed for an intersection, the local traffic engineer will often perform traffic counts at various hours of the day to determine turning movement volumes. Turning movement volumes represent how many vehicles per hour per lane are turning left, turning right, or going straight through the intersection from each approach.

Using the turning movement counts, the signals engineer will assign green time to each of the intersection approaches. For example, an intersection’s main street
northbound lanes have 600 vehicles per hour per lane, and the southbound lanes have 580 vehicles per hour per lane. The east-west side street approaches each have 200 vehicles per hour per lane. The engineer might decide to use a total green time at the intersection of 80 seconds and to apportion this time according to directional volumes. The engineer might then assign 20 seconds to the concurrent side streets and 60 seconds to the concurrent main streets. Because the main streets have three times the traffic volume of the side streets, the main streets receive three times as much green time.

While it is important to know what the green time is, accident investigators do not need to know how it was derived to perform their jobs.

A pretimed signal controller will time a green interval for each phase that never changes. During the day or at night, the pretimed green interval will typically remain the same.

Alternatively, actuated signal controllers have variable green durations that are limited by two values:

- Maximum green, sometimes called max green — An actuated controller responds to traffic demand and will extend the green interval to accommodate user demand. The max green setting in the controller is the upper limit of green time allowed for a particular phase if there is demand for another phase. Typically a controller will keep extending the green interval until the max green time limit is reached, and then the controller will allow another conflicting phase to operate despite continued demand on the original phase.

- Minimum green, sometimes called min green — When a phase receives a green signal indication, the min green timing parameter is the lower limit on how much green time will be provided regardless of user demand. Seven to 12 seconds of min green is often used.

A signal controller will, upon providing the start of the green interval for a particular phase, run the minimum green time while simultaneously searching for actuations, or calls, to that phase. Each actuation extends the green time a predetermined number of seconds until the max green is reached, at which point,
the controller will terminate the original phase and subsequently provide a green to the next phase. This is called *maxing out*. If no conflicting calls are holding and the signal is currently in green for the main street, the signal can be programmed to remain in green until a conflicting call is received. This is consistent with the engineer’s desire to keep main street traffic efficiently flowing unless the controller receives a call for another phase.

The actuated signal controller is constantly “watching” traffic and looking for vehicles moving toward the intersection on each approach. When watching traffic, controllers are designed to look at gaps, or the number of seconds between vehicles. Typical allowable gaps include three seconds between vehicles — meaning the time it takes for the rear bumper of the lead vehicle and the front bumper of the following vehicle to pass the same point. Gap time varies by agency and by geographic location.

Signal controllers can transition a phase from green to yellow when the green interval has *gapped out*. This occurs when the stream of traffic is no longer providing frequent enough vehicles to maintain the green interval. For example, if the signal controller receives a call from a vehicle on Phase 2, a timer clock in the controller will begin to time the gap until another Phase 2 call is received. If the engineer programmed a three-second-gap time for Phase 2 and another Phase 2 actuation is received before the three-second-gap timer expires, then the timer is reset and the green is held for Phase 2. This process continues until the Phase 2 vehicles are no longer traveling in an efficient line such that the gap between vehicles exceeds the three-second programmed gap time, and the gap timer expires before the next vehicle actuation.

Some signal controllers are capable of handling more than one max green time. For example, if an intersection has significantly different *directional volumes* on the inbound and outbound approaches in the morning and evening, the local traffic engineer may use a longer max green in the morning for the office-bound direction and a shorter one for the homebound direction. In the evening the engineer may reverse these max green times. To accomplish this, the engineer would program two different max greens for each affected phase and would also set time-of-day parameters for their use. An accident investigator might need to
ask if more than one max green is associated with the controller, and if so, which one was timing at the time of the accident.

### 4.3 Yellow Interval Timing

Traffic engineers refer to yellow intervals as the *yellow change interval*. Specific guidelines usually exist in each jurisdiction for calculating yellow times since yellow is usually expected to mean a driver needs to slow down and prepare to stop before the red signal.

Yellow change interval calculations take into consideration a normal deceleration rate of about 11 feet per second and a driver perception/reaction time of about 1.5 seconds. The yellow calculations also account for the *approach grade*. Since gravity causes downhill acceleration, more yellow time is allowed for a vehicle on a downhill, or negative grade, approach.

Some traffic signal agencies calculate standard yellow times for any given approach speed and/or grade and publish them in a table. For example, a flat 45 mph phase might use 4.0 seconds of yellow, and a flat 55 mph phase might use 5.1 seconds of yellow time. This method leads to consistency between intersections, and provides a consistent message to drivers passing through many intersections.

Other agencies prefer to calculate every yellow clearance time for every phase on every approach for every signal. This method provides custom yellow times for every intersection. It also provides the driver with consistent feelings of perceived deceleration at every intersection, but it does not provide consistent yellow times between intersections for drivers.

Understanding yellow change interval times is critical for the crash investigator. Many times, locating the vehicles in and around the intersection before the crash can be tied to yellow intervals. Yellow intervals are easily read on the signal controller screen. This is yet another instance where the local traffic engineer can help, in this case by downloading the yellow times to be used in accident
4.4 Red Interval Timing

The yellow change interval is intended to provide drivers with time to slow and to come to a stop at the intersection. In all jurisdictions of which we are aware, it is legal to enter an intersection on yellow but not on red. Thus a driver is allowed to enter the intersection at the last moment of a yellow interval before the red signal is displayed. Traffic engineers usually try to accommodate this legal driver as they proceed across the intersection by not providing a green signal to conflicting traffic until the clearing driver has sufficient time to move completely through the intersection.

In most jurisdictions the red clearance interval is calculated as some function of the distance from the stop line to the far side of the intersection, or the clearance distance a driver would navigate in going through the intersection. Typically this clearance distance is divided by the speed for the approach, and a clearance time is the resultant value. It is common to see red clearance intervals from 1 second to 3 seconds for typically sized intersections.

For example, consider an intersection where the northbound Phase 2 yellow is 4 seconds and the red interval is 2 seconds. As the Phase 2 green expires and the clearance intervals begin to time, conflicting phases have been sitting on red for some time. When Phase 2 receives a red signal, Phase 4 — a side street — has been in red and will remain in red until the Phase 2 red expires after 2 seconds. Then and only then will Phase 4 receive its green indication. As a result, the entire intersection is in red for a period — in this instance, it is timed for 2 seconds. This is called an all-red interval. Many agencies use this method. The all-red method forces all phases to sit on red for a short time while that one last driver who entered the intersection late, but legally, safely crosses through the intersection.

Returning to the previous example, by the time the Phase 4 driver starts forward — based on the all-red time and the start-up time to move forward — the Phase 2
driver is well past the far side of the intersection. It is because of this “extra clearance” from the start-up delay that some jurisdictions don’t use an all-red clearance time. In some locations, as soon as the Phase 2 driver receives a red signal, the Phase 4 driver receives a green indication. With the start-up delay, some locations trust the Phase 2 vehicle should be well through the intersection.

Some agencies say the practice of no all-red time promotes less wasted time at intersections. Other agencies favor an all-red for what they claim as increased safety. This option for signals to use or not use the all-red simply means that an accident investigator must consider the all-red possibility in assessing factors in the crash. Like the yellow interval times, it is easy to obtain the red times from the controller.

Most signal agencies maintain a logbook in their signal cabinets or some other form of recordkeeping back at their office. Every time a technician or engineer goes into the signal cabinet to maintain, repair, or change anything a written record is made of the visit, the date, and the purpose. It is always a good idea to review the logbook to look for any changes that might have had an impact on the operations of the controller or that may have occurred after a certain accident.

Also, a monitor in the signal cabinet can send the intersection into flashing mode if abnormal operation takes place. Agencies are expected to keep records of any need to reset flashing or repair out-of-service signals. If the agency has no record of the signal at the accident needing maintenance or repair on the date of the crash, it is customary to trust that the signal was operating as designed and constructed. It is accepted to assume that the yellow and red clearance intervals programmed into the controller were being used as programmed. This line of reasoning has been used in trials. We are not aware of any jurisdictions regularly disallowing analysis and testimony based on signal controller clearance timing values.

4.5 Pedestrian Interval Timing

Just as green, yellow, and red intervals are calculated for vehicular phases, pedestrian phase WALK and flashing DON’T WALK intervals are also calculated.
The pedestrian interval is intended to provide enough time for the pedestrian to move off the sidewalk and into the crosswalk. Agencies often use a fixed time for all intervals of approximately 7 seconds. In some situations, this interval may be lengthened to accommodate an expected large pedestrian volume leaving the sidewalk. For example, crossings between a university campus and a parking deck, or between a manufacturing facility and a block of lunchtime restaurants, might warrant a longer interval. The WALK interval should provide sufficient time so all the pedestrians in the large platoon will make it off the sidewalk and into the crosswalk during the display of the WALK indication.

Flashing DON’T WALK starts when the WALK interval expires. Flashing is provided to allow pedestrians in the crosswalk the time needed to reach the far side of the crosswalk. This exact distance may vary by agency. Flashing is typically calculated as a function of the length of the crosswalk and the expected pedestrian walking speed. Consider a 100-foot crossing distance and an expected walking speed of 4 feet per second. The calculated flashing interval would be 25 seconds (100 feet/4 feet per second = 25 seconds).

Sometimes the flashing interval might need to be longer for a given crossing distance. For example, a crosswalk between a hospital and a parking deck might regularly be used by patients with canes and other walking assistance devices on their way to physical therapy appointments. A walking speed of 2 or 3 feet per second may be more appropriate than a traditional 4 feet per second in this case.

The third pedestrian interval, the solid indication, is like the red light for pedestrians. The interval initiates when the flashing interval expires. It signals to the pedestrians that they should not be in the crosswalk.

Section 3.4 also discusses the pedestrian intervals in more detail.
5. VEHICLE AND PEDESTRIAN DETECTION

As discussed in Section 3.2, pretimed signals provide predetermined green, yellow, and red intervals for each vehicle or pedestrian phase at an intersection. The pretimed traffic signal controller provides the same green intervals regardless of the traffic volume on any intersection approach.

Actuated signals have the ability to detect traffic and to provide variable amounts of green time. As traffic volumes change, so does the green time allocated to each phase. An actuated signal, however, requires a method of detecting traffic to perform its functions.

The most common detection method for actuated traffic signals is a loop detector. A saw is used to cut a narrow slot in a rectangular, square, round, or diamond shape in the pavement just behind the stop line where vehicles would wait for a green signal. A piece of wire is pushed into the slot and wrapped around the slots several times to form a loop of wire in the pavement. The ends of the wire are connected to a lead-in wire that is connected to the signal cabinet. The saw cut, with the loop wire pushed down inside it, is then sealed with a weatherproof sealant.

When a vehicle drives over the in-pavement loop, the metal (not the weight) in the vehicle alters the electrical field created by the loop of wire. This altered field is sensed by components in the signal cabinet. This actuation is relayed to the controller as a “call.” In its simplest form, this is actuation. Figure 5.1 shows a newly installed loop detector.
The loop sealant is easily seen as a dark line of gray forming two rectangles. The loop, called a *quadrupole loop*, is unusual because it includes an extra lengthwise saw cut in the middle of the 6-foot by 40-foot rectangle. The loop wire is installed in the cut by wrapping it twice in a figure-eight pattern. This provides two layers of wire in the perimeter cuts and four in the center cut. This increases the sensitivity of the loop, making it easier to detect smaller vehicles that might not be located close enough to the wire to activate the call to the controller.

To better understand this form of detection, consider a simple two-phase signal with the major street running north south (Phase 2 plus 6) and the side streets operating east west (Phases 4 and 8). The signal will rest in Phase 2 plus 6 green all day and all night until a vehicle arrives on a loop on either Phase 4 or Phase 8 and places a call which conflicts with the green Phases 2 and 6. The signal controller is programmed to provide a yellow and red interval to Phases 2 and 6, and then progress to a green signal for Phases 4 and 8.

If we assume the loop is installed on Phase 4, when the waiting Phase 4 vehicle receives a green signal and moves forward, it no longer is altering the electrical field of the loop detector. The call on Phase 4 is dropped, and if there is not another call on Phase 4 or 8 within the gap time the controller times a yellow and red interval for Phase 4. This signal returns to green for Phases 2 and 6 and waits for another conflicting side street call. The local traffic engineer has designed and built a signal that recognizes traffic and responds in real time to varying traffic volumes.

### 5.1 Detector Delay

Some controllers are not programmed to immediately detect an arriving vehicle. For example, intersections with dedicated right-turn lanes for side street approaches do not always respond immediately to a vehicle activating detection on the loop.

Traffic engineers can program a *delay* between when a vehicle is detected by a loop detector and when the controller receives a call. In the example intersection
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with a dedicated right-turn lane, the traffic engineer can program a 15-second delay on the side street right-turn loop. When a vehicle arrives on the loop, a timer starts to count a 15-second delay. If the vehicle turns right on red during the 15-second delay, the loop will not call the controller and the controller never “sees” the vehicle. If the right-turning driver is unable to move and remains on the loop when the 15-second delay expires, the call is received by the signal controller and the side street green is requested.

Another common delay is a clipping delay, which is used on left-turn loop detectors. Figure 5.2 shows a main street left-turning truck driving over the left-turn loop for a side street. The continued presence of the long truck on the loop might inadvertently call up the side street phase.

A clipping delay provides a short delay of perhaps three seconds for the side street left-turn loop. This is used because the truck should have driven off the loop before the delay expires, making the truck “invisible” to the signal controller. This clipping delay prevents unwarranted calls for the unoccupied side street to be processed, and thus avoids interrupting main street traffic.

Programmed detector delays can impact the accident investigation and reconstruction processes. Identifying the basics of detection and delay — in other words, where vehicles were during an accident and what signals they could have received from the controller — makes sense when investigating accidents. Delays are used in many situations, and traffic engineers in each jurisdiction tend to have standard situations in which they use standard delay times. It is worth
talking with the local traffic engineer to understand how delays are used in local situations.

Key points about delays should be remembered during accident investigation and reconstruction:

- Delays are associated with the loop, not with the phase. For example, Phase 4, the minor street phase, might have three loops with one loop in each lane. A 15-second delay might be used on the right-turn loop, a 3-second delay might be programmed on the left-turn loop, and no delay might be programmed on the through lane loop. Phase 4 will be called from all of these loops, but after different waiting times.

- Loop detectors can fail, so during an accident investigation be sure to ask a signal technician or engineer to assist during the review of design plans and controller/detector settings, and actually observe traffic on the loop. Failed loop detectors often place a permanent call to the controller for service thus a green interval will be timed on every cycle.

### 5.2 Dilemma Zones

Traffic engineers understand that drivers presented with yellow signal indications at a certain distance from the stop line sometimes have trouble deciding if they should stop or move through the intersection. Traffic engineers call this distance from the stop line the *dilemma zone*. The dilemma zone is defined as the range of distance from a stop line where a driver is uncertain as to whether to slow and stop or to continue through the intersection.

There are near (downstream) and far (upstream) limits of dilemma zones for each approach speed. When determining detection loop locations, traffic engineers incorporate the desire that drivers should not receive a yellow signal when they are inside the dilemma zone. Figure 5.3 shows the distances from the stop line associated with dilemma zones for various speeds.
To limit the number of drivers being caught in the dilemma zone, it is common practice to locate an additional loop beyond the far end of the dilemma zone. When the signal controller senses a vehicle is entering the dilemma zone by this additional loop being activated, it will extend the green to allow the vehicle to get closer to the stop line before showing a yellow signal.

### 5.3 Detector Extension

A loop can be programmed to continue telling the signal controller that a vehicle remains on the loop even after it has left the loop. Called *detector or loop extension*, the loop continues to show a vehicle as being detected for a predetermined time after the rear bumper of the vehicle leaves the loop.

Figure 5.4 shows a car entering the near edge of the detection area provided by a 6-foot by 6-foot square loop placed 300 feet in advance of the stop line. If the car is 20-feet long and it is traveling 45 mph then it will take 0.4 seconds for the
rear bumper of the car to clear the far edge of the loop. During this time, the loop reports a call to the controller. In normal detector operation, often called \textit{presence mode}, the call is dropped after the vehicle leaves this detection area, or in this example, after 0.4 seconds.

![Detection Time Provided by Loop](image)

In extended detection, the call is maintained for a predetermined additional number of seconds after the car leaves the loop. This reduces the likelihood of a driver receiving a yellow signal while in the dilemma zone. This also reduces the likelihood of rear-end crashes and red light running.

The controller will continue to look for gaps between vehicles, holding the green signal until it maxes out or gaps out. Timing values for detector extension need to be considered when analyzing the gap allowed by the controller between vehicles.

### 5.4 Other Detection Methods

While the use of loop detectors with wire looped into saw cuts in the pavement is a traditional detection method and used in most jurisdictions, several alternative above-pavement detection methods can be found at intersections.

\textit{Video detection} is popular for select situations. In this method, a video camera is mounted on top of a signal pole or on a mast arm and aimed at the intersection. The image from the camera is displayed on a monitor or computer, where a
signal technician can use software to indicate an area on the video image that would be the same size and location as an in-pavement loop detector. When the video system senses a change in the pixels inside the designated area, it sends a message to the signal controller alerting it to the presence of a vehicle.

Another method is *microwave detection*, where a small box is mounted on a pole. This unit sends a microwave signal at an angle down to the pavement, covering an area similar to one or more adjacent traditional loops. When a vehicle enters the area covered by the microwave signal, the signal controller receives a call for service.

Key points to remember about non-loop detection methods include:

- The video and microwave systems are above-pavement systems and are used to approximate the area covered by a traditional in-pavement loop.
- The call received by the signal controller from the microwave or video system is no different than the signal from a loop detector.
- The specific detection system used should not make a difference in accident reconstruction unless there is reason to believe that it is not functioning. In this case, the situation may be treated just as a faulty loop would be treated.
6. SIGNAL PREEMPTION

Certain circumstances make it necessary to override, or preempt, the normal traffic signal operations at the intersection. While traffic should flow efficiently at all times, emergency vehicles or railroad trains or boats sometimes require a higher priority than normal pedestrian and vehicular traffic.

