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Signalized Intersection Safety In Europe

U.S.Department of Transportation
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16. Abstract

More than a third of the intersection-related fatal crashes in the United States occur at signalized intersections. The Federal Highway Administration, American Association of State Highway and Transportation Officials, and National Cooperative Highway Research Program sponsored a scanning study of Sweden, Germany, the Netherlands, and the United Kingdom to review innovative safety practices in planning, designing, operating, and maintaining signalized intersections.

The delegation observed that highway safety improvements are a priority in the European countries visited, with an emphasis on reducing fatalities. Programs for intersection safety focus on reducing vehicle speed through innovative methods, using computerized signal timing optimization programs, and providing road users with consistent information.

The scanning team's recommendations for U.S. implementation include developing a model photo enforcement program to reduce red-light running, enhancing dilemma-zone detection at high-speed rural intersections, and promoting roundabouts as alternatives to signalized intersections. The team also recommends controlling vehicle speed through intersections with such techniques as speed tables, pavement markings, and changeable message signs.

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Signalized Intersection Safety in Europe

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FHWA INTERNATIONAL TECHNOLOGY EXCHANGE PROGRAM

The Federal Highway Administration's (FHWA) International Technology Exchange Program accesses and evaluates innovative foreign technologies and practices that could significantly benefit U.S. highway transportation systems. This approach allows for advanced technology to be adapted and put into practice much more efficiently without spending scarce research funds to recreate advances already developed by other countries.

The main channel for accessing foreign innovations is the International Technology Scanning Program. The program is undertaken jointly with the American Association of State Highway and Transportation Officials (AASHTO) and its Special Committee on International Activity Coordination in cooperation with the Transportation Research Board's National Cooperative Highway Research Program Project 20-36 "Highway Research and Technology – International Information Sharing," the private sector, and academia.

FHWA and AASHTO jointly determine priority topics for teams of U.S. experts to study. Teams in the specific areas being investigated are formed and sent to countries where significant advances and innovations have been made in technology, management practices, organizational structure, program delivery, and financing. Scan teams usually include representatives from FHWA, State departments of transportation, local governments, transportation trade and research groups, the private sector, and academia.

After a scan is completed, team members evaluate findings and develop comprehensive reports, including recommendations for further research and pilot projects to verify the value of adapting innovations for U. S. use. Scan reports, as well as the results of pilot programs and research, are circulated throughout the country to State and local transportation officials and the private sector. Since 1990, FHWA has organized more than 50 international scans and disseminated findings nationwide on topics such as pavements, bridge construction and maintenance, contracting, intermodal transport, organizational management, winter road maintenance, safety, intelligent transportation systems, planning and policy.

The International Technology Scanning Program has resulted in significant improvements and savings in road program technologies and practices throughout the United States. In some cases, scan studies have facilitated joint research and technology-sharing projects with international counterparts, further conserving resources and advancing the state of the art. Scan studies have also exposed transportation professionals to remarkable advancements and inspired implementation of hundreds of innovations. The result: large savings of research dollars and time, as well as significant improvements in the nation's transportation system.

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INTRODUCTION

About 25 percent of fatal crashes in the United States are intersection related. Of these, more than one-third occur at signalized intersections. Given this fact, increasing safety at signalized intersections is a priority for the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), the Institute of Transportation Engineers (ITE), and many State departments of transportation (DOTs). Indeed, FHWA has identified intersection safety as one of three priority areas for attention, and AASHTO's Strategic Highway Safety Plan includes improving the design and operation of highway intersections as one of its 22 key emphasis areas.

To this end—improving signalized intersection safety—FHWA and AASHTO sponsored a scanning study in May 2002 to focus on innovative signalized intersection safety practices in Europe. The scanning team visited four countries: Sweden, Germany, the Netherlands, and the United Kingdom. The objective of the study was to identify safety practices and evaluate their applicability to the United States. Through meetings with representatives from each country, site visits, and field observations, the team identified programs and strategies that could work in the United States and potential barriers to their success. This report presents the scan team's observations, findings, and recommendations.

AREAS OF INTEREST

To provide the European hosts with an understanding of the scanning study's objectives and team members' interests in signalized intersections, the team identified six major areas of interest and developed questions accordingly:

- Selecting, designing, installing, operating, and maintaining traffic control devices
- Innovative traffic control devices
- Innovative geometric designs
- Processes and procedures for identifying problems and evaluating and selecting countermeasures
- Low-cost safety improvements
- Research projects focusing on safety

The team sent the questions to the host countries' officials in advance so they could conduct research.

GENERAL FINDINGS AND OBSERVATIONS

Sweden

Overall traffic safety in Sweden is directed by a national policy called "Vision Zero," which has a goal of 50 percent reduction in highway fatalities. The Vision Zero concept is rooted in the belief that preventing highway fatalities is the responsibility of all agencies and entities involved in transportation, including engineers, highway officials, police, and others.

Safety—particularly of pedestrians and bicyclists—is of primary importance, while vehicle mobility is secondary. Traffic safety efforts focus on eliminating fatalities and irreversible-injury accidents and protecting vulnerable road users instead of just reducing overall accident rates. The focus is on reducing crash severity, not frequency. On the basis of this principle, the Swedish National Road Administration (SNRA) converted some signalized intersections to roundabouts, expecting that though the frequency of accidents may increase, the severity of those accidents may decrease, and sought to reduce intersection speed, especially where pedestrians, bicycles, and vehicles share the same space.

An intersection safety technique of note is a system called LHOVRA, in which a series of detectors line an intersection's approach. The detectors determine vehicle type and speed at various points along the approach and adjust the signal timing by increasing the yellow change and all red clearance intervals to minimize the number of vehicles caught in the dilemma zone. In other words, the strategy looks for an opportunity to transition when the dilemma zone is unoccupied. LHOVRA is most effective at high-speed rural intersections, particularly where heavy truck traffic is a safety concern. SNRA has completed before-and-after studies at intersections where LHOVRA has been implemented, and the results are promising. The studies showed that LHOVRA reduced conflicts by one third and cut red-light running from 4 percent of drivers to 1 percent.

Germany

Highway safety improvements are a priority in Germany and, as a result, the number of highway fatalities since the 1990 reunification has decreased dramatically. Safety priorities in Germany are similar to those in Sweden. Goals include the following:

- Safety with an emphasis on reducing the severity rather than the number of crashes
- Mobility throughout the network, including transit
- Intersection and roadway traffic flow and operations

Traffic safety in Germany is a coordinated effort among local and national organizations. The country has about 500 federal and local accident commissions (called KEBU in Frankfurt) made up of local traffic authorities, civil engineering departments at universities, police, and traffic security wardens. These commissions are responsible for identifying high-accident locations, completing studies, implementing solutions, and monitoring the solutions for effectiveness.

Like other European countries, Germany places a high priority on bicycle and pedestrian traffic safety. In some cases, pedestrians and bicyclists are given priority over motorists.

Germany has successfully applied photo enforcement techniques to slow traffic and reduce red-light running. German officials identified two key conditions for successful application: First, the public must be aware that photo enforcement measures are being used. Second, disobeying the posted speed or running a red light must carry a substantial penalty. German speed-enforcement cameras are highly visible, signs warn of photo enforcement, and public messages are broadcast to make motorists aware that the equipment is being used. Germany's fine structure varies for red-light running in a photo-enforced intersection, depending on how late the motorist enters the intersection. If the motorist is only one second late, he is fined $175 (considered low). Progressively later times mean progressively larger fines. Preliminary observations and studies of photo enforcement suggest a dramatic decrease in both the number and severity of accidents.

Other intersection-safety strategies include using highly visible signal back plates, changeable-message signs, audible crossing signals, and flashing warning lights to identify high-accident locations.

The Netherlands

National safety goals guide the Netherlands' approach to intersection safety. The National Traffic and Transport Plan has set goals of a 30 percent reduction in fatalities and a 25 percent reduction in serious injuries by 2010. The plan is based on three principles: First, the form of a traffic system should be designed to follow the intended function and prevent unintended uses. Second, the system should be homogeneous. And third, the system should be predictable even to unfamiliar road users.

As in other European countries visited, heavy pedestrian and bicycle traffic is common at most signalized intersections in the Netherlands. The Dutch use special advanced indicators to warn pedestrians, bicyclists, and motorists of potential conflict situations. A noteworthy practice in the Netherlands, unlike in the United States, is to operate signals at a local, vehicle-actuated level. This limits the maximum signal cycle lengths and accommodates pedestrians, bicycles, and public transport. Occasionally, motorized traffic congestion issues are treated as secondary. Signal synchronization is easily compromised if demand exists for bicycles, pedestrians, or public transport on other approaches to the signal.

The Dutch program for intersection safety focuses on reducing vehicle speed and providing road users with clear, consistent information. Speed is controlled by several methods, including geometric design, speed-warning signs, speed tables, and an extensive and conspicuous use of photo enforcement.

The Dutch spend a sizable amount of money on traffic control, much more than the United States and the other three countries visited spend. They have three Freeway Management Centers in the Randstad that monitor freeways in Amsterdam, Rotterdam, The Hague, and Utrecht, with detectors in and variable message signs over each lane nearly every quarter of a mile. Nearly every spot near complex freeway interchanges is viewable by cameras, and each variable message sign can be controlled remotely. Two other Freeway Management Centers are located elsewhere in the country. The countrywide Traffic Information Center and Freeway Incident Management Center is located in Utrecht. In contrast, because of the local approach to traffic control, major cities like Amsterdam and Rotterdam do not employ an urban traffic management center.

The Dutch promote safety and focus on skilled driving from the start by setting the following requirements for obtaining a diver's license:

- An average of 30 hours of hands-on training, with lessons costing the equivalent of U.S. $30 per hour.
- A 50-question written exam on information taken from a 500-page driver's manual.
- A 35-minute driving test that costs the equivalent of U.S. $163 to take. The test has a 70-percent failure rate, and applicants must take another 10 lessons before retaking the test.

The Dutch, like the Swedes and Germans, prefer roundabouts to signals. If an intersection is already signalized, they look first at converting it to a roundabout. To better accommodate pedestrians and bicyclists, roundabouts are designed with a single lane around the center island and the approaches are not flared. Vehicles approach at 90 degrees to the roundabout so they will slow down to 15 miles per hour or less, and a center refuge island is installed to allow pedestrians and bicyclists to cross the roadway in separate halves. In many cases, roundabouts are not able to deal with the heavy traffic streams.

Enforcement tolerance is set to 7 kilometers per hour for speed limits below 100 kilometers per hour, and 8 kilometers per hour at higher speeds. In urban areas with a speed limit of 50 kilometers per hour, a tolerance of 14 percent is used. On motorways with a speed limit of 120 kilometers per hour, speeding up to 6.7 percent is tolerated with no penalties.

United Kingdom

The United Kingdom's national safety plan, "Tomorrow's Roads—Safer for Everyone," calls for a 40 percent reduction in total roadway fatalities and serious injuries, a 50 percent reduction in the number of children killed or seriously injured, and a 10 percent reduction in the slight-casualty rate. As in the other countries visited, the emphasis in the United Kingdom is on reducing accidents with serious consequences. National authorities are implementing the plan in partnership with local authorities, police, health services, industry, government departments, and road users.

The United Kingdom, like the United States, faces significant traffic congestion in metropolitan areas. It faces the challenge of maintaining a delicate balance among safety, mobility, and congestion in the design and operation of signalized intersections. The British have developed and implemented a number of computerized signal-timing-optimization software packages, such as microprocessor optimized vehicle actuation (MOVA) and optimized signal capacity and delay (OSCADY), to increase intersection capacity, reduce delay and queuing, and improve safety.

Pedestrian safety at signalized intersections is a high priority. To this end, a number of specialized pedestrian crossings such as PUFFIN (pedestrian user-friendly intelligent) and TOUCAN ("two can" cross) have been developed. And technologies such as passive infrared and microwave detection optimize both motorized and nonmotorized traffic operations at signalized intersections.

The United Kingdom uses photo enforcement extensively. At one field site 25 miles outside of London, the scan team was told that a motorist could encounter 16 cameras while driving from the site into London, each camera capable of issuing a violation. Theoretically, one speeding driver could receive 16 citations from a single trip.

The United Kingdom also has a point system, with 12 points in three years resulting in banning of a driver. Speed camera violations usually result in three points, though exceptional speed may result in more. Red-light camera violations result in three points.

The United Kingdom uses a uniform three-second yellow clearance at signals and displays a "starting yellow" of two seconds. The starting yellow comes on simultaneously with the red at the end of the red to indicate that the right-of-way is about to change. Conventional wisdom holds that the starting yellow helps drivers begin moving promptly on the green signal, maximizing junction capacity. Because the time is part of the safety inter-green time, omitting a starting yellow would increase the all-red time. The actual benefits of the starting yellow are being researched.

While not directly related to signals, the United Kingdom is using painted offset crosswalks in lieu of signals to force gaps in traffic. The offset crosswalk is designed to enable and force pedestrians to cross a two-way street one-half at a time, reducing the required gap and decision making in half. Since under some conditions signalization increases crashes, this strategy holds substantial promise.

