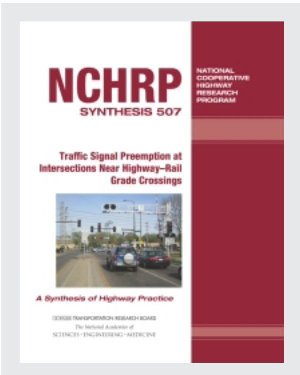


Traffic Signal Preemption at Intersections Near Highway–Rail Grade Crossings

DETAILS

76 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-38995-2 | DOI 10.17226/24769

CONTRIBUTORS

Tom Urbanik and Alison Tanaka; National Cooperative Highway Research Program; National Cooperative Highway Research Program Synthesis Program; Synthesis Program; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 507

Traffic Signal Preemption at Intersections Near Highway–Rail Grade Crossings

A Synthesis of Highway Practice

Consultants
Tom Urbanik
and
Alison Tanaka
Kittelson & Associates, Inc.
Portland, Oregon

Subscriber Categories
Highways • Operations and Traffic Management

Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRB TRANSPORTATION RESEARCH BOARD
The National Academies of
SCIENCES • ENGINEERING • MEDICINE

2017

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research is the most effective way to solve many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

Recognizing this need, the leadership of the American Association of State Highway and Transportation Officials (AASHTO) in 1962 initiated an objective national highway research program using modern scientific techniques—the National Cooperative Highway Research Program (NCHRP). NCHRP is supported on a continuing basis by funds from participating member states of AASHTO and receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine was requested by AASHTO to administer the research program because of TRB's recognized objectivity and understanding of modern research practices. TRB is uniquely suited for this purpose for many reasons: TRB maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; TRB possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; TRB's relationship to the Academies is an insurance of objectivity; and TRB maintains a full-time staff of specialists in highway transportation matters to bring the findings of research directly to those in a position to use them.

The program is developed on the basis of research needs identified by chief administrators and other staff of the highway and transportation departments and by committees of AASHTO. Topics of the highest merit are selected by the AASHTO Standing Committee on Research (SCOR), and each year SCOR's recommendations are proposed to the AASHTO Board of Directors and the Academies. Research projects to address these topics are defined by NCHRP, and qualified research agencies are selected from submitted proposals. Administration and surveillance of research contracts are the responsibilities of the Academies and TRB.

The needs for highway research are many, and NCHRP can make significant contributions to solving highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement, rather than to substitute for or duplicate, other highway research programs.

NCHRP SYNTHESIS 507

Project 20-05, Topic 47-15
ISSN 0547-5570
ISBN 978-0-309-38995-2
Library of Congress Control No. 2016961957

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet by going to

http://www.national-academies.org

and then searching for TRB

Printed in the United States of America

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, non-governmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

The **National Academy of Engineering** was established in 1964 under the charter of the National Academy of Sciences to bring the practices of engineering to advising the nation. Members are elected by their peers for extraordinary contributions to engineering. Dr. C. D. Mote, Jr., is president.

The **National Academy of Medicine** (formerly the Institute of Medicine) was established in 1970 under the charter of the National Academy of Sciences to advise the nation on medical and health issues. Members are elected by their peers for distinguished contributions to medicine and health. Dr. Victor J. Dzau is president.

The three Academies work together as the **National Academies of Sciences, Engineering, and Medicine** to provide independent, objective analysis and advice to the nation and conduct other activities to solve complex problems and inform public policy decisions. The Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Learn more about the National Academies of Sciences, Engineering, and Medicine at **www.national-academies.org**.

The **Transportation Research Board** is one of seven major programs of the National Academies of Sciences, Engineering, and Medicine. The mission of the Transportation Research Board is to increase the benefits that transportation contributes to society by providing leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied committees, task forces, and panels annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

Learn more about the Transportation Research Board at **www.TRB.org**.

Cover figure: Hiawatha LRT Crossing at E. 42nd Street, Minneapolis, MN. *Credit*: Tom Urbanik, Kittelson & Associates, Inc.

ACKNOWLEDGMENTS

This synthesis was developed with help from a variety of sources. As part of the project team, Paul Olson, P.R. Olson Associates Ltd., provided references used throughout the synthesis and reviewed the document in its entirety.

One of the most important components of this project was the case examples. Special thanks to the following people for providing information for the case examples, as well as reviewing the associated documentation:

Adam Moore, Portland Bureau of Transportation
Kevin Duemmel, Ohio Department of Transportation
Sean Skehan, Los Angeles Department of Transportation
David Dokupil, CTC, Inc.

In addition to those who helped develop the synthesis, the panel members provided engaged and insightful reviews throughout the project. Their recommendations helped to produce a synthesis that effectively summarizes the state of practice of traffic signal preemption at intersections near highway-rail grade crossings.

FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Mariela Garcia-Colberg
Senior Program Officer
Transportation
Research Board

Every day millions of people around the United States cross railway tracks without understanding the complex operations and methodologies that have to be taken into account for the creation of effective traffic signaling at those intersections. This synthesis documents the current practices of traffic signal preemption deployed at intersections adjacent to railway grade crossing in both the United States and Canada. The study provides information on practices dealing with traffic signal preemption, maintenance, funding, and operations.

A literature review and detailed survey responses from 40 of 49 U.S. departments of transportation and four Canadian provinces (an 85% response rate) are provided. Detailed case examples of three different states are also included in the report and provide additional insights on the state of the practice, including lessons learned, challenges, and gaps in information.

The synthesis will assist transportation agencies in the design of a railway preemption system for a particular situation and aid in their ability to maintain the system. The information included can help practitioners in seeking solutions for traffic signal operations near railway grade crossings.

Tom Urbanik and Alison Tanaka, Kittelson & Associates, Inc., Portland, Oregon, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

TRAFFIC SIGNAL PREEMPTION AT INTERSECTIONS NEAR HIGHWAY–RAIL GRADE CROSSINGS

SUMMARY

Traffic signal operations near highway–rail grade crossings are important from both safety and mobility perspectives, but practice varies widely. The goal of this synthesis is to document the state of practice of traffic signal preemption deployed at intersections adjacent to highway–rail grade crossings in the United States and Canada. Specific objectives include:

- Learning what practices have been used;
- Identifying ongoing and recently completed research; and
- Learning what problems remain largely unsolved.

Methodology for compiling information for this synthesis included a literature search, a survey of U.S. state and Canadian provincial departments of transportation, and the completion of three case studies (Portland, Oregon, and the states of Ohio and California) to determine additional lessons learned, innovations, and gaps in practice. Forty of 49 states and one of three Canadian provinces responded to an e-mailed survey request; in addition, four Canadian provinces not included in the original survey distribution offered information (Figure 1). Hawaii was not included in the survey because the state has no operating freight or passenger railroads system, and the one United States territory queried did not respond.

The most important conclusion from this synthesis, described in more detail in chapter eight: Conclusions and Suggestions for Further Research, is that the state of the practice does not adequately reflect current state-of-the-art capabilities. Although some highway and railway agencies use advanced capabilities demonstrated in the case examples, the majority of surveyed agencies (55%) uses a simple, two-wire preempt at their highway–rail grade crossings; and of those agencies using two-wire preempt, 58% use normally closed circuits. This two-wire preempt circuit conveys no more information to the traffic signal controller than was available when track circuits were first used to preempt traffic signals.

Railway agencies are regulated by FRA, which governs railway-equipment aspects of crossings. While FRA encourages railway and highway agencies to coordinate joint inspections to verify that railway crossing warning systems interconnected to traffic signals function properly, the survey indicates that few highway agencies coordinate inspections with railway agencies.

There are several opportunities that could lead to improved safety and operation of highway–rail grade crossings. Issues that could be considered, also detailed in chapter eight, include identification and review of key limitations and conflicts in current operations; clear definitions of terms and operational concepts; use of multiple signals and preempts; coordination with railway agencies; agency employee and contractor training; and inspections and performance measures. Development of guidelines for optimal traffic signal operation would also be helpful.

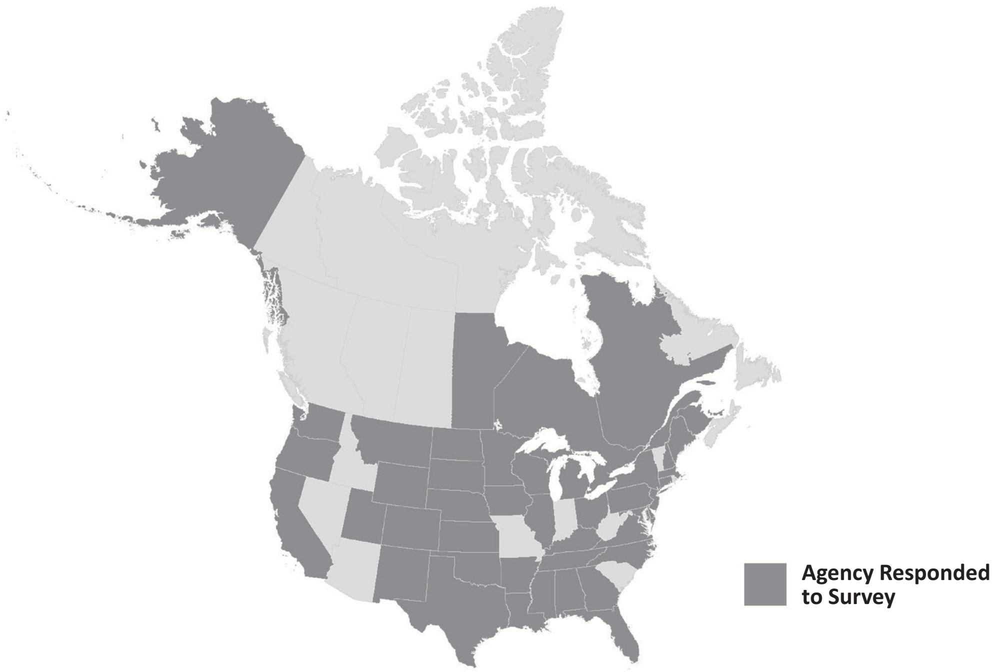


FIGURE 1 Surveyed state and provincial agencies in the United States and Canada.
Source: Kittelson & Associates, Inc.

CHAPTER ONE

INTRODUCTION

BACKGROUND

Highway–rail grade crossings near signalized intersections came to the public's attention on October 25, 1995, when a school bus transporting high school students was hit by a METRA commuter train traveling inbound to Chicago. The 1995 Fox River Grove crash, in which seven students were killed, continues to be cited by the NTSB when investigating subsequent crashes. In its investigation, the NTSB identified the following safety issues related to preemption of traffic signals: "the railroad/highway signal interaction; the coordination and communication between the Illinois Department of Transportation and the Union Pacific Railroad Company, and their oversight of the signal system integration" (Report PB96-916202 NTSB/HAR-96/02 1996).

In 1995, U.S.DOT formed the Grade Crossing Safety Task Force, which focused on (among other issues) traffic signal operations near highway–rail grade crossings located adjacent to signalized intersections. The task force identified five safety-related problem areas (Korve 1999): interconnected traffic signals; vehicle storage space; high-profile crossings; light rail crossings; and special vehicle crossings.

A major finding concerned ineffective communication between multiple parties that use and are responsible for highway–rail grade crossings. After investigating the 1995 crash, NTSB recommended that the U.S. Secretary of Transportation develop a comprehensive and periodic highway–rail grade crossing safety inspection program to be conducted jointly by railway agencies and public entities; the program would require that railway agencies and public entities coordinate changes to highway–rail grade crossings before implementation.

FRA later released statements addressing NTSB recommendations for railway and highway interactions at grade crossings.

On October 1, 2010, FRA issued Safety Advisory 2010-02 to address recommendations I-96-10 and I-96-11. The FRA safety advisory recommends that states, local highway authorities, and railway agencies install, maintain, and upgrade railway and highway traffic signal recording devices at highway–rail grade crossings equipped with active warning systems that are interconnected with highway traffic signal systems. The safety advisory also recommends that agencies perform comprehensive, periodic, joint inspections of highway traffic signal preemption interconnections, including a review of information obtained from any signal recording devices.

On February 17, 2016, FRA Press Release 04-16 called on state departments of transportation (DOTs) to verify that railway crossing warning systems interconnected to traffic signals function properly. The FRA once again urged states to add event recorders to traffic signals connected to railway crossing warning systems so information could be used during inspections to improve safety.

REVIEW OF LITERATURE

Although a list of references is provided later in this report, the following is a summary of literature relevant to traffic signal preemption at intersections near highway–rail grade crossings.

NCHRP Synthesis 271: Traffic Signal Operations Near Highway-Rail Grade Crossings (Korve 1999) summarizes the literature before 1999; the synthesis largely focuses on the interconnection between the railway and highway systems, and the design, operation, and maintenance of the traffic signal system. Ogden (2007) provided an overview of all aspects of grade crossing practice in the revised second edition of the *Railroad-Highway Grade Crossing Handbook*. Current recommended practice is provided by ITE in *Preemption of Traffic Signals Near Railroad Crossings*, which is in the process of being updated. The American Railway Engineering and Maintenance-of-Way Association (AREMA) annually publishes an updated *Communications & Signals Manual*, which describes current railway practice regarding preemption.

Several documents contain guidance specific to the design aspects of preemption. Alroth et al. (1999) set forth some design criteria for the use of pre-signals. Venglar et al. (2000) developed a comprehensive guide for railway preemption issues. Mansel et al. (1999) discussed various approaches to supervised circuits to improve the safety of highway–rail interconnection. Campbell et al. (2015) discussed how supervision improves interconnect circuits. The Institute of Electrical and Electronics Engineers (IEEE) developed a data standard, IEEE 1570-2002, for the interconnection of the railway and highway control systems. IEEE 1570-2002 does not define what should be exchanged or how the data should be used, only the data standard in anticipation of further improvements to the interface.

A number of documents address operational aspects of preemption. The "preempt trap" (discussed in chapter two: Advance Preemption) was an issue identified in Texas Transportation Institute (TTI) Report 1752-9 (Englebrecht et al. 2002), which demonstrated the benefits of two-preempt strategies using advance preemption with gate-down confirmation (discussed in chapter four, Addressing the Preempt Trap). Additional research on the topic was conducted by Yohe and Urbanik (2007) and Sun et al. (2008). Seyfried (2001) provided advice on timing parameters for preemption. In 2003, the Texas Department of Transportation (TxDOT) developed a comprehensive *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway Rail Grade Crossings,* which is widely used.

Moriarty et al. (2012) provided information on recording devices for monitoring the interconnection between the railway and highway control systems. Moore et al. (2015) demonstrated the benefit of monitoring multiple railway outputs, including the island circuit, to understand actual train operations when preemption is activated by the railway warning system (see the Portland, Oregon, case example in chapter seven). Brennan et al. (2010) studied actual preemption performance and the benefits of recording actual operations. Yeh and Multer (2008) provided updated information on driver behavior at grade crossings that affects operations. Recovery strategies from preemption are discussed by Bullock et al. (1998). Schulz and Smadi (1998) and Lin et al. (2014) used simulation to conceptually demonstrate applications of better data and communication to improve grade crossing operation.

Fehon and O'Brien (2015) provide guidance on an objectives-and-performance-based approach to traffic signals in *Traffic Signal Management Plans, An Objectives- and Performance-Based Approach for Improving the Design, Operations, and Maintenance of Traffic Signal Systems*. *NCHRP Report 812: Signal Timing Manual, Second Edition* also uses an outcome-based approach in its description of preemption (Urbanik et al. 2015); some of the concepts presented in the manual are included in this synthesis.

A number of states have developed manuals of various levels of detail. States with comprehensive guidance include Texas (*Rail-Highway Operations Manual* 2015) and Utah (*Preempting Traffic Signals near Railroad Crossings in Utah, A UDOT Manual* 2015). Ohio has guidance included in several related manuals, including the *Traffic Engineering Manual* (TEM) (2016) and the *Ohio Manual of Uniform Traffic Control Devices, 2012 Edition*.

REPORT ORGANIZATION

The synthesis begins with several chapters that provide background information on each piece of the highway–rail grade crossing system. Current practice is discussed in the following chapter, including information from the agency surveys and case examples. The synthesis ends with a description of lessons learned and conclusions about operating highway–rail grade crossings. References and appendices with more detailed information from the agency surveys are provided after the conclusion.

The synthesis is organized into the following chapters:

Chapter one: Introduction provides some historical context for the synthesis and an overview of the literature review performed.

Chapter two: Overview of the Highway–Rail Grade Crossing System describes current practices and types of railway-grade crossing management, including the concept of preemption; and explains the ways different railway-grade crossing systems can operate.

Chapter three: Rail Systems describes how the railway warning time system can provide preempt outputs to the traffic signal.

Chapter four: Traffic Signal Systems focuses on how traffic signals near highway–rail grade crossings use railway outputs to clear vehicles from the track(s).

Chapter five: Interconnection describes how the railway system communicates with the highway traffic system.

Chapter six: Institutional Aspects identifies common regulatory and institutional issues related to preemption practices.

Chapter seven: Case Examples summarize in-depth studies of current practice in Portland, Oregon, and the states of Ohio and California.

Chapter eight: Conclusions and Suggestions for Further Research summarizes gaps in practice identified through this synthesis report and recommends areas of future research.

CHAPTER TWO

OVERVIEW OF THE HIGHWAY–RAIL GRADE CROSSING SYSTEM

Preemption of traffic signals near highway–rail grade crossings fundamentally involves interconnection of the railway warning time system and the highway traffic signal system. The point of connecting these two systems is to ensure that vehicles are not on the track(s) when a train arrives at the crossing. There are many ways that a traffic signal can clear vehicles, but how efficiently that can be achieved depends heavily on the timeliness and accuracy of information provided by the railway agency.

Historically, preemption has involved simple one-way communication from the railway system to the highway system. In recent years, however, AREMA has upgraded its *Communications & Signals Manual* to provide guidance on improved interconnection, including information about the use of multiple railway warning type system events. Traffic signal manufacturers have also improved their controller features to provide additional functionality, giving agencies better options for implementing traffic signal preemption. Although some agencies have implemented these more advanced concepts (as will be discussed in chapter seven, Case Examples), current practice for most agencies has remained unchanged and is widely varied.

CONCEPT OF OPERATIONS

This "concept of operations," which is a non-technical description, explains the different ways a highway–rail grade crossing system can work. The following description focuses on how a state-of-the-art highway-preemption system could operate, so that a practitioner can better understand current practice. Figure 2 illustrates the major components of the railway system and the highway system. The interconnection between them represents the communication that can or does take place between the two systems. The technical details will be detailed in chapters three through five.

The preemption process begins with the railway system detecting the approach of a train. There are a variety of detection technologies ranging from simple detection of presence (i.e., whether or not a train is anywhere in the detection zone) to more sophisticated systems that predict the arrival of a train at the crossing based on its speed in the detection zone. Once a train has been detected and its arrival time at the crossing predicted (which is the design value), the railway warning time system sends a preemption output through the interconnection to the traffic signal system. The actual railway output may vary from the design value as discussed here.

The output from the railway system is often very simple (i.e., "train coming"). If requested by the highway agency and agreed upon by the railway agency, outputs can be more complex, giving advance notification time, status of the railway warning devices, status of the gates, and presence of a train in the crossing area. Typically, the railway system guarantees a minimum amount of time for preemption, but in practice, outputs from the railway system generally assume the same designed amount of time every time, regardless of whether there is any time variance. For example, most systems are unable to account for variable train speeds, which can cause significant variation in when a train arrives at the crossing (as discussed in chapter three).

The traffic signal system takes the railway output (or in some cases multiple outputs) and implements a preprogrammed sequence of events, depending on the nature of the railway output(s) and the capabilities of the traffic signal system. The response is typically simple: Abruptly stop the current operations and move to the track clearance green interval (TCGI). The TCGI is the time that is provided to clear stopped vehicles from the track(s) on the approach to a traffic signalized intersection.

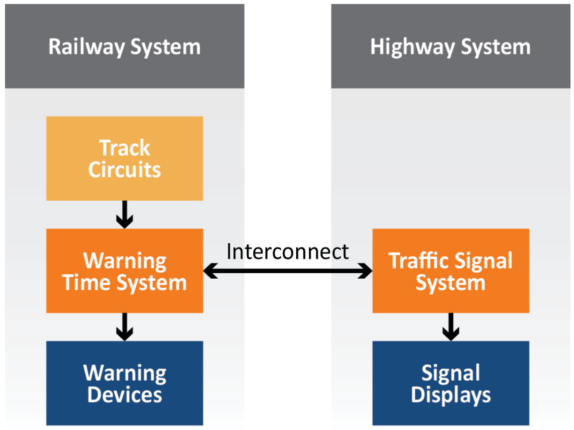


FIGURE 2 Highway–rail preemption system major components. *Source*: Kittelson & Associates, Inc.

The TCGI calculation involves many considerations including minimum green, pedestrian clearance, vehicle clearance, clear storage distance, minimum track clearance distance, design vehicle, vehicle-gate interaction, and others; details of the calculation are not included in this synthesis. More sophisticated systems provide longer advance notice and allow more orderly termination of operations, including, for example, not leaving phases sooner than necessary and providing full pedestrian clearance time (CT).

IMPORTANT CONCEPTS AND TERMINOLOGY

Before providing a more technical description of how these processes can and do work, it is necessary to define terminology and explain conventions used throughout this synthesis. In most cases, railway operations are kept separate from roadway operations, but the two must interact to allow the crossing to be clear of vehicles when a train arrives.