Traffic signals can be designed to recognize specific priority intersection users and to preempt the signals accordingly. Crashes can occur at preempted intersections, so investigators need to understand how preemptions work.

6.1 Emergency Vehicle Preemption

Many fire stations or rescue squad buildings have a \textit{preemption pushbutton} on the wall near the entrance to the truck bays. The drivers are trained to press the button as they run to their trucks when they respond to an emergency call. The button is wired to a nearby traffic signal, and pressing the button activates the signal’s programmed preemption mode.

Figure 6.1 shows a fire station east of an intersection and a fire truck approaching the intersection from the east.
When the signal controller receives a preemption call, it is programmed to terminate all normally operating green intervals for approaches in conflict with the preempted approach, and provide a yellow and red clearance interval to those terminated phases. The controller will then provide a green interval to the preempting approach — in this case, the westbound approach. Any vehicles remaining on the preempting westbound approach will receive a green signal and can safely travel away from the intersection, clearing a path for the approaching fire truck.

In this example the preempted signal controller:

- Knew which approach the emergency vehicle was arriving on
- Stopped all vehicles and pedestrians on conflicting paths with the approaching fire truck
Cleared all vehicles in front of the fire truck from the intersection
Provided a clear intersection for the fire truck

A phasing diagram for this example is shown in Figure 6.2.

![Diagram](image)

**Figure 6.2 – Preemption Phasing Diagram**

The phasing diagram shows a typical two-phase signal with the major street traffic on Phases 2 and 6 running northbound and southbound. Minor street traffic (Phases 4 and 8) operates in an eastbound-westbound manner. The pathways between Phase 2 plus 6 and Phase 4 plus 8 are shown with solid lines between the phase combination circles. Each of these phase combinations can exit to the emergency preemption phase as shown by the dashed lines. Once either of the normal phase combinations of 4 plus 8 or 2 plus 6 go through their
yellow and red clearance intervals then the actual preemption phase, or in this example, Phase 8, would turn green.

In the case of the pushbutton preemption, the signal controller holds the preemption phase green for some predetermined time. This is known as the *preempt dwell green* time. In this case, assume that a 4.0 second yellow is used to terminate all normal phases, and a 1.5 second red is used. Also assume that the local traffic engineer and the rescue drivers have timed how long it takes from the time the button is pushed to the arrival of the vehicle at the intersection to be approximately 35 seconds. In this instance, the traffic engineer prefers for signals to show 1.0 second of a normal phase green before going into a preempt phase.

Based on these parameters, the following sequence of events takes place:

- The driver pushes the button
- If the signal just went into Phase 2 plus 6, it will run for 1.0 second (elapsed time = 1.0 second)
- Phases 2 and 6 green will terminate and yellow will be displayed for 4.0 seconds (elapsed time = 5.0 second)
- Phases 2 and 6 yellow will end and red will be displayed for 1.5 seconds (elapsed time = 6.5 seconds)
- Phase 8, the emergency preempt phase, will turn green
- If four vehicles are stopped on Phase 8, they will receive a green signal and move forward. According to *Greenshield’s formula*, this time is equal to 4.0 seconds plus 2.0 seconds for each vehicle, so the time to get the queue of 4 vehicles moving is approximately 12 seconds (elapsed time = 18.5 seconds)

Subtracting the 18.5 seconds from the 35 seconds needed to get the vehicle from the station to the intersection leaves 16 seconds for any traffic to clear the intersection and pull off to the side to provide the fire truck with a clear passage. The traffic engineer will select a green time for the preempt phase, Phase 8, to dwell that is typically longer than 16 seconds to accommodate unforeseen impedances.
Once the preemption phase has run through the programmed green dwell time, it will terminate with yellow and red clearance intervals just like any other phase. The phasing diagram shows the signal will then progress to Phase 2 plus 6. This exit phase used for preemptions is determined at the traffic engineer’s discretion. In Figure 6.2, the engineer determined that Phases 2 and 6 are likely to have the most accumulated traffic since they are the main street phases. This means investigators need to remember to check the signal timing design to determine any preemption or exit phases.

### 6.2 Optional Preemption Features

In the previous example, there may be a concern for southbound Phase 6 traffic turning right on red during the preempt phase. A Phase 6 driver might see no westbound vehicles approaching on Phase 8 after the initial queue has cleared on preempt dwell green. This same driver might not see or hear the fire truck approaching and might turn in front of the fire truck, causing the fire truck driver to make a panic stop and then follow the slow-moving Phase 6 vehicle on the westbound intersection departure.

This scenario can be prevented by installing a blank-out sign next to the southbound Phase 6 signal heads that would read “NO RIGHT TURN.” Shown in Figure 6.3, the blank-out sign will remain dark until the preemption is active. In the photo example, the sign would be illuminated with a “NO LEFT TURN” message.

Over time some municipalities have developed “fire runs” along major streets likely to be traveled by
vehicles exiting the local station houses. The pushbutton not only preempts the signal controller close to the station, but also sets into motion a series of preemptions along the major street. The preemptions at each successive intersection to be cleared by the emergency vehicle are timed to start a specific number of seconds after each other. The fire truck driver would see a series of green signals unroll in front of his truck. Although the preemption at any given intersection operates the same as any other preemption, you should consult with the local traffic engineer if a question arises as to your signal’s preemption coordination with an adjacent preempted signalized intersection.

6.3 Actuated Preemption

The next level of emergency vehicle preemption involves a signalized intersection that can be preempted for emergency vehicles without any pushbuttons.

Many modern emergency vehicle preempted signal controllers are activated by a signal emitted from the emergency vehicle. A detector at the intersection senses the approaching sound or light signal from the emergency vehicle and sends the traffic signal controller into preemption. One type of commonly seen detector is shown on a signal head span wire in Figure 6.4. Preemption detection can be installed for one, several, or all intersection approaches.

Figure 6.4 – Optical Detection Device for Emergency Vehicle Preemption
The dwell time of the preemptive green activated by the pushbutton described in Section 6.1 was a predetermined length. With actuated preemption, such as with an optical detector, the green time may have a minimum length of 3 to 5 seconds. As long as the receiver is picking up an actuation from an approaching vehicle, the signal controller will hold the preempt dwell green beyond the minimum dwell green. If the approaching fire truck is delayed in heavy traffic, the dwell green will continue to hold the signal in green in order to clear the traffic ahead of the truck. Many agencies also extend the dwell green about 2 to 3 seconds after the actuation signal from the emergency vehicle is dropped. This accounts for the vertical height difference between the sending unit on top of the emergency vehicle and the detector located on a signal span wire or signal mastarm. As the vehicle approaches the intersection, its preemption signal projects toward the next signal. The preemptive green dwell is extended to provide just enough time for the emergency vehicle to pass under the receiver and travel a short distance beyond the intersection before the dwell green terminates.

If investigating an accident at an intersection where it is questioned if the emergency driver might have received a green preempt signal, the sending device on the emergency vehicle as well as the receiving device for the vehicle’s approach should be checked for:

- Actual send and receive capability
- Distance at which signal is received and recognized
- Sight line obstructions if an optical device is used; overgrown trees can block a signal

As seen in Figure 6.5 on the following page, the phasing diagram for a multi-phase signal with preemption on many approaches is not much different than our previous example.
In Figure 6.5, normal paths between the normal phases are illustrated by the solid lines. The dashed lines define the paths taken from normal phase combinations into preemption phases. The dashed line also shows paths taken from one
preemption phase to another. It is not uncommon for an intersection near a fire scene or traffic accident to receive emergency vehicles arriving from many approaches within a few minutes of each other. In such an instance, the signal controller would step from one preemption phase to another on a first-come-first-served basis before returning to normal operation.

6.4 Transit Priority

To encourage motorists to make use of public bus transportation, some agencies have used technology similar to emergency vehicle preemption for approaching busses. The bus passengers receive an express ride as traffic at signals downstream of the bus clears out ahead of the approaching bus. Keep in mind this type of transit preemption is a possibility when investigating accidents.

6.5 Railroad Preemption

Federal guidelines detail how vehicular and pedestrian traffic signals near railroads should be coordinated with the intersection of the local street and the railroad track, called a grade crossing, since the two facilities intersect at the same grade or height. Almost every minor street running perpendicular to or at an angle to a major street that is parallel to a railroad will have both a signalized intersection with the major street and a grade crossing with the rail line. Federal guidelines recommend that signalized intersections within 200 feet of a railroad grade crossing with active devices such as flashers and/or gates be interconnected with the rail intersection. State or local agencies might have more stringent requirements. The local traffic engineer should be able to explain what requirements or guidelines apply in the accident jurisdiction.

Traffic signal railroad preemptions work in a manner that is similar to emergency vehicle preemptions with a few exceptions. A call or actuation from the approaching train is relayed to the traffic signal controller via the railroad crossing equipment. This puts the preemption sequence into operation. The immediate priority is to clear any vehicles stopped between the traffic signal and
the grade crossing to make sure that they move off of the tracks before the train arrives. As seen in Figure 6.6, the vehicles north of the train tracks will be trapped between the flowing traffic on Phases 2 and 6 and the railroad crossing gate closing behind them if the signal were in red for Phase 8.

The activities at the railroad grade crossing and at the preempted traffic signal are coordinated with each other and typically occur in this order:

- Rail crossing flashing lights and bells are activated
- Vehicular and pedestrian phases that are in conflict with Phase 8 are terminated with yellow and red clearance intervals
- A\textit{ track clearance phase} is initiated to clear vehicles from the space between the intersection and the tracks and from the tracks themselves
- Rail crossing gates are lowered
- \textit{Railroad preemption phases} are initiated; phases transition to other phases that do not conflict with the grade crossing
- Train clears grade crossing
- Rail gates rise and bells and lights stop flashing and ringing
- Traffic signal resumes normal operation

Rail preemptions sometimes last a considerable time while long and/or slow moving trains travel through the grade crossings. Traffic signal controllers at most rail-preempted intersections are designed to run a limited inventory of their normal phases grouped together in rail preempt phases. The signal controller is programmed to not progress to phases in conflict with the train, and to cycle back and forth between the phases that have no conflict. Like other types of preemptions, the rail preempt phases typically terminate and exit to the main street phase to relieve standing traffic. Of course, the controller can be programmed to exit to any normal phase.
7. SIGNAL SYSTEMS

How many times have you started driving forward from one signalized intersection upon receiving a green signal, and you look ahead to the next traffic signal and see it turn red? The cost, in terms of economic loss, driver delay, and driver frustration from traffic signals that are not coordinated with one another is significant. Traffic signals along one street can be coordinated, or timed, to run in concert with each other. This keeps traffic flowing without constant stop-and-go conditions.

7.1 Simple Main Street Coordinated Signals

Assume that the distance between two signalized intersections on the same street is 510 feet, and the posted and observed speed limit is 35 mph. If a vehicle passes through the first signal at the posted speed of 35 mph, or 51 feet per second, then it will take ten seconds for the vehicle to reach the second intersection.

Also assume the local traffic engineer programs the signal controller at the second signalized intersection to start its main street green interval ten seconds after the first signal controller. This allows a driver leaving the first intersection on a green signal indication to see the red signal at the second intersection turn to green as he or she approaches the second intersection, allowing the approaching vehicle to move through the second intersection without interruption.

In its simplest form, this illustrates the coordination of a signal system. Each signal controller along a street is coordinated with the adjacent signal controllers to meet an established timeline. This keeps traffic flowing along major highways or corridors, as long as the signal controllers do not drop out of synchronization with the other controllers. When signal controllers are not electrically connected
to each other, they have no real idea of how they are running with respect to the other signals in the system.

To address concerns with traffic signal controllers dropping out of coordination with a larger signal system, some agencies electrically connect the signal controllers. Copper wire and fiber optic cable are two of the most common methods used to electrically interconnect traffic signal controllers. Once interconnected, the signal controllers typically remain in coordination with each other with little concern.

Most modern interconnected signal systems are monitored by a central computer at a traffic control center. The computer can be used by the traffic engineer or the signal system manager to “see” what individual intersections are doing. If necessary, the engineer or manager can remotely alter signal phase and timing parameters.

The central computer in a signal system might contain several different coordinated timing plans, or time-of-day plans. These timing plans are assigned to local signal controllers for use during different time periods of the day, and for different days of the week. Special timing plans might exist for holidays, weekdays, weekends, special events, or seasonal traffic — often used in a beach or ski community. Large traffic generators, such as sports and concert venues, might have special timing plans for the streets leading to and from the venues.

To illustrate time-of-day plans, consider a town with a large industrial and office development on its north side and the majority of the residential development located on its south side. In the morning rush hour, the heaviest traffic flow would be from the southern bedroom community to the northern workplaces. In the evening rush hour, the heaviest traffic flow would occur in reverse — from north to south. These rush hours are also referred to as peak hours, with a differentiation between AM peak hours and PM peak hours. The local traffic engineer would coordinate the signals along the main street, referred to here as North-South Boulevard, to allow traffic to quickly progress northbound in the AM peak hour.
Each traffic signal controller along North-South Boulevard (NSB) would be programmed to have the same cycle length. If one intersection uses a 100 second cycle, then the adjacent signal controllers would also use a 100 second cycle. The central computer in the traffic agency office would ensure that each traffic signal controller along NSB initiated its own Phase 2 (northbound) green at the right time to keep the platoon, or group, of vehicles progressing northward toward the offices and factories.

In the PM peak hour, the central signal system computer would issue a command to the individual signal controllers to ensure that the southbound main street phase is now the coordinated phase. As each individual signal controller starts its southbound green interval at the right time, the platoon of vehicles would head south toward home at the end of the day without delays from red traffic signals.

7.2 Conflicting Phases within Signal Systems — Actuated Signals

In the ideal commuter world, a main street signal would never turn red. In reality, however, most drivers must stop for a red signal even in a coordinated system. Side street vehicles need to receive some green time, and pedestrians need to cross main streets in safety.

As a predetermined end of the green interval for the main street traffic is about to expire, the traffic signal controller checks to see if there are calls for conflicting phases waiting to be serviced. Waiting phases might be vehicular or pedestrian in nature. The signal controller will service the waiting phases in a typical NEMA phase sequence until each phase gaps or maxes out. After the conflicting pedestrian and vehicle phases are serviced, the signal controller returns to its coordinated operation to serve the waiting main street vehicle platoon.

Assume that a signal controller on a 60-second cycle operates with 30 seconds of main street green time (this is too low for typical signals, but is used here for simplicity), 4 seconds of Main Street yellow, and 2 seconds of Main street all red. This cycle is shown in Figure 7.1.
If the signal controller operates on a 60-second cycle, then 24 seconds remain for all phases that conflict with the main street phase. These 24 seconds are the total time allocated for all conflicting (i.e., the phases which cannot run at the same time as main street green) green, yellow, and red intervals.

Imagine that the main street coordinated green interval is about to expire when the controller receives a call on the westbound side street, Phase 8. One car is waiting to cross the main street. When the main street green interval reaches 30 seconds, it expires and the subsequent main street yellow and red intervals are timed. Then the Phase 8 driver would receive a green signal. The Phase 8 vehicle moves forward, leaving the loop detector located at the westbound stop line. According to Greenshield’s formula, it should take approximately 4 seconds for this driver to start to move forward. At normal acceleration rates, the Phase 8 vehicle would clear the loop approximately 3 seconds after the vehicle starts to move forward (length of car = 20 feet, and acceleration = 5 feet per second squared). If the extend time programmed in the signal controller for Phase 8 is 2 seconds, then the total time from initiation of the Phase 8 green to its...
termination is 9 seconds: 4+3+2. The signal controller now times yellow and red intervals for Phase 8 for an additional 4 and 2 seconds. Since no more calls are holding which would conflict with the main street phases (Phase 2 plus 6), the signal controller would return to the main street green and will rest in main street green. This cycle is illustrated in Figure 7.2.

The total time the signal controller spent out of Main Street green was 6 seconds for the main street clearance intervals, 9 seconds of Side Street green, and then 6 seconds for the side street clearance intervals — a total time of 21 seconds. Out of the 60 seconds total cycle, the signal controller provided 39 seconds of main street green time: 60-21 = 39.

Consider an intersection in a coordinated signal system with no conflicting calls holding when the main street coordinated green interval is about to expire. Typically a traffic signal controller in this situation will remain in the main street phase green in the absence of conflicting calls. In this situation, the signal controller will provide 60 seconds of green time for main street traffic. This example is shown in Figure 7.3.
7.3 Conflicting Phases within Signal Systems – Pretimed Signals

In the first example in Section 7.2, the intersection had vehicle or pedestrian detection, so vehicles and pedestrians placed calls to the controller to receive the green. In some signal systems, the individual or local signal controllers are non-actuated and are not able to sense traffic waiting to receive a green signal. These non-actuated signal controllers are programmed to allocate a certain amount of green time for one phase, a certain amount for another phase until all phases present at that particular intersection have received a green interval. Each phase at a pretimed signalized intersection receives some green time regardless of the presence or number of vehicles approaching on that phase.
When a pretimed signal controller is part of a signal system, the controller is not able to determine if calls are holding as the main street coordinated phase nears the end of its green interval. During each cycle through all the programmed phases, the main street traffic will receive yellow and red clearance intervals, and then the conflicting vehicle and pedestrian phases will receive their greens.

Assume that the local traffic engineer has determined that the northbound Phase 5 queue of vehicles in the AM peak hour is always long. To address this, the central signal system computer is programmed to tell the local intersection signal controller in the AM peak hour to always transition into Phase 2 plus 5 before going into Phases 2 and 6, the typical main street coordinated phases. By running this protected main street left turn concurrently with the northbound through and right movements, the traffic engineer reduces the possibility that the northbound left turns will back up into the adjacent northbound through lane, as well as the chance of a northbound rear-end crash. With a signal system and a central computer, the traffic engineer can easily program Phase 2 plus 5 to operate in every cycle in the AM peak hour regardless of actuations. The engineer is acting on the assumption that the lane will fill to capacity. This is also called a saturated left-turn lane.