TEAM RECOMMENDATIONS

On the basis of observations and findings in Sweden, Germany, the Netherlands, and the United Kingdom, the scan team developed five primary recommendations and several secondary ones. The primary recommendations include the following:

1. Develop a model photo enforcement program to reduce red-light running and control speed at high-accident signalized intersections.

2. Enhance dilemma-zone detection at high-speed rural intersections using MOVA, LHOVRA, and similar technologies.

3. Control vehicle speed through intersections using a combination of practices such as speed tables, pavement markings, automated photo enforcement, and changeable-message signs.

4. Promote roundabouts as alternatives to signalized intersections where traffic volumes allow as a way to manage the severity of collisions (taking into

consideration that bicyclists are more vulnerable at roundabouts and that roundabouts make providing controlled pedestrian crossings more difficult).

5. Develop guidelines for improving pedestrian safety at signalized intersections using strategies such as PUFFIN and TOUCAN crossings, countdown indicators, and audible pedestrian signals.

Several scan team members also identified practices and programs that relate to their respective areas of expertise. These practices form the basis of the team's secondary recommendations, including introducing wider pavement markings, requiring a standard interval for all amber signals, and using countdown indicators for pedestrians and bicyclists.

chapter one
INTRODUCTION

BACKGROUND

About 25 percent of fatal crashes in the United States are intersection related, and more than one-third of these fatal crashes occur at signalized intersections. In U.S. cities, about a third of fatal crashes are related to intersections, while about 14 percent occur at signals. This is because a large proportion of fatal crashes in cities involve pedestrians. Accordingly, safety at signalized intersections is a top priority for the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), the Institute of Transportation Engineers (ITE), and a number of State departments of transportation (DOTs). In fact, one of the 22 emphasis areas of the AASHTO Strategic Highway Safety Plan is improving the design and operation of highway intersections. This emphasis area includes four specific strategies. Implementation of the plan calls for an effort to determine the most promising countermeasures, including experimental or innovative countermeasures. Similarly, FHWA has identified intersection safety as one of three priority areas. This priority is reflected in FHWA safety policies, programs, and research. And ITE has developed a Safety Action Plan that includes an aspect titled “Intersection Crashes.” ITE has identified 10 strategies that call for, among other things, promotion of best practices and new technologies for improving intersection safety.

To this end—improving intersection safety—FHWA and AASHTO sponsored a European scanning study to focus on innovative safety practices in planning, designing, operating, and maintaining signalized intersections and junctions. During the May 10-25, 2002, study, the scanning team visited Sweden, Germany, the Netherlands, and the United Kingdom.

STUDY OBJECTIVES

The primary objective of the study was to identify and evaluate promising and readily implementable intersection safety solutions and programs to use in the United States. The team met with representatives of the four countries to discuss intersection safety strategies and programs that, if implemented in the United States, would improve safety at signalized intersections. Through discussions and site visits, the team also identified potential barriers to or special needs of implementation in the United States. The team also observed safety improvements and gathered information about site-specific studies and examples of signalized intersection safety improvements.

SCAN APPROACH AND PLANNING

FHWA and AASHTO identified the need to address safety issues related to signalized intersections in the United States and jointly sponsored a team of experts to identify readily implementable best practices used in Europe. The team conducted a literature search and prepared a desk scan report to identify countries addressing intersection safety with innovative techniques. Based on the desk scan results, the team visited four countries. The scan started in Stockholm, Sweden, and continued to Germany, the Netherlands, and the United Kingdom (Figure 1-1).

Figure 1-1. Map of Europe.

Scan Team

The scanning team's 13 members included representatives from FHWA, AASHTO, State DOTs, municipal transportation agencies, universities, and the private and nonprofit sectors. Co-chairs Gene K. Fong, director of FHWA's Field Services–East, and James H. Kopf, chief engineer and deputy executive director of the Mississippi DOT, led the team. Other members were Philip Clark, deputy chief engineer and director of design for the New York State DOT; Rick Collins, director of the Texas DOT Traffic Engineering Section; Richard A. Cunard, engineer of traffic operations for the Transportation Research Board (TRB); Ken F. Kobetsky, program director for engineering for AASHTO; Nazir Lalani, principal engineer for the Ventura County, California, Transportation Department and past international president of ITE; Fred N. Ranck, safety and geometrics engineer for FHWA's Midwestern Resource Center; Robert K. Seyfried, director of the Transportation Engineering Division of the Northwestern University Center for Public Safety; James W. Sparks, traffic engineer for the City of Phoenix, Arizona; Rudolph M. Umbs, chief highway safety engineer in FHWA's Office of Safety Design; Steve N. Van Winkle, director of public works for the City of Peoria, Illinois; and Kevin L. Slack, senior transportation engineer and vice president at CH2M HILL, who served as the team's report facilitator (Figure 1-2).

Figure 1-2. Scan team members (left to right) Jim Sparks, Rudy Umbs, Gene Fong, Nazir Lalani, Ken Kobetsky, Fred Ranck, Bob Seyfried, Richard Cunard, Rick Collins, Kevin Slack, Jim Kopf, Steve Van Winkle, and Phil Clark.

Figure 1-3. Jake Almborg of American Trade Initiatives, Inc. organized the study and logistics with the host countries.

Amplifying Questions

To provide the European hosts with an understanding of the scanning study's objectives and interests, the team developed questions that focused on six major areas of interest, listed below. The complete set of questions is in Appendix B.

The scanning team was divided into six subgroups according to the areas of interest listed below. Each subgroup was responsible for documenting observations and findings in its respective area of interest:

- Selection, design, installation, operation, and maintenance of traffic control devices at signalized intersections (Steve Van Winkle, team leader)
- Innovative traffic control devices at signalized intersections (Rick Collins, team leader)
- Innovative geometric designs for signalized intersections (Phil Clark, team leader)
- Processes and procedures for identifying safety problems at signalized intersections and evaluating and selecting countermeasures (Fred Ranck, team leader)
- Low-cost safety improvements for signalized intersections (Bob Seyfried, team leader)
- Research projects focusing on safety issues (Rich Cunard, team leader)

Team Itinerary

Figure 1-4 summarizes the scan team's itinerary from May 12 to 25, 2002. During the scanning study, the team met with signalized intersection safety experts representing national and local transportation agencies, research organizations, signal manufacturers, and universities in the host countries. A list of representatives from the host countries is in Appendix C. Meetings with the host agencies were a combination of workshops and site visits to observe intersection operations in the field.

In addition to attending host-country meetings and site visits, the team met several times during the scanning study. At its first meeting, the team confirmed assignments and reviewed the study objectives, amplifying questions, and host agency agendas. The team met again halfway through the trip to discuss findings and observations from Sweden and Germany, the first two countries visited. The team met on the last day of the study to summarize findings, develop preliminary recommendations, and establish the implementation team.

Report Organization

This report summarizes the scan team's observations, findings, and recommendations. During the study, the team had the opportunity to interact with many experienced officials who provided valuable insight on signalized intersection safety from the perspective of their respective organizations. In addition, the team observed firsthand various innovative practices and technologies in the field.

TABLE 1. Scan Team Itinerary

Location	Group Purpose	Date
Stockholm, Sweden	Scan team organizational meeting	May 12
Stockholm, Sweden	Swedish National Road Administration (SNRA) and Peek Traffic	May 13
Stockholm, Sweden	SNRA, City of Stockholm Traffic Service Department, site visits	May 14
Munich, Germany	Siemens Traffic Control Facilities	May 15
Frankfurt am Main, Germany	Site visits	May 16
Bergisch Galdbalt, Germany	Federal Highway Research Institute (BAST)	May 17
The Hague, Netherlands	Team meeting—review meetings in Sweden and Germany	May 18
The Hague, Netherlands	Team meeting—review meetings in Sweden and Germany, prepare for Netherlands and United Kingdom visits	May 19
Utrecht, Netherlands	Dutch Ministry of Transport's Transport Research Center (AVV), site visits	May 20
Delft, Netherlands	AVV, Ministry of Justice, Province Zuid-Holland, consultants' presentations	May 21
Rotterdam, Netherlands	Presentations and site visits	May 22
London, United Kingdom	Department of Transport and Transport for London	May 23
Crowthorne, United Kingdom	Transport Research Laboratory and site visits	May 24
London, United Kingdom	Final team meeting and preliminary recommendations	May 25

The report is organized around the six areas of interest described above. The next seven chapters summarize the general findings and observations by country for each major area of interest. The final chapter summarizes the team's primary and additional recommendations. The primary recommendations focus on implementable strategies to address safety at signalized intersections. In addition, a number of scan team members identified practices and programs that relate to their respective areas of expertise.

chapter two
GENERAL FINDINGS AND OBSERVATIONS

In identifying implementable safety solutions, it is important to understand and acknowledge the cultural differences between the countries visited and the United States. In many cases, specific solutions and practices succeed in Europe because of approaches to public safety, legal issues, public funding, public education, respect for authority, etc. The team identified practices that were innovative and unique, but that would have limited application in the United States because of basic cultural differences. A good example is traffic signal synchronization. In the United States, signal synchronization is important not just for signal safety and efficiency reasons, but also for air quality and fuel conservation concerns. European countries do not have environmentally declared nonattainment areas where signal synchronization is required. For that reason, European traffic engineers have substantially more flexibility than U.S. traffic engineers to use unusual signal phasing and flexible signal cycles.

The following summarizes the general, overarching beliefs and practices that shape intersection safety solutions and programs in the countries the team visited.

SWEDEN

Traffic safety in Sweden is directed by a national policy called "Vision Zero." An interim goal of Vision Zero, begun in 1996, is to reduce highway fatalities by 50 percent by 2007. Previously, primary responsibility for avoiding traffic accidents was placed on the individual road user. The Vision Zero concept is rooted in the belief that highway fatalities are unacceptable and are the responsibility of all agencies and entities involved in transporting people and goods, including engineers, planners, local and national highway agencies, automobile manufacturers, policy makers, police agencies, etc. Vision Zero is being realized in a variety of ways in agencies throughout Sweden.

Most traffic signals in Sweden are located in the Stockholm region of the Swedish National Road Administration (SNRA). As in much of the United States, traffic in this region is increasing at a much faster pace than the population, and SNRA is not able to expand the transportation network swiftly enough to meet the demand. Traffic problems are aggravated by the fact that so much water divides land areas (i.e., the expense of bridging roadways apparently limits the number of available corridors to move traffic to much fewer than are available in U. S. cities). The result is an increase in congestion and associated driver behavior, such as aggressive driving and red-light running. The first priority remains safety, particularly for vulnerable road users (pedestrians and bicyclists). When faced with the mobility-versus-safety issue, safety is paramount. Turning right on red, for example, is prohibited in Sweden.

Traffic safety efforts focus on eliminating fatalities and irreversible injury accidents and protecting vulnerable road users rather than reducing overall accident rates. The primary focus is on crash severity, not frequency. This is an important consideration, particularly at signalized intersections with heavy pedestrian and bicycle traffic (see Figure 2-1). On the basis of this principle, SNRA has converted signalized intersections to roundabouts, recognizing that the frequency of total accidents may increase, but the severity of those accidents may be greatly reduced. Following the same principle, the overall approach to intersection safety is to reduce speed, especially where pedestrians, bicycles, and vehicles share the same space.

Figure 2-1. Pedestrian and bicycle traffic at signalized intersection in Stockholm, Sweden.

The following are statistics on signalized intersections in Sweden:

- Sweden has about 3,000 signalized intersections, with SNRA responsible for about 600 intersections and cities and local jurisdictions responsible for the rest.
- About two-thirds of police-reported accidents (fatalities, injuries, and damage-only accidents) at signalized intersections are related to either red-light running or rear-end crashes. Protected left-turn phasing is used extensively in Sweden and is required for all intersections with approach speeds equal to or greater than 70 kilometers per hour.
- Safety improvements are funded at the national level through appropriations from Parliament and the Ministry. SNRA then works with local agencies to implement safety improvements on a systematic and project-specific basis.
- Tort liability is not a primary concern in Sweden.

- SNRA has the responsibility to organize municipalities, police, and other organizations to improve roadway safety.
- Traffic signals are viewed less as safety improvements than as capacity devices.

Though tort liability is not a primary issue in Sweden, the country is beginning to see an increase in the number of traffic-related lawsuits. Tort liability's limited effect (real or perceived) allows SNRA and local transportation agencies the opportunity and flexibility to test innovative ideas and solutions with limited restrictions and risks.

GERMANY

Highway safety improvements are a priority in Germany and, as a result, the country has experienced a large reduction in highway fatalities since reunification in 1990. The team observed the following safety priorities in Germany, which are similar to Swedish approaches but differ by placing a high priority on efficiency and overall traffic-flow quality:

- Safety of motorized and nonmotorized vehicular traffic with an emphasis on reducing the consequences of crashes rather than the overall number
- Mobility throughout the network, including transit
- Intersection/roadway traffic flow and operations

In Germany, traffic signals are generally the responsibility of local street traffic authorities, whose duties typically include planning, locating, constructing, signing, and marking signalized intersections.