Railway Outputs

Circuits can be used to monitor the track approaches and send information to the railway warning time system and highway traffic signal system. Figure 3 illustrates the different outputs that can be used for railway preemption; note that times are shown for example purposes only. Throughout this synthesis, the railway outputs (RO) will be numbered in chronological order as shown in Figure 3 and used consistently, regardless of the actual number of railway outputs provided to the highway system. The use of a railway output numbering system is necessary because some implementations use more than one railway output, adding complexity beyond the more traditional single railway output.

Minimum Warning Time

In order to know how much time is available for a signal to clear vehicular queues that may be present over the track(s), a practitioner must first know the minimum warning time (MWT) required to activate the railway warning devices; it also known as prescribed warning time in Part 234 of Title 49 of the 2016 *Code of Federal Regulations* (49 CFR 234). MWT is defined as the least amount of time that warning devices shall operate prior to the arrival of a train at a highway–rail grade crossing, and occurs at the same time as railway output 2 (RO2, as per Figure 3). 49 CFR 234 requires that warning time be tested annually by railway agencies or when the warning system is modified.

MWT is the sum of a minimum time (MT) and a clearance time (CT), as shown in Eq. 1. According to the AREMA *Communications & Signals Manual*, the MT is a set value of no less than 20 seconds

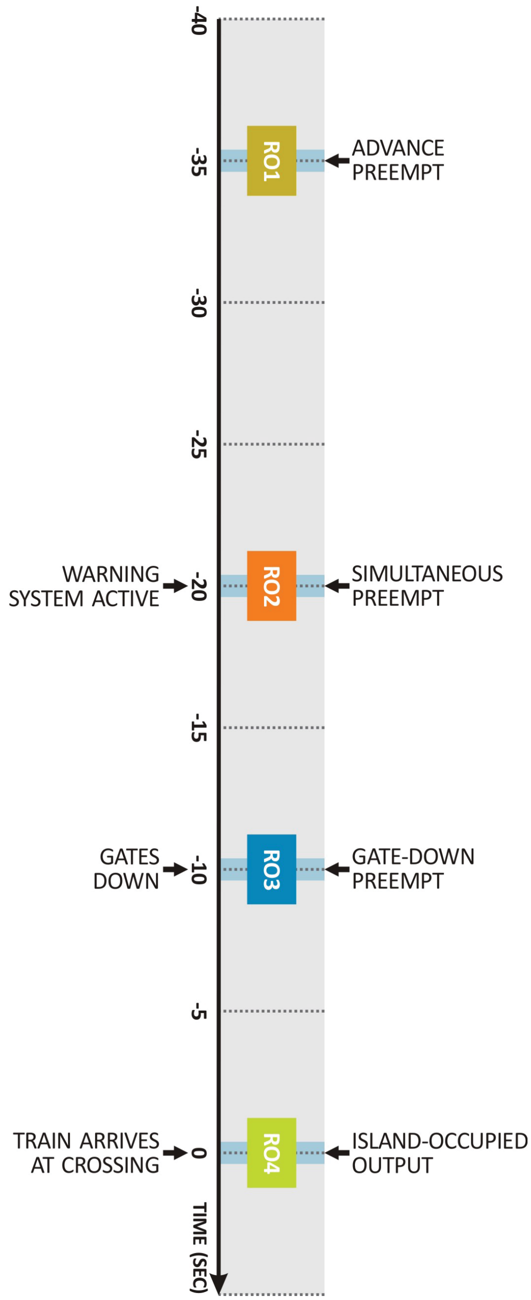


FIGURE 3 Railway outputs. *Source*: Kittelson & Associates, Inc.

as prescribed by the 2009 FHWA *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD), whereas the CT is variable depending on the minimum track clearance distance. Additional clearance time can also be requested by the highway agency, subject to approval by the railway agency.

$$MWT = MT\ (20\text{ seconds}) + CT\ (\text{if required}) \tag{1}$$

where

MWT = minimum warning time (seconds),
MT = minimum time (20 seconds), and
CT = clearance time (seconds).

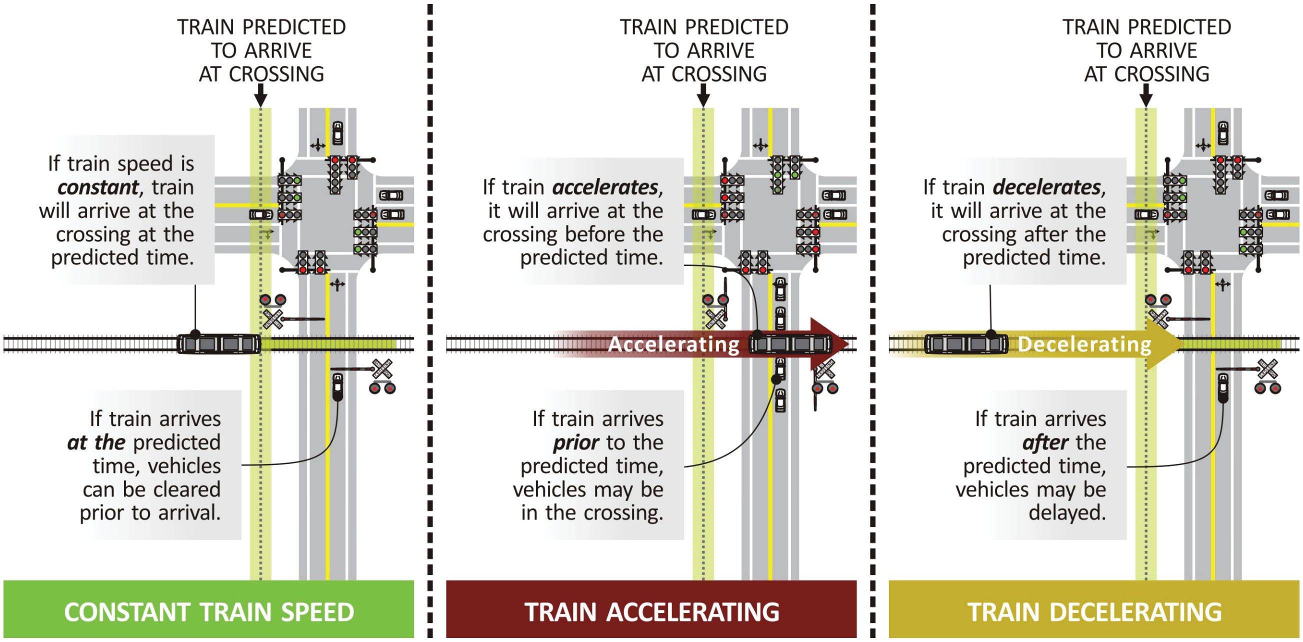


FIGURE 4 Effects of constant train speed, acceleration, and deceleration. *Source*: Kittelson & Associates, Inc.

Depending on highway and railway agency practices, an upper limit for MWT in the range of 35 to 45 seconds may be imposed. Some states have allowed longer times through the use of such tools as four-quadrant gates, median barriers, and traffic conversion to one-way streets.

Constant warning time (CWT) railway detection systems; that is, grade crossing predictors, can generally provide reasonably consistent warning times for this notification if trains are moving at a relatively constant speed (see Figure 4). However, areas with nearby switching are not able to provide consistent warning times because of the variability in train speeds; trains often accelerate or decelerate in switching areas, or as they move into or out of stations or sidings.

Railway Preemption Actions

The actions highlighted in Figure 5 will be used throughout the following section to describe preemption on both the railway and highway sides. Use of colors will be carried throughout to explain various concepts. For example, the time required for right-of-way transfer will be shown in red as highlighted in Figure 5.

Simultaneous Preemption

There are multiple ways that a traffic signal controller can transition a signalized intersection before a train's arrival, but they all depend on the available railway outputs. Most systems use a single preempt that is immediately implemented by the traffic signal controller as the railway warning system is activated (i.e., crossing lights begin to flash). This most basic form of preemption is called simultaneous preemption; Figure 6 demonstrates the concept, with the simultaneous preempt labeled as RO2. Multiple preempt systems will be discussed in chapters three through five.

Entry into traffic signal preemption is the most critical stage of the railway preemption process. In this stage, the right-of-way is transferred to the track clearance green interval (TCGI), which is the green interval associated with the signal phase(s) that clear vehicles queued on the track(s). The time required to transfer the right of way to the TCGI (from the time preemption is activated in the traffic signal controller) is known as the right-of-way transfer time (RTT). The components of RTT include the minimum allowable green for the current conflicting vehicle green phase, the

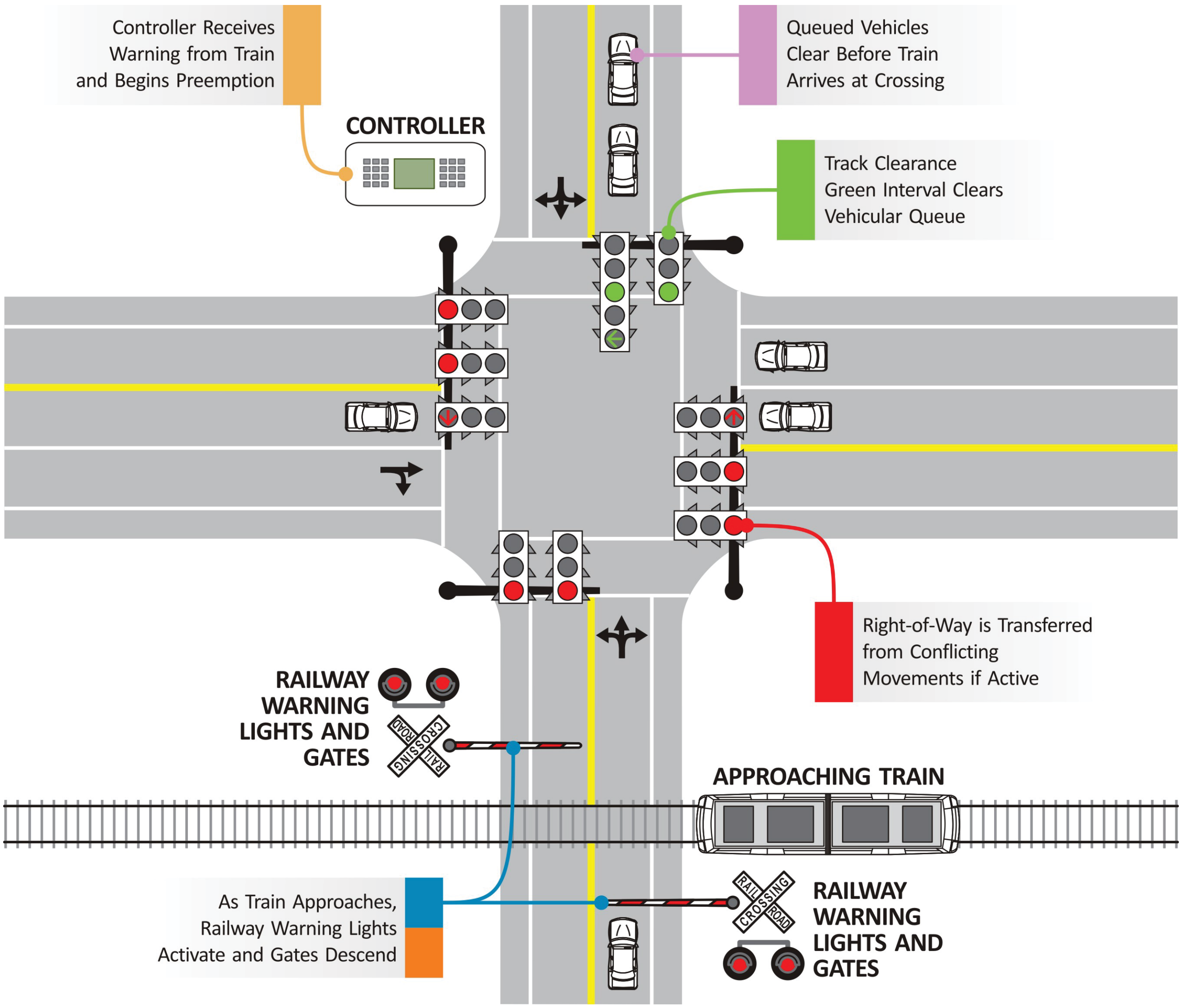


FIGURE 5 Railway preemption actions at an at-grade crossing. *Source*: Adapted from *NCHRP Report 812: Signal Timing Manual*, Second Edition (Urbanik et al. 2015).

time required for the pedestrian clearance if active (if agency policy is to serve the pedestrian phase during preemption), and the time required for the yellow change and red clearance intervals of the active conflicting phase.

The RTT plus the time to clear the vehicular queue must be less than the MWT under simultaneous preemption. Otherwise, vehicles could still be on the track(s) when the train arrives. Many agencies, as allowed by the MUTCD, choose to reduce RTT by not serving (i.e., truncating) pedestrian clearance and/or reducing minimum green to as little as zero seconds. When simultaneous preemption cannot meet MWT needs, advance preemption can be used. Alternatively, some highway agencies will ask for additional CT to allow for more RTT; this is subject to the maximum value that is agreeable to the railway agency.

Advance Preemption

Simultaneous preemption, while common, often requires the shortening of minimum green times and pedestrian clearance times, even if additional CT is provided by the railway agency. The situations in which simultaneous preemption may not be adequate include when it is undesirable for a

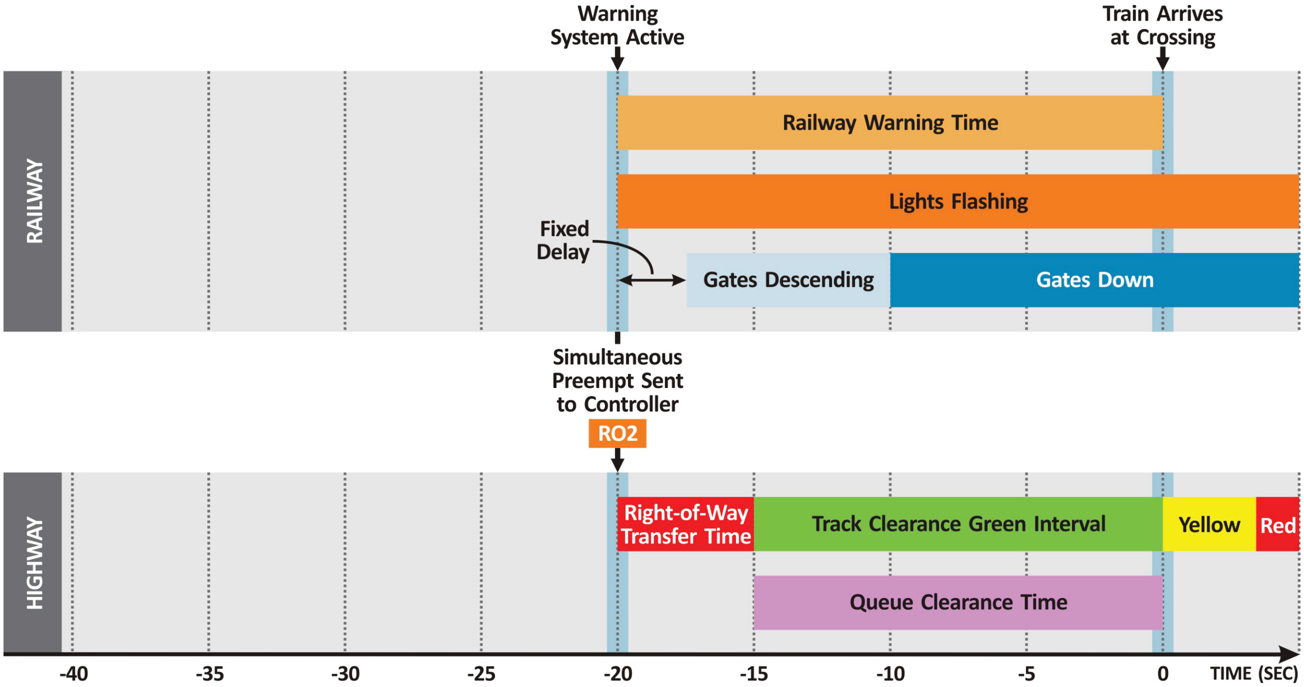


FIGURE 6 Design simultaneous preemption. *Source*: Kittelson & Associates, Inc.

pedestrian phase to be truncated; or when longer queue clearance times require longer TCGIs. Long TCGI queue clearance times may result from substantial space between the intersection and the crossing or when the queue has vehicles with longer start-up lost times (such as trucks).

In such cases, a practitioner can request an advance preemption output from the railway agency (labeled as RO1 in Figure 7), in order to have additional time to transition traffic signal operations. In the example shown in Figure 7, the design RTT ends before the railway warning system is active,

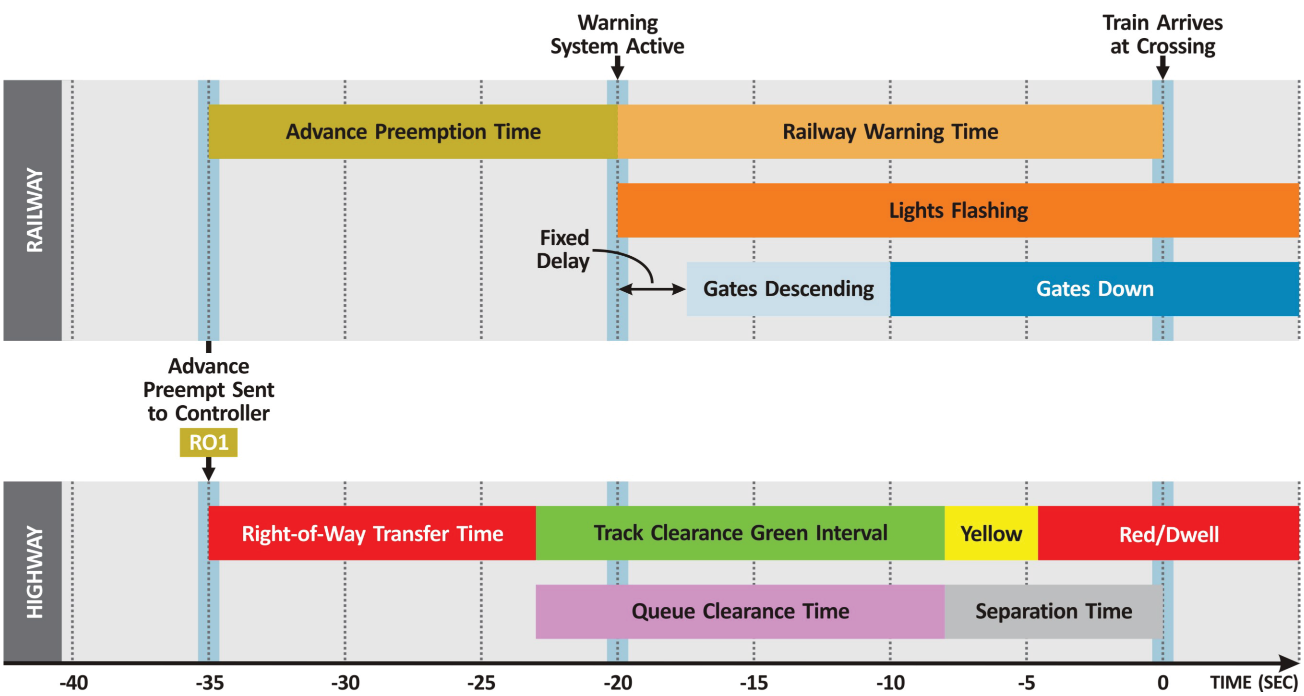


FIGURE 7 Design advance preemption. *Source*: Kittelson & Associates, Inc.

which may or may not be the case in all situations. This example design also provides a separation time after the design vehicle clears the crossing and the train is predicted to arrive. Although separation time is desirable, it is not a requirement and difficult to achieve without a long RTT.

It is important to note that advance preemption is not seen favorably by some agencies because of the potential for a preempt trap (more information provided in chapter four; reference *NCHRP Report 812: Signal Timing Manual, Second Edition* for a complete explanation (Urbanik et al. 2015). Although advance preemption can be avoided in some cases by increasing CT, simultaneous preemption cannot always accommodate longer RTTs required at some locations. It will be seen in the case examples in chapter seven that there are efficient ways to operate a traffic signal using multiple railway outputs to prevent a preempt trap. However, even if a highway agency would like to use advance preemption, some railway agencies may be unwilling to provide multiple outputs (despite being included in the AREMA *Communications & Signals Manual*). This was the case in the Ohio case example in chapter seven.

Traditional Immediate and Smart Preemption

There are two terms (not in current use) that will be used throughout this synthesis in order to clarify the type of railway output being used by the traffic signal system in some highway agencies.

"Traditional immediate preemption" requests that immediate action be taken by the traffic signal upon receipt of the railway output. Historically, this could be an advance request or a simultaneous request, not both.

"Smart" preemption involves receiving information before the railway warning devices become active, but not implementing an immediate termination of current activities at the traffic signal. Instead, the controller implements the TCGI no later than necessary, while also maintaining current operations if there is enough time. Smart preemption requires more than one railway output. This type of preemption is only possible in more state-of-the-art systems and requires collaboration between the highway and railway agencies to achieve a mutually acceptable solution.

Smart preemption is a form of traffic signal operation that is similar to priority control used in transit applications, which is discussed in *NCHRP Report 812*.

CHAPTER THREE

RAIL SYSTEMS

The primary pieces of the railway system (see Figure 3) are the detection system (i.e., track circuits), the warning time system, and the warning devices (i.e., lights and gates). A state-of-the-art detection system like that at the Los Angeles Department of Transportation (LADOT), described in chapter seven, can provide data to the railway warning time system on the speed and location of a train, whereas older systems can only provide data on the presence of a train anywhere in the track circuit. Using the data from the detection, the railway warning time system evaluates the train's location over time and predicts its arrival at the crossing. The railway warning time system then notifies other systems, including the grade crossing warning devices and the traffic signal system, when the train's predicted arrival time is equal to the design value programmed in the railway warning system.