Consider that the local signal controller at this intersection has a loop in the northbound left-turn lane, or Phase 5. An actuated intersection will normally respond to calls on every phase. In the interest of the special northbound left-turn queuing problem, however, the traffic engineer would temporarily remove the local controller’s ability to address Phase 5 actuations and would program a mandatory 2 plus 5.

### 7.4 Local Signal Controllers: On- or Off-Line

A coordinated signal system is intended to provide a correctly timed sequence of green signal intervals along a road to expedite smooth traffic flow. Coordinating signal systems can make sense when traffic volumes are high such as in the AM or PM peak hour, or possibly at other peak hours such as on weekends near a
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tourist attraction. During non-peak periods, however, such as from 11:00 PM to 5:00 AM, it might not make sense to cause side street drivers to wait for a long main street green interval governed by the central signal system

Many traffic agencies allow the local controller within a signal system to operate in a free mode during non-peak time periods. This means that signals that sometimes operate in a coordinated program will respond to calls as they receive them, or will simply run on their own cycles. You might also hear some traffic engineers and technicians refer to free operation as the signal being off-line, or disconnected from the system’s central computer.

7.5 How Do Signal Systems Affect an Accident Investigation?

Signal systems are key to effective investigation and reconstruction of accidents, since they provide many variables that might impact the final determination of cause and responsibility.

Consider that a crash has occurred on Big Commuter Highway. According to the responding officer’s report, the crash occurred at 7:24 AM, and you are called to this crash at 7:45 AM.

During your investigation that morning, you observe that this intersection is signalized and operates with two phases: the main streets run together and the side streets run together. You watch the signal through several cycles, timing the main street green interval at 65 seconds and the side street green interval at anywhere between 7 and 23 seconds, based on the number of cars on the side street waiting for a green. During a previous investigation, you were told that all the signals along this stretch of Big Commuter Highway are on a signal system.

It would be wrong, however, to conclude that the main street coordinated phase is receiving at least 65 seconds of green time and that the side street is receiving however much green time the actuations call for, and that those were the conditions at the time of the crash. Further investigation of the timing plans is warranted.
It is possible that the signal system uses more than one time-of-day plan. Signal systems sometimes change from one plan to another throughout the course of the day. It is common for plan changes to take place before or after the peak hours to accommodate large, and often unidirectional, traffic volumes. In the case of this accident example, the investigator should meet with the local traffic engineer or the local signal system manager to learn more about what main street green time was being used at the time of the crash.

An accident investigator might find an actuated signal in a signal system during the investigation, or a pretimed signal controller might be discovered. The investigation might uncover an actuated local controller that has, during system operation, some of its phases being governed by the system timing plans and not by actual traffic volumes on the street.

Investigating crashes at a signal that is in a coordinated system requires an investigator to consider an additional layer of data. The local signal controller still has phases with green, yellow, and red intervals just like any other signal controller at any other intersection. The investigator needs to be aware that the timing values for the green intervals programmed into the local controller might not be the actual green times that were used at the time of the crash. Communications with the signal systems staff should yield the needed second layer of data to effectively analyze the conditions at the time of the accident.

One other important factor for the investigator to bear in mind about signal systems is that many smaller systems are used on streets. Rather than centrally controlled signal systems operating on long stretches of municipal highway to accommodate large urban traffic volumes, small closed loop signal systems are sometimes in place. Two common locations for signalized intersections that are connected to each other include:

- **Along secondary roads where the secondary road is part of a grade separated interchange with an Interstate-type highway.** Two or more closely spaced signalized intersections are often located on a secondary road and a pair of Interstate ramps. Service roads, truck stops, and shopping centers are commonly located across from the ramps, attracting Interstate
traffic. With two or more closely spaced signalized intersections, it is critical to coordinate through and turning phases. A small coordinated signal system helps congestion in this situation.

- **In small towns where several US or state routes converge.** In small towns near or at tourist attractions such as beaches or ski slopes, it can be helpful to coordinate the downtown intersections, even if the number of intersections is small. When traffic from several moderate volume roadways converges into a downtown area with only a few traffic signals, local signal controllers being placed in a signal system can expedite traffic flow through the small town.

It is important to remember that unless the signal of interest is an *isolated* traffic signal nowhere near any other signals, the investigator needs to ask the local traffic engineer if the signal controller is part of a signal system. The manner in which this system is coordinated will impact the results of an accident analysis.
8. VIDEO DETECTION AT SIGNALS

The technology of video camera systems is being used more often at traffic signal intersections. Traditional methods of detecting vehicles like in-pavement loop detectors might not be feasible in some situations, leaving video detection as a better detection method.

Four uses are typical for video cameras at or near signalized intersections:

- Isolated signal controller detection
- Temporary traffic signal detection
- Red light running cameras
- Video monitoring of traffic

8.1 Isolated Signal Controller Detection

Video cameras may be used as an alternative to traditional loops. Several cameras are typically mounted high on the signal poles or on short mast arms attached to the poles, as shown in Figure 8.1. The cameras can record one or more intersection approaches, depending on their orientation. The video signal travels from the cameras to a processing unit in the signal cabinet, and the live image from the camera can be viewed on a small monitor in the cabinet.
As described in Section 5.4, a signal technician can outline on the monitor screen a detection area or zone on the image of the pavement in the same location where a traditional loop would be located. The video processing software is designed to sense changes in the video pixels within this drawn box. When a vehicle enters the video detection zone, the video processor senses that the pixels have changed and it then forwards a signal to the local traffic signal controller that an actuation has taken place on some particular phase.

The local signal controller, when coupled to a video detection system, receives calls from vehicles just like it would with traditional loop detectors. The signal controller is unaware of the source of the detection; it simply receives a call from some source that a vehicle is on or has just passed over a loop or zone.

### 8.2 Temporary Traffic Signal Detection

During roadway construction projects, such as widening to add more lanes, it often becomes necessary to reroute traffic through existing signalized intersections. Consider a typical scenario where the old existing north-south roadway is constantly packed with traffic. The county decides to add two more lanes to the two existing northbound lanes to accommodate more traffic. The roadway engineer plans for one new lane to be constructed in the grass median currently separating the northbound and southbound lanes, and for the second new lane to be added along the eastern edge of the existing pavement. The maintenance of traffic plans call for the new lane in the median to be built first and to be opened to traffic as soon as possible.

As construction begins and earthmoving equipment starts to push dirt along the eastern side of the existing lanes, the lead-in wires from the existing in-pavement loops will likely be cut by the equipment, rendering the loops inoperable. Installing temporary loops, at an expensive cost, with lead-in to the west side of the roadway is not feasible since construction is underway there as well.

Installing a video detection system at this intersection just before the roadway project begins will make this traffic signal less likely to encounter disruption to
its detection capabilities. As traffic is rerouted onto new lanes, the signal technician can easily draw new detection zones on the video monitor in the signal cabinet to detect traffic in the new lanes. This can be done without disruption to traffic, and with much greater worker safety than sending a crew into traffic to install loops.

8.3 Red Light Running Cameras

It is undeniable that red light running contributes to intersection crashes. Many traffic agencies now use automated video systems to catch drivers as they violate red lights. Most red light camera systems use traditional loop detection to identify an offender running a red light, and then use a camera with a telephoto lens to photograph the offending vehicle’s license plate.

A typical red light camera system includes a series of small in-pavement loops installed near the stop line. The signal from these loops is monitored by a processor either in the traffic signal cabinet or in another cabinet, which is connected to the traditional signal cabinet with conduit and wiring. An example of a series of red light loops is shown in Figure 8.2, and a red light camera is shown in Figure 8.3.
Red light cameras are often in a tamper-resistant housing, and, as shown in Figure 8.3, may include an auxiliary strobe light to illuminate the offending vehicle at night.

The red light running processor senses a vehicle in motion over the loops. When this motion is concurrent with a red signal interval on the monitored phase, the red light system declares a violation situation. Systems differ slightly, but many will capture one photo of the offending vehicle across the stop line with the red signal displayed and one photo with a close-up of the license tag on the vehicle. Both photos are mailed to the registered owner of the offending vehicle and a civil penalty or fine is demanded. Some systems even capture and print on the photos the length of time that the signal had been in the red interval when the vehicle triggered the red light system, as well as the speed of the vehicle. As the offending vehicle passes over the series of detection loops, each loop acquires and then subsequently drops the presence call from the vehicle. The system is programmed to calculate, based on the rate of acquisition and drop, the vehicle’s speed.

Investigators should be aware that red light cameras might be owned by a local or state agency, but they might be operated under contract by a private firm. Many traffic agencies contract services to outside vendors for red light system management and maintenance. A conversation with the local traffic engineer should identify the correct party from whom red light photos and data may be obtained.
8.4 Video Monitoring of Traffic

With several video-monitoring cameras mounted on tall poles or atop tall buildings in strategic locations, such as in Figure 8.4, traffic-engineering staff is able to monitor incidents that impact traffic, such as crashes or blocked intersections. They are able to make adjustments to surrounding traffic signals and message signs to accommodate any immediate traffic issues. Some traffic agencies now allow their camera signals to be rebroadcast by local media sources such as television stations and websites to allow commuters an opportunity to check traffic conditions.

The video images captured by these cameras might be recorded. One agency that does not record camera images explained that this practice prevents their staff from being subpoenaed to testify in accident cases on a regular basis, and thus leaving them short staffed. You will want to check to see if video cameras are used in the area of the accident you are investigating and determine if recorded images are available.

Figure 8.4 – Traffic Monitoring Video Camera
9. TRAFFIC SIGNAL AGENCIES AND STAFF

Throughout this text, crash investigators have been encouraged to initiate and maintain a working relationship with the local traffic engineer. Information about traffic signals in the area can be invaluable during investigations, and might turn out to be key in solving a tough case.

In addition to local practices, it is helpful to be aware of statewide practices. Most states tend to have traffic signal ownership and maintenance divided between several agencies. In some states, the traffic signals along state-owned roads and along U.S. highways are owned and maintained by the state’s Department of Transportation (DOT). Traffic signals inside major municipal areas are often owned and maintained by the city’s or county’s DOT, while signals in smaller towns are typically owned by the state DOT and maintained by the state or under contract to the small town or contractor.

State DOT’s are often divided into districts or divisions. Each district or division might encompass several counties. Typically, a Division or District Traffic Engineer oversees all traffic-related activities in the division, including traffic signals. The Division Traffic Engineer might report to the Division Chief Engineer or to the Division Operations Engineer.

The Division or District Traffic Engineer might supervise one or more Assistant Traffic Engineers. These assistants might each handle all traffic issues for one county or other geographic area, including overseeing congestion management, new development, traffic signals, or signing. Only one engineer, however, will typically be responsible for the traffic signal that controls traffic at a particular intersection.

The traffic signals staff extends beyond the traffic engineer’s office to include traffic signal technicians and possibly a signal system manager. Signal technicians can be a valuable resource to crash investigators. Technicians might
work in a shop repairing signal equipment, or in the field installing and maintaining signals. They typically know the phasing, timing, and intricacies of each signal for which they are responsible. They usually know exactly when a signal was out of service, when it was repaired and by whom, and when parts such as a monitor or controller were changed due to problematic operations or maintenance.

If the jurisdiction has one or more centralized signal systems, there is often an individual who manages these systems and the signal system control center. This person may be a traffic engineer or may work for the traffic engineer.

What is detailed on the traffic signal plans might not be what is found in the field. As much as signal agencies try to design and prepare plans for signal installations in a comprehensive manner, many installations differ from the design plans. This can be due to equipment constraints or modifications that occur over time as traffic conditions dictate the changes. Asking a signal technician or a signal system manager to explain the actual signal operations at an intersection might reveal differences in what the original design plans show from how the signal operates.

Many traffic agencies maintain websites with useful organizational information and contact information. Beginning with a search for the state DOT’s website and then searching the DOT structure for traffic groups can provide valuable information regarding who is responsible for traffic signals at a particular intersection. City or county websites also list municipal or county traffic agencies.

When investigating an accident, it is most helpful to first contact the traffic engineer’s office. Because the engineer has likely been educated in liability issues, it might be necessary to explain your role in the accident investigation. Consider asking general questions and assuring them that you are not pointing fingers at them or their traffic signal. As mentioned previously, having an existing relationship with the engineer will help establish an understanding of your questions and your intentions.
10. ACCIDENT RECONSTRUCTION AT TRAFFIC SIGNALS

An investigator’s time spent reconstructing a crash at a signalized intersection is likely to be allocated similar to the distribution shown in Figure 10.1.

![Figure 10.1 – Time Spent Reconstructing an Accident at a Signalized Intersection](image)

The time spent forming conclusions is a small part of the total reconstructive effort. Time spent crunching numbers and performing analysis is more significant than the amount of time devoted to honing conclusions. The vast majority of time and energy expended during a reconstruction, however, is spent long before the investigator ever receives the assignment. The bulk of the time is spent learning about and understanding how traffic signals function.

The material in this chapter is intended to be a “how-to” guide. It outlines several typical reconstruction methods. Each topic refers to relevant discussions in previous chapters so the reader may go back and review more material on
specific issues to strengthen an understanding of the traffic signal concepts used in the crash analysis.

The reconstruction examples in Chapter 10 are not all-inclusive. Each example case is detailed sufficiently in select technical areas to illustrate specific traffic signal and reconstruction concepts, and to enhance the basic information presented in previous chapters. In almost all of the examples, some of the field data, important analysis, and the resultant concepts have been omitted. While an astute investigator needs to pursue these factors during a real crash case, that level of detail typically does not add information to the example scenario. The case study in Chapter 11, however, will develop details in all aspects of the crash investigation including, but not limited, to traffic signals.

10.1 In What Phase Was the Signal?

Traffic signals are either on or off, and if they are on then they must be in either flashing mode or in one of the pre-programmed phases. Based on driver and witness statements, the investigator can usually eliminate the possibility of the signal being in flashing mode or being off. Determining which phase the signal was in, however, just before the crash and during the crash can be elusive. Knowing what phase the signal was in or was about to go into is often a defining point in the accident analysis. With knowledge of the phasing and timing parameters programmed in the signal controller, an investigator can create a timeline by which events preceding the crash can be tied down to a specific point in time.

Carefully gathering witness and driver statements about traffic conditions is often critical in determining which phase the traffic signal was operating in. Questions to ask drivers, passengers in the involved vehicles, and non-involved witnesses include:

- On which intersection approaches were you traveling/stopped just before the crash?
- Which lane were you in just before the crash? If a pedestrian, where were you with respect to the roadway?

- Could you see the traffic signal heads for your direction of travel?

- What color signal indications did you see as you moved toward the intersection (or from your stopped position)?

- If you saw a green signal indication (or yellow, or red), had it been that color for a long time or did you see it change to that color? Since people are not always accurate when estimating time, consider asking questions that don’t elicit exact time responses: Was the green signal a “stale green” or a “fresh green”?

- Did you see the signal change to another color as you approached the intersection or sat in traffic waiting?

- Can you identify a landmark that defines the point at which you saw a particular signal color? (A response might be, “I was next to the animal hospital when I saw the signal turn yellow.”)

- How many vehicles did you see queued in any lane?

- How many seconds were the vehicles queued in the lanes?

- Did the traffic signal seem to be working?

- Did you see any driver run a red light or turn from a lane not designated for turns?

- Did you see a driver enter the intersection at the end of a yellow interval?

- Could you see the signal indications for any other intersection approach than the one you were on? (If the witness could see another approach’s signal faces, the investigator should repeat the same questions for that approach.)

Traffic signal controllers assign green to one or more phases at a time. Other conflicting phases must wait while the phases with the current green time are served. As drivers wait to receive a green signal indication, they form queues. These queues of traffic are excellent indicators of what phase the signal is not operating in. The investigator needs to keep in mind that most drivers at a signalized intersection crash are potential witnesses, even if stopped on red or
looking away from the crash. Their presence in a queue is excellent evidence of possible phases of signal operation.

After gathering and reviewing witness statements about traffic and signal conditions, and making field observations, the investigator should use the knowledge of the local signal engineer and technician. Sketching a phasing diagram for the crash intersection can be helpful at this time. Information gathered from the field and from interviews needs to include:

- What are all of the vehicle and pedestrian phase combinations (use circles to group combinations or single phases as shown in Chapter 3)?
- What are the lanes and movements that have a green signal indication (indicate in the phase circles)?
- Are the left turns protected?
- Are the left turns permitted?
- Are the left turns protected/permitted?
- Are split side streets used?
- Using lines between the phase circles sketch, how does the signal controller move from one phase combination to another?
- Is this intersection programmed for any signal preemptions? (If so, include them in the phasing diagram, perhaps using dashed lines to connect the preemption phases with the normal phases.)

If the phasing information is from a design plan in a file drawer, the investigator should check the actual phasing in operation in the signal controller. In the field with a signal technician or engineer can be a good time to ask about any recently reported signal problems. Many agencies keep a logbook in the signal cabinet into which all maintenance and repair visits are logged. Asking to take a look at the logbook (or at online logs in the engineer’s or system manager’s office) can prove helpful during accident analysis. If permitted, making a copy of the entries before and after the crash will allow an investigator to document any reported malfunctions before, during, or after the crash.
Once you have on-street information about traffic conditions and signal conditions just before and during the crash, and you understand what phases and phase combinations are possible at this intersection, now you can begin analyzing the crash.

**ACCIDENT SCENARIO # 1**

Assume you have two drivers involved in a crash. Both claim to have had a green signal on conflicting phases. The accident has three witnesses, one of whom was a passenger in one of the involved vehicles. After meeting with the traffic engineer and the senior signal technician, you understand how this 5-phase signal operates and you prepare a sketch of the signal-phasing diagram (shown in Figure 10.2).