German law requires traffic engineers to follow standards and codes in designing and operating traffic signals, including rigorous signal timing and clearance calculations for all modes of traffic. Failure to follow these standards can result in criminal and civil liability on the part of the owning agency or engineer of record. German law, however, limits tort liability related to innovative traffic control devices by making it illegal for one to enter an intersection until it is clear. To avoid tort liability issues with innovative control devices, operators of signal systems must meet extensive clearance calculations and other required safety criteria (performance criteria).

Like other European countries, Germany places a high priority on bicycle and pedestrian traffic safety and protection of vulnerable road users. In some cases, pedestrians and bicyclists are given priority over motorized vehicle traffic. Extensive intersection pavement markings are used to identify bicycle and pedestrian crossings within intersections (Figure 2-2).

Figure 2-2. Pedestrian and bicycle crossings in Germany.

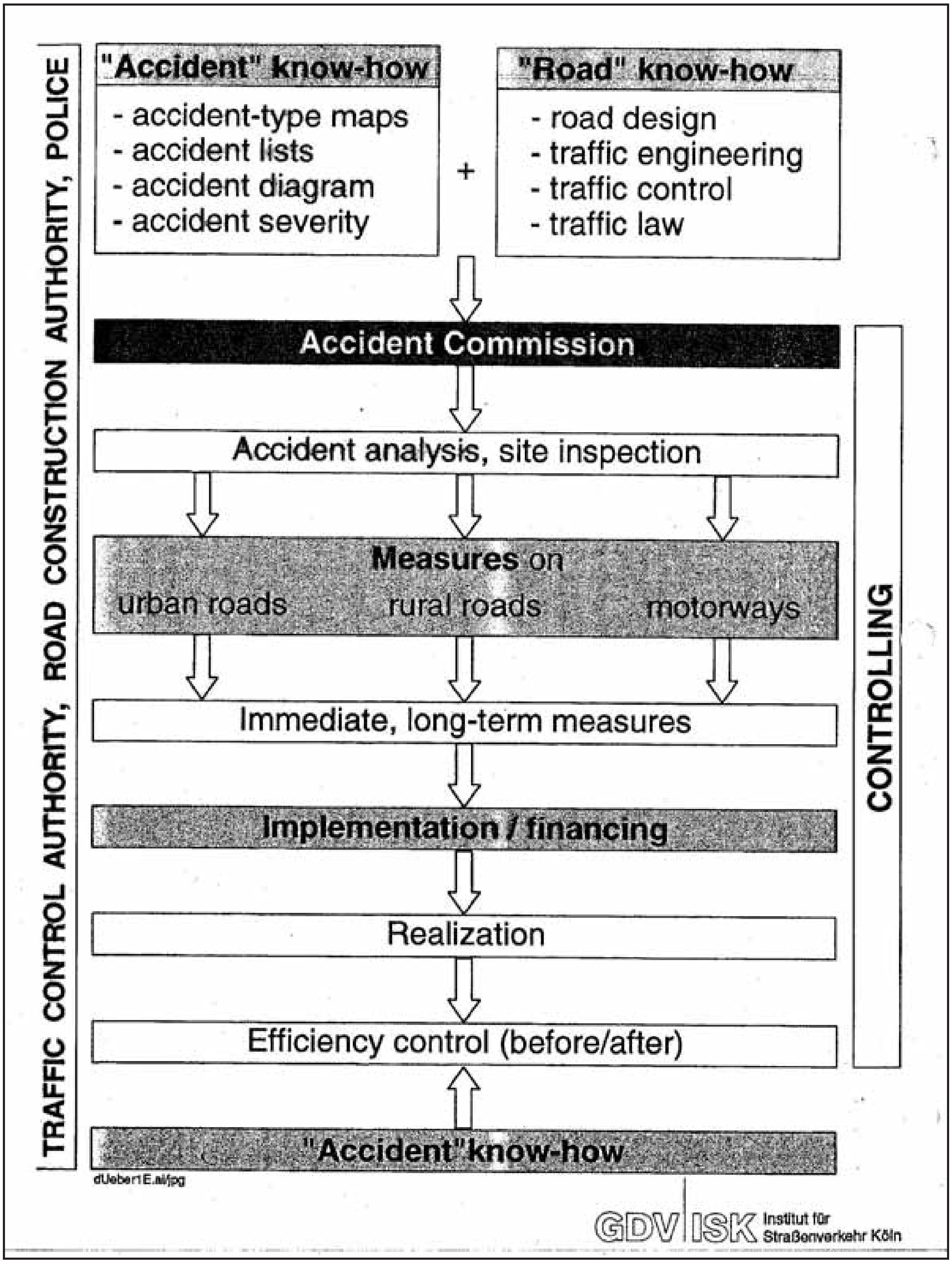
Frankfurt, Germany, has 764 signals, all of which operate on 10-volt power with halogen signal locations. Experience has shown a gain in energy savings equivalent to using light-emitting diode (LED) technology, and 10-volt power is safer for employees to operate.

German officials do a substantial amount of simulation, both to optimize signal timing and to demonstrate to the public how signals work. Officials made a point of saying they do not allow "apple pie" simulation to sell a project and that the simulation is vital to accurately portray real traffic flow. They indicated the simulation process is considered a "contract" with their constituents.

Germany installs red-light enforcement cameras without warning signs. Additionally, extra camera locations and wiring at alternate locations are installed so that the cameras can be rotated among locations. Penalties for violating the red-light law are severe and are graduated based on how extensively the motorist violated the law (i.e., how many seconds into the red he entered the intersection).

Traffic safety in Germany is clearly a coordinated effort among local and national organizations. The German government has assembled about 500 accident commissions at the federal and local levels (the commission in Frankfurt is called KEBU). These commissions combine engineering, law enforcement, and other authorities, including local traffic authorities, civil engineering departments at universities, and traffic security wardens (similar to the U.S. National Safety Council). Depending on the nature of the safety problems, other organizations such as cyclist groups or public transit authorities participate in the commissions. These commissions are responsible for identifying high-accident locations, completing engineering studies, implementing solutions, and monitoring the solutions for effectiveness (Figure 2-3). In addition, the commissions provide general traffic safety training to school children and the general public.

Figure 2-3. Responsibilities of Germany's accident commissions.



The performance of these commissions varies throughout the country. Developing a successful commission can be a lengthy process and is highly dependent on having a qualified person or group in a leadership position. To address these issues, the Germans have developed a three-day training course for local commissions. German experience has shown that the most effective commissions are those with the highest degree of training and technical knowledge.

Funding for the safety commissions and the improvements they recommend comes from general federal transportation funding sources. The level of priority and the amount of money directed to safety improvements is left up to the commissions and local authorities (projects and funding are not earmarked solely for safety priorities).

Though Germany uses roundabouts for speed control, officials said a significant disadvantage of roundabouts is that they take control away from engineers. The geometric design and yield to the roundabout rule prevail, and it is not possible to give priority to buses or bicycles.

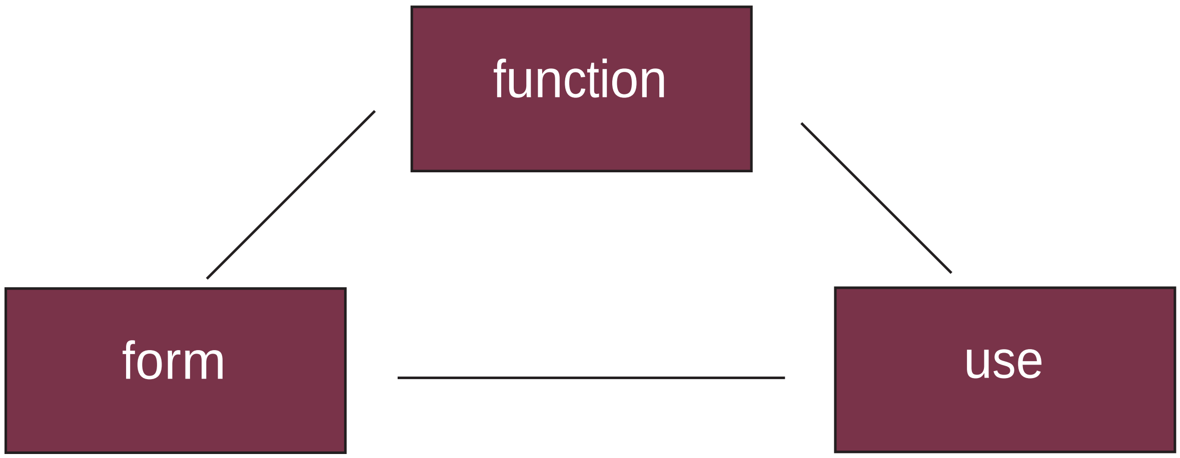
THE NETHERLANDS

The Ministry of Transport, Public Works, and Water Management (RWS) is the national road authority in the Netherlands. RWS provides some funding for intersection safety improvement, but decisions on how to best direct funds to meet specific needs are determined largely by local agencies.

The Netherlands has about 5,300 signalized intersections. Eighty-one percent are located in urban areas and 19 percent in nonurban areas. Seventy-seven percent of the signals are actuated. In 2001, 1,085 traffic fatalities were reported, about 11 percent at signalized intersections. In that year, 18,510 people were hospitalized as a result of traffic accidents.[1] The number of fatalities in 1972 was 3,250, and since then both fatalities and hospitalizations have been decreasing an average of 4 percent a year.

The Netherlands has national safety goals guiding its approach to intersection safety. The National Traffic and Transport Plan has set goals of a 30 percent reduction in fatalities and a 25 percent reduction in serious injuries by 2010. The program is based on developing sustainable safety solutions and is built on three primary principles (Figure 2-4). First, the form of the system should be designed to follow the intended function and prevent unintended uses. Second, the system should be homogeneous. The Dutch believe that a highly homogeneous system improves safety, and they try to prevent major variations in vehicle speed, direction, and mass on their higher-speed facilities. Finally, the system should be predictable even to users unfamiliar with the road.

Principles of Sustainable Safety



function:	use of the road as intended by the road authority
form:	the physical design and layout of the infrastructure
use:	actual use of the infrastructure and behaviour of the road user

Figure 2-4. The Netherlands' primary principles to achieve sustainable safety.

In December 2001, the Ministry of Transport's Transport Research Centre (AVV) published the second edition of its report "Sustainable Safety: A Preventable Road Safety Strategy for the Future." This report is available in English and presents the principles of sustainable safety, phase implementation plans, and specific implementation measures.[2]

The Dutch have developed regional traffic enforcement task forces that target five safety areas: speeding, red-light running, driving under the influence, safety belt use, and moped helmet use. All 26 police regions have task forces that work with national enforcement officers who rotate around the country. The general speed-limit tolerance level is 10 percent with both cameras and police officers. Enforcement locations are determined by reviewing accident and violation statistics. The revenue generated by these task forces goes to the national government's treasury department, and the money is reinvested in sustaining the programs.

The Dutch spend considerable effort and resources on engaging the public in developing and maintaining a safe and sustainable transportation system. A nongovernmental association known as 3VO is at the forefront of public awareness efforts and campaigns. The association's mission is to provide never-fading attention to traffic safety, start at the lowest level (interact with civilians), share knowledge with others, and work with as many allies as possible. The association recently changed its approach from pointing the finger at problem areas to disseminating safety messages with an emphasis on solutions and interaction.

Like other European countries visited, heavy pedestrian and bicycle traffic is common at most signalized intersections in the Netherlands. The Dutch have developed and deployed special signal indicators to warn pedestrians, bicyclists, and motorists of potential conflict situations. A noteworthy practice in the Netherlands is to limit maximum signal cycle lengths to better accommodate pedestrians, bicycles, and public transport vehicles. Under certain political conditions, motorized traffic congestion issues are treated as secondary. This approach is in contrast to typical practice in the United States, where intersections are timed, phased, and operated to minimize delay to motorists.

The Dutch promote safety and focus on skilled driving from the start by requiring the following for obtaining a driver's license:

- An average of 30 hours of hands-on training, with lessons costing U.S. $30 an hour.
- A 50-question written exam on information taken from a 500-page driver's manual.
- A 35-minute driving test at a cost of U.S. $163. The failure rate is 70 percent, and an additional 10 lessons are required before retaking the test.

The Dutch program for intersection safety focuses on reducing speed and providing road users with clear, consistent information. Speed is controlled by several methods, including geometric design, speed-warning signs, speed tables, and an extensive use of the latest technology, including conspicuous automated photo enforcement.

If traffic volumes allow, the Dutch make extensive use of roundabouts that are conservative in design (one-lane roundabouts with sharp entrance angles to assure vehicle speed reduction are preferred).

To measure speeds, the Dutch have made substantial investments in detection. Their limited-access freeways (equivalent to the U.S. Interstate system) have speed/volume detection in each lane every quarter mile. One signalized intersection the team visited had as many as 78 detectors to sense vehicle speed and traffic volume and revise signal timing.

The Dutch extensively use oversized signal indications and back plates for conspicuity (much more so than any of the other countries visited). Their largest signal indications are equivalent to 12-inch heads used in the United States, but the back plates are substantially larger than any in the United States. The back plates are oval, with the border painted white for contrast.

A significant portion of the intersection safety program in the Netherlands focuses on pedestrians and bicyclists, who suffer severe consequences when involved in accidents at signalized intersections.

Tort liability is not a major concern in the Netherlands, but the rising number of civil lawsuits creates concern.