For the purposes of this synthesis, this chapter focuses on railway warning time systems with lights and two-quadrant gates as well as constant warning time track circuits that predict the arrival of trains (typically used by mainline railway agencies). It is important to note that some transit railway cannot use the CWT systems described in this synthesis. Although complex systems exist (e.g., four-quadrant gates), they are specialized applications requiring specialized skills. This synthesis focuses on the operational capabilities of typical mainline railway systems, not the many design details necessary for specialized applications (e.g., detection systems not based on track circuits or intersections requiring preemption on multiple approaches).

TYPES OF DETECTION SYSTEMS

Monitoring the track approaches to a highway–rail grade crossing is the typical means of detecting the approach of trains. Historically, railway agencies have used simple direct current (DC) circuits in three regions—the approach from each direction and the island (as shown in Figure 8).

Simple motion-sensitive DC circuits are still used at many crossings today (Ogden 2007), but they only measure a train's presence in the track circuit and if it is moving. The time it takes a train to arrive at the crossing from when it is detected depends on its speed, but simple motion-sensitive presence detection has to activate the grade crossing warning devices and preemption at the traffic signal based on an assumed travel speed. In order to be conservative, the circuit length is constructed based on the fastest train so that there is enough time to meet MWT requirements. That means that if there is a situation where a track circuit has been constructed to provide 20 seconds of warning time for a train traveling at 60 mph, the slowest train traveling at 30 mph may arrive at the crossing 20 seconds after it was predicted to arrive; however, this variability could be significantly greater.

Although there are several alternative circuits that may meet special needs, a CWT system or grade crossing predictor currently provides information about both train speed and distance from the crossing. A CWT system measures speed at a single point and activates the appropriate railway outputs based on the predicted arrival time (calculated from the location and speed measurement). However, even though a CWT system bases the train arrival on a measured speed, if the train accelerates or decelerates after activation, the arrival time will still be sooner or later than the calculated value.

Variability in train arrival time caused by speed variation is addressed by railway agencies through buffer time (BT). The railway may indicate to the highway agency that the required warning time is 20 seconds—i.e., vehicles should be cleared from the track(s) within 20 seconds. However, the

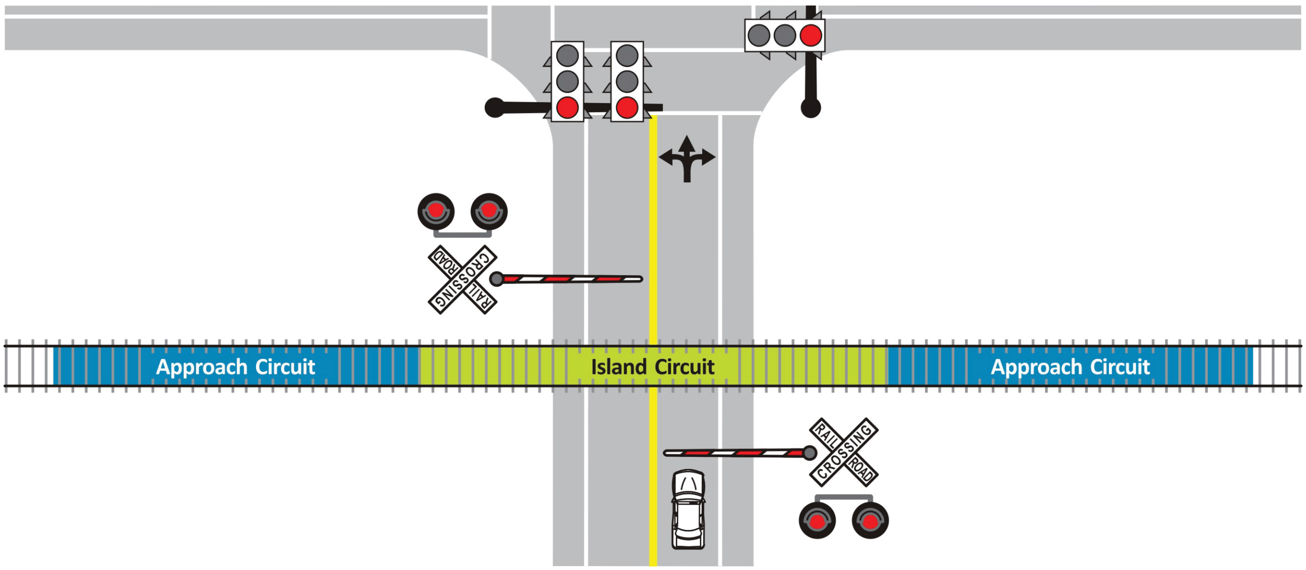


FIGURE 8 Track circuits. *Source*: Kittelson & Associates, Inc.

railway may add five seconds of BT to assure the 20 seconds is generally met. This means that under typical field conditions, a train may be moving at a constant speed and the highway agency may observe that it takes the train 25 seconds to reach the crossing after preemption activates instead of the designed 20 seconds of warning time. Although it might appear that there are five seconds of unused time, there may not be 25 seconds of warning time available to the highway agency because trains may, on some occasions, be speeding up as they approach the crossing. The highway agency should verify preemption design times with the railway agency, not from field observation.

TYPES OF INTERCONNECT CIRCUITS

While the many details of interconnect circuits are beyond discussion in this synthesis, the basic principles and important alternative concepts are discussed relative to traffic signal operations. Preemption at the traffic signal can be operated differently depending on the types and number of outputs provided by the railway warning time system (options described in chapter four). Note that not all of these outputs may be available at a particular location; the outputs will depend on the specific location, highway agency requests, and railway agency policies.

Simultaneous Preemption Circuit

The simplest railway systems predict the time at which the train is at the design MWT point on the approach (actual value may vary owing to BT and train speed variability). When this event occurs, the railway system activates the railway warning system using a relay, known in the railway industry as the "XR" or "XC." This is the same process that activates the simultaneous preempt relay for the traffic signal, that is, railway output 2 (RO2) in Figure 3. Note that it may either be the only railway output or one of several.

Advance Preemption Circuit

As discussed in chapter two, simultaneous preemption may not provide adequate RTT to meet the required TCGI in many conditions based on highway and railway agency practices, particularly considering pedestrian clearance intervals and vehicle queue clearance times. To provide more time for the traffic signal to finish timing these clearances, advance preemption time (APT) can be provided. APT is obtained by extending track circuits to detect trains at a greater distance than required for the MWT. APT is railway output 1 (RO1) in Figure 3.

The APT is provided to the traffic signal before the railway warning system is activated, so that the traffic signal system can begin an immediate preemption to clear vehicles off the track(s) (described in more detail in chapter four). The railway warning time system then uses a second prediction to determine when to activate the warning devices (RO2). In simple APT systems, RO2 is only sent to the railway warning devices; in some systems, RO2 is also sent to the traffic signal system.

In theory, the time between the APT and when the warning devices activate is to be equal to the APT in the system design, but the warning devices may activate sooner (if the train speeds up) or later (if the train slows down). This variability can be addressed in several ways, as discussed in detail in chapter five.

Gate-Down Circuit

A concept that can be used to address the preempt trap (discussed in chapter four) and the variability in train speeds is called gate-down (GD) confirmation. Although there are other methods (*NCHRP Report 812*), they are less efficient from an operational standpoint. The GD concept allows the TCGI to dwell in green until the gates are down and then time the final portion of the TCGI. Use of the GD output (RO3) creates an additional complication if the gates are not confirmed to be down (e.g., broken gate). If the GD output is not given as a result of a broken gate, the dwell in TCGI will continue until the preempt is lifted by the railway warning time system.

This gate issue can be addressed in two ways. The first way is to “wrap” the island circuit with GD (i.e., parallel outputs) so that the GD output is provided by the island circuit output if GD is not confirmed. A simpler solution is to dwell in TCGI until the railway warning system is active (RO2) and then time the final portion of the TCGI using the time required for the gates to drop (10–15 seconds) plus the amount of time for the TCGI to continue after the gates are down (also discussed in chapter four). This approach provides the same desired TCGI regardless if the gates are broken or not.

Island Circuit

The railway uses the island circuit to know when a train is in the crossing and when it leaves, so it can terminate the railway warning system. The island circuit (RO4 in Figure 3), whether used with GD or alone, can provide an important piece of data for operational understanding. First, it can be noted that the island circuit is larger than the roadway width, so the circuit is active a few seconds before the train enters the crossing. This provides a margin of safety for railway system operations, as the railway agency uses the island-circuit output to turn off the warning devices once the train leaves the island circuit.

The highway authority may request the island-circuit output, but the railway agency may or may not be willing to provide it because it is optional in the AREMA *Communications & Signals Manual*. If provided, the highway authority can use the island-circuit output to better understand the actual time relationships of various railway outputs. This is helpful in understanding railway “train-handling” issues resulting from variable speeds or switching activities. It can also provide information on false preemption calls. The Portland case example in chapter seven demonstrates how multiple outputs (including GD and island-occupied systems), along with traffic signal controller data, can be used to understand train-handling issues.

CHAPTER FOUR

TRAFFIC SIGNAL SYSTEMS

This chapter focuses on how traffic signals near highway–rail grade crossings use railway outputs to clear vehicles from the track(s). It is important to understand that over the past six decades, the "area near grade crossings" has had various definitions. The 1948 MUTCD suggested that preemption be considered for traffic signals within 500 to 1,000 feet of a railway crossing. In the 1961 MUTCD, the distance was reduced, for reasons that are not documented but may have reflected the complexity of dealing with larger distances, to 200 feet. The 1988 version indicated that preemption be limited to 200 feet except under unusual circumstances. However, the 2000 MUTCD added language that stated coordination with the flashing-light signal system be considered for traffic control signals located farther than 200 feet from the highway–rail grade crossing. Factors to be considered include traffic volumes, vehicle mix, vehicle and train approach speeds, frequency of trains, and queue lengths.

Figure 9 illustrates the case where there is an immediate simultaneous preemption (RO2) occurring when the warning devices become active and the traffic signal is already in the TCGI. If preemption is activated when the controller is in the same phase as the TCGI, the actual right-of-way transfer time is zero (Urbanik et al. 2015), as shown in Figure 9.

Although a RTT of zero seconds may give a first impression of an acceptable scenario, Figure 10 illustrates that for immediate advance preemption (RO1), the TCGI can terminate before the lights start to flash and the gates start to come down (Urbanik et al. 2015). In what is referred to as the "preempt trap," a queue may form over the track before the gates descend. Once the gates lower, the queue between the gates and the intersection will not be served by the controller until preemption is removed, potentially leaving the vehicles stranded on the track(s). In addition, actual advance preemption time may be longer than its design value as a result of decreased speeds as the train approaches the crossing. This extended APT furthers the potential negative effects of the preempt trap if the TCGI is shorter than the actual APT.

ADDRESSING THE PREEMPT TRAP

In order to eliminate the preempt trap and reduce the resultant safety concerns, several treatments can be implemented using existing railway and traffic signal technology (see *NCHRP Report 812* for additional information). One such treatment is the installation of a not-to-exceed timer by the railway operation that forces the railway warning devices to activate no later than the end of the design APT (*Communications & Signals Manual* 2016). Implementation of the not-to-exceed timer should be coupled with a TCGI duration in the traffic signal controller that is at least equal to the APT. This strategy ensures that irrespective of both the variability in train speed and the corresponding APT, the railway warning devices will be activated before the TCGI ends, reducing the potential for vehicle queues over the track(s). This approach can result in much longer than necessary TCGIs.

Another approach incorporates the gate-down output from the railway system into the traffic signal controller as a second preempt (RO3), as shown in Figure 11 (Yohe and Urbanik 2007; Sun et al. 2008). With this treatment, the controller receives the conventional advance preemption call, times RTT if any (in this example, actual RTT = 0), and holds (i.e., dwells in) the TCGI until a second preempt is received from the railway informing the controller that the warning gates are down. The GD preempt, assigned a higher preempt priority, releases the green hold resulting from the advance preempt and enters a timed TCGI (Engelbrecht et al. 2002).

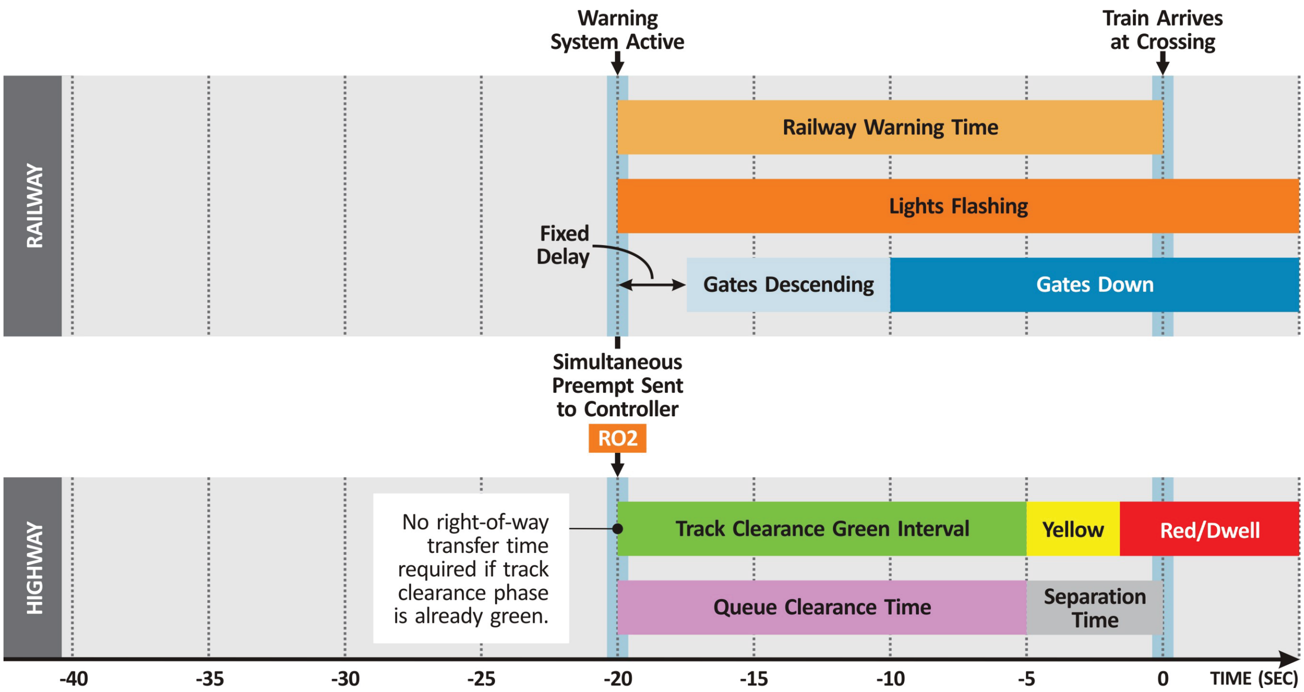


FIGURE 9 Simultaneous preempt operation with no right-of-way transfer time. *Source*: Kittelson & Associates, Inc.

A simpler alternative to the GD preempt is the use of a simultaneous preempt (i.e., railway warning system active) output (RO2) as a second preempt in addition to the advance preempt (RO1) to time the final design TCGI, as shown in Figure 12. This alternative begins the design TCGI when the warning devices are activated. Additional time for the gates to come down can be added to the timed TCGI in Figure 11 to account for the time required for the gates to descend. Note that Figure 12 illustrates a RTT of zero when the advance preempt occurs.

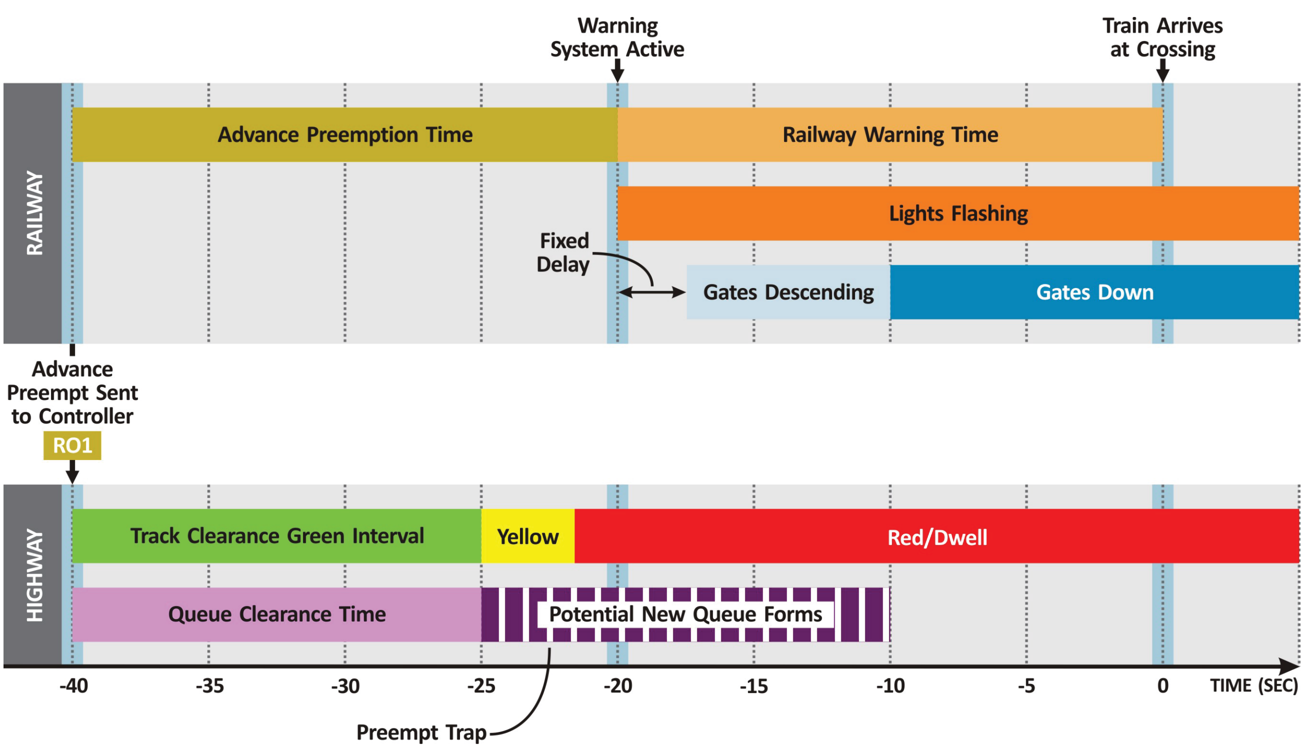


FIGURE 10 Example of preempt trap when RTT is zero and there is no mitigation. *Source*: Kittelson & Associates, Inc.

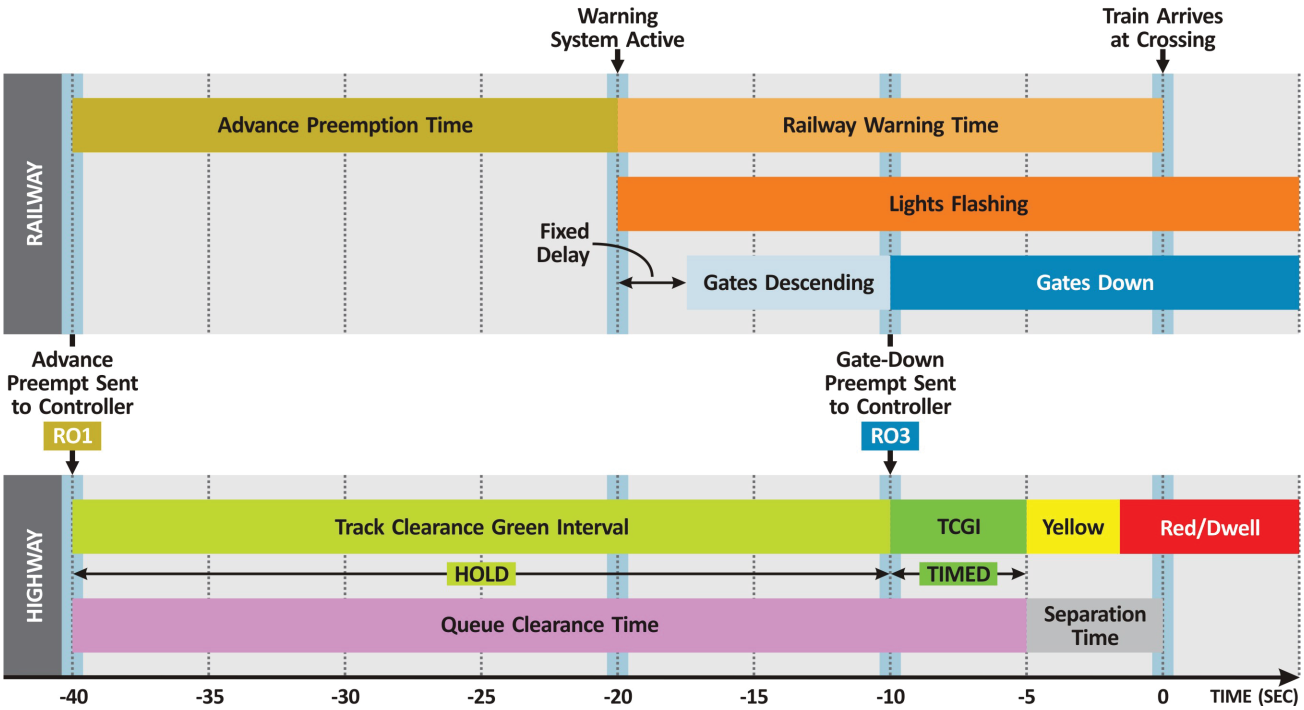


FIGURE 11 Gate-down preempt operation. *Source*: Kittelson & Associates, Inc.