You know that the main street traffic runs north south and the main street left turns are protected with arrow signal indications. The intersection has no main street right-turn lanes — main street right turns operate in a lane shared with the through traffic. All side street traffic operates together in a 4 plus 8 phase combination.

You prepare a sketch of the intersection and locate the drivers and witnesses on the sketch, shown on the following page in Figure 10.3.

Figure 10.2 – Phasing Diagram for Mall Entrance Crash
Figure 10.3 – Witness and Driver Locations
Witnesses have provided the following information:

- Witness #1 was in a car leaving the shopping mall on the eastbound approach: “The cars ahead of me went through on a green, and then we got this yellow light and I couldn’t speed up enough so I stopped just before it turned red.”

- Witness #2 was a maintenance worker in a bucket truck changing street lights at a convenience store on the southeast corner: “I really didn’t see the crash. I looked at the intersection and saw three cars stopped and waiting to turn left into the car wash in front of me. A black car was in the front, and then two others. I really don’t remember what kind of cars they were. Then I looked up at the light I was changing, and heard a loud bang so I looked back at the intersection. The black car was crashed out in the intersection.”

- Witness #3 was a passenger in the black car: “We waited for a long time and then got a green arrow, and then all of a sudden this guy comes through and hits us. I remember really paying attention to the green arrow because I had been watching it for a long time waiting for it to change from the red arrow.”

- Driver of the black car (Driver 1): “I stopped at the red arrow and folded down the mirror for a second because my contact lens was bothering me. My passenger told me that we had a green so I put the mirror back up and drove forward. I guess I really never looked at the signal after we stopped.”

- Driver of the northbound through truck (Driver 2) involved in the crash: “There were a bunch of cars and one tractor trailer truck stopped to turn into the mall. The back of the truck was in my lane and I had to swerve and use the other lane. Then this black car just turned in front of me and hit me. I know I had a green signal because I had seen it when I got close to the mall right before that trucker blocked me and I had to swerve. I never saw a yellow or red.”

The sketch of the pre-crash traffic conditions described by the witnesses and drivers is shown in Figure 10.3. By comparing the sketch of traffic conditions with the phasing diagram you start to eliminate phase combinations in which the signal was likely not operating just before the crash. You also begin to see what most likely happened at the time of the crash. This analysis yields the following:
The Phase 1 queue would not be consistent with the signal being in Phases 1 plus 5 or 1 plus 6. Vehicles would not be waiting if they had a green signal.

The Phase 5 queue would not be consistent with the signal operating in Phases 1 and 5 or 2 and 5.

The signal could have been in Phases 4 and 8 or in 2 plus 6, but the driver leaving the mall reported an expiring stale green as she approached the intersection.

This means the signal was in Phases 4 and 8 just before the crash.

This is further supported by the northbound driver’s recollection of a long queue of traffic waiting to turn into the mall on Phase 5. The maintenance worker further supports this by recalling a queue of southbound Phase 1 traffic.

If the signal controller was in Phases 4 and 8 right before the crash and then responded to calls holding on the main street, it would serve Phases 1 and 5 first since vehicles were waiting on both 1 and 5.

By comparing the driver and witness statements to the phasing diagram, you are able to eliminate the phase combinations that were not operating just before the crash and you can conclude that the signal controller was moving from Phase 4 plus 8 to 1 plus 5 just before the crash. The northbound through driver did not have a green signal indication in either of the phase combinations. The northbound through driver thus ran a red light and caused this crash.

The northbound driver’s view of the signal may have been blocked by the large truck, or the driver might have seen the green signal for Phase 5 traffic and mistook it for a northbound through signal. Or the driver might not have been paying attention and simply drove right through the red signal.
10.2 Where Were the Vehicles and When Were They There?

**ACCIDENT SCENARIO #2**

A westbound delivery truck driver starts forward on a green signal from a one-lane intersection approach. The driver is operating a moderately loaded mid-sized truck that is struck in the front right side by a southbound sports car when out in the intersection. The delivery truck’s sliding doors are latched in an open position and the hood ornament from the sports car flies into the truck’s cab at impact, injuring the truck driver. Several witnesses and other drivers stop to help the injured truck driver, and provide statements to the responding officer. All the witnesses agree that the truck driver had a green signal and the sports car driver had a red light.

The sports car driver is silent and refuses to give any statement. The sports car driver’s attorney offers a small settlement to the truck driver and her family. This attorney claims that the truck driver could have easily seen the approaching sports car before she started forward and she thus contributed to her own injuries by not taking evasive maneuvers. The truck driver and her family may recover nothing if the defense attorney is able to convince a jury of this sports car driver’s defense.

The truck driver’s attorney retains you to investigate the crash and answer one question: where was the sports car driver when he received a yellow signal and then a red signal? The plaintiff’s attorney believes that when the truck driver started forward the intersection was clear and had every reason to proceed forward and into her left turn with no reason to suspect the oncoming car even existed.

You make a field visit and determine that the truck driver moved about 24 feet from the stop line to the eastern edge of the rightmost northern travel lane as shown in Figure 10.4.
The truck driver then traveled across two northbound lanes and a turn lane, and then was partly into the first southbound lane when struck by the sports car. You measure the lanes to all be 12 feet wide. Thus she traveled a total of 24 feet plus 42 feet for a total of 66 feet. Using an acceleration rate of 3.2 feet per second squared, you calculate that it took the truck driver about 6.4 seconds to travel from her stopped position to impact \( \frac{1}{2}at^2 \).

Using Greenshield’s formula, you allow 4.0 seconds for the truck driver to start moving forward after receiving a green signal. Combining this 4.0 seconds with the 6.4 seconds she was in motion, you now understand that the truck driver had a green signal indication for about 4.0 plus 6.4 seconds for a total of 10.4 seconds before impact.

During a site visit with the local traffic signal technician, you verify that the signal was operating normally at the time of the crash and that no signal
malfunctions were reported within a month before the crash or for a month after the crash.

The responding officer noted no pre-crash skids for the sports car. You have no reason to doubt that the driver was traveling the posted speed of 45 mph. Using a sports car pre-crash speed of 45 mph, or 66 feet per second, you plot the pre-crash location of the sports car on the timeline. For each second of time pre-crash you back the sports car up 66 feet northward from the area of impact. You measured the distance from the area of impact to the southbound stop line to be 56 feet. Thus the sports car driver was outside of the intersection, or north of the stop line, just under one second before the crash. You continue to back the sports car up at 66 feet per second until the arbitrary time of zero, or when the truck driver received her green signal. You discover that the sports car was 630 feet (686 – 56) north of the southbound stop line, when the truck driver received a green signal.

Figure 10.5 shows a timeline for both the truck and the sports car. This timeline is based on the timing values from the traffic signal controller and from your calculations of the truck’s position pre-crash.

Figure 10.5 – Pre-Crash Timeline
You use the initiation of the green signal for the truck driver as an arbitrary “zero” on the timeline. You plot the truck driver’s position as being stationary through 4.0 seconds and then traveling forward for 6.4 seconds.

When you report this to the truck driver’s attorney, he feels confident that a jury will believe that his client looked out and saw no obvious threat to entering the intersection. Once she was already into the intersection, the truck driver directed her attention to her left-turn maneuver, so logically she would not notice a sports car approaching from her right at high speed.

During your deposition, the defense attorney grills you on your assumptions in your analysis. In particular the attorney questions your use of 4.0 seconds of Greenshield’s start-up time from when the truck driver received the green to when she actually initiated her forward motion. You explain that even if you used a 2.0 second start-up time, as you might do for a faster and lighter vehicle with an automatic transmission, the resulting calculation still places the sports car driver 554 feet north of the intersection when the truck driver received a green signal.

The traffic signal provided a timeline by which the investigator can locate both vehicles pre-crash. This tool can be expanded to include other signal timing parameters, as will be shown in Chapter 11. Some values used in typical analyses are not exact numbers, such as the start-up time from Greenshield’s formula. They are values based upon traffic engineering literature, education, and experience.

The astute investigator should be prepared to be challenged on the use of such numbers and be capable of making personal observations to justify the range of commonly used values. For example, an investigator could observe traffic at a signal and time the actual start-up times of several vehicles. This exercise can be taken one step further by classifying the drivers and their vehicles by vehicle type and weight. Having a small table with averages of many observed starts for different vehicle types should help to repel any legal challenges of your use of these values. This same methodology can be used for average acceleration rates. An investigator can easily measure the distance from the rear edge of a stop line
to some point such as a crosswalk on the far side of the intersection and then time vehicles traveling from a stop to the line. The acceleration rates of these vehicles can then be easily calculated and used for future reference.

### 10.3 Flashing Crash

**ACCIDENT SCENARIO #3**

An afternoon thunderstorm caused a short-lived blackout in a neighborhood. The power outage caused several local traffic signals to turn off. When the power came back on a short time later, the signals went into the ten-second start-up flash before entering normal operation. One of the signals, at the intersection of Major Street and Minor Street, failed to enter into normal operation after ten seconds of start-up flash and remained in flashing mode. After receiving calls from several citizens, the city signal technician responded to the intersection and reset the conflict monitor. The signal entered normal operation. The technician was not able to determine the exact cause for the signal to have remained in flash mode.

A crash occurred between a teenage driver on the eastbound intersection approach and an elderly driver on the northbound intersection approach. The teenager was at football camp at a nearby high school and left early when practice was cut short by the storm. He reports that he drove through two traffic signals before getting to this intersection. The first signal was not operating, and he treated it as a four-way stop. The second signal was working normally, and he had a green light when he went through the intersection without stopping. When the teenage boy arrived at this intersection he remembered that it was flashing yellow so he slowed a bit, and proceeded through the intersection. Halfway through the intersection a car suddenly crashed into his passenger side.

The elderly man operating the northbound car is quite shaken up after the crash. The airbag deployment and the crash itself took a toll on him, and as the investigating officer, you are not able to gain much information from him at the scene. During an interview with him the next day at his home you learn that he
had been driving for about an hour on the day of the crash, and was almost home. His travel from Distant Town had been almost totally on Major Street, the north-south main route through his hometown.

The elderly driver recalls that he drove through a storm, and then as he came into town he came through several intersections that were dark and then he drove through two that were on flash. He remembers having a flashing yellow light at these two intersections before reaching the crash intersection. The older driver tells you that up until a few months ago, he drove southbound on Major Street five mornings a week at 5:45 AM to meet a friend for coffee before all the commuters got to the doughnut shop. He had driven through these intersections for many years and knows that they flash on yellow for Major Street because he had seen it many mornings. He had not, however, driven the route at the early morning hour recently.

Figure 10.6 shows a sketch of the intersection, the drivers' recollection of their paths pre-crash, and their locations at impact.

**Figure 10.6 – Flashing Crash Diagram**
When you initially arrived at the crash intersection on the day of the accident, you noted that the traffic signals were operating in their normal five-phase manner. The signal was not on flash. One witness, a medical doctor, told you he had stopped at the crash to check on the drivers. He reported that the signals were flashing when he drove up right after the crash, and that a yellow city truck was there and a man was working in the signal cabinet. After the crash, the signal technician talked with the physician; learned that no serious injuries had occurred, and told the doctor that he had to leave since many others signals needed attention after the storm.

You are faced with conflicting stories, no witnesses to provide a statement, and no firsthand knowledge of what the signal was doing since it was back in normal operation when you arrived.

A call to the city traffic engineer yields the name of the signal technician who was at the intersection during the crash. After contacting the technician, you agree to meet at the intersection. During your meeting, the technician reports being bent over to work in the cabinet as he tried to figure out why the signal had not automatically resumed normal operation, and then he heard a loud crash. A doctor stopped to help, and nobody was hurt badly. The technician recalls then resetting the monitor and the signal went into normal operation.

You ask the technician which intersection approaches flash yellow and which flash red. The technician responds that the north-south approaches on Major Street used to flash yellow, but since Minor Street, the east-west roadway, was widened a few months ago, the signal flashes yellow for the eastbound and westbound approaches and red for north-south traffic.

The technician then looks down all four intersection approaches and sees no cars close to the intersection. He flips a switch in the signal cabinet and puts the intersection into flash mode: Minor Street flashes yellow and Major Street flashes red.
Subsequent conversations with the local traffic engineer reveal that traffic has increased along the Minor Street as new neighborhoods developed to the west and east sides of Major Street, and traffic had decreased along Major Street as populations dwindled in other neighborhoods. The recent widening project made Minor Street a major route through the intersections east and west of Major Street. The signals flashed yellow for Minor Street at these other intersections, so the design engineers in the City just made this intersection at Major Street also flash yellow for the east-west approaches.

This analysis results in the elderly gentleman being charged with failure to stop and yield the right-of-way at a flashing red traffic signal.

This scenario reminds an investigator of a few key issues:

- Traffic signals will almost always flash yellow for one pair of opposing approaches and red for the other pair.
- Traffic signal cabinets have two flash relays in them — one for red flash and one for yellow flash.
- Each signal head is wired to one of the flash relays in the signal cabinet, so a particular signal head can only flash either red or yellow.
- While it might sound like a solid foundation for analysis, one witness’s recollection of the way things were for a long time might not correctly reflect the conditions at the time of the crash.
- Having a signal technician put an intersection into flash is the best way to see how the system really works in that mode. While the design plan in the cabinet might still show Major Street as flashing yellow, putting the intersection into flash mode will prove what it is actually programmed to show.

10.4 Pedestrian Crash

**ACCIDENT SCENARIO #4**
You are investigating a pedestrian fatality at a signalized intersection. An elderly woman was crossing the intersection in a crosswalk from the southwest corner to the southeast corner. The crash occurred at 6:50 PM in December. The pedestrian was wearing dark clothing as she crossed Market Street to attend Wednesday evening church services, and the intersection was illuminated so the pedestrian should have been visible to the northbound driver.

The northbound driver is a woman in her mid-30s who has lived in this small town her entire life and is married to the local police captain. At the time of the crash, she and her two children were traveling to her father’s house to take him supper. She travels this exact same route at about this same time four nights a week, and her sister delivers meals on the other three evenings. To ensure an unbiased investigation of the crash, the local police sergeant called the Highway Patrol district office 30 minutes away from the town. The Patrol agrees to send you, their crash reconstructionist, to assist with the investigation.

You arrive at the crash scene at 8:15 PM. The victim’s body has been removed, and the scene has been secured by the local police. There were no witnesses to the crash. You interview the priest who was just inside the front door of the church when he heard tires skidding. The priest rushed outside and saw the car stopped almost in the center of the northbound lane. He then ran to the victim, whom he instantly recognized as one of his parishioners. She was lying in the roadway almost at the curb on the eastern side of the road. She was deceased upon his arrival. Lying near her body he found reading glasses, and a black purse. You observe the car in the position described by the priest, and you measure 55 feet of skid marks. You also measure the coefficient of friction to be 0.70. The skids start 52 feet north of the center of the crosswalk where the pedestrian was crossing. This is shown on the following page in Figure 10.7.
Figure 10.7 – Pedestrian Crash Scene

The skid marks stop at the car’s rest position. The car did not travel any appreciable distance after skidding. The front of the car is damaged right of center, including a broken right headlamp, dented hood, and a circular fracture in the windshield near the right side A-pillar consistent with a head impact. Later
that night you learn that the victim had a right side pelvis fracture, a broken right collarbone and shoulder, and severe head trauma on the right side.

You conclude that the pedestrian was in fact crossing from left to right with respect to the car’s travel path. You also conclude that the pedestrian was almost across the crosswalk when she was struck by the car. If the car was centered in the 12-foot wide northbound lane at the time of impact, then the pedestrian was about 4 feet from the eastern curb at impact. She had already crossed the southbound lane before the northbound lane so she had walked about 20 feet (12 + 8 = 20) before impact.

During your investigation, you note that the posted speed limit for the car is 35 mph. You also see that the intersection has pedestrian pushbuttons and pedestrian signal heads. You test the pushbutton for pedestrians crossing from the southwest corner to the southeast corner and it actuates the pedestrian signal head as expected. You note the following about the signal timing:

- The yellow clearance for northbound vehicular traffic is 4 seconds.
- The red clearance for northbound vehicular traffic is 1.5 seconds.
- The WALK signal for eastbound peds is illuminated for 7 seconds.
- The flashing DON’T WALK signal for eastbound peds is illuminated for 6 seconds.
- When the eastbound pedestrians receive a WALK signal, the parallel vehicular signal is also green.
- The flashing DON’T WALK signal ends at the same time as the start of the parallel vehicular yellow. The eastbound vehicular yellow interval is 4.2 seconds and the eastbound red interval is 1 seconds. So, the minimum parallel vehicular green is the same length of time as its associated WALK and flashing DON’T WALK combined (7+6 = 13 seconds).

The accident driver tells you that she had a green signal, was driving 35 mph, and never saw the woman in the crosswalk. The driver tells you that she heard and felt the impact and slammed on her brakes.
A day after the crash your line sergeant tells you that a possible witness has asked to speak with you. The witness heard about the fatal crash on the news and remembers driving through the intersection just seconds before the crash. The witness says that he was some distance from the intersection traveling eastbound and saw the traffic signal turn green just before his arrival at the intersection. He proceeded through the intersection without slowing or stopping and remembers seeing the old lady, dressed in black, starting to cross the intersection in the crosswalk on his right side. He doesn’t remember a northbound car to his right, but he really wasn’t looking for it since he was traveling through the intersection on a green signal.

Using a common skid to stop formula \( \text{speed} = \sqrt{30 \times \text{skid distance} \times \text{coefficient of friction}} \), you calculate the vehicle’s speed to be just less than 35 mph. You further conclude that at such a speed it appears that since she was traveling about 51 feet per second (35 mph x 1.467 = 51.3 fps) and she traveled 52 feet from the center of the crosswalk to the start of the skids then it is likely that her total perception and reaction time was about 1 second. This would be a reasonable time for someone to react to a sudden collision by braking. These conclusions are consistent with the driver’s statement that she never saw the pedestrian and hit the brakes when she heard the crash.