UNITED KINGDOM

Institutional structure in the United Kingdom is similar to that in the United States. The central government sets overall policy and legislates countrywide standards to achieve uniformity. The central government also allocates funding and provides advice and guidance to local agencies through the traffic management department. Local governments implement national policies and make local traffic regulation orders (e.g., access control measures) to best meet their goals and needs.

England has 149 local highway authorities with a broad range of objectives, including reducing congestion, promoting modal shift, and improving road safety, air quality, and the quality of local space.

A number of mechanisms are in place to help accomplish those objectives:

- White papers
- A 10-year plan
- National air quality strategy
- Local transport plans
- Legislation
- Commitments to select committees and commissions

The United Kingdom's national safety plan, "Tomorrow's Roads—Safer for Everyone," calls for a 40 percent reduction in total roadway fatalities and serious injuries, a 50 percent reduction in the number of children killed or seriously injured, and a 10 percent reduction in the slight-casualty rate. As with the other countries visited, the emphasis is on accidents with serious consequences. The plan is being implemented in partnership with local authorities, police, health services, commerce and industry, other government departments, and road users.

The Highways Agency is responsible for the 10,000 kilometers of the national system. The United Kingdom has about 350,000 kilometers of local roads. The Highways Agency is responsible for more than 1,700 signalized intersections (plus 860 signalized pedestrian crossings), while local agencies are responsible for more than 12,000 signalized intersections (plus 13,800 pedestrian crossings).

The United Kingdom, like the United States, faces significant traffic congestion in metropolitan areas. It faces the challenge of maintaining a delicate balance among safety, mobility, and congestion in the design and operation of signalized intersections. The British have developed and implemented several computerized signal-timing optimization software packages, such as microprocessor optimized vehicle actuation (MOVA) and optimized signal capacity and delay (OSCADY), to increase intersection capacity, reduce delay and queuing, and improve safety.

Pedestrian safety and the effect of pedestrian traffic on motorized traffic are also high priorities in the United Kingdom. A number of specialized pedestrian crossings have been developed, including the PUFFIN (pedestrian user-friendly intelligent) and TOUCAN ("two can" cross) crossings, to improve pedestrian and bicyclist safety and operations at signalized intersections. Leading-edge technologies (including passive infrared and microwave detection) optimize both motorized and nonmotorized traffic operations at signalized intersections. The PUFFIN crossing has pedestrian detection and can forego the pedestrian phase if detection shows the pedestrian has changed his mind or crossed the street on the "don't walk" sign, and can extend the "walk" time if a pedestrian lingers in the street.

It has been demonstrated in the United States that care is needed in marking crosswalks because they may actually encourage pedestrians to relax their guard while crossing, so crossing technology favoring pedestrians might have downsides. During a briefing on traffic in highly congested parts of London, officials reported that up to 29 percent of the crashes at signals involve pedestrians.

Transport for London (TFL) is responsible for traffic management in the greater London area. It owns and operates about 4,500 traffic signals and 600 enforcement cameras. Over the past two years, TFL has developed a Road Safety Unit, which emphasizes enforcement and education. As with the safety commissions and task forces in the other countries visited, the unit is made up of representatives from multiple agencies. The team visited the London Traffic Control Centre and was surprised to hear that although traffic engineers are accountable for all signal timing, if the centre detects the need for changes on the basis of the extensive camera system, officials must call Scotland Yard to make the changes. (Traffic management and police-related functions, however, are becoming more integrated).

Like other countries visited, tort liability has not been an issue in the United Kingdom, but lawsuits are becoming more prevalent and transportation officials must follow standards and rigid engineering practices to avoid civil liability. Typically, local agencies work with the Transport Research Laboratory (TRL) to research and test new ideas before they are implemented. TRL has developed a sophisticated vehicle simulator (Figure 2-5) that allows engineers to test signal operations and design plans in a laboratory setting before full-scale implementation, reducing risk and limiting liability associated with new ideas. Several lawsuits related to the use of red-light cameras have been unsuccessful.

Figure 2-5. Vehicle simulator to test extended amber timing in the United Kingdom.

chapter three
DESIGN, OPERATION, AND MAINTENANCE OF TRAFFIC CONTROL DEVICES

Traffic signal cycle aspects differ from country to country in Europe. Germany and the United Kingdom use a “start-up yellow” interval before the beginning of a green indication. This short interval displays the yellow and red indications at the same time to let the motorist know the green phase is coming. Sweden also uses a start-up yellow before the beginning of a green indication and a “return to green during yellow” as one of the options of the LHOVRA technique. Because this is a significant difference from U.S. practice, some European practices on phase change intervals cannot be directly transferred to the United States.

SWEDEN

Traffic signals are installed on a case-by-case basis after engineering studies using a three-to-five-year analysis period.

Design and operation of traffic signals in Sweden are based on a code of statutes. Adherence to these codes is an absolute requirement. They address vehicular, pedestrian, and other types of signals; where signals should be placed; number of signals per approach; safety timing of the signals; and phasing of the signals. Signalized intersection design specifications are defined in three primary documents:

- “Code of Road”
- “Code of Road Design”
- “Code of Construction Specifications for Traffic Signals”

One design approach to improve intersection safety in Sweden is to require specific geometric and operational intersection features based solely on design speed. The philosophy is to minimize conflicts (vehicle-vehicle and vehicle-pedestrian) as approach speeds increase. For example, the codes dictate that signalized intersections with posted speeds of 70 kilometers per hour (about 43 miles per hour) or more must have protected left-turn lanes with protected phasing. Left turns are prohibited from roadways with speed limits in excess of 70 kilometers per hour.

When high-accident locations have been identified, progressive solutions are developed on the basis of engineering studies that evaluate safety among vehicles, pedestrians, and bicyclists; mobility (delay); and traffic demand. In some cases, where accident severity is high, Sweden has removed traffic signals and replaced them with roundabouts, recognizing that overall accident rates may increase and line-of-sight may be degraded, but the rate of severe (fatal and injurious) accidents will decrease. Replacing signals with roundabouts seems to be motivated by political and police pressure. In urban areas, unsignalized roundabouts can have a negative systemwide effect because it is difficult to control and manage platooning and traffic progression.

In some cases, the Swedes have installed traffic signals at roundabouts, but signalizing roundabouts is not a preferred approach and is done on a limited basis to improve pedestrian and bicyclist safety (Figure 3-1).

Figure 3-1. Signalized intersection in Stockholm, Sweden.

Sweden clearly places intersection safety above operational considerations and capacity. The following are examples:

- The maximum signal cycle length used in Sweden is 100 seconds. This practice is driven not by capacity, but by pedestrian and bicyclist safety. Relatively short signal cycle lengths reduce the likelihood a bicyclist or a pedestrian will cross against the red signal, particularly during the long winter months.
- Sweden does not allow right turns on red. This limits capacity but improves pedestrian and bicyclist safety.
- In general, red clearance intervals are not used because they increase delay for pedestrians and bicyclists.

Most traffic signals in Sweden are treated as isolated intersections without interconnections. Master signal systems are used, but the primary focus is monitoring signal timing to make capacity adjustments.

GERMANY

In Germany, the design and construction of signals and guidelines on their placement are found in federal standards, laws, and regulations. These guidelines (including detailed timing calculations at signalized intersections) must be followed and correctly applied, or the owning agency or responsible engineer may face criminal or civil liability.

The following is a list of standards used to plan, design, and operate traffic signals in Germany:

- HAV—sign installation
- R-FGU—pedestrian design
- RMS—pavement markings
- Risla—traffic signals (timing and controller programming)
- DIN VDE 0832—technical specifications for safety related to electronics and maintenance intervals
- BO-Straub—special aspects of trolley traffic signals
- EAHV—geometric standards for intersection design

These standards set rigorous clearance and signal-timing calculations that must be completed and documented for all modes of traffic at each signalized intersection.

Figure 3-2 shows an intersection in Frankfurt and summarizes the results of the timing calculations. The different colors represent the phase change intervals evaluated. Pedestrian crossing paths are shown in yellow, motorized vehicle paths are shown in red and green, and the trolley path is shown in blue. Yellow change and red clearance intervals are varied, depending on the approach speed and the conflict calculations for all traffic modes. Frankfurt has an extensive trolley system that also must be considered in phase change calculations. If an accident occurs and the signal timing is in question, the courts refer to these timing tables to help assess driver liability and to determine if a violation occurred.[3]

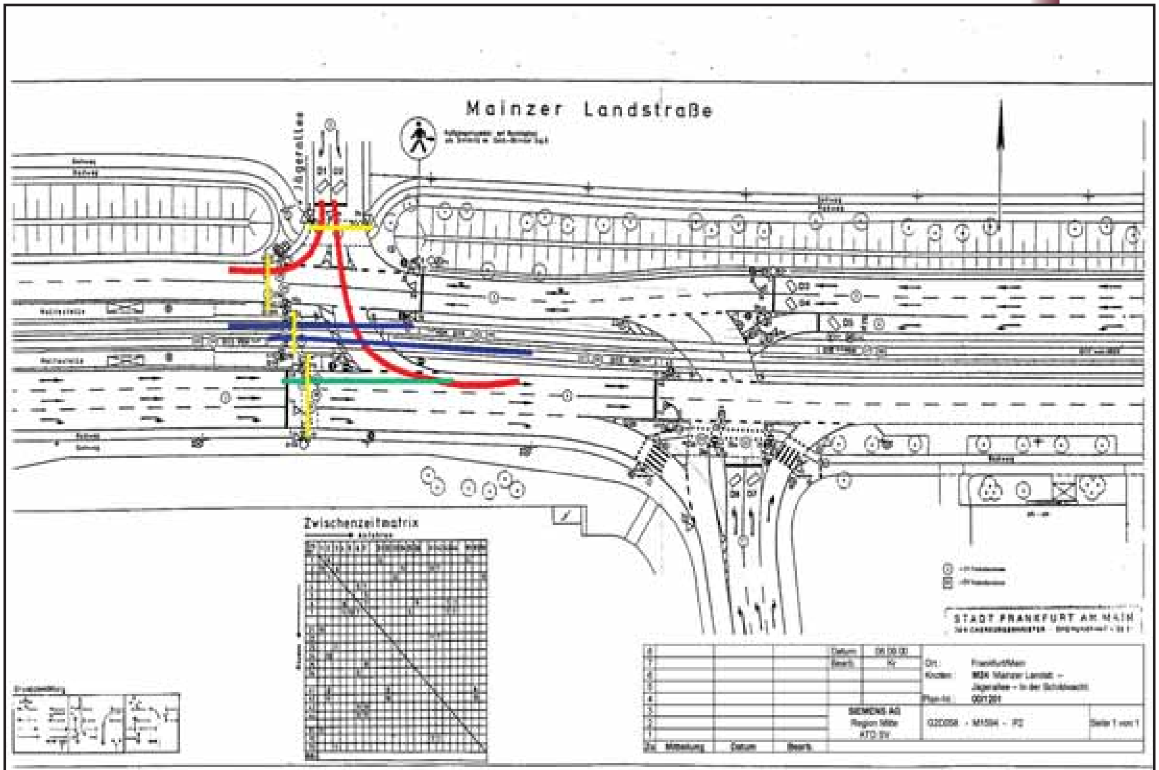


Figure 3-2. Signalized intersection layout in Frankfurt, Germany.

Pedestrian-crossing indications in Germany are placed on the near side of the crossing and are supplemented by a “please wait” indication on the far side to indicate that the pedestrian button has been activated. The nearside indication is either red or green (Figure 3-3). During the red phase, the “please wait” indication on the far side of the crossing is lit. This combination of crossing signals appears to be less confusing to pedestrians than the use of farside signals with a flashing green man, and results in fewer pedestrians crossing during the red phase.

Figure 3-3. Audible pedestrian signal head in Germany.

Like Sweden, Germany uses shorter cycle lengths at signalized intersections primarily to accommodate heavy bicycle and pedestrian traffic. The maximum cycle length used is 120 seconds. Frankfurt routinely uses 90-second cycle lengths for its coordinated traffic signals. The use of short cycle lengths is also driven by the desire to minimize wait times for pedestrians and bicyclists.

Frankfurt has successfully restricted intersection operations at a number of sites to address safety concerns and conflicts with left-turning traffic, whether they are vehicle-vehicle or pedestrian/bicycle-vehicle. In certain circumstances, Frankfurt traffic engineers have prohibited left turns and instead installed special signs directing motorists to make a series of right turns. Officials stressed that this is not a traditional treatment and that the site conditions and traffic demand must be suitable for this technique to succeed.

The location of pedestrian crossings, particularly midblock crossings, can pose special safety concerns. Frankfurt uses the results of signal-timing calculations and progression analyses to identify the optimum location for midblock pedestrian crossings. Doing so helps place pedestrian crossings in locations that minimize the disruption to traffic progression and maximize the amount of green time available for pedestrians and bicyclists to cross a street. Surprisingly, the Germans believe that pedestrian crossings must be signalized if a roadway has more than two lanes to be crossed. Pedestrian crossings at intersections that cross more than two lanes must have a protected pedestrian-only phase.