Another approach is a "smart" traffic signal controller sequence (described in chapter two) following the advance preempt (Sun et al. 2008). This "smart" preemption approach is discussed in the California case example in chapter seven. The city of Portland, Oregon, also has a complex intersection with a smart implementation of multiple railway outputs. The operation includes two railway outputs before the warning system is active as well as gate-down, island-occupied, and traffic signal health. The concept, which has a number of practical benefits, is detailed in chapter seven.

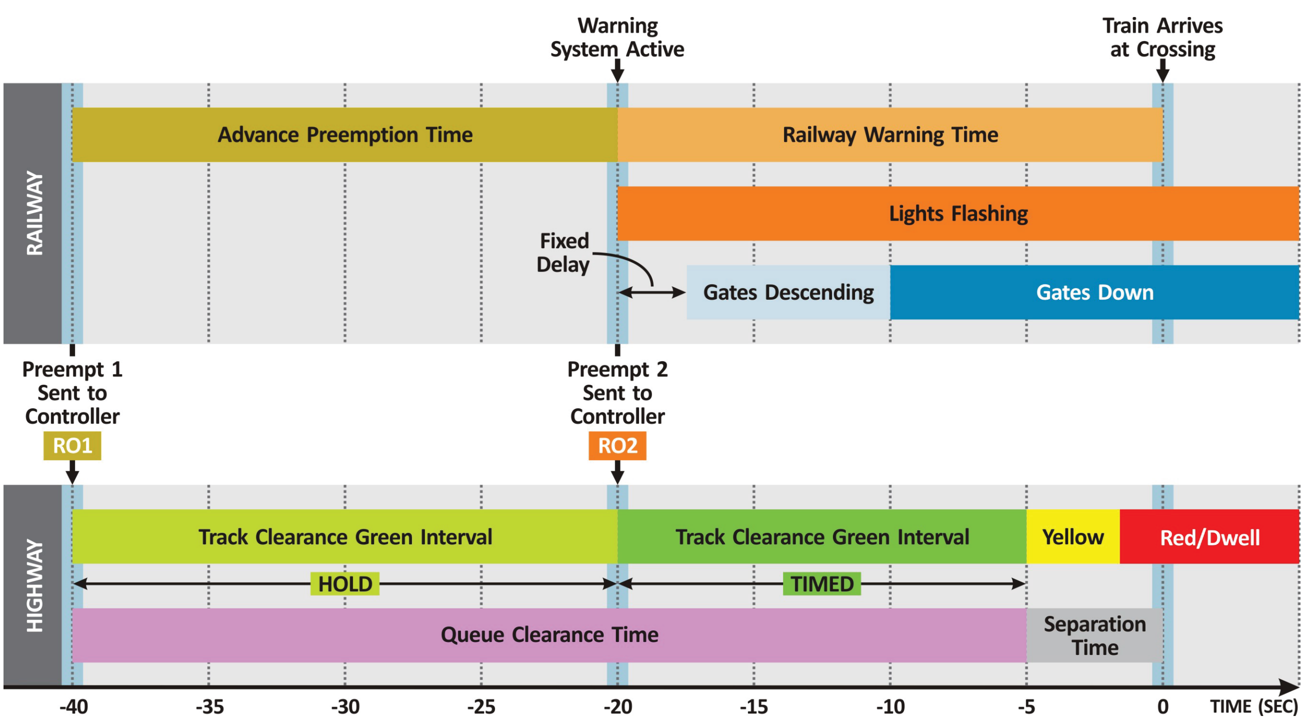


FIGURE 12 Two-preempt operation [Preempt 1 (RO1) and Preempt 2 (RO2)]. *Source*: Kittelson & Associates, Inc.

QUEUE MANAGEMENT

Queue management is a proactive approach to reducing the potential for vehicles stopping on the railway track(s). This is often addressed using pre-signals or queue cutters. Both techniques have strengths and weaknesses. The Utah Department of Transportation (UDOT) has provided guidance on this topic in *Preempting Traffic Signals near Railroad Crossings in Utah, A UDOT Manual*.

Pre-Signals

A pre-signal is a supplemental traffic signal head that is operated as part of the nearby intersection traffic signal, located in a position that controls traffic approaching the highway–rail grade crossing and signalized intersection (Korve 1999). Figures 13 and 14 demonstrate the operation of a pre-signal at an at-grade crossing when it is used in combination with two preempts (RO1 and RO2).

MUTCD guidance suggests that if the traffic signal is located within 50 feet (or 75 feet if multi-unit vehicles regularly cross at the grade crossing), consideration should be given to use of a pre-signal. If a pre-signal is used, it should display steady red during the TCGI. The pre-signal operation may also include a timed offset from the downstream intersection in order to keep the area between the track(s) and the intersection clear of stopped vehicles every traffic signal cycle. When appropriately timed, the space between the crossing and the downstream stop bar would be cleared every cycle. In addition, detection can be added for unusual conditions to further extend the green time for the downstream intersection if needed.

An extensive discussion of pre-signals can be found in the *Railroad-Highway Grade Crossing Handbook* (Ogden 2007). Several states, including Illinois, Michigan, South Carolina, and Ohio, have standards for pre-signals when crossings are close to signalized intersections. Michigan uses pre-signals without a TCGI (Alroth et al. 1999).

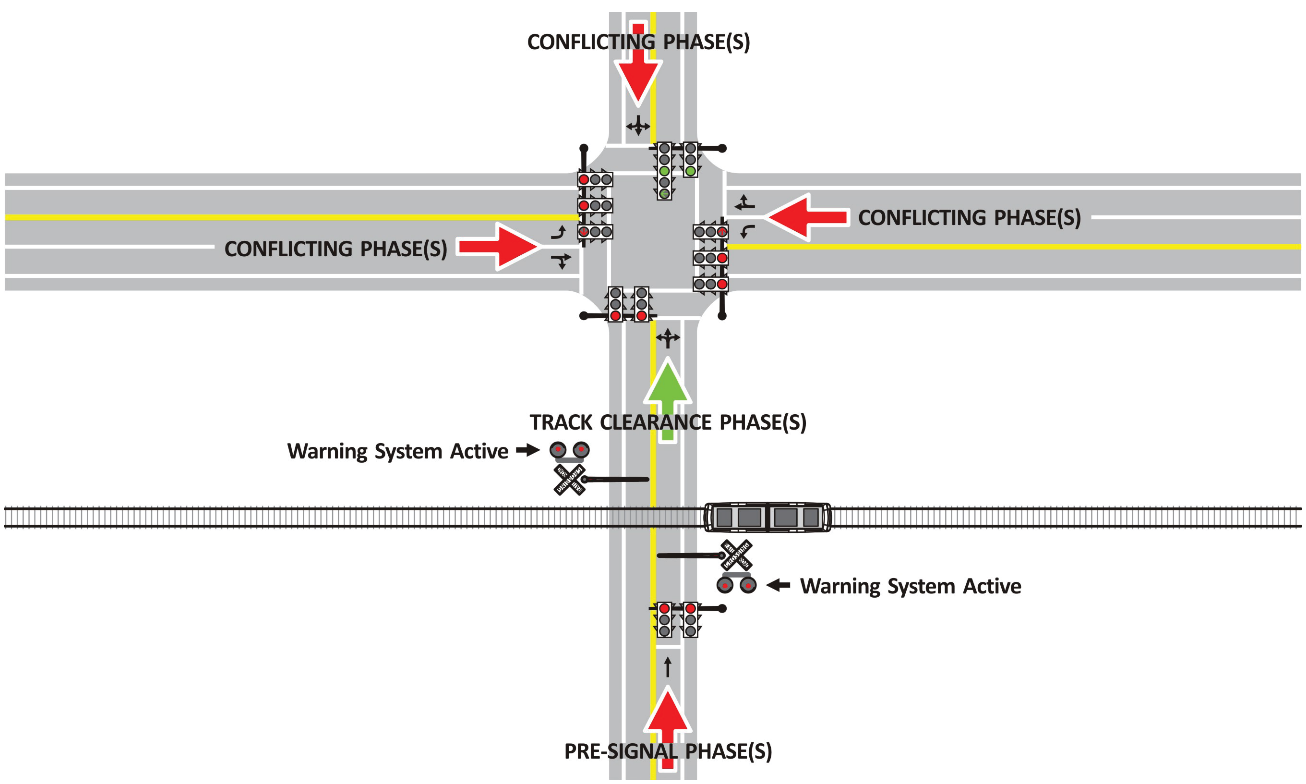


FIGURE 13 Example of a pre-signal at an at-grade crossing. *Source*: Kittelson & Associates, Inc.

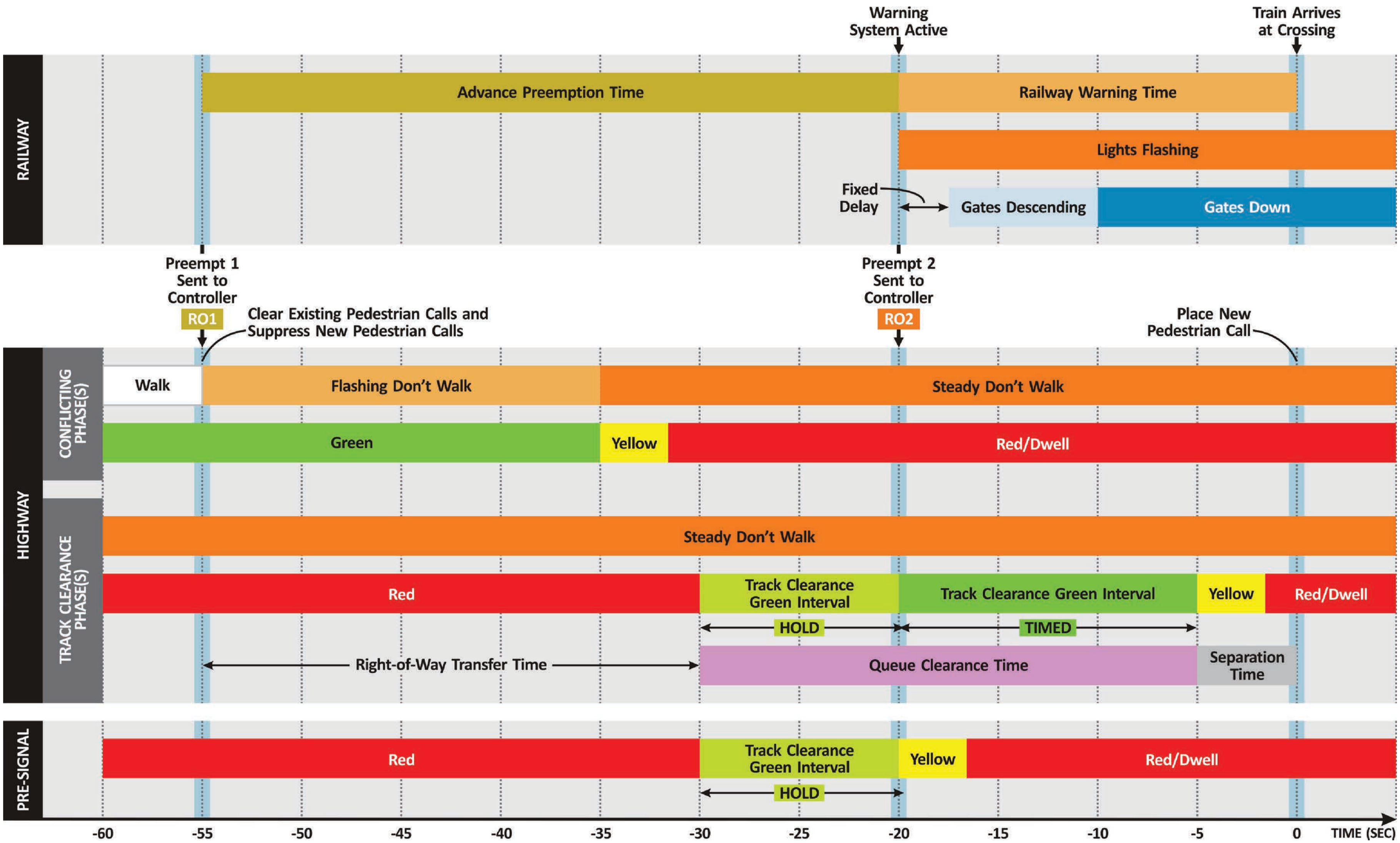


FIGURE 14 Example of a pre-signal with two-preempt operation [Preempt 1 (RO1) and Preempt 2 (RO2)]. *Source*: Kittelson & Associates, Inc.

Queue Cutters

The use of queue cutters is less common. Definitions of queue cutters include a separate traffic control signal upstream of a grade crossing that is:

- Intended to prevent vehicular queuing across the track(s) at a highway–rail grade crossing where traffic queuing occurs;
- Activated for one direction of travel by either an approaching train or actuation from downstream queue detection; or
- Activated independently of or coordinated with an adjacent intersection traffic control signal.

The intention is to react to building queues from a downstream signal in order to prevent queuing across the track(s) at locations that are at distances that make conventional preemption problematic. Either proactively, or in concert with preemption, queue cutters aim to prevent queuing across the track(s) by essentially storing excess vehicular demand upstream of the railway crossing. They can also be used upstream of roundabouts near grade crossings.

CHAPTER FIVE

INTERCONNECTION

Interconnection is the process by which the railway system communicates with the traffic signal system, as shown in Figure 3. Historically, the interconnection has been a simple two-wire preempt. Even this simple circuit comes in at least two types, which will be discussed in more detail in the following section. Conversely, the most sophisticated communication involves serial communication using IEEE 1570-2002, which allows for two-way communication, multiple data items, and the ability to update the data over time.

SIMPLE SINGLE-PREEMPT CIRCUITS

The simplest preemption circuits basically call for “preempt” or “don’t preempt.” However, this simple circuit has been implemented in two ways: normally open or normally closed. The MUTCD standard (Section 8C.09) calls for the circuit to be normally closed (i.e., the relay has power applied to keep the circuit closed), indicating no train. In that case, the loss of power (for instance, if the cable is cut) opens the circuit and sends the traffic signal into preempt. The power source can be either AC (typically 120 volts) or DC (typically 24 volts). Because 120 VAC is readily available, it is commonly used. However, DC control circuits pose less risk for maintenance personnel.

In a typical design, the traffic signal cabinet provides 120 VAC to the railway cabinet to power the preempt relay. The normal state of the preempt relay would be closed until the railway warning time system detects a train and decides when to preempt the traffic signal by opening the preempt relay. Opening the railway-preempt relay removes power from the traffic-signal-preempt relay, which subsequently opens the traffic-signal-preempt relay.

Figure 15 shows the operation of these two-wire circuits and their associated relays. This is the most basic and common interconnection. The primary limitation of this circuit is that the circuit can be compromised if the two wires are shorted together, preventing the traffic-signal relay from recognizing a call. A supervised circuit monitors the health of the electrical interconnection between the railway warning system and the traffic signal system, and is an alternative to a simple normally closed circuit, as indicated in the MUTCD standard. There are a number of supervised interconnect circuit designs that can address most of the failure modes. Discussion of the many alternative designs is beyond the scope of this synthesis, as there are no typical implementations. Supervised circuits are discussed further in chapter five.

MULTIPLE-PREEMPT CIRCUITS

To improve traffic signal operation during preemption, some agencies have upgraded their practice to receive multiple preempts from the railway warning time system. These additional railway output circuits do not require train-detection circuits beyond those needed for advance preemption. The advance preemption circuit (RO1) can provide additional time to address the largest design RTT when simultaneous preempt cannot meet agency requirements. Because the railway agency has to activate the railway warning devices, a second preemption circuit (RO2) can readily provide a second preemption to the traffic signal system when the railway warning system becomes active.

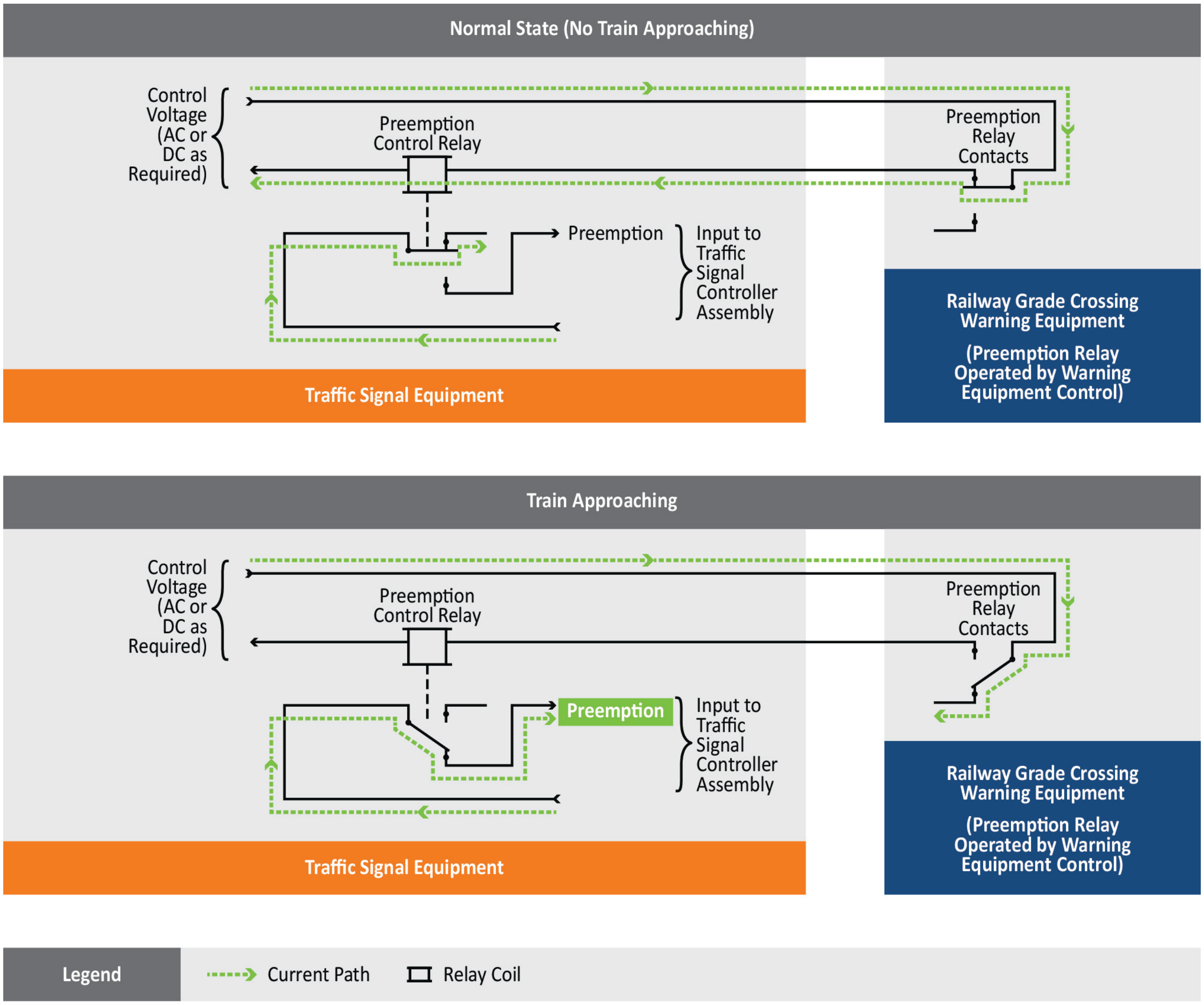


FIGURE 15 Simple two-wire interconnection (normally closed). *Source*: Adapted from Mansel et al. (1999).

The railway can also provide a gate-down output (RO3), but this requires additional railway logic to determine when all the gates are down and provide a backup output (i.e., gates broken) when the island is occupied. As noted in chapter four, a simultaneous preempt output (RO2) can be substituted for the GD circuit, with the only change being added time for the gates to reach a horizontal position (10–15 seconds). The last railway output that can be used by the traffic signal system is the island circuit. This provides train arrival information at the crossing.

SUPERVISION

To provide a fail-safe design, the preempt interconnect should be held closed, or energized. A circuit failure (for example, a simple break) results in a preempt request. However, because the interconnect cable can be compromised in several ways (shorts, loose connections, or open circuits), supervision is desirable. Double-break relays offer the most protection because energy switches between positive and negative energy. Because of the large number of different solutions available, specific supervised circuit designs will not be provided in this synthesis. The practitioner should understand that although supervision improves safety, relay-based designs get more complicated as the number of railway interconnection circuits increases.

ADVANCED SYSTEMS

Typical interconnection systems are based on relays in the railway warning time system and the highway traffic signal system. Although relay-based systems are extremely reliable, there are more state-of-the-art approaches to interconnection that increase functionality. The IEEE 1570-2002 interface is designed based on fail-safe and closed-loop principles, and is flexible enough to accommodate both current practice and additional functionality. The only significant implementation is the LADOT system's serial communication to the traffic signal controller using RS-232, RS-422, or RS-485 systems, which is discussed in chapter seven.