You draft a list of possible pre-crash scenarios and work through them to eliminate unlikely ones. Your list includes the following:

- Pedestrian never used the pushbutton and just walked into the intersection against a DON’T WALK signal.
  - This is not likely since the eastbound driver told you that the signal turned green just before his arrival.
  - The eastbound driver also told you that he saw the pedestrian start across the intersection just after he received a green signal. The pedestrian doing so would coincide with the eastbound pedestrian signal still receiving the solid WALK display, as long as the vehicular green was concurrently displayed with and was a direct result of the eastbound WALK display being shown in response to a pedestrian button actuation.
− The local signal technician confirmed that the signal was operating properly, so the side street green was most likely a result of the pedestrian actuating the eastbound pedestrian signals with a pushbutton since no other east or westbound vehicles appeared to have actuated the signal.

− The pedestrian not using the button does not appear to be a likely scenario.

• The eastbound vehicular green and pedestrian intervals had expired and the slowly walking woman was still in the crosswalk when the northbound driver struck her. The northbound green had returned after the complete eastbound phase was complete.

− While interviewing the priest a second time, you learn that the deceased had no difficulty walking. She walked at a normal pace and without a cane. This makes it highly unlikely that she was still in the intersection on an expired pedestrian phase when the northbound car arrived.

− When the eastbound vehicular green expired, the parallel solid DON’T WALK message also expired. A 4.2 second eastbound yellow and a 1 second eastbound red would have been displayed before the northbound green interval started. This means that the pedestrian had a total of \(7.0 + 6.0 + 4.2 + 1.0 = 18.2\) seconds to cross the street.

− A normal walking speed of 4 feet per second is typically used for signal timing. If she did cross the 20 feet in 18.2 seconds then she was walking at 1.1 feet per second. This is almost four times slower than the typical 4.0 feet per second used in signal timing, and is inconsistent with her normal walking speed.

− You conclude that it is not likely that, in the absence of extenuating circumstances, the pedestrian was still in the walkway when the northbound approach received a green signal.

− You further conclude that if the pedestrian was still in the intersection when the northbound driver approached the crosswalk then the northbound driver should have seen the pedestrian in the lighted intersection, regardless of which signal indication was presented for either travel direction.
• The northbound driver did not pay attention to the signals at the intersection which were “always green” for her frequent trips on this route, and she ran a red light while colliding with the pedestrian.

During a second interview with the northbound driver and her attorney, you present your analysis to them. You tell them that the investigation has ruled out all possible scenarios except that she was inattentive and ran a red light. She seems very upset, and speaks with her attorney for a moment. She then admits that she doesn’t remember much about her approach to the intersection after turning onto the northbound street a few blocks before the crash intersection. She was disciplining her children who were fighting with each other in the back seat. She distinctly remembers seeing a green signal and then turning to reach behind her to separate the children. The next thing she remembers is the sound of the crash.

10.5 Detection Crash

**ACCIDENT SCENARIO #5**

The intersection of Market Street at Williams Road is controlled by a six-phase traffic signal. The northbound and southbound intersection approaches have protected left turns. A pick-up truck, Vehicle 1, was headed northbound on Market Street on Phase 2, the through movement. The truck was in the leftmost of the two northbound through lanes. On Phase 1, a minivan, Vehicle 2, was southbound on Market Street and was making a left turn to head east on Williams Road. The pre-crash scene is illustrated in Figure 10.8.
The truck and the minivan collided in the intersection. Both drivers claim to have had a green light. Driver 1 stated that she saw a red light a block away from the intersection, and took her foot off the gas, but never braked. She was almost at the intersection when she saw the signal turn green so she pressed the gas and then skidded just before she was hit by Vehicle 2. She did recall seeing one other nondescript car that turned left through the intersection, just before Vehicle 2 turned the same direction. She remembers that the preceding car turned a while before Vehicle 2 — definitely more than a few seconds, but not a full minute.

Driver 2 told the responding officer that he was traveling southbound on Market Street at about 45 mph, put on his left-turn signal, started to slow down as he
entered the southbound left-turn lane on a green arrow, and then made his left turn on a green arrow. He also reported seeing a car turning left ahead of him, but he does not remember that car being in the turn lane when he entered the turn lane.

The northbound and southbound intersection approaches each have:

- Two signal heads over the through and right lanes, each of which has three circular signal faces.
- One signal head over the left-turn lane, which has three left-turn arrow signal indications.

These signal head arrangements are shown in Figure 10.9.
As described in more detail in Chapter 3, phasing for this traffic signal involves a NEMA standard dual-ring controller diagram and a NEMA standard phasing organization diagram. These are illustrated in Figures 10.10 and 10.11.

Figure 10.10 – NEMA Dual-Ring Controller Phase Organization

Figure 10.11 – NEMA Standard Traffic Signal Phasing

[From Traffic Management and Signal System Unit Design Manual, North Carolina Department of Transportation, 2004, Sect. 2.0, Sheet 1 of 3.]
The phasing analysis reveals the following key elements:

- The phases on one side of a barrier in Figure 10.1 cannot operate concurrently with phases on the other side of a barrier.

- Any phase can operate with another phase, provided the second phase is vertically or diagonally aligned with the first phase and they are both on the same side of the barriers.

- When Phase 2 (the northbound through/right movement) in Figure 10.11 is operating, it can run concurrently with Phase 5 (the northbound left-turn movement) or with Phase 6 (the southbound through and right movement).

- When Phase 1 (the southbound left-turn phase) is running, it can operate concurrently with Phase 5 (the northbound left turn) or with Phase 6 (the southbound through movement).

- When Phase 2 is running, all conflicting movements will have a red signal indication. Conflicting movements include the side street phases on the other side of the barrier and any phases on Phase 2’s side of the barrier that are not running concurrently with Phase 2. For example, if Phase 2 plus 6 were operating, Phase 1, Phase 5, and all the side street phases would have red displays.

- When Phase 1 is running, all conflicting movements will have a red signal indication. Conflicting movements include the side street phases on the other side of the barrier and any phases on Phase 1’s side of the barrier, which are not running concurrently with Phase 1. For example, if Phase 1 plus 6 were operating, Phase 2, Phase 5, and all of the side street phases would have red displays.

To properly analyze this crash, the detection for the Phase 1 southbound left-turn lane must be reviewed:

- A 6-foot by 40-foot in-pavement detection loop (DL) is located at the stop line for Phase 1 (the southbound left-turn phase).

- The DL has a 3-second clipping delay, which is used to prevent Phase 4 left-turning large trucks from running over the Phase 1 DL and unnecessarily calling Phase 1.
The 3-second clipping delay does not operate when Phase 1 is green.

The gap time programmed for Phase 1 is 2 seconds, so the signal controller will look for 2-second gaps between vehicles passing over the DL.

When a vehicle arrives on the Phase 1 DL and places a call to the detector the call is initially held, or delayed, for 3 seconds as the programmed clipping delay runs. Then the detector releases the call to the controller, and the controller eventually provides a green signal indication to Phase 1.

In this crash, both drivers reported seeing a southbound left-turning car before the minivan turned left. This correlates with Driver 1 seeing a Phase 2 red signal indication a block or so before arriving at the intersection, since the Phase 2 red was assigned in concert with the Phase 1 green.

Both drivers agree that a gap existed between the first Phase 1 left-turning car and Vehicle 2. The timing plan shows that Phase 1 might have gapped out after this first vehicle left the DL, and the signal controller returned the green indication to Phase 2 plus 6 where the green rests unless calls are placed on other conflicting phases.

A visit to the intersection with the signal technician verifies that no malfunctions or service calls were reported at this traffic signal near the time of the crash. The DL for Phase 1 is reviewed, and is working correctly with the actual design timing values in use.

To analyze the circumstances of the crash, it is necessary to evaluate how far apart two vehicles must be to cause Phase 1 to gap out. If a vehicle were 20 feet long, then when the rear of the first vehicle clears the downstream end of the Phase 1 DL, the call to the controller would be extended for the programmed gap time of 2 seconds. If the front of a second vehicle traveling 20 mph arrives on the Phase 1 DL at 1.99 seconds after the first Phase 1 vehicle leaves the DL, the second vehicle will cover about 58 feet in that 1.99 seconds (20 x 1.467 x 1.99 = 58.4). When added to the length of the loop that is 40 feet, the result is a following distance of 98 feet. The following Vehicle 2 should cover this distance in less than 4 seconds.
This 98 feet and 4 seconds is the maximum following distance and time at which Driver 2 could be following the car ahead of him to have caused an extension of the Phase 1 green. Statements from both drivers indicate that Driver 2’s following distance was greater than this.

Based on analysis, driver statements, and a review of the phasing and detection at this traffic signal the most likely accident scenario is:

- Driver 1 saw a Phase 2 red when the first southbound left-turning vehicle called Phase 1.
- Driver 2 saw the green arrow for Phase 1 quite a while before arriving in the southbound left-turn lane, provided for the vehicle ahead of him.
- Phase 1 gapped out after receiving no calls from vehicles closely following the first left-turning car.
- Driver 2 entered the intersection after the Phase 1 green expired.

Analysis indicates that the minivan driver most likely caused this crash, mistaking the length of an earlier green signal.

While it was not used in the analysis of this example crash, it would be possible to calculate where the two vehicles might have been when the Phase 2 green initiated. This information could then in turn be used to calculate when the Phase 1 yellow and red expired. This analysis is typically performed separately from the detection analysis.

**10.6 What Phase is Next?**

Traffic signal controllers are programmed to work in predictable patterns. Sometimes witness and driver statements might differ from one another, so understanding how signal phases change from one to the next can be critical in analyzing a crash.

**ACCIDENT SCENARIO #6**
An accident occurs at an intersection where two drivers both claim to have received green signals. The following basic information is gathered from four drivers:

- Driver 1 was westbound on the main street. She claims that she had a green signal as she started to drive through the local intersection at 35 mph.

- Driver 2 was northbound on the side street. He says he had a green signal as he approached the intersection, and then had to stop for a red light.

- Driver 3 was northbound in the left-turn lane. He remembers waiting on a red arrow signal for some time, and then receiving a green arrow.

- Driver 4 was stopped in the southbound left-turn lane on a red signal. He looked down at his cell phone for a moment, heard a crash, and looked at the accident. After a short while, he looked up at the signal and saw a green arrow signal for his left turn. He remembers some southbound cars driving straight through and one southbound car making a right turn in the lane next to him while he was stopped on red. All of these other cars passed him before the crash.
The crash diagram in Figure 10.12 shows that the east-west road is the main street, and that Driver 1 was approaching on Phase 6. Vehicle 2 was approaching from the south on Phase 8. Next to Vehicle 2 was Vehicle 3 on Phase 3. Driver 4 is southbound on Phase 7.

The drivers of the colliding cars, Drivers 1 and 3, both claimed to have received a green signal. Meeting with the traffic engineer or technician to obtain a phasing diagram for this signal and checking the maintenance log for the signal will help determine what the intersection signals were showing at the time of the crash.
The plans show that this signal controller runs an eight-phase pattern with protected left turns on all four-intersection approaches. The laneage and the approach speed of 35 mph are the same for all approaches, and no overlaps are programmed. The phasing diagram for this intersection is shown in Figure 10.13 and the signal heads used on all four approaches are shown in Figure 10.14.

The statement from northbound Driver 2 of a green signal turning to red indicates that the signal controller would have been in Phase 8 shortly before the crash, and the Phase 8 green interval would have terminated just before the crash. The phasing diagram in Figure 10.13 shows that the signal could have been in Phase 3 plus 8 or in Phase 4 plus 8. The statement of Driver 3, however, that he arrived on a red arrow indication means Phase 3 plus 8 could not have been active at that time.

This means that the signal was in Phase 4 and 8 shortly before the crash. This is supported by Driver 4 who, while waiting on Phase 7, recalled vehicles moving forward on Phase 4.
Since the signal had been in Phase 4 and 8, the phasing organization in Figure 10.15 shows the phasing would have had to pass over the barrier and move to a main street Phase: 1, 2, 5, or 6.

Since no witnesses reported waiting vehicles on Phases 1 or 5, the controller would sequence next to Phase 2 plus 6 for the following reasons:

- The signal controller is not able to move back to the side street phases on the right side of the barrier in Figure 10.15.
  - Once the controller is in Phase 4 plus 8 and vehicles arrive on the side street left-turn phases of Phases 3 and 7, they must wait for main street calls to be answered before they can receive a green.
  - The top ring and the bottom ring of the controller phase structure must progress to address all main street phases. Thus, the controller will hold Driver 3 (Phase 3) and Driver 4 (Phase 7) on a red signal indication until Phases 2 and 6, set to minimum recall, have been serviced with a green signal indication. In this example, minimum recall (discussed in Chapter 3) is effectively a programmed call to Phase 2 and 6 on every cycle. This forces the signal controller to rest in green for the main street until a side street vehicle places a call for service.

- When the signal controller leaves the side street phases (the right-hand section of Figure 10.15), it assess whether any calls are waiting on the main street phases. It then responds to them in numerical order.
In this example, no calls on Phases 1 or 5 have been placed, and Phases 2 and 6 have “ghost calls” since the controller is programmed for min recall for Phases 2 and 6.

With no calls waiting on Phase 1, the controller provides a green signal to the next sequential phase that has an unserviced call on it: Phase 2.

The controller also searches for phases with calls waiting which are compatible with Phase 2 (as shown by the arrows in Figure 10.15).

Phase 2 can operate concurrently with Phase 5 or Phase 6. No calls are waiting on Phase 5, and the programmed minimum recall has placed a call to Phase 6.

As a result, the controller will also provide a green indication for Phase 6 as it runs Phase 2 plus 6.

This discussion explains how the signal controller progressed from Phase 4 plus 8 to Phase 2 plus 6. This phase progression analysis also eliminated phases in which the signal was not operating before the crash. As a result, it is possible to determine which phase combination was operating just before the crash — Phase 4 plus 8 — and during the crash — Phase 2 plus 6.

Based on this analysis, it is most likely that Driver 3 entered the intersection on a red signal during the early part of Phase 2 plus 6.

10. Yellow Trap Crash at Railroad Preempted Traffic Signal

As discussed in Chapter 3, yellow traps are a situation when a driver is attempting to make a permitted left turn on a circular green, pulls into the intersection to wait for a green signal, sees the green turn to yellow, and scoots through the intersection on a yellow or red signal. This driver’s movement is legal since the vehicle entered the intersection before the red interval. The opposing through movement green is not always terminated, however, and sometimes continues to display a circular green indication. In this instance, the
left-turning driver might turn across the path of an oncoming car thinking the oncoming car will be stopping on its own red signal. Because the opposing car does not have a red signal, an angle or partial head-on crash occurs.

In the following accident scenario, a thorough understanding of complex traffic signal phasing, signal head, and railroad preemption terminology is needed. Some of this material was presented in Chapter 6, but repeating it in conjunction with a real crash case should prove helpful.

**ACCIDENT SCENARIO #7**

At the four-approach intersection shown in Figure 10.16, two cars are involved in a crash. Both claim to have operated their vehicles lawfully, according to the signals they received.

Commerce Street is the main route and runs north south. Rail Depot Avenue is the east-west street. The intersection includes northbound and southbound left-turn lanes. Speed limits for all approaches are 25 mph in this small town business district.

An at-grade railroad crossing is located immediately north of the intersection. The railroad tracks run parallel to Rail Depot Avenue. Rail crossing gates and flashers are located at this street-rail intersection, and these
devices are interconnected to the traffic signals at the Commerce Street/Rail Depot Avenue intersection.

Figure 10.16 shows Driver 1 was on the northbound Commerce Street Phase 2 approach and was preparing to make a left turn. Driver 2 was on the southbound Commerce Street Phase 6 approach, traveling across the railroad tracks and then straight through the intersection.

- Driver 1 reports having a circular green signal indication as she entered the northbound Phase 2 left-turn lane. She faced a long line of oncoming traffic and pulled slightly into the intersection to wait for a gap in oncoming through traffic to make her left turn. She reported that the Phase 2 signal heads changed from circular green displays to yellow, and then red. She saw an oncoming car when she saw the yellow and red signals appears, and assumed it would receive a red signal and stop. Because she was already across the stop line and did not want to block traffic in the intersection once Rail Depot Street received a green signal, Driver 1 made a quick left turn and was hit by the oncoming car, Vehicle 2.

- Driver 2 reported that he began to hear the crossing bells and saw the lights flash on the gate arm as he approached the railroad crossing. He saw a circular green signal indication at the intersection, and sped up to clear the tracks before the gate closed. He made it through the gate just in time, and the gate closed right behind Driver 2’s car. He claims that he still had a green signal at the intersection when a car turned in front of him and he hit it.

- A pedestrian witness told the officer, “I saw the car (Vehicle 1) go out into the intersection and wait for a long time, and then when they had a red signal they tried to turn but they were hit by the guy coming the other direction. They both get a red light at the same time because I’ve seen it myself every day when I am out here walking my dog.”

The investigating officer observes the traffic signal’s operation for about 30 minutes and notes that every single time that Phase 2 receives a green signal Phase 6 also receives a green signal. Every single time that Phase 6 displays a yellow and red signal; Phase 2 displays a yellow and red indication as well. Based on his observations of the signal operations, the officer cites Driver 2 for
running a red light. Driver 2 is convinced that he did have a green signal at the time of the crash. You are retained as the crash investigator to examine what happened.

After visiting the intersection and examining the signal’s operation when a train crosses Commerce Street, it is apparent that a yellow trap can occur when a train is detected while the signals are green for Phases 2 and 6. Both drivers were correct in reporting the signals they saw.

The traffic engineer agrees to meet with you at the intersection. The signal did not have any reported malfunctions at the time of the crash, and the engineer is aware of the potential for a yellow trap at this low-speed local intersection. The engineer explains that based on slower speed vehicles, however, a yellow trap related crash at this intersection is unlikely. In such cases where a yellow trap is created, the vehicles are usually moving slowly in the 25 mph zones, and can safely maneuver around each other.