As in the United States, Germany has safety problems at high-speed rural intersections. To address the issue, the Germans do not place traffic signals at intersections with approach speed limits greater than 70 kilometers per hour. On facilities with higher speed limits, either the crossings are grade separated or the speed limit is lowered before intersections. Lowering the speed limit requires effective enforcement, and in many cases photo enforcement techniques have been used to successfully control approach speeds. Photo enforcement techniques are discussed in more detail in Chapter 4, which addresses innovative traffic control devices.

Intersection maintenance is an important safety issue in Germany. Frankfurt has a formal maintenance procedure. A detailed matrix table listing items such as relamping, housing cleaning, etc., is developed. In addition, the maintenance frequency is established and logged for each signal or system. For example, the city recently converted some signals to a 10-volt halogen system. Officials concluded that it provides the same energy savings as 20-watt bulbs at half the price of LEDs.[4]

Germany uses preemption systems for buses, trolleys, and emergency vehicles. Preemption techniques rely on several technologies, including switches in trolley rails, coil devices triggered by trams and buses, loop detectors in bus lanes, and microwave detectors and radio signals for buses. With the exception of emergency vehicles, signal preemption is considered a transit improvement, not a safety improvement.

The Germans are completing a safety audit process intended for use in planning, designing, constructing, and operating signalized intersections. The audit process can be applied to existing high-accident intersections to help identify appropriate countermeasures, but the real focus of the program is addressing safety issues in the design phase. They have developed a training program and courses for professionals to become certified as road safety auditors. The program is scheduled to begin by the end of 2002.

Roundabouts typically are not signalized in Germany. Signalizing roundabouts is considered a last resort and is considered only in special circumstances to improve traffic flow, accommodate special pedestrian conditions, accommodate the trolley system, etc.

In Germany, right turns on red are permitted only if the following criteria are met:

- Motorized traffic has clear lines of sight to all bicycle or pedestrian crossings.
- Signals are present to control pedestrian crossings.
- Conflicting pedestrians do not cross more than two lanes.
- No bicycle traffic is present.
- No more than two serious accidents have occurred at the intersection in the past three years.

THE NETHERLANDS

In the Netherlands, selection, design, installation, operation, and maintenance of traffic control devices for signalized intersections are outlined in a number of publications developed under the sponsorship of CROW (Information and Technology Centre for Transport and Infrastructure). CROW is a national, independent, nonprofit partnership among the national government, provinces, local authorities, contractors, consultants, public transport companies, and research and education groups.

CROW's national standards are described in a number of handbooks addressing signalized intersection design and operation and sustainable safety:[5]

- "Recommendations for Traffic Provisions in Built-up Areas"—ASVV
- "Handbook on Road Design"
- "Handbook on Roundabouts"
- "Handbook on Traffic Control Systems"
- "Handbook on Marking and Signposting"

The ASVV includes several chapters on signalized intersections, including criteria for installing and removing signals at intersections, design processes for control systems, and design suggestions for signalized intersections. The guidelines suggest that solving traffic flow and road safety problems with traffic control systems should be considered only as a last resort and that limited reconstruction is often a better solution. The ASVV provides guidance on removing a traffic signal if traffic conditions change, making the signal undesirable by volume and time-loss criteria.

Crossing against the red signal is the primary cause of serious pedestrian and bicyclist accidents at signalized intersections. The Dutch, like the Germans and Swedes, use short cycle lengths to minimize pedestrian and bicyclist wait times and decrease the likelihood of their crossing during the red phase. Sixty percent of Dutch signals use a 90-second-maximum cycle, and 90 percent are shorter than 180 seconds (Figure 3-4). When actuated signals are used, the real maximum cycle time is considerably less.

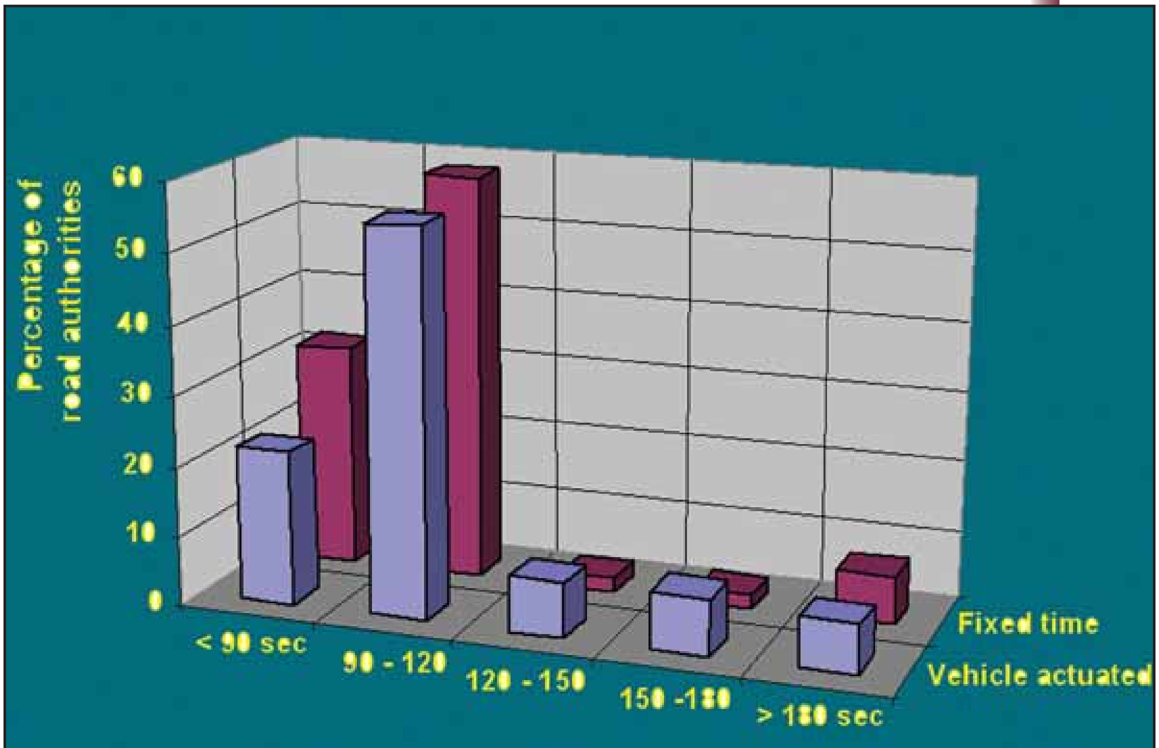


Figure 3-4. Distribution of signal cycle lengths used in the Netherlands.

Seventy-seven percent of the intersections in the Netherlands are vehicle actuated, and about 30 percent of all signals are operated on a coordinated network. If traffic signals are less than 400 meters apart, the goal is to coordinate their operation, a practice that, while providing safety benefits, appears to be driven more by capacity and traffic flow.

The use of permitted and protected phasing is not mandated in design standards and guidelines. A survey of traffic jurisdictions, municipalities, and provinces found that about 30 percent never allow secondary conflicts (permitted phasing) between motorist and nonmotorist traffic. About 65 percent of survey respondents indicated they would allow secondary conflicts, depending on the situation. The guidelines (not mandated) are designed to provide protected phasing only for facilities with speed limits greater than 50 kilometers per hour.

A limited number of traffic signals in the Netherlands are set to dwell in the all-red mode when traffic is not present at an intersection. This practice means that approaching traffic sees a red signal and slows down. The practice is consistent with the overall safety practice and philosophy of reducing speed in potential conflict areas. In one instance, the Dutch installed speed detection linked with a changeable message sign that tells drivers that they must “slow down to receive the green light.” If they do not, the signal holds the red light.

In rural areas, where allowable speeds are as high as 80 kilometers per hour, the Dutch use loop detectors before intersections to adjust signal timings with the goal of minimizing the number of times motorists are caught in the dilemma zone. This application is equivalent to some features of the LHOVRA technique used in Sweden at isolated (nonsynchronized) signals at high-speed rural intersections.

Legally, all signal heads in the Netherlands are placed before conflict points (i.e., few farside signals exist). This way, users have a better understanding of the intersection and the cross-street traffic cannot see the indication of the conflicting signal (Figure 3-5). This practice requires additional clearance times, as the stop line has to be situated farther from the intersection, but officials believe safety considerations outweigh capacity issues. This effect is minimized by the location of a bicycle lane in front of the stop line and by the clearance time needed for pedestrian and bicycle phases.

Figures 3-5. Nearside signals in the Netherlands.

LED signals are used in the Netherlands, and a special code of practice addresses lamp monitoring and gradual failure. The Dutch have found that LED lights have a significant positive impact on signal visibility.

Signal control plans, which are driven by the goal to provide simple, understandable operations, include the following techniques:

- Use short cycle lengths.
- Avoid unnecessary waiting for motorized and nonmotorized traffic.
- Provide adequate green times, based on speed and traffic conditions, for traffic to clear the intersection.
- Modify green times on the basis of traffic demands.

Meeting these requirements necessitates actuated traffic control systems with an extensive network of loop detectors and powerful signal controllers capable of two-way (i.e., uploading and downloading) communication (Figure 3-6). Several four-way intersections the team visited required more than 60 loop detectors.

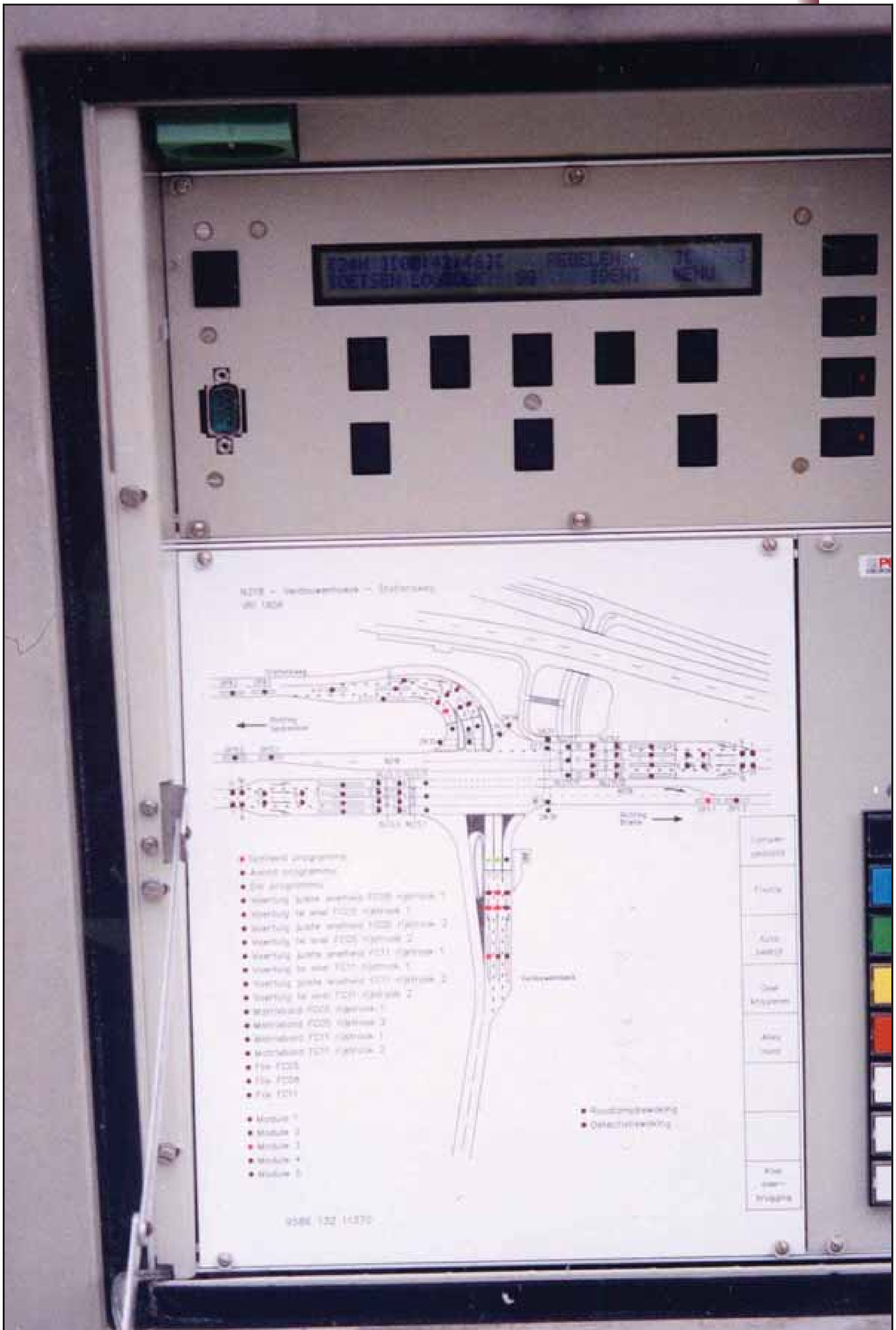


Figure 3-6. Diagram in controller cabinet at a four-leg intersection in the Netherlands.