A second advanced system, also designed based on fail-safe and closed-loop principles, operates on the traffic signal side, residing in the traffic signal cabinet. It is a parallel interconnect with separate circuits for each railway output, using typical 14 AWG traffic signal cable in conduit. The interface in the traffic signal receives the railway outputs and intelligently processes them, sending several processed preempts to the traffic signal controller (typically preempts 1-6). The interface includes intelligent supervision, control of auxiliary devices such as preempt confirmation lights, and data recording options. The system can also provide traffic signal health to the railway, allowing earlier activation of the railway warning time system in the case of traffic signal failure.

CHAPTER SIX

INSTITUTIONAL ASPECTS

This chapter presents common regulatory and organizational issues related to preemption and information on traffic signal management. For more information, refer to the *Railroad-Highway Grade Crossing Handbook* (Ogden 2007), which contains extensive information about the institutional aspects of highway–rail grade crossings, including history, safety, funding, responsibilities, and legal considerations; and *Traffic Signal Management Plans, An Objectives- and Performance-Based Approach for Improving the Design, Operations, and Maintenance of Traffic Signal Systems* (Fehon and O'Brien 2015). For guidance on prioritizing interconnection at signalized intersections near highway–rail grade crossings, refer to "A Decision Tree Model to Prioritize Signalized Intersections near Highway-Railroad Crossings for Railroad Interconnect" (Brennan et al. 2010).

REGULATORY CONSIDERATIONS

As part of "Highway-Rail Grade Crossings Overview," FRA identified that in 2015, there were 129,582 public crossings and 80,073 private crossings in the United States. Most jurisdictional aspects related to highway–rail grade crossings reside with the states. However, how responsibility is assigned varies widely from state to state. Within some states, the responsibility is divided between several public agencies. In others, jurisdiction over highway–rail grade crossings is assigned to a regulatory agency such as the public utility commission, public service commission, or state corporation commission. Still other states divide the authority among public administrative agencies of the state, county, city, or town, assigning jurisdiction based on the agency responsible for the highway. State and local law enforcement agencies are responsible for the enforcement of traffic laws at highway–rail grade crossings. In a number of cases, local governments are responsible for certain operational matters related to crossings, which is accomplished through various ordinances.

U.S.DOT has published *Compilation of State Laws and Regulations Affecting Highway-Rail Grade Crossings, 6th Edition* (Office of Railroad Safety 2013). This sixth edition is a reference for researchers, engineers, students, and legal practitioners in the field of highway–rail grade crossings safety who are seeking state-specific laws and regulations affecting highway–rail grade crossings. The publication provides an overview of new and existing state laws and regulations as of February 2013. Each chapter presents a different highway–rail grade crossing subject area and contains an introductory overview of the subject; chapter six covers active warning device crossings. State regulations vary widely from no specific requirements to extensive requirements.

Federal requirements are contained in 49 CFR 234. These regulations largely apply to the railway, although they do affect the highway authority in preemption-related applications. The regulations largely cover maintenance, inspection, and testing. Section 234.261: Highway Traffic Signal Pre-emption states: "Highway traffic signal pre-emption interconnections, for which a railroad has maintenance responsibility, shall be tested at least once each month." Section 234.259: Warning Time requires that each highway–rail grade crossing warning time system be tested for the prescribed MWT at least once every 12 months and whenever the warning time system is modified because of a change in speeds. Prescribed warning time is the railway's design warning time less any buffer time and equipment response time. Prescribed warning time is never less than 20 seconds for normal operations.

In October 2010, FRA's Safety Advisory 2010-02 stated that "Railroads should not rely solely on the operation of a relay or the opening of a control circuit to the traffic signal control housing.

In fact, the preferred method of testing highway traffic signal pre-emption is by observation of a train movement and the actual pre-emption function. Therefore, FRA recommends that railroads conduct comprehensive joint inspections of the highway traffic signal pre-emption interconnection with state and local highway authorities." FRA also suggests inspections be done whenever conditions change, but at least once per year. FRA 2010-02 also recommends the use of event recording devices at all new and improved crossings with preemption.

In a February 2016 press release (FRA 04-16), the FRA called on state DOTs to verify that railway crossing warning systems interconnected to traffic signals function properly. The agency also urged states to add event recorders to traffic signals connected to railway crossing systems so information obtained during inspections can be used to improve safety. "Simply put: We strongly recommend that state and local transportation officials, together with railroad officials, visit crossings in their region and monitor and test crossing signals and adjacent traffic signals to ensure that the signals are synced and operating properly."

In October 2012, FHWA published *Recording Devices for Interconnected Grade Crossing and Intersection Signal Systems: An Informational Report* (Moriarty et al. 2012). It contains technical information to assist highway and railway agencies with integrating effective event-recording devices within interconnected/preempted highway–rail grade crossing signal systems. The report covers both railway and highway recording applications.

SURVEY RESULTS OVERVIEW

The synthesis survey, focusing on the breadth and depth of current practice, was emailed to agencies in 49 U.S. states, one United States territory, and three Canadian provinces. Between December 2015 and February 2016, responses were collected from 40 states and one of the three provinces, as well as four Canadian provinces not included in the original survey distribution, who later forwarded the survey from other respondents (reference Figure 1). (Hawaii was not included in the survey because the state has no operating freight or passenger railroads system).

Forty-one (41) of the initial agencies queried provided feedback based on their operation of highway–rail grade crossings, which is summarized throughout the following sections. (Percentages for individual questions are based on the number of agencies responding, as not all agencies responded to all questions.) Topics included general practice, preemption timing practice, grade crossing operations, design practice, maintenance practice, and monitoring activities. Appendix A contains a copy of the online survey, and Appendix B summarizes the responses that were received. Overall results from the survey indicate that there is a wide variation in practice. Three case examples at the end of this chapter focus largely on agencies with advanced or upgraded practices.

GENERAL PRACTICE

Fifty-one percent (51%) of agencies, 21 of 41 respondents, have their own written policy or guidelines on preemption. Several agencies without their own documentation use MUTCD (seven responses) or *Transport Canada Standards* (two responses). Other national guides used as policy proxies include the following:

- *Railroad-Highway Grade Crossing Handbook* from FHWA (Ogden 2007) (two responses)
- *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway Rail Grade Crossings* (Texas Department of Transportation, TxDOT 2003) (two responses)
- *Preemption of Traffic Signals Near Railroad Crossings, A Recommended Practice of the Institute of Transportation Engineers* (Institute of Transportation Engineers, ITE 2006) (one response).

Thirty-eight percent (38%) of agencies, 15 of 39 respondents, have state highway–rail grade crossing action plans. Three agencies commented that their lack of an action plan is related to low crash rates.

Fifty-eight percent (58%) of agencies (22 of 38 responses) have written procedures for contacting the railway agency regarding activities near grade crossings. Fifty percent (50%, 19 of 38 responses) use contract maintenance, and 37% of those (seven of 19 responses) have specific procedures regarding coordination with the railway agency for contract maintenance staff.

Thirty-nine percent (39%) of responding agencies, 15 of 39, have training for maintenance staff. Five respondents noted that training is the responsibility of the local agencies. UDOT has provided comprehensive guidance on railway preemption practices in *Preempting Traffic Signals near Railroad Crossings in Utah, A UDOT Manual*.

RAIL SYSTEMS PRACTICE

Forty-seven percent (47%) of responding agencies (19 of 40) indicated a majority of existing crossings use constant warning time (CWT) systems or grade crossing predictors, with 33% unsure (13 of 40 responses). Sixty-four percent (64%, 25 of 39 responses) indicated that CWT systems or grade crossing predictors are used at new or upgraded locations. Two agencies noted that the rail agency makes the determination whether to use such systems based on technical issues.

Fifteen percent (15%) of agencies, six of 40, use simultaneous preemption exclusively, with 77% (31 of 40 responses) using other types of preemption as well. Two agencies noted that only their older installations use simultaneous preemption, while new installations utilize advance preemption (two responses). For those agencies using simultaneous preemption exclusively, the maximum warning time that is requested varies between zero and 108 seconds. Although the warning time of 108 seconds is used on a high-speed rail system; for non-high-speed-rail crossings that agency uses a warning time of 66 seconds.

Sixty-seven percent (67%) of respondents, 27 of 40, have advance preemption at existing locations. Comments from four agencies indicate that the use of advance preemption can range from nearly every crossing to only a few (four responses). Seventy-five percent (75%) of agencies (30 of 40 responses) are likely to use advance preemption at new locations.

For those agencies using advance preemption, 71% (24 of 34 responses) have a standard procedure for calculating the advance preemption time. Ten (10) agencies stated that the Texas Department of Transportation (TxDOT) procedure (currently being updated) is their standard (10 responses); in addition one agency noted procedures by AREMA, one agency referred to ITE, one to LADOT, and one to Transport Canada. Two agencies also noted general procedures that are based on field measurements and one the time needed to serve the critical movement at the intersection.

Thirty-eight percent (38%) of agencies (15 of 40 responses) request additional rail outputs. Gate-down is requested most frequently (17 of 18 responses), with requests for supervised outputs (six of 18 responses).

TRAFFIC SIGNAL SYSTEMS PRACTICE

Seventy-two percent (72%) of respondents, 29 of 40, preempt signals that are more than 200 feet from the crossing. Twelve (12) reported that they apply preemptive based on queuing characteristics at an intersection; for example, some of the agencies reported that if queues routinely exceed 200 feet, they will use preemption.

Seventy percent (70%) of agencies (28 of 40 responses) have a standard practice for determining TCGI. Nine (9) agencies use the TxDOT procedure, one agency uses Greenshield's formula, and one other reported using a procedure developed by LADOT. Three agencies reported the use of a general procedure based on field measurements (three responses) or time to serve the critical movement at the intersection (one response).

Fifty-five percent (55%) of agencies (22 of 40 responses) time a minimum green interval before terminating a phase that is transitioning to the track clearance interval. According to seven respondents, minimum green values vary from one to seven seconds.

Seventy-five percent (75%) of agencies (24 of 32 responses) routinely truncate the pedestrian interval. Four agencies responded that they prefer to serve the entire pedestrian clearance interval, but will allow truncation on a case-by-case basis. Considerations include the number of pedestrians, walking speeds, effect on countdown displays, frequency of trains, and funding available to make changes (four responses).

Sixty-seven percent (67%) of agencies (26 of 39 responses) cycle through non-conflicting movements during the preempt hold ("dwell") intervals. Six agencies noted that they use multiple strategies (e.g., dwell on parallel arterial, flashing yellow on parallel arterial, flashing all-red, dwell in all-red), with operations depending on location characteristics such as geometry, train speed, and crash history.

Of the surveyed agencies, 87% (34 of 39 responses) restrict conflicting turns across the track(s) during preemption through blank-out signs or exclusive phases. However, seven agencies noted that the application is location-specific, with storage distance for vehicles being a major factor. In one case, both exclusive phases and blank-out signs are used.

Ninety percent (90%) of agencies (36 of 40 responses) either do not use smart recovery strategies or do not know if they do. Three noted that they were unsure of the meaning of "smart" recovery strategies versus being unsure if their agency uses any.

Twenty percent (20%) of agencies (eight of 40 responses) use second-train-coming logic on new or upgraded systems. One type of second-train-coming event occurs when the time between two preempts is short; short times between events can cause problems if the traffic signal has inadequate time to respond to the second event. A second type of second-train-coming event occurs when the first preempt event is ending and the gates are rising, and a second preempt event starts the gates back down before the first preempt is complete; gates going up (incompletely) and down is difficult for drivers.

Although 45% of agencies (18 of 40 responses) have situations with train stations near highway–rail grade crossings, 32% of agencies (seven of 22 responses) make special provisions for trains stopping at stations. One uses preemption time-out and preemption restart procedures, while two others keep the gates down. One agency reported having specific operating rules to address this issue.

Twenty-seven percent (27%) of agencies (10 of 37 responses) report having light-rail-transit (LRT) preemption, and 31% of agencies (four of 13 responses) have written practices for LRT preemption. One agency responded it defers to the LRT agency or uses design plans in place of written policy.

Sixty-seven percent (67%) of responding agencies (27 of 40) allow fire preemption at rail preemption intersections. Seventy-one percent (71%, or 29 of 41) prioritize preempts, with 12% not prioritizing (five of 41 responses) and 17% unsure if they prioritize (seven of 41 responses). Although 93% of agencies (27 of 29 responses) made the highest preempt for rail, two of the 29 had special cases of higher priority (e.g., bridge lift).

INTERCONNECTION PRACTICE

Fifty-five percent (55%) of agencies (22 of 40 responses) report using a simple two-wire preempt. Of those agencies, 18 of 31 (58%) reported using a normally closed circuit; three of 31 (10%) use a normally open circuit, and 10 of the 31 (32%) reported being unsure. Those agencies using other types of circuits (i.e., beyond two-wire circuits) reported a variety of options including:

- Three-wire (with braiding/shield on each conductor) (one response)
- Four-wire (four responses)
- Eight-wire (one response)
- Ten-wire (one response)
- 14-wire (one response)
- Serial (one response).

Five of 39 respondents (13%) indicated that they use advanced train detection or railway interconnection technology. Agencies that referenced to advanced technologies mentioned an incremental train control system (ITCS) (one response); DAX outputs from a CWT system (one response); railroad preemption interface system (one response); monitor stations at select crossings (one response); and hardwired and radio connections (one response).

DESIGN PRACTICE

Seventy-five percent (75%) of respondents (30 of 40 responses) use battery back-up at new installations.

Ninety-eight percent (98%), 40 of 41, use LED signal indications at new installations.

Twenty-two (22) of 41 agencies (52%) use vehicle gates at all new or upgraded crossings. Issues considered when installing gates include train volumes (two responses), train speeds (two responses), sight distance and vehicle AADT (one response), funding (one response), intersection geometry (one response), and railway agency preference (two responses).

Thirty-seven percent (37%), 15 of 41, have used pedestrian gates, but 11 reported that they use them at limited locations. Considerations for installation include the crossing's proximity to schools (one response) and quiet zones (one response), as well as railway agency preference (two responses).

Fifty percent (50%) of respondents (20 of 40) use pre-signals: Five agencies described their use as limited. Considerations for installation include crossing geometry (one response), storage distance (one response), and interaction with near-side signals at the intersection (one response).

Thirty-four percent (34%) of agencies (14 of 41 responses) indicated they have used queue cutters, generally at a few locations (five responses). Considerations for installation include crossing geometry (one response), specifically if there is a long distance between the intersection and track (one response).

Four-quadrant gates are used by 41% of responding agencies (17 of 41). Ten (10) agencies noted that they install them in quiet zones (10 responses). Other locations where agencies have installed four-quadrant gates include locations with safety issues (four responses), high-speed corridors (two responses), locations where traffic can easily go around two-quadrant gates (one response), and multi-lane roadways (one response).

MAINTENANCE PRACTICE

Seventy-four percent (74%) of agencies (28 of 38 responses) shop test cabinets and controllers before installing them in the field. Two agencies noted that preemption is tested under both normal circumstances and failure (two responses).

Eighty-seven percent (87%, or 33 of 38 responses) restrict timing changes at interconnected traffic signals to pre-approved staff. Some agencies restrict changes for certain timing parameters. Restricted parameters may include preempt parameters (two responses), minimum green (one response), yellow clearance (two responses), red clearance (two responses), or pedestrian clearance (one response).

Sixty-one percent (61%, 24 of 39 responses) perform routine inspections and/or maintenance of the preemption system. Two agencies indicated that maintenance is not their responsibility, either because it is the role of local agencies or because they are not the maintaining agency. Those that perform inspections and/or maintenance reported that the frequency varies between once per month to every five years. The most common frequency for inspections and maintenance is yearly (18 of 27 responses), with six agencies performing those tasks as part of other routine maintenance or on an as-needed basis.

Eight percent (8%) of responding agencies, three of 38, coordinate with the railway agency's monthly testing of preemption. For those agencies that do coordinate, three schedule their annual inspection to coordinate with the railway agency's monthly inspection (three responses). Two agencies indicated that testing is the responsibility of the local agencies (two responses).

Thirty-seven percent (37%) of agencies (14 of 38 responses) periodically review crossings to determine the need for upgrading the railway warning time system or traffic signal system. Two agencies reported that considerations for upgrades include findings from inspections, complaints, crashes, and development reviews. Three agencies indicated that upgrade reviews are the responsibility of the maintaining agencies, but for those that complete reviews, the frequency varies between once per year and once every five years. Sixty percent (60%) of respondents, nine of 15 complete reviews on an as-needed/requested basis (i.e., no set schedule).

MONITORING ACTIVITIES

Six of 38 respondents (16%) record detailed railway warning type system events beyond a traffic signal controller preempt log. Types of monitoring include railway-interconnection or traffic signal malfunctions (one response), remotely accessible video (one response), and voltage monitors (one response).

Sixty-two percent (62%, 23 of 37 responses) compare design assumptions to actual operations in the field.

Four of 37 agencies (11%) have research or demonstration projects. Two agencies commented that their projects are related to available circuit outputs (e.g., island circuit). TxDOT is also in the process of updating its highly used preemption form, in order to simplify and clarify some of the more challenging aspects (one response).

CHAPTER SEVEN

CASE EXAMPLES

PORTLAND, OREGON CASE EXAMPLE

This case example highlights both the complexities of preemption near highway–rail grade crossings and state of the art approaches to addressing variability in both train speeds and actual right-of-way transfer time. The study site is atypical (with unique geometry and both heavy and light rail running through the crossing), but this single location is able to offer valuable insights into many of the issues related to preemption of traffic signals near highway–rail grade crossings as it involves three different railway operations in a single corridor.

The study site has two tracks that are utilized by Union Pacific Railroad (UPRR) and Amtrak service as well as two additional and adjacent tracks that are utilized by TriMet MAX light rail transit (LRT) (reference Figure 16). The four tracks are inside an integrated set of lights and gates, which provide railway outputs to the traffic signal. The crossing also has a pre-signal that clears traffic through the downstream traffic signal using an actuated trailing overlap between the tracks; this minimizes the possibility of vehicles stopping on the tracks even in the absence of trains.

In Order 50979 (December 5, 2012), the Rail Division of the Oregon Department of Transportation (ODOT) required an advance preemption time of 67 seconds at the study site. This time was computed using a slightly modified version of the TxDOT guidelines, and did not take into account the presence of the pre-signal, which is an issue that has been raised by the city of Portland and TriMet. Subsequently, ODOT issued an amendment revising the advance preemption time to 60 seconds. The analysis of the data was conducted before the order was amended reflecting the effectiveness of the pre-signal.

ODOT typically uses two railway preempt outputs (RO1 and RO2) at crossings with pedestrian clearance considerations. These railway outputs are called pedestrian clear-out interval (PCOI) and vehicle clear-out interval (VCOI), which correspond to typical advance and simultaneous outputs, RO1 and RO2, respectively. This two-preempt strategy was developed to prevent the preempt trap by clearing the pedestrian phase independently of the vehicle phase. However, the study site uses a more complex set of railway outputs than the typical ODOT crossing; there are four railway outputs (RO0, RO1, RO3, and RO4 in Figure 17) provided to the traffic signal system, and there is one output that the traffic signal system provides back to the railway system (RO1). The Portland case example is an example of “smart” preemption with gate-down confirmation. The controller only terminates active phases as quickly as necessary to enter the track clearance green interval (TCGI) before the warning system becomes active for LRT trains. Trains on the UPRR tracks do not use the smart preemption owing to train arrival variability.

For consistency with the rest of this synthesis, the railway/LRT outputs at the study site will be referenced according to the railway output sequence rather than using ODOT terminology. Railway outputs will be numbered in chronological order (RO0, RO1, RO3, and RO4). RO0 is a railway output provided only by the UPRR and not TriMet LRT prior to the advance preempt output (RO1). The traffic-signal-health output is numbered RO1. Figures 17 and 18 summarize the outputs used in this case example. (RO1 was later reduced to 60 seconds after the data was collected.)