The traffic engineer shows you the plans and explains the phase progression under railroad preemption circumstances. This traffic signal has a rail clearance and a rail preemption phase. The traffic signal phasing diagram is shown on Figure 10.17.
Figure 10.17 shows that this traffic signal uses a simple two-phase operation. Phases 2 and 6 operate on Commerce Street, and Phases 4 and 8 run on Rail Depot Avenue. Under normal conditions, when no train is present, this fully actuated traffic signal rests in Phase 2 plus 6, until a side street call on Rail Depot Avenue is serviced. Phases 2 and 6 are programmed for minimum recall to make the signal rest in main street green.

Figure 10.17 also shows a railroad clearance phase, Phase 1 plus 6. Approximately 45 feet lies between the southbound Phase 6 stop line and the railroad tracks. When the rail gates lower as a train approaches, a vehicle or several vehicles could be caught on the tracks if they were corralled between a Phase 6 red signal indication and a closed rail crossing gate. To prevent this, the signal was designed to be aware of calls from the rail equipment that a train is approaching. Upon receiving this call, the controller goes into preemption, bringing all vehicular movements opposing Phase 6 to a stop, and then allows Phase 6 to have a green signal to clear traffic off the tracks.

Phase 6 has two sets of signal heads, as shown in Figure 10.18.

The signal heads for Phase 6 are:

- **Heads 61 and 62** — These are the typical signal heads on the far side of the intersection.

- **Heads 63 and 64** — These are the nearside heads, and they are mounted on the northern side of the railroad crossing as seen in Figure 10.18.
During normal operations the nearside heads, numbered 63 and 64, operate in concert with Heads 61 and 62. In Phase 2 plus 6 all four of the Phase 6 heads have the same signal faces illuminated. A green ball on Head 61 is displayed to drivers simultaneously with a green ball on Head 62. We see a drawing of this in the phasing diagram in Figure 10.17: the southbound Phase 6 movements in the Phase 2 plus 6 circle are depicted as two pairs of movements — one pair south of the railroad tracks and one pair north of the tracks.

The railroad clearance phase circle in Figure 10.17 shows that the northern pair of Phase 6 traffic movements is stopped and the southern pair receives the green signal indication. The signal controller communicates this to the drivers by illuminating a circular green and a green arrow on Head 61 and a circular green on Head 62. This signal display is shown in Figure 10.19.

Figure 10.19 shows that signal heads 63 and 64 have circular red indications during the Rail Clear Phase, or Phase 1 plus 6. All other signal heads at this intersection display a circular red signal indication during the railroad clearance phase. The Rail Clear Phase is a fixed-time phase.

These factors were key to explaining the assumptions and perceptions of the drivers involved in this crash. After reviewing the plan, you are able to understand that a yellow trap led Driver 1 to assume she had no opposing traffic in conflict with her left turn while Driver 2 had circumvented the normal safety precautions by traveling at a higher speed than expected over the railroad crossing. You report your findings to your attorney client and prepare a few simple sketches to illustrate your analysis and conclusions. The charges against Driver 2 are dropped, and charges are brought against Driver 1 for failing to yield.
11. **CASE STUDY: APPLYING THE LESSONS**

Chapters 1 through 9 presented roadway design and traffic signal design concepts. Chapter 10 provided many examples of how to apply the signal engineering principles to accident reconstruction. Chapter 11 will take this one step further: this chapter presents an extended case study involving a crash at a traffic signal. This is based on a real court case, which has been adjudicated; the names of the parties have been changed. This case study is a complete investigation including driver avoidance analysis.

11.1 Perez v Smith — **Background**

In the mid-afternoon hours of June 3, a two-car crash occurred at the intersection of Western Boulevard at Method Road. Western Boulevard is a multi-lane high-volume roadway with a posted speed limit of 45 mph. The topography is rolling, and the surrounding land uses are commercial and retail. The westbound Phase 2 approach to Western Boulevard’s intersection with Method Road is shown in Figure 11.1. Method Road is a local street running in a north-south direction. The southbound approach to this intersection on Method Road is shown in Figure 11.2.
Ms. Perez (Driver 1) was stopped on Method Road in the left-turn lane. From her southbound approach to the intersection, she intended to head east on Western Boulevard. Ms. Perez was operating her older model small sports car.

Ms. Smith (Driver 2) was westbound on Western Boulevard. She was operating a late model sport utility vehicle in the left most westbound through lane. The photo in Figure 11.1 was taken standing in this lane.

The Smith SUV and the Perez car collided in the intersection. Specifically, the front of Ms. Smith’s SUV collided with the rear half of the driver’s door on Ms. Perez’s car. The impact occurred in the left most westbound through lane on Western Boulevard, and was within the bounds of the intersection. Ms. Smith’s SUV was totaled and she walked away unharmed. Ms. Perez suffered significant injuries and her car was demolished in the crash.

**11.2 Field Investigation**

In addition to collecting typical field data such as physical measurements and sketches made at the intersection, as well as taking photos of the intersection, I interviewed the responding officer after reviewing his report. The responding officer from Capitol Police reported that both drivers claimed to have a green light. There were no allegations of speeding on the part of either Ms. Perez or Ms. Smith.
Ms. Perez reported the following to the responding police officer:

- She approached Western Boulevard on a green arrow signal for her left-turn lane. She was southbound on Method Road.
- She reported that there was one car in front of her, and she saw it turn left immediately before the green arrow signal for her lane changed to a yellow arrow and then to a red arrow.
- She remembered stopping just before her southbound left-turn signal became red.
- She remained stopped on the red arrow signal for a short time, and then started to make a left turn on a green arrow. Ms. Perez was adamant that she had received a green arrow before starting to move forward.

Ms. Smith reported the following to the responding officer:

- She was traveling at 45 mph on Western Boulevard on her way to work.
- When she passed the service station immediately east of the crash intersection, she saw a green signal for through traffic on Western Boulevard.
- She remembers seeing several cars stopped in the lane to her left as she approached the crash intersection.
- The signal for westbound traffic on Western Boulevard was definitely green as she approached the intersection and as she entered the intersection.
- Suddenly a small car darted out from her right side. She hit the brakes but never skidded before hitting the small car.

Witness statements collected by the police include:

- Witness 1 was stopped in the westbound left-turn lane on Western Boulevard, waiting on a red arrow signal. He did not see the crash, but instead heard it and looked over to see the vehicles sliding to a stop. Witness 1 was driving the second of three cars in the westbound left-turn queue.
- Witness 2, a dentist, reported being stopped for a red light on northbound Method Road. He intended to drive straight across the intersection, but never made it across because of the crash. He did not see the crash, but he heard it.
The dentist reported turning on his emergency flashers, leaving his car at the northbound stopline, and performing emergency medical care on Ms. Perez until paramedics arrived.

- Witness 3 was a salesman who was standing on the southwestern intersection corner on his used car lot. He saw the small car start forward and then the SUV come over the hill and then he saw the crash. Witness 3 did not remember what the traffic signal was doing.

- Witness 4, a volunteer firefighter in another community, was stopped on a red signal for some time waiting to turn left from northbound Method Road onto westbound Western Boulevard. The dentist’s car was to his right. He reported receiving a green arrow signal, and then driving forward. He saw the small car (Vehicle 1) moving forward just before the crash. He did not, however, see the small car before it was already moving forward. Then he saw the crash to his right side. He did not remember seeing the SUV (Vehicle 2) before the crash. Witness 4 completed his left turn, stopped immediately, and ran back to the crash to direct traffic until the police arrived.

The police officer was unable to reconcile the conflicting statements by the drivers that they both had a green light, and the witness statements. Neither driver was charged by the officer.
11.3 Analysis

I was retained by Ms. Perez’s attorney to investigate, analyze, and report on this crash. Ms. Perez had no medical insurance and had incurred significant medical...
expenses as a result of this crash. She initiated a lawsuit against Ms. Smith after unsuccessful attempts at collecting medical reimbursements from Ms. Smith’s insurance provider.

After collecting information from the officer’s notes and report and meeting with the officer, it was time to better understand the traffic signal operation. I corresponded with the city traffic engineer and learned that this intersection was controlled by an eight-phase fully actuated traffic signal with protected only left turns for all four approaches. The signal-phasing diagram for this intersection is shown in Figure 11.4.

The main street phases, 1, 2, 5, and 6, as seen on the left side of the phasing diagram in Figure 11.4, are allowed to back up because there is no left-turn trap problem with protected only left-turn phases. In other words, Phase 2 plus 6 can transition to Phases 2 and 5 if vehicular demand is present. The side street phases for Method Road, Phases 3, 4, 7, and 8, seen on the right side of the phasing diagram, are not allowed to back up because Phases 2 and 6 are operated on min recall. The possible transitions of one phase combination to another are shown in the phasing diagram by the arrow paths between the phase combination circles.
During communications with the city traffic engineer, I learned that all of the detection loops at this signal were operational. I also learned that this signal was part of a citywide interconnected signal system. The system acquires malfunction reports from local signal controllers and relays them to the traffic engineer’s office. The traffic engineer checked both the local signal log and the central signal system computer and found no reported malfunctions in the week prior to or during the week after the crash.

During a site visit, I noted the location and type of the signal heads for the westbound intersection approach, shown in Figure 11.5. The signal heads for the southbound Method Road approach are shown in Figure 11.6.

All four intersection approaches have protected left-turn arrow signal displays, and standard circular green displays for through and right movements.

During my site visit I noted two things about the southbound Method Road approach:

- On the signal span for the southbound Phase 3 and 8 signal heads there was a “no turn on red” sign.
- The stop line for southbound traffic was 32.1 feet north of the northernmost edge of Western Boulevard.

Stop lines at signalized intersections are typically located 10 to 15 feet from the nearest edge of the intersecting travel way. The MUTCD recommends that in the absence of extenuating circumstances, a stop line not be located more than 30 feet from the nearest edge of the travel way. This particular stop line at which Ms. Perez was stopped before this accident was, in fact, farther north of Western Boulevard than design standards typically recommend.
Conversations with the city traffic engineer revealed that there had been a history of crashes at this intersection. It seems that eastbound tractor semi-trailer trucks would make a left turn from Western Boulevard onto northbound Method Road to access a nearby shopping center. On more than one occasion, the turning trucks had partially run over cars stopped on a red signal on the southbound Method Road approach. The city traffic engineer had intentionally moved the southbound stopline back to a position far enough north of the intersection to prevent run-over crashes.

When the new stop line was installed it became apparent that southbound drivers, if stopped at the new stop line, could not see westbound traffic approaching on Western Boulevard. The city did not want these drivers, attempting to turn right on red, to creep up to better see vehicles approaching from their left side. So the city installed the “no turn on red” sign. Aside from determining the intersection dimensions, the location of this stop line seemed somewhat trivial during the initial investigation, but became very significant later in the avoidance analysis.

The first part of the crash analysis involved comparing the driver and witness statements to the phasing diagram for this traffic signal. My intent was to isolate the phase or phases in which the signal was operating just before the crash. This analysis proceeded as follows:

- According to Witness 1, three cars were queued in the westbound left-turn lane. These drivers were waiting for the Phase 5 green signal. Thus the signal was not in, and had not recently been in, Phase 1 plus 5 or Phase 2 plus 5.
- Witness 2 described his being stopped on the northbound intersection approach for a Phase 4 red signal. This is consistent with the traffic signal not being in Phase 4 plus 7 or Phase 4 plus 8.
- Witness 3 remembered seeing Driver 1 start forward from a stopped position in the southbound left-turn lane.
  - This is consistent with Driver 1 receiving a green Phase 3 left-turn arrow in Phase 3 plus 7 or Phase 3 plus 8, or
This is also consistent with Driver 1 simply running a Phase 3 red light after being stopped at the same red light.

Witness 4 recalled being stopped for some time on a Phase 7 northbound left-turn red signal. He then distinctly remembers receiving a Phase 7 green left-turn arrow and starting to move forward at the same time as did Vehicle 1. Witness 4's receiving a green arrow is consistent with the signal being in Phase 3 plus 7 or Phase 4 plus 7.

At this point I began crossing out “unlikely” phases at the time of the crash on the phasing diagram as well as “likely” phases, and produced the sketch in Figure 11.7.

![Figure 11.7 Likely and Unlikely Phases](image-url)
Accident Reconstruction
at Traffic Signal Intersections

Figure 11.7 illustrates that:

- Phases 1 plus 5 and 2 plus 5 are eliminated (Witness 1).
- Phases 4 plus 7, 3 plus 8, and 4 plus 8 are eliminated (Witness 2).
- All Western Boulevard phases are eliminated (Witness 4).

This analysis leaves only one possible phase combination at the time of the crash — Phase 3 plus 7. This conclusion supported the driver represented by the attorney by whom I was retained. That was wonderful news for my client. It was also a red flag for me to be certain that I explored a reasonable explanation of why Ms. Smith, Driver 2, believed that she had a green signal.

The phasing diagram shown in Figure 11.7 illustrates that before being in Phase 3 plus 7 (the phase we concluded that the signal was in at the time of the crash), the only possible phase for the signal to have been in was Phase 2 plus 6. This is indicated by the paths from one phase combination to the other combinations. The only line entering Phase 3 plus 7 originates at Phase 2 plus 6. This is supported with a glance at a NEMA phase organization chart shown in Figure 11.8.
As the traffic signal controller leaves Phase 2 plus 6 it must cross the center barrier, and thus goes into an all red clearance interval. At this time the entire intersection has red signals. Then the signal controller proceeds to the next phase or phases, in numerical order, on the right side of the center barrier, which has waiting vehicular calls. Vehicle 1 and Witness 4 had placed calls for service on Phases 3 and 7, thus the signal controller progresses to Phase 3 plus 7 after leaving Phase 2 plus 6 and the subsequent all-red.

Driver 2, Ms. Smith, reported seeing a green signal on her Phase 2 approach when she was east of the intersection. This is likely a true statement since the signal was in Phase 2 plus 6, with vehicles queuing as described by the witnesses, when she was east of the intersection. At this point in the investigation I was left with the conclusion that Ms. Smith saw a green signal for her direction of travel at some distance from the intersection, and for whatever reason, failed to take notice of the signal heads again on the remainder of her approach to the intersection. Any conclusions as to why Driver 2 failed to observe the signals closer to the intersection would have been speculation.
I presented the preceding analysis and conclusions to my attorney client. She then asked me to go one step further and determine approximately where on the westbound approach Driver 2, Ms. Smith, was when Driver 1, Ms. Perez, received a green signal, and when Driver 2 received the preceding yellow and red signal when Phase 2 plus 6 ended.

11.4 Vehicle Locations before Crash

Using the crash sketch from Figure 11.3, I measured the travel path for Vehicle 1 from a stopped position on the southbound approach to the area of impact to be 63 feet. Using a typical acceleration rate of 7 feet-per-second squared, I calculated that it took 4.2 seconds for Vehicle 1 to cover this distance \(d = \frac{1}{2}at^2\) and \(v = at\). Using Greenshield’s formula, I added 2.0 seconds to the 4.2 seconds to arrive at the time from the initiation of the Phase 3 green to impact of 6.2 seconds. The additional 2.0 seconds account for the time for Driver 1 to see the green arrow signal, to react to it, and for her car to actually start to move forward.

Using the yellow and red interval timing values for this traffic signal I further calculated that:

- The Phase 2 red interval was 1.0 seconds and started \((4.2 + 2.0 + 1.0) = 7.2\) seconds before impact.
- The Phase 2 yellow interval was 4.5 seconds and started \((4.2 + 2.0 + 1.0 + 4.5) = 11.7\) seconds before impact.

The defendant, Driver 2, had not skidded prior to impact, and I assumed that she had been driving the posted speed limit of 45 mph. Using Driver 2’s approach speed of 45 mph, or 66 fps, I calculated that Driver 2’s location with respect to the traffic signal intervals and the location of Vehicle 1 to be \(d = \text{time} \times 66\):

- Phase 2 yellow starts 11.7 seconds before impact — Vehicle 2 was \((11.7 \times 66) = 772\) feet east of the collision
- Phase 2 red starts 7.2 seconds before impact — Vehicle 2 was \((7.2 \times 66) = 475\) feet east of the impact area
- Phase 3 green starts 6.2 seconds before impact — Vehicle 2 was 409 feet away east of the collision.

- Vehicle 1 starts to move forward 4.2 seconds before impact — Vehicle 2 was 277 feet east of the collision.

Our analysis indicated that Driver 2, Ms. Smith, had received a yellow signal 772 feet before the impact, and then a red signal 475 feet away — and still entered the intersection on red and caused this crash. My attorney client was pleased to hear that this was not just a close call, but was rather a case where the defendant had significant enough time and distance to have slowed to a stop on yellow and red signals in order to avoid the crash that injured her client, Driver 1.

When presented with my analysis in a settlement opportunity, the opposing attorney responded with, “Ms. Perez (Driver 1) had every opportunity to see Ms. Smith (Driver 2) approaching from her left side, and could easily have prevented this crash and thus her own injuries.”

### 11.5 Accident Avoidance

My attorney client now asked me to investigate what evasive opportunities her client, Driver 1, had in this accident. I returned to scene of the accident. Figure 11.9 is Ms. Perez’s view of westbound traffic from her stopped position on Method Road.
As the reader can see in Figure 11.9, several sight obstructions exist for a southbound driver including vegetation, poles, and a traffic signal cabinet. Remember also that the city had installed a “no turn on red” sign for the adjacent southbound lane because of these sight obstructions. It was recognized that drivers on the southbound approach couldn’t see oncoming westbound traffic on Western Boulevard except for one small section or “cone” of visibility, as shown in Figure 11.10.

Also, Figure 11.10 shows Vehicle 2’s travel path to the collision with the distance and number of seconds before impact noted along the path. As the reader will recall, we concluded earlier that when Driver 1 started to move forward from her stopped position, Vehicle 2 was 4.2 seconds and 277 feet east of impact. This location is east of the cone of vision available to Driver 1. It is a logical conclusion therefore that when Driver 1, Ms. Perez, received a green
I questioned the plaintiff, Ms. Perez, about her actions before the crash. She remembered looking to the left, seeing all the shrubs and the signal cabinet, and then pulling forward on a green arrow. She reported that once she was moving forward she looked along her travel path and at the opposing left-turning car (Witness 4) to avoid colliding with his car out in the intersection.