Because public transport has been a priority in the Netherlands since the early 1970s, the green phase for public transport is hastened or extended over nonprioritized control. About 50 percent of transportation authorities allow extensive priority for public transport. In only 21 percent of cases is priority to public transport not given at all. The amount of priority given is hardly related to the punctuality of the specific tram or bus. In most cases, the technique applied relies on local selective detection, like vehicle tagging, but new techniques based on radio and global positioning systems (GPS) are emerging.[6]

UNITED KINGDOM

The U.K. Highways Agency, under agreement with the Department of Transport, provides design guidance for signal-controlled intersections in two primary documents: “Design Standards for Signal Controlled Junctions” (document TD50/99) and “Layout of Large Signal Controlled Junctions” (document TD89/02). These documents outline the design principles and practices for at-grade intersections and roundabouts, including visibility requirements, lane widths, nonmotorized-user provisions, and signal equipment provisions.

Most U.K. traffic signals are actuated or linked. Vehicle-actuation equipment relies on buried inductive loops or aboveground detectors, such as microwave and video. Standard vehicle-actuated signals include three loops (placed at 12, 24, and 39 meters) per approach and work well at speeds up to about 50 kilometers per hour (35 miles per hour) (Figure 3-7).

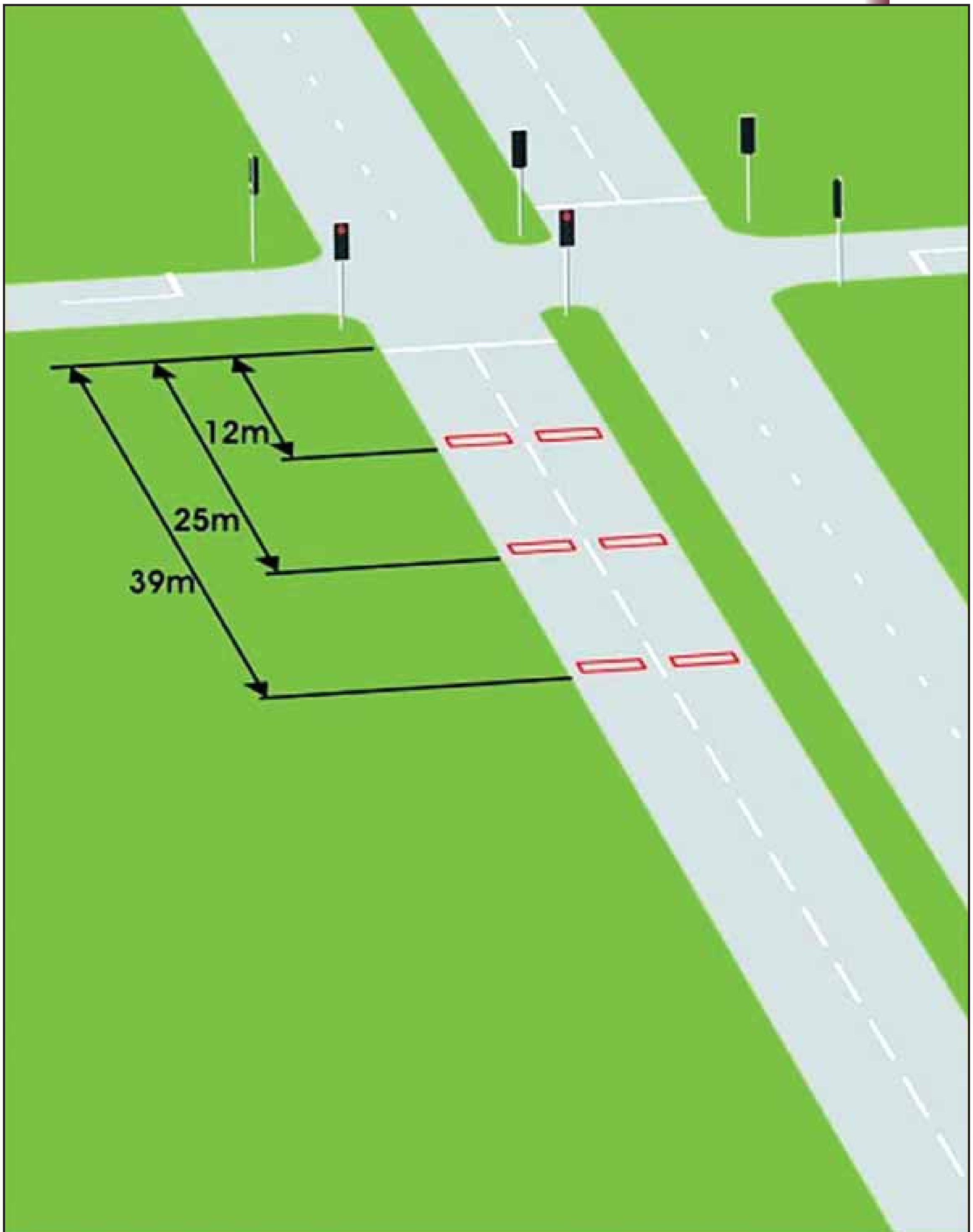


Figure 3-7. Actuated signal layout for intersections with approach speeds under 35 miles per hour.

At intersections with speeds above 50 kilometers per hour, special controller equipment and additional loop detectors are used to cater to drivers in the dilemma zone.

Through speed discrimination and extension (SDE), special consideration is given to designing signal timing that avoids transitioning the signal when traffic is in the dilemma zone (the area in which 10 to 90 percent of drivers stop when the signal changes to amber) and minimizing red-light running, particularly at higher-speed rural locations (Figure 3-8). The goal is to measure the occupancy of the dilemma zone. If it is occupied when the side street calls, the side street is not given a green signal until the vehicles have cleared the intersection. The system times out at a maximum green time, but only if it has already failed to terminate early because the dilemma zone continues to be occupied.

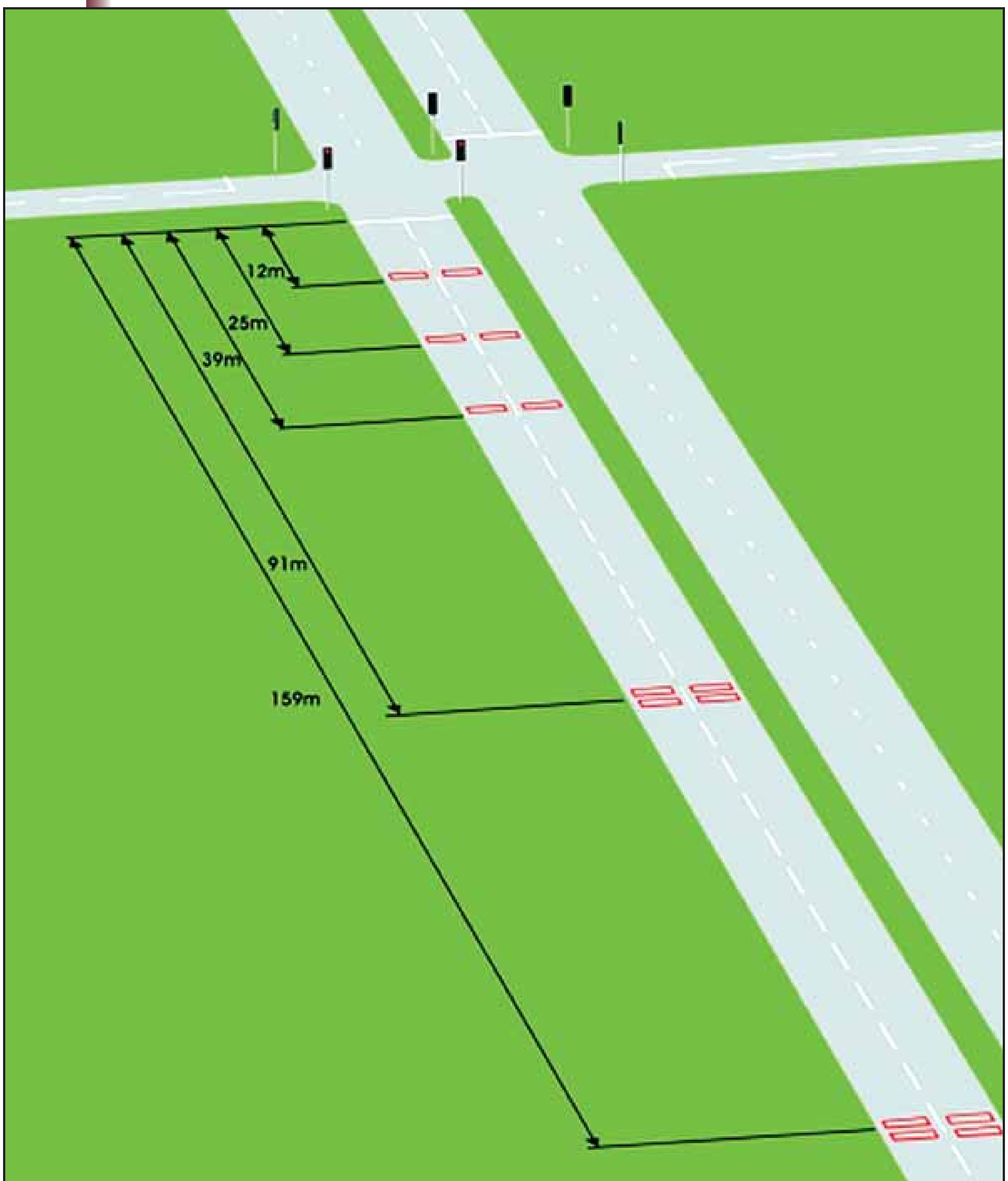


Figure 3-8. Layout of speed discrimination and extension configuration for speeds over 45 miles per hour.

Amber time in the United Kingdom is three seconds plus or minus a quarter of a second. Research studies indicate that increasing the amber time would increase the number of accidents. Similar research looked at providing a warning that the green phase is ending (green indicator flash for two seconds before yellow). This practice also was found to have a negative impact on intersection safety.

Linked traffic systems in the United Kingdom typically rely on the TRANSYT signal coordination computer program to coordinate the system. The split-cycle offset optimization technique (SCOOT) program was recently introduced and is a method of using on-street information provided by loop detectors to automatically update offsets and splits based on current traffic conditions. Forty percent of London's signals are controlled by SCOOT, and changes to timing plans can be made from a control center.[7] The use of the various linked signal system packages is driven primarily by capacity and delay considerations, and not much research has been done to determine measurable safety results.

Other optimization packages, such as microprocessor optimized vehicle actuation (MOVA), are used routinely in the United Kingdom to improve intersection efficiency (Figure 3-9). MOVA's features include the following:

- Holds the green for traffic flowing at saturation rate.
- Detects accurately the end of saturation flow.
- Decides after saturation flow ends whether to end or continue green.
- Makes maximum green times no longer critical.
- Detects oversaturation lane by lane.
- Switches to capacity-maximizing control when overloaded.

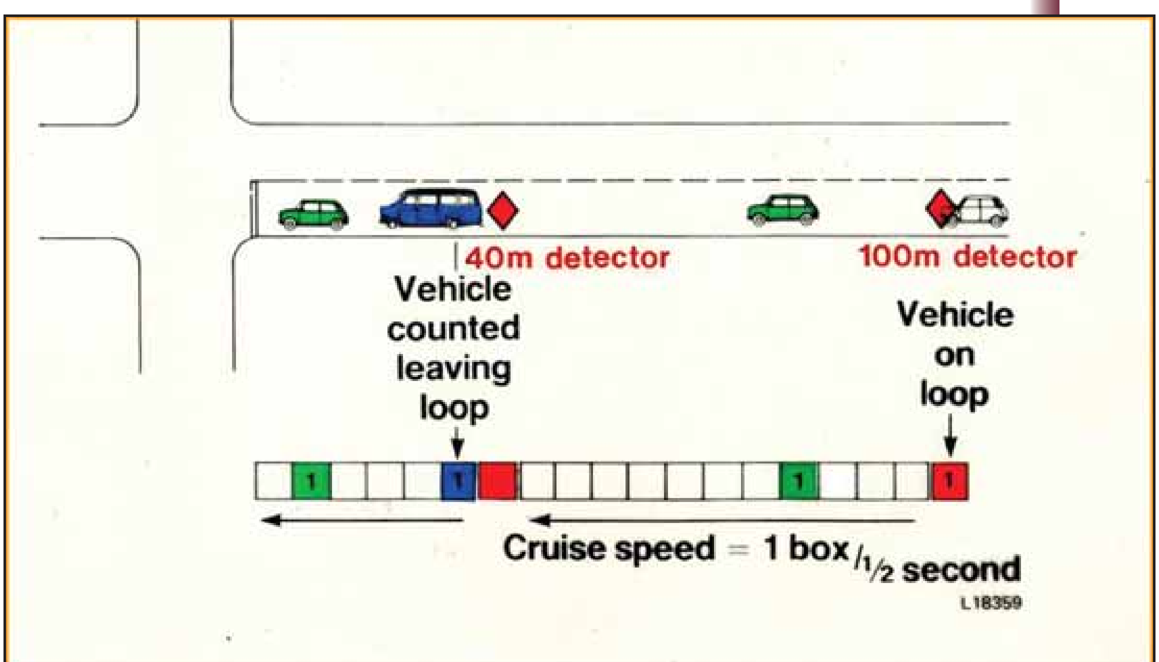


Figure 3-9. Microprocessor optimized vehicle actuation (MOVA) traffic model.