In the Portland case example, heavy-rail switching operations within the approach circuit make train arrivals quite variable. The railroad (UPRR and Amtrak) design for RO0 is 77 seconds (longer

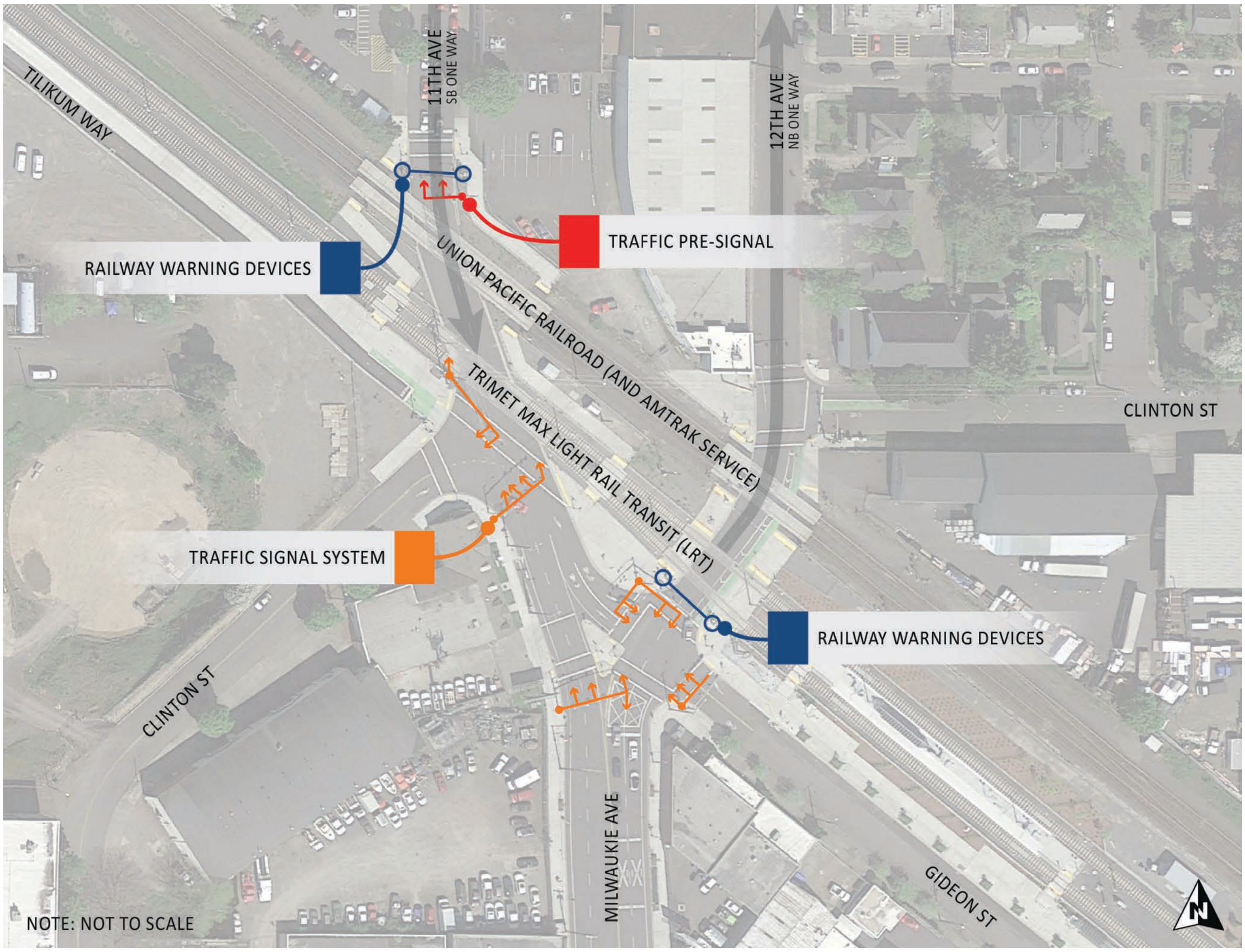


FIGURE 16 Portland, Oregon, case example site. *Source*: Kittelson & Associates, Inc.

than the crossing order value of 67 seconds) resulting from switching operations, acceleration and deceleration, and limitations of the railway detection technology which is based on a consistent speed at any point in time. When trains—that may or may not enter the crossing—start moving at 5 mph or faster toward the crossing, the railway system immediately sends RO0 without knowing if or when the train will enter the crossing. The 77-second value is likely derived by the railway authority to account for the time to detect a slow-moving train. RO0 is highly variable, with trains arriving at the crossing two minutes or more after RO0 is sent (Moore et al. 2015).

RO1 can originate from either the heavy rail detection system or the LRT detection system; the combined output occurs when either one or both systems determine the design value is achieved. It has a design value of 70 seconds, which was selected by the railway agency so that it is long enough to address pedestrian clearance time and queue clearance time specified in the 67-second crossing order. RO1 is treated as a traditional advance preempt, but the preemption sequence at the traffic signal depends on the type of train that is approaching. If both RO0 and RO1 have been sent, the traffic signal system knows that a heavy-rail train is approaching, which often experiences greater variability in train arrival times. In that case, the traffic signal immediately transitions to the track clearance green interval. If only RO1 has been sent, the traffic signal system knows that a LRT train is approaching. The LRT trains have operating rules that prevent early arrival, so they are consistent in their arrival times (observed through output monitoring) (Moore et al. 2015). In the case of an LRT train, the traffic signal controller can use a smart preemption feature called time to green (TTG). Instead of immediately transitioning to the track clearance

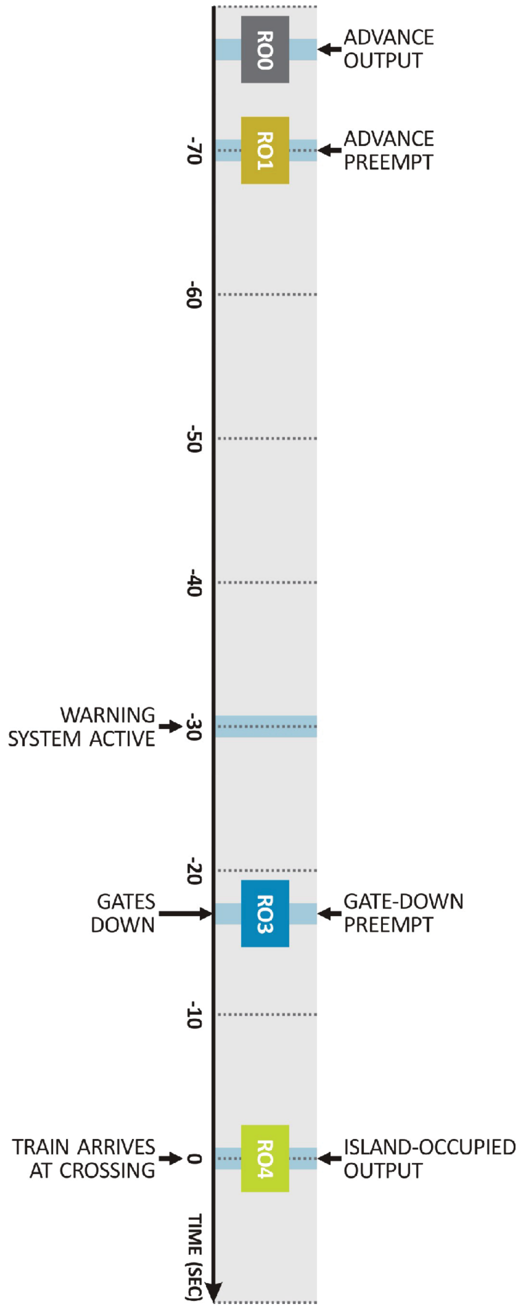


FIGURE 17 Railway outputs for Portland, Oregon, case example. *Source*: Kittelson & Associates, Inc.

green interval, TTG only shortens phases the amount needed to achieve TCGI at the design time or sooner.

The preempt trap is prevented using a two-output strategy (RO1 and RO3 in the case of Portland). RO1 calls a preempt that includes adequate RTT for pedestrians. When the clearance interval (pedestrian and/or vehicle) is complete, the traffic signal dwells in TCGI until RO3 (gate-down) is received. RO3 initiates a short, fixed-time interval in the traffic signal controller before it enters limited service (also known as dwell) following the clearance interval.

The Portland Bureau of Transportation (PBOT), the traffic signal operating agency, also monitors RO4 (island circuit). RO4 confirms the presence of a train in the crossing area. It can be used by the

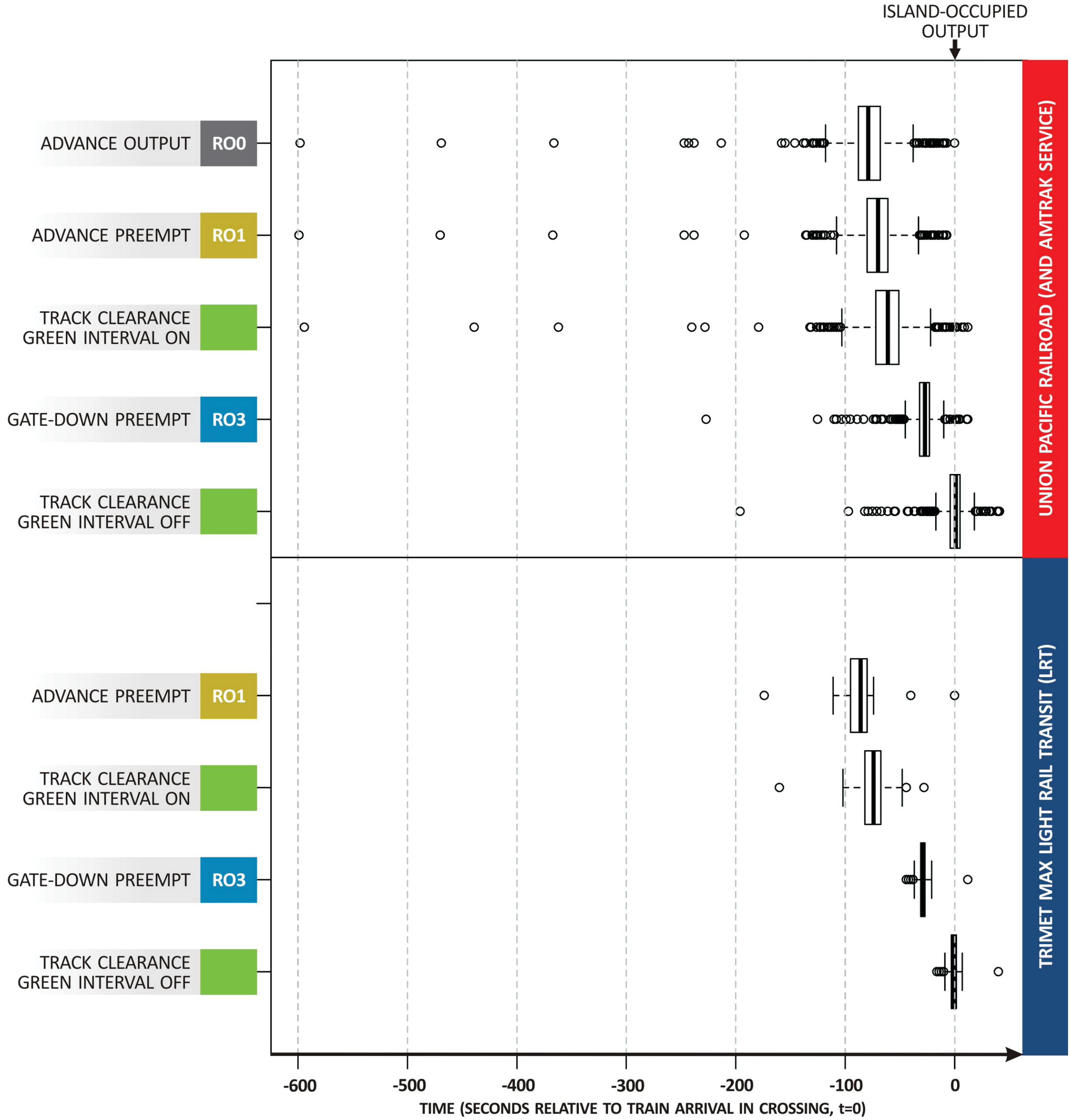


FIGURE 18 Railway output functions for Portland, Oregon, case example.

railway to generate a gate-down output in case the gate-down event does not occur (i.e., broken gate). Alternatively, it can also be used by the traffic signal for the same purpose, ending RO1 which would stay in TCGI in the absence of RO3.

Because an island circuit is able to detect when a train is in the crossing area, its output can provide valuable information for adjusting timing parameters. Figure 19 demonstrates the type of information available from the use of an island circuit. In this example, the island circuit output (i.e., when the train is in the crossing area) occurs at zero on the horizontal axis. Various events can be referenced to train arrival at the crossing, in order to determine variability in arrival predictions.

UPRR and Amtrak trains are shown in the top graph, while TriMet MAX LRT trains are shown in the bottom graph. The distribution of arrival times is much greater for trains than for light rail

51%	HAVE WRITTEN POLICY OR GUIDELINES ON PREEMPTION
38%	HAVE STATE HIGHWAY-RAIL GRADE CROSSING ACTION PLANS
58%	HAVE WRITTEN PROCEDURES FOR CONTACTING THE RAILWAY AGENCY
39%	PROVIDE TRAINING FOR MAINTENANCE STAFF
47%	USE CONSTANT WARNING TIME AT THE MAJORITY OF EXISTING CROSSINGS
64%	USE CONSTANT WARNING TIME AT NEW OR UPGRADED LOCATIONS
15%	USE ONLY SIMULTANEOUS PREEMPTION
67%	HAVE ADVANCE PREEMPTION AT EXISTING LOCATIONS
75%	WOULD LIKELY USE ADVANCE PREEMPTION AT NEW LOCATIONS
71%	HAVE A STANDARD PROCEDURE FOR CALCULATING ADVANCE PREEMPTION TIME
38%	REQUEST ADDITIONAL RAIL OUTPUTS
72%	USE PREEMPTION AT SIGNALS THAT ARE MORE THAN 200 FEET FROM THE CROSSING
70%	HAVE A STANDARD PRACTICE FOR DETERMINING THE TRACK CLEARANCE GREEN INTERVAL
55%	TIME A MINIMUM GREEN INTERVAL BEFORE TRANSITIONING TO THE TCGI
75%	ROUTINELY TRUNCATE THE PEDESTRIAN INTERVAL
67%	CYCLE THROUGH NON-CONFLICTING MOVEMENTS DURING THE PREEMPT HOLD INTERVALS
87%	RESTRICT CONFLICTING TURNS THROUGH BLANK-OUT SIGNS OR EXCLUSIVE PHASES
10%	USE SMART RECOVERY STRATEGIES
20%	USE SECOND-TRAIN-COMING LOGIC ON NEW OR UPGRADED SYSTEMS
32%	MAKE SPECIAL PROVISIONS FOR TRAINS STOPPING AT STATIONS NEAR CROSSINGS
27%	HAVE LIGHT-RAIL-TRANSIT PREEMPTION
67%	ALLOW FIRE PREEMPTION AT RAIL PREEMPTION INTERSECTIONS
71%	PRIORITIZE PREEMPTS

FIGURE 19 Statistical distribution of railway outputs relative to train arrival at crossing. *Source*: Adapted from Moore et al. (2015). *Note*: The diagram is a box plot (a.k.a. box-and-whisker diagram), which is a standardized way of displaying the distribution of data based on: minimum, first quartile, median, third quartile, and maximum.

(*continued on next page*)

FIGURE 19 (*Continued*).

trains, relating back to the switching activities near the highway–rail grade crossing. The difference in train arrival variability between the railroad and LRT trains was the reason for the city of Portland to implement two different timing strategies at the traffic signal, as discussed previously.

There are a number of lessons learned from this case example:

- Monitoring railway performance is very important to proper traffic signal operation.
- Use of more than one preempt, either advance or simultaneous, greatly increases operational flexibility.
- Advance features can improve operations on the highway side by reducing unnecessary time for the TCGI.
- Traffic authorities must take the time to understand whether "train handling" affects the variability of preempt outputs.

OHIO CASE EXAMPLE

In 2008, ODOT and the Ohio Rail Development Commission began engaging stakeholders (railway and traffic agencies) when upgrading its guidance regarding preemption of traffic signals near signalized intersections. Guidance at the time largely followed the limited *Ohio Manual of Uniform Traffic Control Devices*. This engagement resulted in a major update to Section 800 of the ODOT *Traffic Engineering Manual* (TEM).

This 2010 update defined purpose, operation, traffic signal interface, and approved traffic signal controllers and interface hardware for use with railway preemption within Ohio. The interface provided a design that would accommodate advance preemption, simultaneous preemption, island-occupied, gate-down, gate-up, and traffic signal health. It was also important that the traffic signal be capable of providing an output for illuminated blank-out signs. The interface was to be 24-volt DC contact closure actuation, to be capable of testing various circuits, and to include indicator lights. The 2010 update also provided guidance on planning and programming for new or upgraded traffic signals. The guidance included battery back-up, pre-signals, queue cutter signals, and other design guidance. Issues to be considered included the influence of RTT on pedestrian clearance.

In a 2014 TEM update, ODOT reorganized its interconnection design guidelines. The changes moved many of the specific details of the traffic signal interface to ODOT Supplemental Specification (SS) 919 and ODOT Standard Construction Drawing TC-86.10. This 24-volt-DC-supervised and 12-volt-DC traffic signal health interface is capable of providing advance preemption, preventing a preempt trap, monitoring train-handling issues, and providing feedback to the railway system when traffic signal health requires a different strategy. With a traffic signal in flashing operation, the traffic signal health circuit can be used to activate the railway warning time system sooner, in order to provide more time to clear the track(s) in the absence of a TCGI.

Despite having worked with the railway agencies on the development of these comprehensive guidelines, implementation on projects has found that some mainline railway agencies in Ohio were generally committed to maintaining their traditional practice. Simply stated, the railway agencies were willing to provide a single preempt—advance or simultaneous—but were disinclined to monitor traffic signal health. This experience indicates the obstacles that still exist to improving the interconnection of the railway warning time system with the highway traffic signal system.

CALIFORNIA CASE EXAMPLE

California has a number of agencies involved in traffic signal preemption practice at the state and local agency levels including Caltrans, Caltrain, Southern California Regional Rail Authority, Metrolink, and the city of Los Angeles. Both Caltrans and LADOT have developed guidance on determining time requirements for traffic signal preemption. This case example will provide an overview of California interconnection practice.

Typical California guidance for interconnection recognizes the limitations of two-wire interconnection and encourages state of the art practice including supervision, gate-down, and traffic signal health (e.g., if the railway uses event recording, it could monitor the track-clearance-green event) based on fail-safe, closed-loop principles. A supervised six-wire interconnect is suggested for simultaneous preemption, and a supervised ten-wire interface is suggested for advance preemption using gate-down and traffic signal health.

Provision is also made for using IEEE 1570-2002 standards. Although California guidance recommends using gate-down to prevent a preempt trap, it also recognizes alternative methods, including a not-to-exceed timer on the railway side (to provide a consistent maximum advance preempt time) and using the island circuit as a backup to gate failure. The need for second-train-coming logic to prevent gates from rising when a second train is on approach is also documented. One type of second-train-coming event occurs when the time between two preempts is short; short times between events can cause problems if the traffic signal has inadequate time to respond to the second event.

A second type of second-train-coming event occurs when the first preempt event is ending and the gates are rising, and a second preempt event starts the gates back down before the first preempt is complete; gates going up (incompletely) and down is difficult for drivers.

The city of Los Angeles and Metro Link tested an IEEE 1570 serial preemption interconnection using LADOT 2070 firmware (Sun et al. 2008). This demonstration showed the basic capabilities of a vital serial interface. Although the experiment did not demonstrate all the potential of a "smart" interface, it used two preempts—advance (RO1) and warning system active (RO2)—in concert with smart-transition logic to arrive at the TCGI. The system assured that the gates were down before the TCGI ended and minimized the number and amount of truncated pedestrian clearance times. LADOT has since expanded use of the interconnection to 26 locations, and uses the IEEE 1570 interconnection on all new projects.

CHAPTER EIGHT

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The most important conclusion from this synthesis is that the state of the practice does not adequately reflect state of the art capabilities. Although some highway and railway agencies use advanced capabilities, as demonstrated in the case examples, the majority of surveyed agencies (55%) use a simple, two-wire preempt at their highway–rail grade crossings; and of those agencies using two-wire preempt, 58% use normally closed circuits. This two-wire preempt circuit conveys no more information to the traffic signal controller than was available when track circuits were first used to preempt traffic signals.

The most significant innovation that is widely used by railway agencies is a constant warning time (CWT) system (or grade crossing predictor), which improves the consistency of warning times in most cases, but is not able to address variability at locations with trains that accelerate or decelerate on the approach circuit. However, even this innovation is used by 64% of surveyed agencies at new or upgraded locations. Improving practices has been difficult because of the multiple agencies involved, their diverse perspectives, and different business practices.

For highway agencies, highway–rail grade crossings are a small part of practice, and the survey reveals significant gaps in technical understanding. Many surveyed highway agencies indicated a lack of understanding about topics such as gate-down, island circuit, “smart” recovery strategies, second-train-coming logic, and accommodations for train stations near crossings. The lack of technical understanding is compounded by the fact that there is limited technical guidance and no standard for the traffic signal interface hardware to interconnect highway and railway control systems. Furthermore, state agencies sometimes defer to local agencies regarding traffic signal operations at highway–rail grade crossings, resulting in widely varied practices.

Although the FRA encourages railway and highway agencies to coordinate joint inspections to verify that railway crossing warning systems interconnected to traffic signals function properly, the survey indicates that few highway agencies coordinate inspections with railway agencies.

There are several initiatives that could lead to improved safety and operation of highway–rail grade crossings. First, identification and research of key limitations and conflicts in current operation would likely result in a better understanding of how to operate highway–rail grade crossings in a variety of operating environments. Issues that might be addressed in future research include:

- Clear definitions of terms
- Concept of operations
- Traffic signal operational concepts
- Traffic signal operational strategies
- Alternatives to truncation of pedestrian clearance interval
- Count-down pedestrian signals
- Advance preemption strategies
- “Smart” recovery strategies
- Second-train-coming logic
- Supervised circuits
- Use of multiple preempts
- Use of pre-signals
- Use of queue cutters
- Use of blank-out signs for turn restrictions

- Strategies near train stations
- Coordination with railway agencies
- Periodic inspections
- Use of traffic signal performance measures
- Training of staff (including contractors).

Second, guidance and training would likely bridge gaps in understanding and improve coordination between railway and highway agencies. Training would include both railway issues and highway issues, regardless of the audience.

Third, improvement of the interconnection between the railway and highway is currently limited by the lack of a traffic signal standard that defines the minimum functionality for interconnection hardware. Using a systems engineering process, a standard could be produced that considers how a traffic signal is to operate in various operating environments.

ABBREVIATIONS AND ACRONYMS

APT	Advance preemption time
AREMA	American Railway Engineering and Maintenance-of-Way Association
BT	Buffer time
CT	Clearance time
CWT	Constant warning time
GD	Gate down
LADOT	Los Angeles Department of Transportation
LRT	Light rail transit
MUTCD	*Manual on Uniform Traffic Control Devices for Streets and Highways*
MWT	Minimum warning time
ODOT	Ohio Department of Transportation
RTT	Right-of-way transfer time
TCGI	Track clearance green interval
TTG	Time to green
TxDOT	Texas Department of Transportation
UPRR	Union Pacific Railroad

REFERENCES

Alroth, W.A., D.M. Mansel, and J.T. Siques, "Design Considerations for Pre-signals at Highway-Railroad Grade Crossings," presented at the *Enhancing Transportation Safety in the 21st Century ITE International Conference*, Kissimmee, Fla., 1999.