### 11.6 The Trial

Defense counsel felt strongly about this case and I was soon taking the stand in front of a jury. Using exhibits similar to the figures in this Chapter, I explained to the court my investigation and conclusions. Using analysis showing which signal phases simply were not possible based on independent witness statements, based on the analysis of where Driver 2 was located when she received a yellow and subsequent red signal, and based on analysis showing that Driver 1 could not have seen Driver 2 as Driver 1 left her stopped position, the jury took less than 30 minutes to find for the plaintiff.

The points to take away from this case study are:

- All witness statements have value, even if the witness didn’t see the crash.
Always meet with the traffic engineer and/or signal technician and learn how the signal operates, determine if there were any signal malfunctions, and what the timing values are.

- Sketch the phasing diagram.
- Locate all drivers, vehicles, and witnesses on a scale drawing of the crash area.
- Note sight obstructions, and include on scale drawing.
- Eliminate unlikely signal phases and recognize likely signal phases.
- Go back and re-interview drivers and witnesses if needed; in particular, ask about traffic conditions surrounding them just before the crash.
- Keep calculations simple. Pencil, paper, and a simple calculator are much easier to explain later than elaborate computer programs.
- Perform sensitivity analyses with your input values. For example, in this case, what if Driver 1 took longer than 2.0 seconds to move forward after receiving a green signal? Opposing counsel, not realizing that the answer actually places his client farther east on the timeline, may ask this to make you look like your assumptions are not valid. What if, during trial, the defendant decides she was traveling 50 mph or 38 mph instead of the 45 mph speed limit? You might want to know how these would affect your conclusions.
- Prepare simple figures to explain to other investigators or to attorneys. Always put things in terms of what we as drivers see on the street. The closer your analysis is to everyday occurrences a common driver sees in their daily commute the more likely they are to understand and believe you. People see traffic signals every day, and many have no idea how they work. If you can explain in layman’s terms how a signal operates, people will be much more likely to believe the rest of your analysis.
- Re-use these sketches for trial exhibits. Hand-drawn sketches enlarged by a copy shop are inexpensive and have a more genuine look than fancy computer-generated graphics. Don’t be embarrassed to testify that you reused your original sketches.
Accident Reconstruction
at Traffic Signal Intersections

- Explain traffic signal terminology just to the extent necessary to convey the signals concepts in your case. This is not the time to convince the court that you know all there is to know about signals.

- There is always another side to the story even when the analysis seems to overwhelmingly favor one side. Your investigation needs to seek out the other story. You need to be able to explain the other story.
GLOSSARY AND PAGE INDEX (page noted in parenthesis)

--A--

**Actuated** — A signal controller that responds to actuations, or calls, from pedestrians or vehicles. Green times are adjusted to accommodate actual traffic conditions. (19)

**Actuated preemption** — A preemption sequence initiated by an external device such as a sending unit on an emergency vehicle. (87)

**Actuations** — Communications between vehicles and pedestrians and the signal controller. Each time a vehicle passes over a detection device in or above the pavement, an actuation is sent to the controller. An actuation is understood to be a call for service if the signal is in yellow or red, or a call to extend an existing green if the vehicle is arriving on a green signal. (51)

**All-red** — That short period of time when a red signal is displayed for all intersection approaches. When the controller is transferring right-of-way from the side street to the Main Street or visa-versa, the controller will display an all-red in most jurisdictions. (52)

**All-red flash** — The signal controller is programmed or the signal cabinet is wired to flash the signal heads in red for all intersection approaches. Typically one pair of directions flashes yellow and the other pair flashes red. The all-red flash might be used in poor sight distance locations. (61)

**Approach grade** — The uphill or downhill slope on one approach to an intersection. Expressed as percent. A -2% grade means that for every 100 feet of run, there is a 2-foot vertical drop. (69)
**Approach lane** — One or more lanes entering an intersection. The lanes leaving an intersection are called departure lanes. (12)

**Arrow** — Arrow traffic signal indications are used for protected movements. When left-turning drivers sees a left-turn arrow, they are being given a protected opportunity to turn left. All opposing traffic has been stopped with a red signal. (24)

**Audible pedestrian signals** — Used to accommodate blind pedestrians. The small box typically sits on top of the pedestrian signal heads and contains a loudspeaker. Two different bird-like tones are emitted to let blind pedestrians know that they have right-of-way to cross in one direction or in the other direction. (22)

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**Back up** — When a traffic signal is in green for the through movements and it clears to protected left turns for the same approaches. For example, a signal might back up from Phase 2 plus 6 to Phase 1 plus 5. Backing up is allowed when the left turns are protected movements. Backing up is not allowed when the left turns are progressing from permitted to protected, because this creates a yellow trap. (62)

**Barrier** — An imaginary line through which is drawn between the main and side street phases, and again between the Side Street and main street phases. When a signal controller leaves the main street phases and enters the side street phases all signal heads will be red. This occurs again when the controller clears from the side street phases, crosses the end barrier, and enters the main street phases. (49, 157)

**Base mounted cabinet** — Traffic signal cabinet installed on a foundation, typically made of concrete. (21)

**Blank-out sign** — Illuminated sign on span wire or mast arm. In normal operation, a blank-out sign is dark and no message is displayed. During special
operations, such as railroad preemption, the blank-out sign will be illuminated to show a message such as, “NO LEFT TURN — TRAIN.” (85)

---C---

**Calls** — A vehicle or pedestrian waiting for service, or waiting for a green signal, places a call to the signal controller through a vehicle detector or a pedestrian pushbutton. (51)

**Channelizing devices** — Pavement markings, cones, barrels, or barricades used to guide traffic into designated lanes. (10)

**Clearance distance** — Used in calculating the red clearance interval, it is the distance across an intersection. The exact start and end points may differ slightly by jurisdiction. (71)

**Clipping delay** — Main Street, left-turning large trucks may run over a detector loop on a side street approach. A short delay of about 3 seconds may be used on such a loop to make it invisible to short-duration false calls from these trucks. (76)

**Closed loop signal system** — As opposed to a citywide large signal system, a closed loop system interconnects, monitors, and controls traffic signals at a smaller group of signals. (100)

**Concurrent phases** — NEMA phases which can operate together without conflict. For example, Phases 2 and 6, the main street through movements, can operate concurrently as they are parallel and opposite, and do not cross, or conflict, with each other. (34)

**Conflict flash** — When signal equipment senses a fault the intersection “goes into flash.” Normal signal operations are quickly suspended, and all signal faces are placed into flashing operation. Conflict flash does not reset automatically; a
technician must manually reset the equipment after the fault is identified and corrected. (61)

**Conflict monitor** — Also called a signal sequence monitor, or a malfunction management unit. The monitor is separate from the signal controller and watches many electrical and timing functions in the signal cabinet. When the monitor senses an actual operation out of the programmed range of allowable values, it will send all signal heads into flashing operation. Examples of faults might include a yellow interval less than 4.0 seconds, or simultaneous green indications on conflicting phases such as Phase 5, the northbound left-turn phase, and Phase 6, the southbound through phase. (61)

**Conflicting phases** — NEMA phases which, if run together, would place vehicles or pedestrians on a path for collision with each other. For example, Phase 1, the southbound left-turn phase, and Phase 2, the northbound through phase, are in conflict with each other. (51)

**Controller** — The “brain” of a traffic signal. Controllers are small computers, often of a 386 or older generation. Controllers contain programmed commands, phase sequences, and timing values for signal operation. Controllers also communicate, through modems, with central computers if the intersection is part of a larger signal system. (17)

**Controller cabinet** — Metal box with hinged door on front and often a second door on rear. Typically made of aluminum. Protects electrical wiring, controller, and other components from weather and vandalism. Can be mounted on a wood or metal pole or on a concrete foundation. (18)

**Coordinated** — When several traffic signals are timed so as to provide drivers with sequentially initiating green intervals. We typically see the main street phases coordinated to promote uninterrupted traffic flow. (92)

**Countdown pedestrian signal heads** — Digital timers display the flashing DON’T WALK time in a countdown fashion. This provides pedestrians with a better idea of how much time they have to cross the street. (58)
Cycle — A complete evolution of traffic signal intervals. A cycle is the total duration for a signal controller to time all the green, yellow, and red intervals and to come back to the start of the first green interval. (66)

--D--

Dedicated lane — A lane with only one traffic movement allowed from it. A left-turn only lane is a dedicated lane. (12)

Delay — Sometimes it may not be desirable for the controller to receive a call for service at the same instant the call is placed by a waiting vehicle. For example, a right-turn lane on a side street may receive many actuations, or calls for service, from arriving vehicles, but most of the vehicles will turn right on red. The signal would be programmed with a 15 second delay on all calls from this turn lane to allow such vehicles to make their turn on red before the call is actually recognized and main street traffic stopped to service the side street. (75)

Departure lane — A lane leaving an intersection. (12)

Detector or loop extension — Sometimes it might be desirable to make the duration of a vehicular call longer than the short time the vehicle is actually driving over the detection loop. For example, a small loop placed in advance of the stopline might use several seconds of extend to carry the vehicle closer to the intersection before the green expires. (78)

Dilemma zone — An area upstream of the stopline where drivers approaching the traffic signal, when presented with a yellow signal indication, are not sure if they should stop or go through the intersection. Detection is often placed so as to minimize impact from dilemma zone confusion. (77)

Directional arrow — An arrow painted on the pavement upstream of the intersection to provide the driver with information about the intended lane use. Through, right, left, and combination arrows are commonly seen. (12)
**Directional volume** — The number of vehicles traveling one way on a highway. In the AM peak hour, the directional volume from the residential area toward the factory district will likely be heavier than traffic volume traveling from the factories toward the houses. (69)

**DON’T WALK** — One of the three messages shown to pedestrians. Solid DON’T WALK means to stay on the curb and do not start across the intersection. This is similar to a red signal for vehicles. (72)

**Dual call** — One detection loop may place calls to more than one phase. A typical application is for a left-turn loop to call the permitted phase, such as Phase 2, and to also call the protected left-turn phase, Phase 5. If a vehicle arrives and then waits on the dual call loop during the permitted phase until some programmed delay expires, the controller will provide a protected left-turn phase for that driver. (54)

**Dual entry** — A programmed setting allowing the controller to run phases with no demand on them concurrently with phases which do have calls on them. For example, if Phase 4 is programmed for dual entry, and there is a call on Phase 8, the controller will allow both Phase 8 and Phase 4 to operate in green. (54)

**Dual-ring** — NEMA controllers are programmed to organize the signal phases and to then sequence through them in a pattern which resembles two rows with the top row consisting of Phases 1, 2, 3, and 4, and the bottom row containing Phases 5, 6, 7, and 8. The name “ring” dates back to the old electromechanical signal controllers where there were two moving discs that activated switches. Each disc or ring contained specific phases. (49)

**Electro-mechanical controller** — An old motor driven signal controller. Two slowly rotating discs held pins that turned switches on and off as the pins passed the switch toggles. The pins could be placed into different holes or notches along the disc to create different time intervals for each switch to be on. The switches controlled the actual signal displays. (20)
Exit phase — When a preemption sequence terminates, the controller will return to normal service. Some controllers are programmed to do so by passing through an exit phase that is used to serve a queue of vehicles that stacked during the preemption phase(s). (85)

Extend — See definition 2 for Gap.

--F--

Face — A single signal indication, such as one 12-inch circular red signal face. (23)

Flash mode — When a signal goes out of normal operation by design or because of a detected fault, the signal operates in flash mode. Typically the main street signal heads flash yellow, and the side street heads flash red. Typically protected left turn indications flash red regardless of their location. (51)

Flash relay — An electrical switch in the cabinet that rapidly and automatically alternates between on and off. When connected to either the yellow or red signal faces the flash relay sends current to the faces causing them to illuminate in flash mode. One flash relay is typically assigned to all the heads designated to flash red, and a second flash relay is assigned to the heads that will flash yellow. (124)

Free mode — A traffic signal that is normally part of a coordinated signal system may be allowed to operate freely or disconnected from the system at select times. Many locales allow signals to be in free run or free mode late at night. (99)

--G--

Gap — 1) The distance between vehicles following one another in traffic. Sometimes called a headway. 2) The extension of the green interval provided when a vehicle passes over a detection loop. For example, if the gap time for a phase is programmed in a controller at 2.0 seconds, and a vehicle places a call,
then the controller will extend the green for up to 2.0 seconds while waiting for a following vehicle to cross the detection loop or zone and place a subsequent call. (24)

**Gap out** — If the actual space between vehicles traveling toward an intersection becomes greater than the distance associated with the gap time programmed in the controller for a particular phase, the controller may elect to terminate the green for that phase and assign it elsewhere. Gapping out is the opposite of maxing out whereby the vehicles remain in an efficient, closely spaced platoon and keep extending the green, but the green interval demanded eventually exceeds the maximum green programmed in the controller. (69)

**Grade** — 1) The steepness of a roadway, presented as a percentage. If the roadway is at 3% grade, there are 3 feet of vertical gain for every 100 feet of horizontal run. 2) The elevation at a specific location. If two roadways intersect at the same elevation, an engineer may say that they cross at the same grade. (11)

**Grade crossing** — Typically refers to a railroad crossing a roadway at the same elevation, or grade. As opposed to a rail crossing with an over- or underpass, a grade crossing places vehicles and trains in conflict with each other. (89)

**Grade separated interchange** — The location where two or more non-parallel roads cross each other and traffic may move from one route to another, but the roadway approaches are at different elevations. An Interstate overpass with ramps is an example of a grade separated interchange. (11)

**Grade separation** — Two points or areas at different elevations. An example might be a railroad underpass where the train tracks are grade separated from the highway. (11)

**Green ball** — Technically, as used in traffic engineering terminology, a “circular green signal indication.” This is the alternative to the green arrow signal indication. (26)
Green extension — A signal controller is typically programmed for a minimum green value for a particular phase (min green) and a maximum green time (max green). Once the green interval has started, the min green will be lengthened up to the max green by an incremental value known as the green extension time for every vehicle that causes an actuation. Technically, the green extension timer starts when the min green expires. If a vehicle causes an actuation before the timer expires, then the timer is reset to zero and the green extension time starts over. A driver “sees” the green being extended. The controller is actually looking for long gaps in traffic that suggests a lighter flow. (48)

Greenshield’s formula — Used to calculate the time needed for a queue of vehicles to move from a stopped position into an intersection. Time = 4.0 sec. + (Number of Vehicles in Queue x 2.0 sec. per Vehicle). The 4.0 seconds is to get the first vehicle moving, and the 2.0 seconds is to get following vehicles moving. The 4.0 seconds for the initial vehicle may be shortened to about 2.0 seconds for smaller, lighter, and faster vehicles. If number of vehicles is not known exactly, consider using available queue length divided by 20 feet; this assumes that a vehicle and the space between it and the next vehicle is 20 feet. (84)

Head — A signal head is the housing for the signal faces. Heads are made from polycarbonate or aluminum, and may be painted yellow or other colors. Heads contain electrical splices between the bulb leads and the cables supplying power from the cabinet. Heads may be suspended from span wires or attached to mast arms. (24)

Interchange — The location where more than one non-parallel roadways meet. Interchanges are made from roadways on different grades, or elevations. Under- and overpasses with ramps connecting the upper and lower roadways are examples of interchanges. (11)
**Intersection** — The location where more than one non-parallel roadway meet. Intersections are on the same grade, or elevation. When used to describe the exact boundaries of the common area shared by the intersecting roadways, be aware that different jurisdictions define these boundaries in different ways. (11)

**Interval** — The length of time one color indication is displayed for one phase. There is a Phase 2 green interval, and a Phase 5 red interval, etc. (20)

**Isolated signal** — A traffic signal that is not part of a coordinated signal system. For example, a stand-alone traffic signal possibly in a rural area. (101)

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**Late night flash** — Some jurisdictions place signals into flashing operation between 11:00 PM and 6:00 AM or similar hours. This is to reduce wasted fuel from start-and-stop vehicles under low traffic volumes. (61)

**Limited-access roadway** — A highway facility, such as an Interstate route, with no driveways or at-grade intersections. Access to the highway is only available by interchanges with ramps. Sometimes called a control-of-access or controlled-access roadway. (11)

**Local roadway** — A neighborhood street. Low speed limits and bicycle and maybe pedestrian use along with motor vehicle use would be expected on a local roadway. Serves small business or residential connections. On-street parking may be typical, as may be sidewalks. (11)

**Local signal controller** — The traffic signal controller in a signal cabinet at an intersection. In a computerized signal system, many local controllers will be interconnected by fiber optic cable, radio waves, or copper wire. The central computer may decide how long the green time for each phase will be, and the order of the phases for a particular time of day, but the local controller typically dictates the yellow and red times. (93)
Logbook — Typically a hardbound journal, similar to a surveyor’s field book, kept in the signal cabinet. Every time a technician or engineer opens the cabinet, an entry is made in the book. Some agencies with computerized signal systems keep computer-based records. (72)

Loop detector — A loop of wire buried in or under the pavement and connected to the signal controller through a detector amplifier. When a vehicle arrives on the loop, the metal in the vehicle disturbs an electrical field created by the loop wire. This disruption causes a signal to be sent to the detector amplifier from where the signal is relayed to the signal controller. (74)

Main Street — At an intersection, one roadway will typically have a higher traffic volume than the other street(s). Unless other reasons prevail, the roadway with the highest volume is usually considered the main street. Main street signals usually flash yellow, and main street detection and timing may differ from what is found on side, or minor, streets. (20)