Implementation of MOVA technology has resulted in substantial delay savings, depending on site and traffic conditions, and this remains the case with more than 500 MOVA-controlled intersections in the United Kingdom. Initially, MOVA was shown to improve intersection safety by reducing incidents of red-light running at high-speed sites by 50,000 per year and reducing injury accidents at four high-speed sites by 30 percent. Later results have not been as favorable, with safety remaining unchanged at 31 high-speed sites recently studied.[8] Further research into MOVA safety results is under way.

The United Kingdom built many of its roundabouts at freeway interchanges many years ago. Traffic has grown to the point that ramp metering, although still at the pilot stage, is used to prevent traffic backing up onto high-speed motorways. Since many roundabouts were built on structure, they cannot be enlarged, and signalization has been the only way to give priority to the off-ramps to prevent backups on the mainline. U.K. roundabouts are sometimes signalized to improve capacity and safety conditions, particularly at locations with heavy traffic or unbalanced traffic volumes along approaches. Though signalizing a roundabout is typically a last-resort solution, doing so can increase capacity, manage approach queues, and reduce speeds. The decision to signalize a roundabout is typically based on engineering studies and research rather than on guidelines (Figure 3-10). MOVA and SCOOT signal-timing and operational techniques have been successfully applied at roundabouts throughout the United Kingdom.[9]

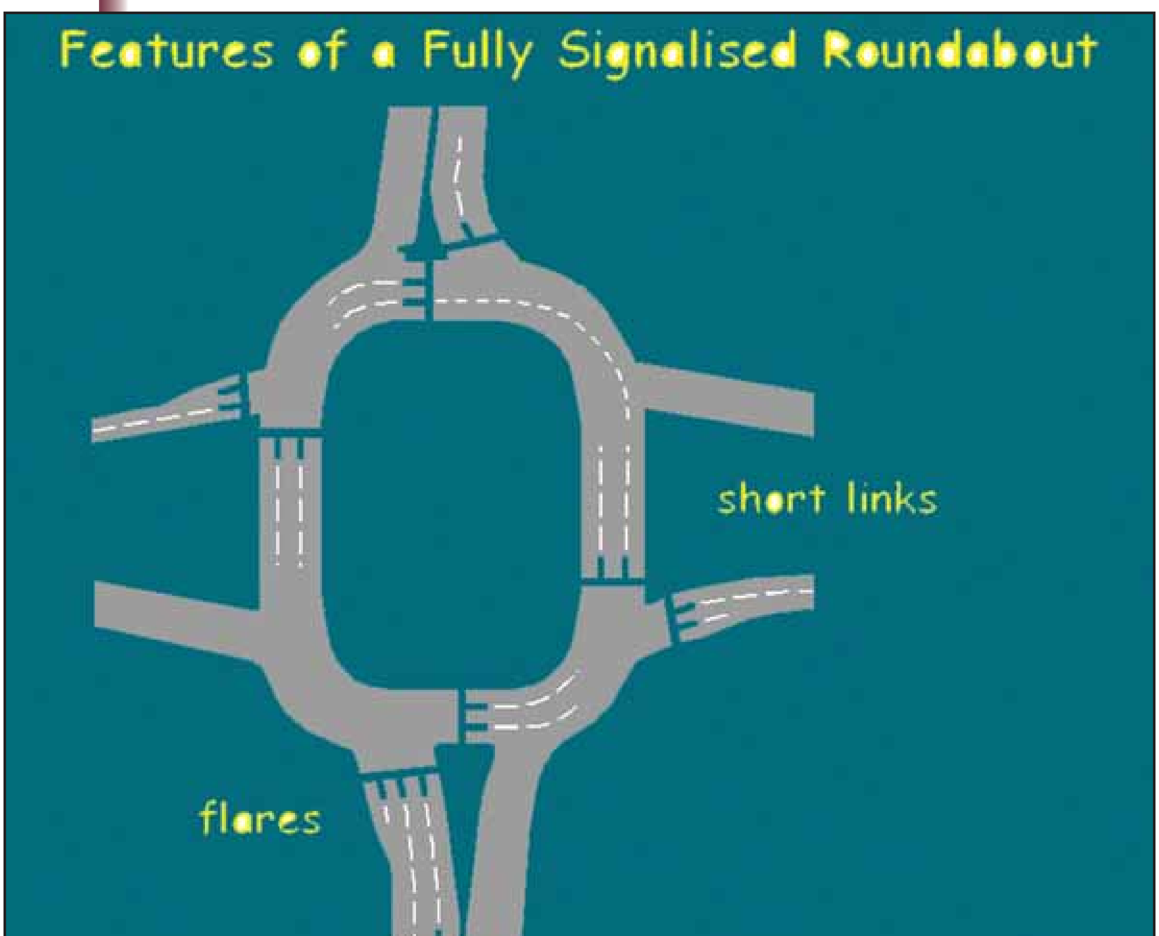


Figure 3-10. Features of a fully signalized roundabout in the United Kingdom.

chapter four
INNOVATIVE TRAFFIC CONTROL DEVICES

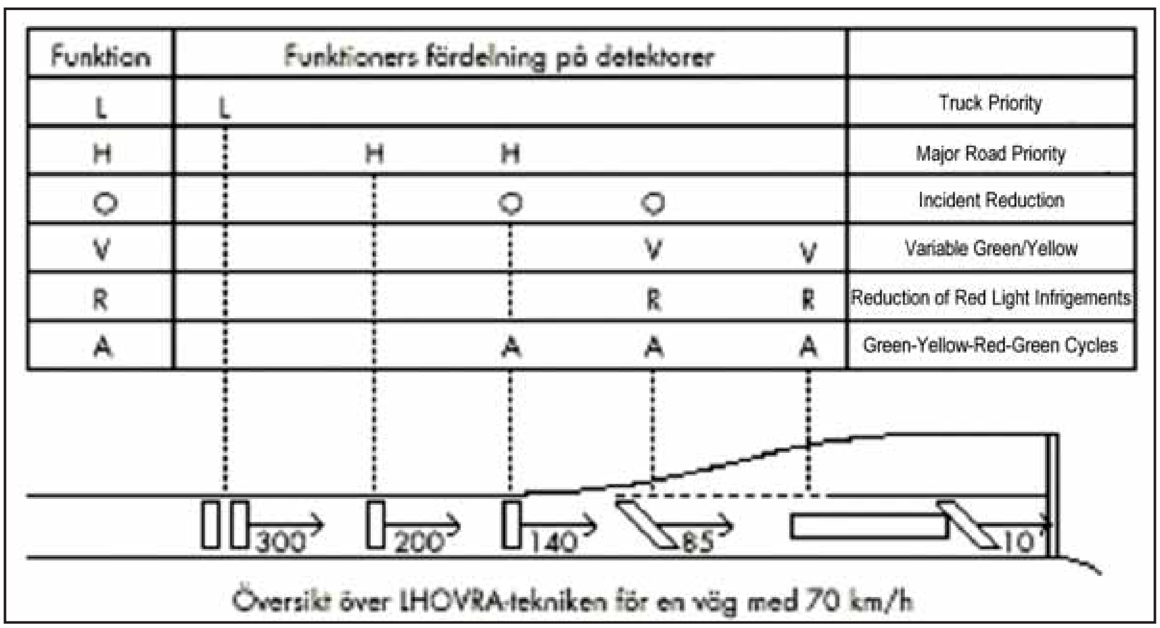
SWEDEN

Sweden uses a number of innovative traffic control devices to improve safety at signalized intersections. Some measures have been in place for some time and have been shown to be effective, while others are new and considered experimental.

LHOVRA System

Perhaps the most intriguing and comprehensive intersection safety technique being used by the Swedes is a system called LHOVRA.[10] The LHOVRA system consists of a series of detectors placed along the approach to an intersection. The detectors determine vehicle type and speed at various locations along the approach and adjust the signal timing by increasing the yellow change and all red clearance intervals to minimize the number of vehicles caught in the dilemma zone (Figure 4-1). LHOVRA was originally designed to accommodate heavy trucks, but the system appears to be flexible and can be programmed to optimize several features.

Relation between detectors and LHOVRA-function



Distances are related to 70 km/h and scalable to any speed.

Figure 4-1. Detector layout and relationship for LHOVRA system.

The LHOVRA system has been successfully implemented and is most effective at high-speed rural intersections, particularly where heavy truck traffic is a safety concern. SNRA has completed before-and-after studies at intersections where LHOVRA has been implemented, and the results are promising. Figure 4-2 summarizes before-and-after studies in which incident reduction (the O function in LHOVRA) was the primary goal.

Type of conflicts*) and the number with the O-function

*) with conflict technique analysis methodology

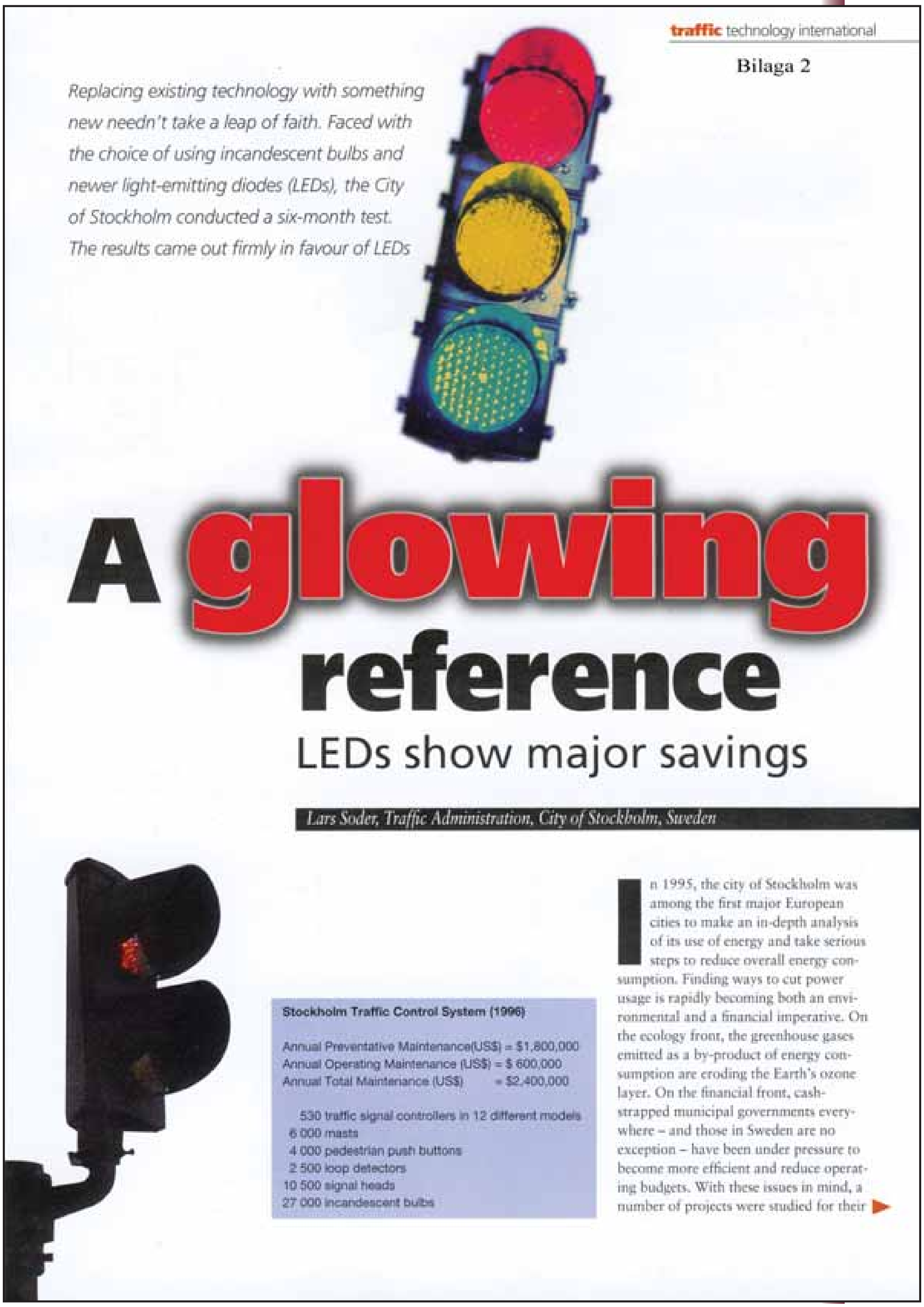
	Before LHOVRA = Trad. signals	With LHOVRA
Rear-end conflicts	30	7
Miscellaneous	4	3
Total	34	10

Figure 4-2. Summary of before-and-after studies of implementation of LHOVRA system.

A number of issues should be considered before the LHOVRA system is implemented, and a location study must be completed to ensure that the technology will function properly and improve intersection safety performance. It is possible for the technology to be used improperly by road users (motorists and pedestrians).[11] A comprehensive report on developing and implementing LHOVRA is available through SNRA, "Signal Control Strategy for Isolated Intersections" (publication 1991:51E). For more information, contact Alf Peterson, SNRA. See Appendix C for contact information.