Brennan, T.M., et al., "A Decision Tree Model to Prioritize Signalized Intersections near Highway-Railroad Crossings for Railroad Interconnect," *Transportation Research Record: Journal of the Transportation Research Board*, *No. 2192*, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 116–126.

Bullock, D., T. Urbanik, and A. Catarella, "Traffic Signal System Progression Recovery from Railroad Preemption," *Proceedings of the Fifth International Symposium on Railroad-Highway Grade Crossing Research and Safety*, Knoxville, Tenn., 1998.

Campbell, R., D. Dokupil, and N. Jackson, "Railroad Preemption Interconnect Circuits: How to Improve Operations and Safety," *IMSA Journal*, Nov./Dec. 2015.

Code of Federal Regulations, Title 49, Subtitle B, Chapter II, Part 234: Grade Crossing Safety, 2016.

Collision of Northeast Illinois Regional Commuter Railroad Corporation (*METRA*) *Train and Transportation Joint Agreement School District 47/155 School Bus at Railroad/Highway Grade Crossing in Fox River Grove, Illinois, on October 25, 1995*, Report PB96-916202 NTSB/HAR-96/02, National Transportation Safety Board, Washington, D.C., 1996.

Communications & Signals Manual, American Railway Engineering and Maintenance-of-Way Association, Lanham, Md., 2016.

Engelbrecht, R., S. Sunkari, T. Urbanik II, S. Venglar, and K. Balke, *The Preempt Trap: How to Make Sure You Do Not Have One*, Report 1752-9, Texas Transportation Institute, Arlington, Tex., 2002.

Federal Railroad Administration, "Safety Advisory 2010-02," *Federal Register*, Vol. 75, No. 190, Oct. 2010, pp. 60863–60864.

Federal Railroad Administration, "Highway-Rail Grade Crossings Overview," 2015 [Online]. Available: https://www.fra.dot.gov/Page/P0156.

Federal Railroad Administration, "FRA to States: Verify Traffic Lights Connected to Railroad Crossings Function Correctly," Press Release No. FRA 04-16, Feb. 17, 2016 [Online]. Available: https://www.fra.dot.gov/eLib/Details/L17344.

Fehon, K. and P. O'Brien, *Traffic Signal Management Plans, An Objectives- and Performance-Based Approach for Improving the Design, Operations, and Maintenance of Traffic Signal Systems*, Report FHWA-HOP-15-038, Federal Highway Administration, Washington, D.C., 2015.

Guide for Determining Time Requirements for Traffic Signal Preemption at Highway Rail Grade Crossings, Form 2304, Texas Department of Transportation, Austin, 2003.

IEEE 1570-2002 Standard for the Interface Between the Rail Subsystem and the Highway Subsystem at a Highway Rail Intersection, Institute of Electrical and Electronics Engineers, New York City, 2002.

Korve, H.W., *NCHRP Synthesis 271: Traffic Signal Operations Near Highway-Rail Grade Crossings*, Transportation Research Board, National Research Council, Washington, D.C., 1999.

Lin, P., et al., *Coordinated Pre-Preemption of Traffic Signals to Enhance Railroad Grade Crossing Safety in Urban Areas and Estimation of Train Impacts to Arterial Travel Time Delay*, Florida Department of Transportation, Tallahassee, 2014.

Mansel, D.M., V.H. Waight, and J.T. Sharkey, "Supervised Interconnection Circuits at Highway-Rail Grade Crossings," *Transportation Research Record: Journal of the Transportation Research Board*, *No. 1692*, Transportation Research Board of the National Academies, Washington, D.C., 1999, pp. 42–47.

Manual on Uniform Traffic Control Devices for Streets and Highways, Federal Highway Administration, Washington, D.C., 2009.

Moore, A., P. Zebell, P. Koonce, and J. Meusch, "A Method to Verify Railroad Interconnect with Highway Traffic Signal Systems," presented at the *2015 Joint Rail Conference*, San Jose, Calif., 2015.

Moriarty, K., et al., *Recording Devices for Interconnected Grade Crossing and Intersection Signal Systems: An Informational Report*, Report FHWA-SA-12-020, Federal Highway Administration, Washington, D.C., 2012.

Office of Railroad Safety, *Compilation of State Laws and Regulations Affecting Highway-Rail Grade Crossings, 6th Edition*, Federal Railroad Administration, Washington, D.C., 2013.

Ogden, B.D., *Railroad-Highway Grade Crossing Handbook*, Report FHWA-SA-07-010, Federal Highway Administration, Washington, D.C., 2007.

Ohio Manual of Uniform Traffic Control Devices, 2012 Edition, Office of Traffic Engineering, Ohio Department of Transportation, Columbus, 2012 [Online]. Available: http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/OhioMUTCD/Pages/OMUTCD2012_current_default.aspx.

Preempting Traffic Signals near Railroad Crossings in Utah, A UDOT Manual, Utah Department of Transportation, Salt Lake City, Dec. 2015 [Online]. Available: http://www.udot.utah.gov/main/uconowner.gf?n=29256830125849243.

Preemption of Traffic Signals Near Railroad Crossings, A Recommended Practice of the Institute of Transportation Engineers, Institute of Transportation Engineers, Washington, D.C., 2006.

Rail-Highway Operations Manual, Texas Department of Transportation, Austin, 2015 [Online]. Available: http://onlinemanuals.txdot.gov/txdotmanuals/rho/rho.pdf.

Schulz, L.A. and A. Smadi, *Application of ITS at Railroad Grade Crossings*, Department Publication No. 123, Upper Great Plains Transportation Institute, North Dakota State University, Fargo, 1998.

Seyfried, R.K., "Timing of Traffic Signal Preemption at Intersections near Highway-Railroad Grade Crossings," presented at the Institute of Transportation Engineers (ITE) 2001 Annual Meeting and Exhibit, Chicago, Ill., 2001.

Sun, X., T. Urbanik II, S. Skehan, and M. Ablett, "Improved Highway-Railway Interface for the Preempt Trap," *Transportation Research Record: Journal of the Transportation Research Board, No. 2080*, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 1–7.

Traffic Engineering Manual (*TEM*), Ohio Department of Transportation Office of Traffic Engineering, Columbus, 2016 [Online]. Available: http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/traffic/TEM/Pages/default.aspx.

Urbanik, T., et al., *NCHRP Report 812: Signal Timing Manual,* Second Edition, Transportation Research Board of the National Academies, Washington, D.C., 2015.

Venglar, S.P., M.S. Jacobson, S.R. Sunkari, R.J. Engelbrecht, and T. Urbanik, *Guide for Traffic Signal Preemption near Railroad Grade Crossing*, Report FHWA/TX-01/1439-9, Texas Department of Transportation, Austin, 2000.

Yeh, M. and J. Multer, *Driver Behavior at Highway-Railroad Grade Crossings: A Literature Review from 1990–2006*, Report DOT/FRA/ORD-08/03, Federal Railroad Administration, Washington, D.C., 2008.

Yohe, J.R. and T. Urbanik II, "Advance Preempt with Gate-Down Confirmation: Solution for Preempt Trap," *Transportation Research Record: Journal of the Transportation Research Board, No. 2035*, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 40–49.

APPENDIX A

Survey Questionnaire

NCHRP 47-15 Survey Questionnaire

Survey of Agencies on Traffic Signal Preemption at Intersections Near Highway-Rail Grade Crossings

As part of the National Cooperative Highway Research Project 20-05, Synthesis of Practice Project 47-15, we would appreciate it if you would take time out of your busy schedule to complete the following survey. All responses will be summarized in the final report, so individual responses will remain anonymous.

Responses are requested by January 6, 2016.

Questions can be addressed to the principal investigator:

Tom Urbanik
Kittelson & Associates, Inc.
4332 Teravista Club Dr #75
Round Rock, TX 78665
turbanik@kittelson.com
512-670-8074

If any of your responses indicate you have written policy or guidance, we would appreciate receiving an electronic copy by email, U.S. mail, or you can upload to:
http://www.kittelson.com/ftp
UserID: preempt
Password: traffic

All questions have space for comments if clarification or qualification is needed.

1. Please provide the name and contact information of the primary person completing this survey (even if portions of the survey require assistance from others).

Name	
Title	
Agency	
Address	
Address 2	
City/Town	
State	
ZIP	
Telephone	
Email	

2. Does your agency have written policy or guidelines on the preemption of traffic signals near highway-rail grade crossings?

- Yes
- No
- Unsure

Comments

3. Does your state have a state highway-rail grade crossing action plan?

- Yes
- No
- Unsure

Comments

NCHRP 47-15 Survey Questionnaire

Preemption Timing Practice

Does your agency's preemption timing practice address the following issues?

4. Do you only use simultaneous preemption?

- ◯ Yes
- ◯ No
- ◯ Unsure

Comments

5. If the answer to Question #4 is yes, what is the maximum warning time you would request?

Seconds

6. If the answer to Question #4 is no, do you have a standard procedure to calculate your advance preemption time?

- ◯ Yes
- ◯ No
- ◯ Unsure

Comments

7. Do you have a standard practice to calculate the track green clearance interval?

- Yes
- No
- Unsure

Comments

8. If the answer to Question #7 is yes, does it allow the routine truncation of pedestrian clearance?

- Yes
- No
- Unsure

Comments

9. How do your signals generally operate during preempt hold intervals?

- Dwell on parallel arterial
- Flash yellow on parallel arterial
- Flash all-red
- Cycle through non-conflicting movements
- Other (please specify below)

Comments

10. Do you time a minimum green interval before terminating a phase that is transitioning to the track clearance interval?

- Yes
- No
- Unsure

Comments

11. Do you restrict conflicting turns across the tracks during preempt through blank-out signs or exclusive phases?

- Yes
- No
- Unsure

Comments

12. Do you use any smart recovery strategies?

- Yes
- No
- Unsure

Comments

13. At multiple-track locations, do you request second-train-coming logic from the railroad for the railroad warning system on new or upgraded installations?

- ◯ Yes
- ◯ No
- ◯ Unsure

Comments

14. Do you have train stations near crossings?

- ◯ Yes
- ◯ No
- ◯ Unsure

Comments

15. If the answer to Question #14 is yes, do you make special provisions for trains stopping at stations?

- ◯ Yes
- ◯ No
- ◯ Unsure

Comments

16. If the answer to Question #15 is yes, describe the special provisions that are made for trains stopping at stations.

17. Do you have fire preemption at rail preempt intersections?

- ○ Yes
- ○ No
- ○ Unsure

Comments

18. Do you prioritize which preempts can override other preempts?

- ○ Yes
- ○ No
- ○ Unsure

Comments

19. If the answer to Question #18 is yes, describe priority for your first six preempts. Preempt 1 has the highest priority, but more than one preempt may have the same priority (first come, first serve).

(1)

(2)

(3)

(4)

(5)

(6)

NCHRP 47-15 Survey Questionnaire

Grade Crossing Operations

How does your agency typically operate grade crossings?

20. Do you use a simple, two-wire preempt?

- Yes
- No
- Unsure

Comments

21. If the answer to Question #20 is yes, is the circuit from the railroad normally closed (when no preempt) or normally open (when no preempt)?

- Normally closed
- Normally open
- Unsure

Comments

22. If the answer to Question #20 is no, describe your preempt circuitry (e.g., four-wire, serial, or other).

23. Do the majority of crossings have grade crossing predictors ("constant" warning time)?

- Yes
- No
- Unsure

Comments

24. Do you preempt signals that are more than 200 feet from the crossing?

- Yes
- No
- Unsure

Comments

25. Do any existing locations have advance preemption?

- Yes
- No
- Unsure

Comments

NCHRP 47-15 Survey Questionnaire

Design Practice

Does your design practice address the following issues?

26. Do new installations or upgrades include "constant" warning train detection?

- Yes
- No
- Unsure

Comments

27. Do new installations have battery back-up?

- Yes
- No
- Unsure

Comments

28. Do new installations have LED signal indications?

- Yes
- No
- Unsure

Comments

29. Would you likely use advance preemption at a new location?

◯ Yes

◯ No

◯ Unsure

Comments

30. Do you request additional rail outputs (e.g., gate-down, island circuit, or other)?

◯ Yes

◯ No

◯ Unsure

Comments

31. If the answer to Question #30 is yes, which outputs?

32. Do you use vehicle gates at all new or upgraded crossings?

◯ Yes

◯ No

◯ Unsure

Comments

33. Do you use pedestrian gates at gated crossings?

- ◯ Yes
- ◯ No
- ◯ Unsure

Comments

34. Do you use presignals?

- ◯ Yes
- ◯ No
- ◯ Unsure

Comments

35. Do you use queue cutters?

- ◯ Yes
- ◯ No
- ◯ Unsure

Comments

36. Do you use four-quadrant gates?

- ◯ Yes
- ◯ No
- ◯ Unsure

Comments

37. If the answer to Question #36 is yes, when do you use four-quadrant gates?

38. Do you use any advanced train detection or railway interconnection technology?

- ◯ Yes
- ◯ No
- ◯ Unsure

Comments

39. If the answer to Question #38 is yes, describe the advanced train detection or railway interconnection technology.

NCHRP 47-15 Survey Questionnaire

Maintenance Practice

What does your maintenance practice include?

40. Do you have railroad-preemption-specific training for your maintenance staff?

- Yes
- No
- Unsure

Comments

41. Do you have written procedures for contacting the railroad regarding activities near grade crossings?

- Yes
- No
- Unsure

Comments

42. Do you perform routine inspections and/or maintenance of your preemption system?

- Yes
- No
- Unsure

Comments

43. If the answer to Question #42 is yes, how often do you perform inspections and/or maintenance?

44. Do you coordinate with the railroad's monthly testing of preemption?

- Yes
- No
- Unsure

Comments

45. Do you periodically review crossings to determine the need for upgrading the rail warning system or traffic signal system?

- Yes
- No
- Unsure

Comments

46. If the answer to Question #45 is yes, how often do you review crossings?

47. Do you shop test your cabinet and controller before installation?

- Yes
- No
- Unsure

48. Do you restrict timing changes at interconnected traffic signals to those that have been pre-approved by an appropriate staff member?

- Yes
- No
- Unsure

Comments

49. Do you use contract maintenance?

- Yes
- No
- Unsure

Comments

50. If the answer to Question #49 is yes, do you have specific procedures developed regarding coordination with the railroad?

- Yes
- No
- Unsure

Comments

NCHRP 47-15 Survey Questionnaire

Monitoring Activities

What do your monitoring activities include?

51. Do you record detailed rail-warning-system events beyond the preempt log in the traffic signal controller?

- Yes
- No
- Unsure

Comments

52. Do you compare design assumptions to actual operations in the field?

- Yes
- No
- Unsure

Comments

53. Do you have traffic signals preempted by street-running LRT?

- Yes
- No
- Unsure

Comments

54. If the answer to Question #53 is yes, do you have written practices on the signal operation?

- Yes
- No
- Unsure

Comments

55. Do you have any highway-rail grade crossing research or demonstration projects underway?

- Yes
- No
- Unsure

Comments

56. If the answer to Question #55 is yes, please provide contact information including a name, email, and phone number.

Contact Name

Email

Phone Number

APPENDIX B

Survey Responses

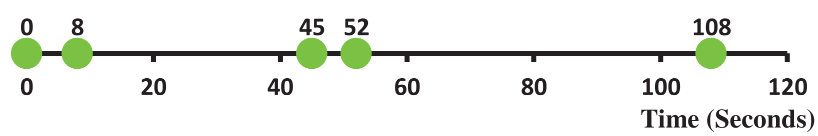
Table B1 summarizes responses to the survey as well as the number of responses received. The numbers in parenthesis indicate the number of responses that reference the associated information. Note that agency comments may be summarized in multiple statements.

TABLE B1
SUMMARY OF SURVEY RESPONSES

QUESTION		# OF RESP.	YES / NO / UNSURE
GENERAL PRACTICE			
Q2	Does your agency have written policy or guidelines on the preemption of traffic signals near highway-rail grade crossings?	41	YES 51% / NO 46% / UNSURE 3% • Several U.S. agencies use the MUTCD as their policy. (7) • Two Canadian agencies use *Transport Canada Standards* as their policy. (2) • Other national guides used as policy proxies include: - FHWA *Railroad-Highway Grade Crossing Handbook*. (2) - TxDOT *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings*. (2) - ITE *Preemption of Traffic Signals Near Railroad Crossings, A Recommended Practice of the Institute of Transportation Engineers*. (1) • Some agencies have their own guides, which include preemption sections: - Alabama DOT *Traffic Signal Design Guide* and *Timing Manual*. (1) - Georgia DOT Design Guides. (1) - Michigan MUTCD. (1) - Montana DOT *Traffic Engineering Manual*. (1) - Ohio DOT *Traffic Engineering Manual*. (1) - Oregon DOT *Traffic Signal Policy and Guidelines*. (1) - Oregon DOT *Traffic Signal Design Manual*. (1) - Oregon DOT *Railroad Preemption Design and Operation*. (1)

TABLE B1
(*continued*)

	QUESTION	# OF RES P.	YES	NO	UNSURE
Q3	Does your state have a state highway-rail grade crossing action plan?	39	38%	44%	18%
			• Several agencies cite not having plans because they have low crash rates. (3) • Specific action plans include: - Iowa DOT Railroad Investment Plan. (1) - Nebraska DOR Rail-Highway Crossings Program. (1) - Transport Canada guidelines. (1) • General action plans include: - Systematically reviewing crossings annually in coordination with the railway agencies. (2) - Developing a priority list of improvements each year based on accident prediction numbers. (1)		

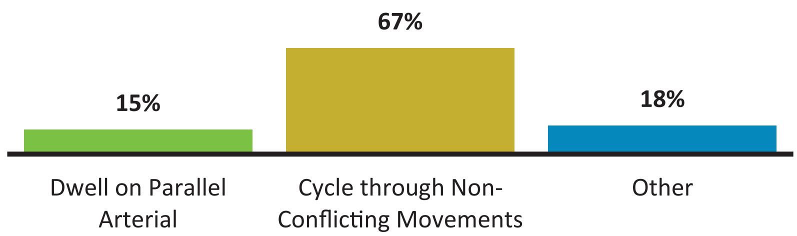
	QUESTION	# OF RES P.	YES	NO	UNSURE
	PREEMPTION TIMING PRACTICE				
Q4	Do you only use simultaneous preemption?	40	15%	77%	8%
			• Two agencies only use simultaneous preemption at older installations; one agency noted that these existing locations are on an upgrade list for advanced preemption. (2) • One agency exclusively uses simultaneous preemption. They do not find that advanced preemption provides benefit because of its complexity, maintenance requirements, and reduced reliability. (1)		
Q5	If the answer to Question #4 is yes, what is the maximum warning time you would request?	5			
			• The 108-second warning time is for a high-speed rail system. For non-high-speed-rail crossings, the agency uses a minimum warning time of 66 seconds. (1)		

(*continued on next page*)

TABLE B1
(*continued*)

	QUESTION	# OF RESP.	YES	NO	UNSURE	
Q6	If the answer to Question #4 is no, do you have a standard procedure to calculate your advance preemption time?	34	71%	23%	6%	• Several agencies use the TxDOT procedure. (10) • Other procedures referenced include: - AREMA procedure. (1) - ITE TENC-99-06 procedure. (1) - LADOT procedure. (1) - Transport Canada RTD 10 procedure. (1) • Other general methods are based on the following: - Field measurements. (2) - Time to serve the critical movement at an intersection. (1) - Right-of-way transfer time plus track clearance green time. (1)
Q7	Do you have a standard practice to calculate the track green clearance interval?	40	70%	27%	3%	• Several agencies use the TxDOT procedure. (9) • Other procedures referenced include: - Greenshield's formula. (1) - LADOT procedure. (1) • Other general methods are based on the following: - Field measurements. (3) - Time required for queue clearance plus a separation time; one agency noted that they use 9 seconds of separation. (2) - Minimum of 15 seconds. (1) - Time provided by the railway agency. (1) - Time to serve the critical movement at an intersection. (1)
Q8	If the answer to Question #7 is yes, does it allow the routine truncation of pedestrian clearance?	32	75%	19%	6%	• Several agencies prefer to serve the entire pedestrian clearance interval, but will allow truncation on a case-by-case basis. (4) • Considerations for truncating pedestrian clearance include the number of pedestrians, walking speeds, effect on countdown displays, frequency of trains, and funding available to make a change. (4) • One agency uses signs to warn pedestrians of the possibility of reduced time. (1) • One agency referenced that they reduce pedestrian clearance in accordance with MUTCD Section 4D.27. (1)

TABLE B1
(continued)