Malfunction management unit — Also called a signal sequence monitor, and a conflict monitor. This device oversees operations in the signal cabinet and places the intersection into flashing mode should any processes fall outside predetermined bounds. For example, a monitor may be programmed to not accept any controller-initiated yellow interval less than 4.0 seconds. If a signal technician accidentally programs the controller to use a 3.7 second yellow for a particular phase, the first time that yellow operated, the monitor will send the whole intersection into flash mode until a technician visits the signal and manually resets the monitor to allow normal operation. Arguably the most important function of a monitor is to send the intersection into flash if conflicting green indications are run by the controller. (61)

Manual on Uniform Traffic Control Devices — Commonly known as the MUTCD. This book is published by the Federal Highway Administration. The MUTCD details the design and use of traffic signals, signs, pavement marking
devices, and other traffic control devices. Some jurisdictions may have their own supplement to the MUTCD. (8, 10)

**Mast arms** — Metal poles with horizontal arms that support traffic signal heads and signs. The poles are bolted to buried concrete foundations. Mast arms are typically the most expensive support system, but are often aesthetically desirable. (10)

**Max green** — The maximum time limit for a green interval. The min green is extended by vehicle actuations until the max green is reached. (68)

**Max out** — Under heavy traffic conditions, the min green will be incrementally extended to the max green. If conflicting calls are waiting, the controller will terminate the current phase green upon max green and will provide a green interval to the next waiting phase. (68)

**Microwave detection** — A small detector unit typically mounted high on a pole. It uses microwaves to detect vehicular or pedestrian movement within an aimed detection zone. Provides a detection signal to the controller just like a traditional loop detector would do. Sometimes used in temporary conditions where cutting loops in pavement may not be feasible. (80)

**Mid-block signalized pedestrian crossing** — A crosswalk located between traditional vehicular intersections. Likely actuated by pushbuttons for the pedestrians. (60)

**Min green** — The minimum green time assigned to a phase. For example, the min green time for Phase 2 might be 12 seconds. Based on the number of actuations received by the controller, the min green may be extended to some total green time less than or equal to the max green. (68)

**--N--**

**Nearside head** — A signal head mounted on the side of the intersection closest to the driver as opposed to typical signal heads mounted on the far side of the
intersection. Typically used to supplement the normal far side heads in situations where sight obstructions block an approaching driver’s view of the far side heads. (145)

**NEMA** — National Electrical Manufacturers Association, an electrical industry group. Traffic signal components typically meet NEMA requirements. NEMA standards are used for signal phasing. (21)

---O--

**Off-line** — Individual signal controllers may occasionally operate independently from a signal system that normally keeps them in coordinated operation. When such operation exists, the controller is said to be operating off-line. May also be called “free-run” mode. (99)

**Omit** — A signal controller programming or wiring function. Omit tells the controller to ignore a designated phase. For example, “Omit 2 during 1 on,” would tell the controller to ignore calls to Phase 2 every time that Phase 1 is green. (64)

**Overlap** — When two or more normally conflicting phases are programmed to provide a green signal indication simultaneously. A common example is when a main street left turn is green at the same time as the side street right turns to the left of the left-turning vehicles. In this example, Phase 1, the left turns, would be in conflict with Phase 4, the side street movement. Special wiring and/or programming allow only the Phase 4 right turns to operate with the Phase 1 left turns. (38)

---P--

**Parent phases** — The phases, when active, which call an overlap. (See Overlap entry.) Phases 1 and 4 would be the parent phases in the example given for the Overlap definition. (45)
Pavement markings — Painted lines and symbols, thermoplastic lines and symbols, or raised markers used to delineate lanes of travel, crosswalks, and other key directions, and to convey messages to roadway users such as intended lane usage. (10)

Peak hour — Sometimes called the rush hour. This is the hour with the highest traffic volume compared to other times of the day. Typical traffic volumes have an AM peak hour and a PM peak hour. Some locations may have a peak hour at other times. For example, the peak hour for an intersection serving a large retail store may have a peak hour on a Saturday mid-morning. (93)

Peds — Pedestrians. (56)

Ped recall — Controller setting whereby a phase placed on ped recall received a forced call on every cycle regardless of actual demand. For example, if a controller is set for Phase 2 ped recall, the controller will run the Phase 2 pedestrian signals on every cycle whether a ped pushes the button or not. (57)

Pedestrian pushbuttons — At an actuated signal installation, a pedestrian is required to push a post-mounted button, or switch, to place a call for service to the signal controller. (55)

Permitted — Left turns, when allowed to turn through gaps in opposing through and right-turning traffic are said to be permitted left turns. Traditionally governed by a green ball signal indication. Some new traffic signals use a flashing yellow arrow for permitted left turns. (26)

Phase — A distinct vehicular or pedestrian movement recognized by the signal controller and assigned green, yellow, and red intervals. (22)

Phasing diagram — Schematic representation with arrows showing which vehicular and pedestrian movements are allowed to operate, or have a green signal, at the same time. May also show stopped movements or may not show stopped movements at all. Also indicates which movements occur before others
such as the main street left turns operate before the main street through and right-turn movements. (23)

**Platoon** — The pack of vehicles leaving a traffic signal. As the platoon leaves the signalized intersection, it becomes less dense. The platoon will become compact at the next red traffic signal. (94)

**Preempt dwell green** — During a preemption phase, the green interval may be programmed to hold for a predetermined time. The signal controller is said to dwell, or to rest, in green for this specified time. (84)

**Preemption** — Specially programmed phasing sequence to accommodate trains, emergency vehicles, or mass transit vehicles. For example, a signal controller may operate in a special rail preemption sequence just before a train arrives at a rail-highway crossing to clear vehicles out of a signalized intersection near the railroad tracks to ensure that no vehicles are backed up onto the tracks. (81)

**Preemption pushbutton** — Some emergency vehicle preemptions are initiated by a pushbutton typically located just inside the doorway of the fire station or rescue squad. Emergency personnel, on their way to a call, push the traffic signal preemption button, then open their bay door, and start their emergency vehicle run. The preemption button is connected to a nearby traffic signal controller, and when activated, alerts the controller that the preemption phase needs to be activated. (81)

**Presence mode** — A detector loop and amplifier combination can be set to create and send a pulse to the signal controller for the entire length of time which the vehicle occupies the loop. In other words, as long as the vehicle is present the call will be received by the controller, hence “presence” mode. Opposite of this is “pulse” mode whereby a short pretimed burst is sent to the controller regardless of the time a vehicle remains on or near the detection loop. (79)

**Pretimed** — A signal controller without means for responding to traffic demand. Green intervals are provided for predetermined lengths of time, and are the same from one cycle to the next. (19)
**Programmed flash** — Some signal controllers are programmed to flash the signal heads in yellow or red at predetermined times of the day such as from 11:00PM to 6:00AM. (61)

**Protected** — A traffic movement with no conflicting movements. A driver receiving a green left-turn arrow at a traffic signal has a protected left-turn whereby all opposing movements have a red signal. (24)

**Protected/permitted** — Left-turn phasing which, based on time of day programming or on vehicle demand, can provide either a protected green arrow for left turns or a permitted green ball for the same lane. (26)

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**Quadrupole loop** — An in-pavement detection loop installed in a figure-eight pattern so that typically two wires are placed in the outer longitudinal saw cuts and four wires in the center longitudinal saw cut. This configuration causes a stronger electrical field to be created in the center of the loop, thus facilitating better detection of small vehicles such as motorcycles. If many loops of wire were used in the perimeter of the loop, the increased sensitivity would cause unwanted detection of vehicles in adjacent lanes. (75)

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**Railroad preemption** — A signal controller at an intersection adjacent to a railroad crossing may be programmed to interrupt normal signal operations when a train approaches. The preemption programming would then operate in special phases to safely accommodate the train, roadway vehicles, and pedestrians. (89)

**Railroad preemption phase(s)** — Specially programmed phases operating during a rail preemption to accommodate an approaching train or a train already present. Typically this includes a rail clearance phase to clear vehicles and pedestrians from being trapped between the tracks and an adjacent signalized highway intersection. After the rail clear phase expires, some form of typical
vehicular and/or pedestrian phases modified to accommodate the presence of the train will operate until the train leaves the crossing. (90)

**Recall** — A programmed setting in the signal controller causing a particular phase to experience a “ghost call” for service on every cycle. (54)

**Red clearance interval** — The period of time after a yellow signal display when the signal controller provides a red display to drivers. Red signal indications make it unlawful for a driver to enter an intersection. The length of the red interval is typically the time for a vehicle, traveling at the posted speed, to clear the intersection before conflicting movements receive a green signal. (71)

**Red light camera** — A camera system aimed at the rear of vehicles entering an intersection used to capture an image of a vehicle as the driver runs through a red signal light without stopping. The red light camera system is triggered by 1) the traffic signal being in red for the monitored phase, and 2) a vehicle crossing the stop line. Typically a photo of the offending license plate and the signal head showing a red signal indication are sent to the registered owner of the vehicle with a demand for payment of a fine. (104)

**Right-of-way** — The land owned by a highway agency. A five-lane roadway might have a curb-to-curb width of 66 feet with 20 feet of right-of-way on each side of the roadway. Thus the right-of-way would be 106 feet wide. (17)

**Rings** — An imaginary organization of signal phases within a signal controller’s programming. Similar to two rows with Phases 1 through 4 on the top ring, or row, and Phase 5 through 8 on the bottom ring, or row. Specific relationships exist between phases on each ring that determine the order in which the phase may operate, and which phases may operate concurrently with other phases. (50)

**Saturated** — A lane or approach that contains more vehicles than it can efficiently process. Roadways have established maximum volumes beyond
which flow efficiency deteriorates. A saturated lane is said to be overloaded. (98)

**Shared lane** — An approach lane to an intersection with more than one designated traffic movement. For example, it is common to see a shared lane with a through and a right movement in one lane. (12)

**Side street** — The minor street at an intersection. This is typically the approach with the lesser traffic volume. (19)

**Signal sequence monitor** — Also called a malfunction management unit, and a conflict monitor. This device oversees operations in the signal cabinet and places the intersection into flashing mode should any processes fall outside predetermined bounds. For example, a monitor may be programmed to not accept any controller-initiated yellow interval less than 4.0 seconds. If a signal technician accidentally programs the controller to use a 3.7 second yellow for a particular phase, the first time that yellow operated, the monitor will send the whole intersection into flash mode until a technician visits the signal and manually resets the monitor to allow normal operation. Arguably the most important function of a monitor is to send the intersection into flash if conflicting green indications are run by the controller. (61)

**Split side street phasing** — When the minor street approaches to an intersection do not receive a green signal indication concurrently. Each of the minor approaches receives an independent green signal, usually one after the other. Split sides may be used when poor horizontal or vertical alignment might allow a head on or angle crash to occur if both side street approaches had a green signal simultaneously and the drivers could not see each other in time to yield to the other vehicle. (34)

**Start-up flash** — When electrical power is applied to a signal controller, the controller will typically operate in flashing mode for a predetermined time before entering normal operation. This allows motorists to be alert that a signal has been turned on. Typically the main street signals flash yellow and the side street
approaches flash red. Protected left turns typically flash red regardless of their location on a side or main street approach. (60)

**Storage bay** — That part of a turn lane that is a full lane width and is available for vehicles to queue. The storage bay is typically preceded by a turn lane taper. (26)

**Temporary traffic signal** — A signal installation used to control traffic in some non-permanent situation such as for an intersection under construction where the lanes will be changing in the future. Also a signal installed for a temporary purpose such as to allow construction equipment to cross a busy highway during a large project; such a signal would be removed after the construction project is completed. (102)

**Thermoplastic** — Thick pavement markings made from melted plastic. May contain tiny plastic beads to create a reflective marking. (12)

**Thoroughfare** — A larger roadway with fewer driveway connections and maybe higher speed limits. Typically allows users to travel through a town on more of an express route compared to traveling on a series of slower local streets. (11)

**Time-of-day plans** — Some signal controllers are programmed to allow longer or shorter green intervals at different times of the day to accommodate fluctuating traffic volumes such as rush hour traffic. Time-of-day plans may also allow unique phase combinations to operate at specific times of the day or days of the week to accommodate identified surges in directional volumes. An example would be to have a programmed plan to allow a manufacturing plant driveway to have more green time and a protected left turn in the evening rush hour as the first shift of employees exit the plant and enters a highway. There would be no need for this special phasing or timing in the other 23 hours of the day. (93)
Timed overlap — An overlap called by one or more parent phases that operate for some predetermined time. For example, every time Phase 2 green expires it may be advantageous to have an overlap called by Phase 2 hold its green indication a few extra seconds to allow traffic to clear from some part of the intersection after typical Phase 2 traffic has come to a stop. (48)

Track clearance phase — Also known as a railroad clearance phase, this specially-programmed signal phase provides green time to vehicles between a traffic signal and an adjacent railroad-highway crossing to travel away from this space before the train arrives. Without a track clear phase, some drivers might be caught between the closed rail gates and a red traffic signal. (90)

Traffic control devices — Signs, markings, cones, barrels, traffic signals, or other devices used to channelize and direct traffic. In the U.S., the design, installation, and maintenance of such devices are prescribed by MUTCD. (10)

Traffic engineering — The application of math and science to design and to design the construction and maintenance of facilities such as roadways, parking decks, traffic signals, signs, and support structures, and the electrical and computer systems associated with them. (9)

Transit preemption — Preemption sequence initiated by an approaching bus. The downstream signals change to green for the bus to give the mass transit vehicle priority at a series of traffic signals. (89)

Turning movement volume — The number of vehicles or pedestrians making one particular movement at an intersection in a specified time period. For example, the left-turn movement volume for northbound traffic may be 346 vehicles per day. May be from actual traffic counts or from projected data from accepted engineering sources. (67)

Vertical crest — The top of a hill along a roadway. (34)
Vertical sight distance — The distance along a roadway not obscured by the top of a hill. (34)

Video detection — A specially designed camera system used to identify the presence of a vehicle at an intersection and to place a call for service to the signal controller on behalf of the vehicle. May be used in place of traditional in-pavement loop detectors. Video detection is often used in temporary signal situations where construction activity may damage buried loop wires. (79)

Video detection zone — The area monitored by a video system for the presence of an arriving vehicle. Typically described by an imaginary rectangle or square drawn on a video monitor that simulates a traditional detection loop. (103)

Video monitoring — The use of video cameras to watch traffic at strategic locations around a city or other jurisdiction. Traffic signal technicians or engineers may use the real time traffic data to remotely alter timing or phasing plans to accommodate suddenly changing on-street traffic conditions, such as an accident blocking two of three approach lanes to an intersection. (106)

--W--

WALK — Pedestrian signals provide a WALK text message or a symbol of a walking person to indicate that pedestrians are allowed to step off the curb and enter the crosswalk. The pedestrian WALK indication is similar to the vehicular green indication. (72)

Wheelchair ramps — Used to allow handicap access to crosswalks. Provides a gradual transition from the sidewalk elevation down to the pavement elevation. (55)

--Y--

Yellow change interval — The timed display of yellow color provided to drivers. Alerts drivers that the green interval has ended and the red interval is
about to start. The length of the yellow interval is calculated to accommodate the anticipated approach speed and grade. (69)

**Yellow trap** — A three-step situation whereby:

1) 1) All traffic on a street has a green signal, including the through and left movements in both directions, thus these left turns are operating in a permitted manner, and the traffic in one direction receives a yellow signal as a precursor to the opposing side operating with a protected left turn

2) The left-turning (permitted) driver receiving a yellow signal assumes that the opposing traffic also has a yellow, and this driver waits until the yellow interval expires or is almost expired so as to turn left through a gap in the oncoming through traffic which, to this driver’s belief is also stopping

3) A crash occurs when the oncoming traffic, still on a green signal, violates the left-turning drivers assumptions

Most signal controllers are not allowed to “back-up” from a permitted left to a protected left so as to avoid yellow traps. (62)
13. ABOUT THE AUTHOR

Daren E. Marceau, P.E. is a former police officer with the City of Raleigh Police Department in Raleigh, North Carolina. As a beat officer, he responded to traffic accidents and learned field investigation techniques. After leaving the City of Raleigh, Mr. Marceau completed both his bachelor’s and master’s degrees in Civil Engineering at North Carolina State University.

Mr. Marceau has managed an engineering practice since 1995 with two focuses: designing traffic signals for state and local public agencies as well as private clients, and investigating, reconstructing, and testifying about accident cases. He possesses a unique mix of law enforcement experience, an advanced engineering degree, and significant engineering design and forensic engineering experience. This mix allows Mr. Marceau to rely on many example collisions and signal designs on which he has personally been the responding officer, lead engineer, or project manager.

Mr. Marceau believes that remaining actively involved in traffic signal, signing, and pavement marking design projects as the engineer of record is critical to being a good accident investigator and reconstructionist. Traffic signal technology and practices change over time. Staying up-to-date with current practices and being a leader in the traffic engineering community is important to Mr. Marceau’s design practice. Not only does this keep his understanding of signal design current, but it also is important to supporting the accuracy and effectiveness of his forensics practice.
In addition to his role as a traffic signals project manager at Kimley-Horn and Associates, Inc. in Raleigh, Mr. Marceau also teaches continuing education classes on a variety of accident investigation and reconstruction topics as well as engineering topics. His students include fellow engineers, engineering technicians, members of the insurance industry, and law enforcement personnel.

As a licensed Professional Engineer in several states, Mr. Marceau is often retained to reconstruct accidents and testify in court regarding his findings. He has testified for both the prosecution and the defense in accident cases. He maintains his professional objectivity by not working with one side significantly more than the other. Clients often call upon him to assist them in understanding work performed by other accident investigators and reconstructionists. He also contributes to cases by providing behind-the-scenes litigation support through suggesting interview, deposition, and trial questions for attorneys to use. With a full-service nationwide consulting firm and a strong graphics department supporting his practice, as well as volumes of exemplary designs to use, the preparation of exhibits for deposition and trial is a simple task. It is with these exhibits that Mr. Marceau does what he loves to do — teach others about how traffic signals work and how an accident likely happened.

Daren Marceau has formed his own forensic engineering firm and is no longer employed by Kimley-Horn and Associates.

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