QUESTION		# OF RESP.	YES / NO / UNSURE
Q9	How do your signals generally operate during preempt hold intervals?	39	 • Several agencies use multiple strategies, with operations depending on location (i.e., geometry, train speed, crash history, etc.). (6) • Strategies not listed in the survey include: - Flashing all-red. (3) - Flashing yellow on parallel arterial. (2) - Dwell in all-red. (1)
Q10	Do you time a minimum green interval before terminating a phase that is transitioning to the track clearance interval?	40	 • Several agencies determine the use of a minimum green interval based on location. (4) • Values provided by agencies include: - 7 seconds for mainline movements. (1) - 5 seconds minimum. (3) - 2-6 seconds. (1) - 1 second plus 1 second delay time. (1) - 1 second so that the default minimum green is not triggered by a value of 0. (1)
Q11	Do you restrict conflicting turns across the tracks during preempt through blank-out signs or exclusive phases?	39	 • Several agencies restrict conflicting turns across the track(s) through signs and exclusive phases, but the application depends on location. (7) • Specific practices being used include: - Use of exclusive phases to restrict movements across the track(s), and use of blank-out signs when more emphasis is required. (1) - Use of blank-out signs for right-turns with 200 feet or less of storage. (1) - Use of blank-out signs if exclusive phases are not present and the storage distance is less than 100 feet. (1) - Use of flashing yellow arrows for left-turns. (1)

(continued on next page)

TABLE B1
(*continued*)

	QUESTION	# OF RESP.	YES / NO / UNSURE
Q12	Do you use any smart recovery strategies?	40	YES 10% / NO 47% / UNSURE 43% • Several agencies are unsure of the meaning of "smart" recovery strategies versus unsure if they have any. (3) • Agencies that use "smart" recovery strategies indicated that applications vary by location. (3) • Specific strategies being used include: - Quick recovery methods that allow reentry into coordination with other signalized intersections. (1) - Use of a single controller for several intersections to guarantee coordination. (1) - Unique selection of traffic signal exit phases and/or calls on a case-by-case basis. (1) - Simultaneous activation and deactivation of warning devices at locations where the track crosses two legs of an intersection (i.e., triangle). (1)
Q13	At multiple-track locations, do you request second-train-coming logic from the railroad for the railroad warning system on new or upgraded installations?	40	YES 20% / NO 50% / UNSURE 30% • One agency receives separate preemption information from each track and direction. (1) • One agency releases preempt calls immediately after the train passes (and before the gates start to ascend). They use the clearance interval if a second train approaches. (1)
Q14	Do you have train stations near crossings?	40	YES 45% / NO 42% / UNSURE 13%
Q15	If the answer to Question #14 is yes, do you make special provisions for trains stopping at stations?	22	YES 32% / NO 36% / UNSURE 32% • One agency uses constant warning at all crossings, including those with train stations. (1) • One agency determines special provisions on a case-by-case basis. Considerations include the distance between the crossing and the station (and other nearby crossings). (1)
Q16	If the answer to Question #15 is yes, describe the special provisions that are made for trains stopping at stations.	10 (+3)	• Flash if gate-down is too long. (2) • Near-side stations do not activate crossings until requested. (2) • Gates remain down during the dwell time. (2) • Preemption time-out and preemption restart procedures. (1) • Use of a controller feature that activates the crossing as soon as motion is detected (to prevent short warning times due to accelerating trains). (1) • Limiting acceleration made by trains leaving stations. (1) • Delay timer applied by the railway agency. (1)
Q17	Do you have fire preemption at rail preempt intersections?	40	YES 67% / NO 18% / UNSURE 15% • Two agencies use fire preemption on a case-by-case basis. (2)

TABLE B1
(*continued*)

QUESTION		# OF RES P.	YES	NO	UNSURE	
Q18	Do you prioritize which preempts can override other preempts?	41	71%	12%	17%	
			• Several agencies noted that rail preemption overrides emergency vehicle preemption. (4) • Specific preemption prioritization considerations include: - MUTCD recommendations. (1) - Track(s) crossing multiple legs of an intersection. (1) - Railway and bridge-lift preemption coordination. (1)			
Q19	If the answer to Question #18 is yes, describe priority for your first six preempts. Preempt 1 has the highest priority, but more than one preempt may have the same priority (first come, first serve).		RAIL	EMERGENCY	TRANSIT	OTHER
			• Preemption uses included in the "Other" category include: - Bridge. (4) - Ramp. (3) - Queue/congestion. (3) - Aircraft taxiway. (1)			
		29	93%			7%
		28	39%	57%		4%
		19	5%	53%	21%	21%
		13		54%	31%	15%
		8		38%	38%	24%
		4		75%	25%	
GRADE CROSSING OPERATIONS						
Q20	Do you use a simple, two-wire preempt?	40	55%	13%	32%	
			• Two agencies use two-wire preempt at some but not all locations. (6) • Two agencies are no longer installing two-wire preempt, but have older crossings that use it. (3) • One agency noted that they are in the process of upgrading crossings that have two-wire preempt. (1)			

(*continued on next page*)

TABLE B1
(*continued*)

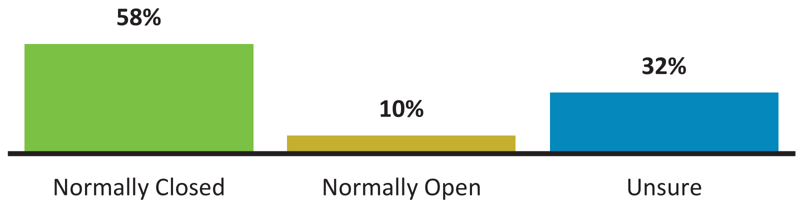
QUESTION		# OF RES P.	YES / NO / UNSURE
Q21	If the answer to Question #20 is yes, is the circuit from the railroad normally closed (when no preempt) or normally open (when no preempt)?	31	 • Two agencies use both types of circuits depending on location. (2) • One agency uses normally open circuits on mainline tracks and normally closed circuits on tracks not used as frequently, such as short spurs. (1)
Q22	If the answer to Question #20 is no, describe your preempt circuitry (e.g., four-wire, serial, or other).	13	• Three-wire (with braiding/shield on each conductor, equivalent to a six-wire double-break design). (1) • Four-wire. (4) • Eight-wire. (1) • Ten-wire. (1) • 14-wire. (1) • Serial interconnect. (1)
Q23	Do the majority of crossings have grade crossing predictors (“constant” warning time)?	40	 • One agency uses predictors at the majority of crossings, with the exception of lower-speed crossings and locations with electrified rail. (1) • One agency uses predictors depending on the characteristics of an individual crossing. (1) • One agency noted that predictors are used at new crossings. (1)
Q24	Do you preempt signals that are more than 200 feet from the crossing?	40	 • Several agencies decide to apply preemption based on the queueing characteristics at an intersection. Some of these note that if queues routinely exceed 200 feet, preemption is used. (12) • Two agencies make the decision to use preemption at signals that are more than 200 feet from the crossing on a case-by-case basis. (2) • Two agencies commented that this scenario is not common. (2) • One agency indicated they have a policy to preempt signals up to 215 feet from the crossing. (1)
Q25	Do any existing locations have advance preemption?	40	 • Use of advance preemption ranges from nearly every crossing to only a few. (4) • Two agencies noted that all new installations have advance preemption. (2) • One agency prefers the use of simultaneous preemption. (1)

TABLE B1
(*continued*)

	QUESTION	# OF RES P.	YES	NO	UNSURE	
DESIGN PRACTICE						
Q26	Do new installations or upgrades include "constant" warning train detection?	39	64%	13%	23%	• Two agencies noted that constant warning train detection depends on the railway agency. (2) • Two agencies noted that most new installations have constant warning train detection. (2) • One agency noted that the use of electrified rail may prevent the use of constant warning devices, or if train speeds are low, it may not be cost effective. (1)
Q27	Do new installations have battery back-up?	40	75%	13%	12%	• Use of battery back-up may depend on the following: - Location and traffic volumes. (3) - Time for an electrician to respond and history of power outage frequency and duration. (1) • One agency noted that battery back-up is installed on a case-by-case basis. (1) • One agency noted that traffic signals do not have battery back-up, but railway equipment does. (1)
Q28	Do new installations have LED signal indications?	41	98%		2%	
Q29	Would you likely use advance preemption at a new location?	40	75%	10%	15%	• Several agencies decide to use advance preemption based on the characteristics of the crossing. (5) • One agency noted that they will only not use advance preemption if the track is so close to the intersection that traffic always stops on the other side of the grade crossing. (1)
Q30	Do you request additional rail outputs (e.g., gate-down, island circuit, or other)?	40	38%	42%	20%	• Two agencies noted that it depends on location. (2) • One agency chooses to only use simultaneous preemption for simpler maintenance and reliability. (1) • One agency noted that cost and maintenance prevents them from using additional outputs. (1)

(*continued on next page*)

TABLE B1
(*continued*)

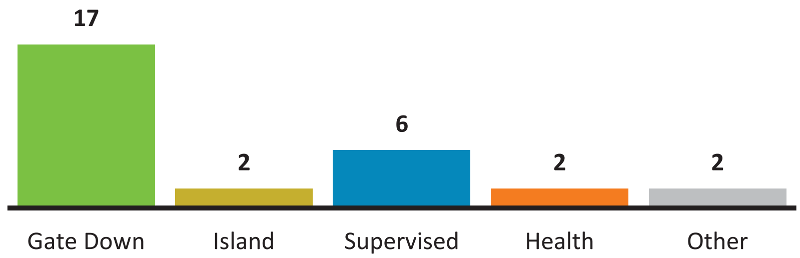
QUESTION		# OF RESP.	YES / NO / UNSURE
Q31	If the answer to Question #30 is yes, which outputs?	16 (+2)	 • Gate-down. (9) • Gate-down and supervised. (4) • Gate-down, supervised, and health. (1) • Gate-down, supervised, health, and island. (1) • Gate-down, island, gate up. (1) • Gate-down and second gate-down. (1)
Q32	Do you use vehicle gates at all new or upgraded crossings?	41	YES 54% / NO 29% / UNSURE 17% • Several agencies install vehicle gates on a case-by-case basis. (10) • Installation of vehicle gates may depend on the following: - Train volumes. (2) - Train speeds. (2) - Sight distance and vehicle AADT. (1) - Available funding. (1) - Intersection geometry. (1) • Two agencies report that installation of gates is determined by the rail way agency. (2) • One agency noted that they have found vehicle gates do not work well when the track runs through the center of the intersection. (1)
Q33	Do you use pedestrian gates at gated crossings?	41	YES 37% / NO 46% / UNSURE 17% • Several agencies with pedestrian gates report that they have them installed at some locations (not all). (11) • Installation of pedestrian gates may depend on the following: - Proximity to schools. (1) - Proximity to quiet zone. (1) • Two agencies report that installation (or lack thereof) of gates is determined by the railway agency. (2) • One agency noted that they do not have any pedestrian gates but would install them if warranted. (1)

TABLE B1
(*continued*)

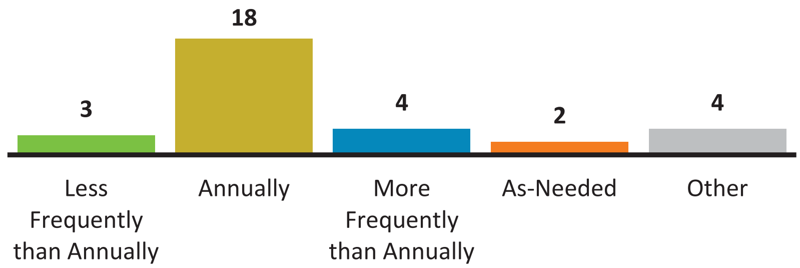
QUESTION	# OF RES P.	YES / NO / UNSURE
Q34 Do you use pre-signals?	40	YES 50% / NO 40% / UNSURE 10% • Several agencies with pre-signals report that they have them installed at a limited number of locations. (5) • Two agencies report that they have used pre-signals in the past but have not found them effective. (2) • Installation of pre-signals may depend on the following: - Crossing geometry. (1) - Installed where the storage distance is inadequate to store a design vehicle. (1) - Existence of near-side indications that can cause issues with pre-signals. (1) • One agency noted that they do not have any pre-signals but would install them if warranted. (1)
Q35 Do you use queue cutters?	41	YES 34% / NO 46% / UNSURE 20% • Several agencies with queue cutters report that they have them installed at a limited number of locations. (5) • One agency reported that they have used queue cutters in the past but have not found them effective. (1) • Installation of queue cutters may depend on the following: - Crossing geometry. (1) - Used with long throats between intersection and track. (1) • One agency noted that they use a similar detection strategy to turn on signs that warn drivers not to stop on the track(s) when queues get close to the crossing. (1) • One agency noted that they do not have any queue cutters but would install them if warranted. (1)
Q36 Do you use four-quadrant gates?	41	YES 41% / NO 41% / UNSURE 18% • Several agencies note that they use four-quadrant gates in limited situations. (8) • One agency noted that the railway agency prefers not to have four-quadrant gates. (1)
Q37 If the answer to Question #36 is yes, when do you use four-quadrant gates?	20 (+2)	• Quiet zones. (10) • Locations with safety issues. (4) • Higher-speed rail corridors. (2) • Where traffic from nearby roadways can easily go around the entrance gates. (1) • Multi-lane roadways. (1) • Main railway routes. (1) • All situations. (1) • When other measures are insufficient. (1)

(*continued on next page*)

TABLE B1
(*continued*)

	QUESTION	# OF RESP.	YES / NO / UNSURE
Q38	Do you use any advanced train detection or railway interconnection technology?	39	YES 13% / NO 49% / UNSURE 38%
Q39	If the answer to Question #38 is yes, describe the advanced train detection or railway interconnection technology.	5	• Incremental Train Control System (ITCS), which utilizes GPS and communications to provide advance activation of the crossings. (1) • DAX outputs from CWT systems. (1) • Railroad Preemption Interface System. (1) • Monitor stations at select crossings. (1) • Hardwired and radio connections. (1)
	MAINTENANCE PRACTICE		
Q40	Do you have railroad-preemption-specific training for your maintenance staff?	39	YES 39% / NO 51% / UNSURE 10% • Several agencies indicated that they do not have training because they are not a maintaining agency. Training is the responsibility of the local agencies. (5) • One agency has two levels of formal traffic signal field maintenance training plus on-the-job training. (1) • One agency has preemption information is included with signal systems training. (1)
Q41	Do you have written procedures for contacting the railroad regarding activities near grade crossings?	38	YES 58% / NO 26% / UNSURE 16% • Communication conducted through planning division or agency railway-specific coordinator/engineer/office. (5) • Warning notices posted in both railway and traffic cabinets. 24-hour contact information is provided, with notice that pre-approval of changes is required. (2) • Right-of-way entry agreement is used, but may not be required if not on/near track. (1) • Agency has railway phone number for reporting track circuit issues. (1) • Transport Canada guidelines contain statement about notifying railway authority of work. (1)
Q42	Do you perform routine inspections and/or maintenance of your preemption system?	39	YES 61% / NO 21% / UNSURE 18% • One agency indicated that it does not conduct inspections because they are not a maintaining agency. • One agency responded that inspections are the responsibility of the local agency. (2) • One agency pointed out that Transport Canada guidelines contain requirements for inspecting and testing preemption. (1)

TABLE B1
(*continued*)

QUESTION	# OF RESP.	YES / NO / UNSURE
Q43 If the answer to Question #42 is yes, how often do you perform inspections and/or maintenance?	25 (+2)	 • Every five years. (1) • Every three years. (2) • Every year. (18) • Bi-annually. (1) • Every three to four months. (1) • Monthly. (1) • Performed on a monthly basis as part of other maintenance. (1) • As-needed, or if malfunctions are identified. (2) • Organized by the railway agency. (2) • Performed as part of routine maintenance with varying frequency. (1) • If a major upgrade/change is made to signal or railway equipment/track. (1)
Q44 Do you coordinate with the railroad's monthly testing of preemption?	38	 • Coordinate annual inspection with railway monthly inspections. (3) • Two agencies indicated that they do not coordinate testing because they are not a maintaining agency or that they do not have the authority. • One agency noted that railway staff and traffic staff test preemption on their respective systems when conducting other maintenance. (1) • When conducting inspections (with varying frequency), one agency coordinates their activity with the railway agency. (1)
Q45 Do you periodically review crossings to determine the need for upgrading the rail warning system or traffic signal system?	38	 • Several agencies indicated that they do not review crossings because they are not a maintaining agency. • Ongoing/as-needed reviews conducted based on findings from inspections, complaints, crashes, development reviews, etc. (2) • Upgrades are periodically made as enhancements are developed. (1) • Request feedback on operational issues from local agencies, and provide support/direction on upgrades. (1) • Based on FSP program ranking. (1)

(*continued on next page*)

TABLE B1
(continued)

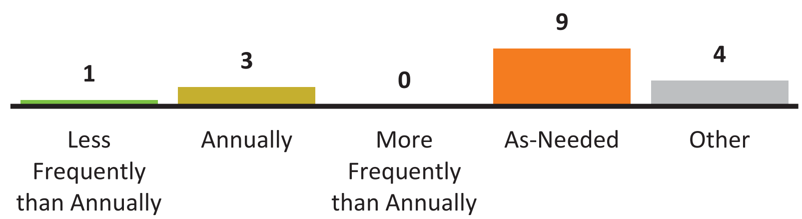
QUESTION		# OF RESP.	YES / NO / UNSURE
Q46	If the answer to Question #45 is yes, how often do you review crossings?	14 (+1)	 • Every five years. (1) • Annually. (3) • As-needed/requested (i.e., no set schedule). (9) • Depends on funding. (1) • As part of highway projects. (1) • During joint railway inspection. (1) • When the railway reports changes to rail traffic. (1)
Q47	Do you shop test your cabinet and controller before installation?	38	 • Vendors' responsibility to test/factory-tested. (2) • Preemption is tested under normal circumstances and failure. (2) • One agency indicated that they do not shop test because they are not a maintaining agency. (1) • Equipment for new crossings is shop tested. Equipment for existing locations with added preemption is reviewed in the field. (1) • Controllers are shop tested but cabinets are not. (1) • Some example shop tests include the following: - Preemption during each interval. (1) - Preemption calls during manual control on. (1) - Power interruption during preemption. (1) - Power start-up during preemption. (1)

TABLE B1
(*continued*)

QUESTION	# OF RESP.	YES	NO	UNSURE	
Q48 Do you restrict timing changes at interconnected traffic signals to those that have been pre-approved by an appropriate staff member?	38	87%	8%	5%	• Changes can only be made by trained signal timers. (2) • Two agencies require notifications from the local agencies making changes. (2) • Parameters with restrictions include the following: - Preempt parameters. (2) - Minimum green. (1) - Yellow clearance. (2) - Red clearance. (2) - Pedestrian clearance. (1) • Changes must be reviewed and approved by agency. (1) • Warning labels posted in both railway and traffic cabinets. (1) • Controllers are password protected, and additional security locks are used on cabinets. Only pre-approved controllers are allowed, which must meet safety criteria. Critical program data (affecting signal sequence or preemption) is protected by Cyclic Redundancy Check. (1) • One agency indicated that they do not have restrictions because they are not a maintaining agency. (1)
Q49 Do you use contract maintenance?	38	50%	45%	5%	• Several agencies use limited contract maintenance, performing most work in-house. (4) • A few agencies note that the use of contractors depends on the local agency. (3) • Two state agencies contract work to local agencies. (2)
Q50 If the answer to Question #49 is yes, do you have specific procedures developed regarding coordination with the railroad?	19	37%	42%	21%	• Local agencies are required to contact the state agency with changes or conflicts related to preemption. (1) • Warning notices posted in both railway and traffic cabinets. 24-hour contact information is provided, with notice that pre-approval of changes is required. (1) • Coordination efforts are dependent on the local agency. (1) • Right of Entry Agreement states to contact railway maintainer, who should be on site for inspection. (1) • Required coordination indicated on signal permit plans. (1) • Transport Canada guidelines outline procedures. (1)
MONITORING ACTIVITIES					

TABLE B1
(*continued*)

	QUESTION	# OF RESP.	YES / NO / UNSURE
Q51	Do you record detailed rail-warning-system events beyond the preempt log in the traffic signal controller?	38	YES 16% / NO 66% / UNSURE 18% • Two agencies noted that logging is determined by the local agencies. (2) • One agency noted that there are limited locations with additional logging capabilities. (1) • Examples of detailed railway-warning-system events include: - Traffic-signal or railway-interconnect malfunctions. (1) - Remotely accessible video. (1) - Voltage monitors. (1)
Q52	Do you compare design assumptions to actual operations in the field?	37	YES 62% / NO 22% / UNSURE 16% • Performed during final inspection. (1) • Verified after implementation. New installations, or existing locations undergoing considerable changes, require a joint inspection during the activation process. (1) • Queue dissipation times for track clearance green interval are compared in the field. (1)
Q53	Do you have traffic signals preempted by street-running LRT?	37	YES 27% / NO 59% / UNSURE 14% • Future system planned. (1) • Existing systems include: - Northampton, Massachusetts. - Camden, New Jersey. - Charlotte, North Carolina.
Q54	If the answer to Question #53 is yes, do you have written practices on the signal operation?	13	YES 31% / NO 46% / UNSURE 23% • Agency may not have written practices, but LRT agency does. (1) • Signal plans showing signal heads, preemption, and railway detection. (1)
Q55	Do you have any highway-rail grade crossing research or demonstration projects underway?	37	YES 11% / NO 59% / UNSURE 30% • Intersection with recording device. (1) • Island circuit. (1) • Revising TxDOT preemption form to simplify and clarify some of the more challenging aspects. (1)

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

TRANSPORTATION RESEARCH BOARD
500 Fifth Street, NW
Washington, DC 20001

ADDRESS SERVICE REQUESTED

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

The nation turns to the National Academies of Sciences, Engineering, and Medicine for independent, objective advice on issues that affect people's lives worldwide.
www.national-academies.org

ISBN 978-0-309-38995-2

NON-PROFIT ORG.
U.S. POSTAGE
PAID
COLUMBIA, MD
PERMIT NO. 88