Conversion of Signals from Incandescent Bulb to LED

Stockholm recently converted all of its signals (more than 10,500 heads and 27,000 lenses) to LED. It is the largest city in the world to have made the complete conversion, and it did so in response to the national government's offer of large grants for energy conservation. The conversion to LED, driven by the need to conserve energy, cost the equivalent of U.S. $5.3 million (almost all paid by the national government) and is estimated to save about U.S. $870,000 a year in energy costs. The LEDs have an estimated life of 10 years, and the investment is expected to be paid off in six years. While no data on the safety advantages is available yet, LED lighting improves visibility and public response has been positive.[12]



traffic technology international

Bilaga 2

Replacing existing technology with something new needn't take a leap of faith. Faced with the choice of using incandescent bulbs and newer light-emitting diodes (LEDs), the City of Stockholm conducted a six-month test. The results came out firmly in favour of LEDs

A glowing reference

LEDs show major savings

Lars Soder, Traffic Administration, City of Stockholm, Sweden

Stockholm Traffic Control System (1996)

Annual Preventative Maintenance(US$) = $1,800,000
Annual Operating Maintenance (US$) = $ 600,000
Annual Total Maintenance (US$) = $2,400,000

530 traffic signal controllers in 12 different models
6 000 masts
4 000 pedestrian push buttons
2 500 loop detectors
10 500 signal heads
27 000 incandescent bulbs

In 1995, the city of Stockholm was among the first major European cities to make an in-depth analysis of its use of energy and take serious steps to reduce overall energy consumption. Finding ways to cut power usage is rapidly becoming both an environmental and a financial imperative. On the ecology front, the greenhouse gases emitted as a by-product of energy consumption are eroding the Earth's ozone layer. On the financial front, cash-strapped municipal governments everywhere – and those in Sweden are no exception – have been under pressure to become more efficient and reduce operating budgets. With these issues in mind, a number of projects were studied for their

Figure 4-3. Report summarizing conversion to LED lighting in Stockholm, Sweden.

Handheld Transponders

Stockholm is experimenting with handheld transponders that extend green signals at signalized crossings for pedestrians. When the transponder is held up to a pole-mounted sensor, the green period is extended, allowing a group of children, for example, to cross the street completely. Transponder use is limited to kindergarten teachers and crossing guards in selected school zones with large numbers of students. Responses from test groups have been positive, but the city is concerned about receiving a flood of requests from other special-user groups interested in seeing the technology implemented on a broader basis. Use beyond school zones would have a significant negative impact on traffic flow synchronization and intersection operations.[13]

Portable Variable-Message Signs

Sweden is also experimenting with portable variable-message signs in school zones. When a motorist approaches the school zone traveling at a speed greater than the posted limit, the sign lights up with a message that indicates the motorist is speeding in a school zone.

Audible Crossing Indicators

Many pedestrian crossings in Stockholm are equipped with acoustic indicators. The devices serve two purposes. First, they reinforce the visual crosswalk indicators by emitting a fast ticking sound during the green pedestrian phase, an even-faster ticking during the pedestrian-clearance phase, and a slow ticking during the red pedestrian phase. Since the same ticking sounds are used on both streets, it is essential that the speakers emitting the sound be aimed directly at the pedestrians waiting at each crosswalk. The team believes this is a particularly effective approach (superior to the chirping sounds used in the United States). Second, they provide clear “walk” and “don’t-walk” indications for the visually impaired. Some pedestrian-crossing push buttons are equipped with a special locator tone that helps the visually impaired locate the button (Figure 4-4).

Figure 4-4. Pedestrian push button equipped with acoustic locator tone in Sweden.

Raised Crossings

Sweden has also implemented the use of raised and "virtually" raised pedestrian crossings to slow vehicles approaching a crossing. Raised crossings have been somewhat successful in reducing vehicle speed and increasing the likelihood a motorist will yield the right-of-way. Surveys show that pedestrians generally favor the raised walk. One exception is the visually impaired, for whom detecting a raised crossing is difficult.

Virtually raised pedestrian crosswalks are painted on the roadway surface and give the optical illusion of a raised surface (Figure 4-5). This approach is most effective and appropriate in locations where the majority of motorists are unfamiliar drivers.

Figure 4-5. Virtually raised crosswalks in Sweden.

GERMANY

Photo Enforcement Equipment

Automated enforcement techniques have been shown to be effective in Germany. The Germans use photo enforcement to control speed on roadway segments and high-speed intersection approaches. As discussed in Chapter 3, Germany does not signalize intersections with approach speeds greater than 70 kilometers per hour. For situations in which signals are required on higher-speed roadways, the speed limit is reduced before the intersection. This practice is effective, however, only if motorists obey the reduced-speed limits.

To address this need, Germany has successfully applied photo enforcement techniques to slow traffic and reduce red-light running. Officials identified two keys to successful application. First, the public must be aware that the cameras are in place. Second, a substantial penalty must be associated with disobeying the posted speed or running a red light. German speed-enforcement cameras are highly visible, signs warn of photo enforcement, and public messages are broadcast to make motorists aware that the equipment is being used. The Germans are studying the effectiveness of the cameras, but based on preliminary observations and before-and-after studies at several intersections, the reduction in the number and severity of accidents has been dramatic. Officials noted that in some cases, though, the number of less-severe rear-end accidents has increased because motorists are not willing to chance running a red light by speeding through an intersection. Photo enforcement has also been shown to reduce vehicle speed on roadway segments with high-speed-accident problems. Problems with photo enforcement have included vandalism and equipment tampering at some locations.

Based on the results to date, the Germans want to expand the use of photo enforcement as part of their safety program, but the cost of camera equipment and the labor required to process photographs and issue citations has limited the number of locations that can be equipped. (Officials noted that initially cameras can generate substantial revenue, but once the public becomes aware of them, the number of violations drops dramatically, resulting in less revenue.) To broaden the use of photo enforcement and control costs, the Germans are evaluating rotating cameras among multiple sites. The approach is to construct the photo enforcement infrastructure (including the highly visible pole-mounted camera box, signs, etc.) at multiple locations and move a camera randomly from site to site. They anticipate that a single camera could control traffic at 15 locations.

Portable Radar and Message Signs

The Germans also use portable radar and message signs before intersections with speed-related accident problems. A portable radar detector records motorists' speeds, and if they are traveling above the posted limit, a message that tells them they are traveling too fast is activated. This technology has been shown to reduce speeds by 5 to 8 kilometers per hour.

Signal Back Plates

At intersections where signal visibility has been determined to be a contributing factor to high numbers of accidents, back plates are sometimes used to enhance the visibility of the traffic signals (Figure 4-6).

Figure 4-6. Traffic signal with back plate in Germany.

Yellow Flashers

Special care is taken to protect pedestrians at locations with a sight obstruction between motor vehicle traffic and a pedestrian crossing or where a pedestrian crossing phase conflicts with a motorized vehicle phase (Figure 4-7). For example, if an obstruction exists in the sight triangle of an intersection and a right-turning vehicle cannot see the pedestrian crosswalk, a yellow flasher warns the motorist of the possibility of pedestrian traffic around the corner.

Figure 4-7. Supplemental signal warning right-turning motorists about pedestrians.

Audible Crossing Indicators

Audible pedestrian signals are used to supplement signal indicators. The audible signals are designed with a variable-volume feature controlled by the surrounding traffic noise. As the level of traffic noise increases, so does the volume of the audible crossing signal (Figure 4-8).

Figure 4-8. Pole-mounted audible signal in Germany.

THE NETHERLANDS

The use of traffic control devices in the Netherlands is focused largely on the desire to control traffic speed. The Dutch strive to provide visible and easily understood traffic signal controls by doing the following:

- Post “signal ahead” warning signs before high-speed intersections (Figure 4 9).
- Paint signal poles with high-contrast black and white stripes (Figure 4-10).
- Consistently use large black back plates bordered by a white stripe (Figure 4-11).
- Use colored pavement to distinguish bike lanes from motorized vehicle lanes (Figure 4-12).

Figure 4-9. "Signal ahead" warning sign in the Netherlands.

Figure 4-10. Signal poles with high-contrast stripes.

Figure 4-11. Large back-plate bordered by white stripe.

Figure 4-12. Colored pavement used to distinguish bike lanes in the Netherlands.

Officials recognize, however, that optical messaging alone is not enough to eliminate accidents at signalized intersections and that they must lower speeds to reduce the severity of accidents.

Photo Enforcement Equipment

Photo enforcement to reduce speed and red-light running is used extensively in the Netherlands and has been shown to be effective. The program's success is based largely on visibility and public awareness. In Rotterdam, cameras are marked with red and blue stripes and are clearly visible to the public (Figure 4-13). In addition, many intersections with photo enforcement equipment are clearly signed in advance (Figure 4-13). Like the Germans, the Dutch rotate one camera among multiple sites. The Netherlands has 600 to 700 camera posts, with an average ratio of one camera for every four posts. Wet film technology is used to photograph violators. Digital camera technology has been tested, but the lack of secure data lines between the camera installations and police agencies coupled with file size requirements of digital images have made digital imaging prohibitive for now.

Figure 4-13. Photo enforcement camera for red-light running in the Netherlands.

Figure 4-14. Photo enforcement warning signs in the Netherlands.

Studies have shown photo enforcement programs to be extremely effective. After about six months of enforcement, the number of violations drops to nearly zero (Figure 4-15). In cases where the public realizes that a camera is not always in use, the number of violations tends to increase. When such an increase is recognized, the enforcement time at that particular location is increased, and violation rates drop again.

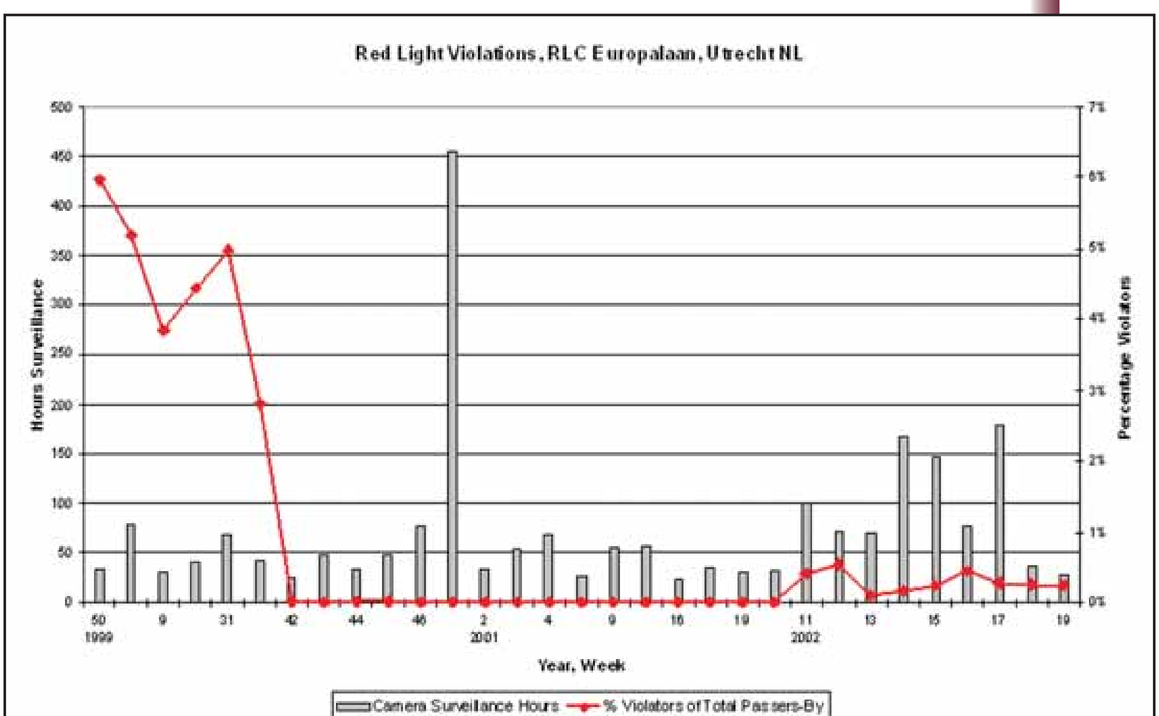


Figure 4-15. Effectiveness of photo enforcement in Utrecht, Netherlands.

To change motorists' behavior, the Dutch have invested considerable time and money in a public awareness campaign aimed in part at photo enforcement goals but more broadly at overall road-user safety.[14]

The Dutch have not yet concluded studies that confirm the safety effectiveness of the photo enforcement program. The program is viewed as having two phases: the first to change driver behavior and the second to evaluate the impact on safety. Because the Dutch started the program in 1999 and they believe it takes about two years to change motorist behavior, they are just beginning to research the safety effects of photo enforcement.

Variable-Message Signs

The Dutch use variable-message signs before high-speed (50 kilometers per hour or greater) intersections to warn motorists that they are traveling above the posted speed limit (Figure 4-16). Often these signs are used in conjunction with clearly marked and signed speed tables located just beyond the stop bar (Figure 4-17). Speed tables, carefully designed so that traffic traveling at or below the speed limit passes over them comfortably, are not safety hazards for traffic traveling over the speed limit. Speed tables are more comfortable than speed bumps for long vehicles (buses, trailers) in particular, but the speed reduction of heavy traffic still remains.[15]

Figure 4-16. Variable message signs on approaches to high-speed intersections in the Netherlands.

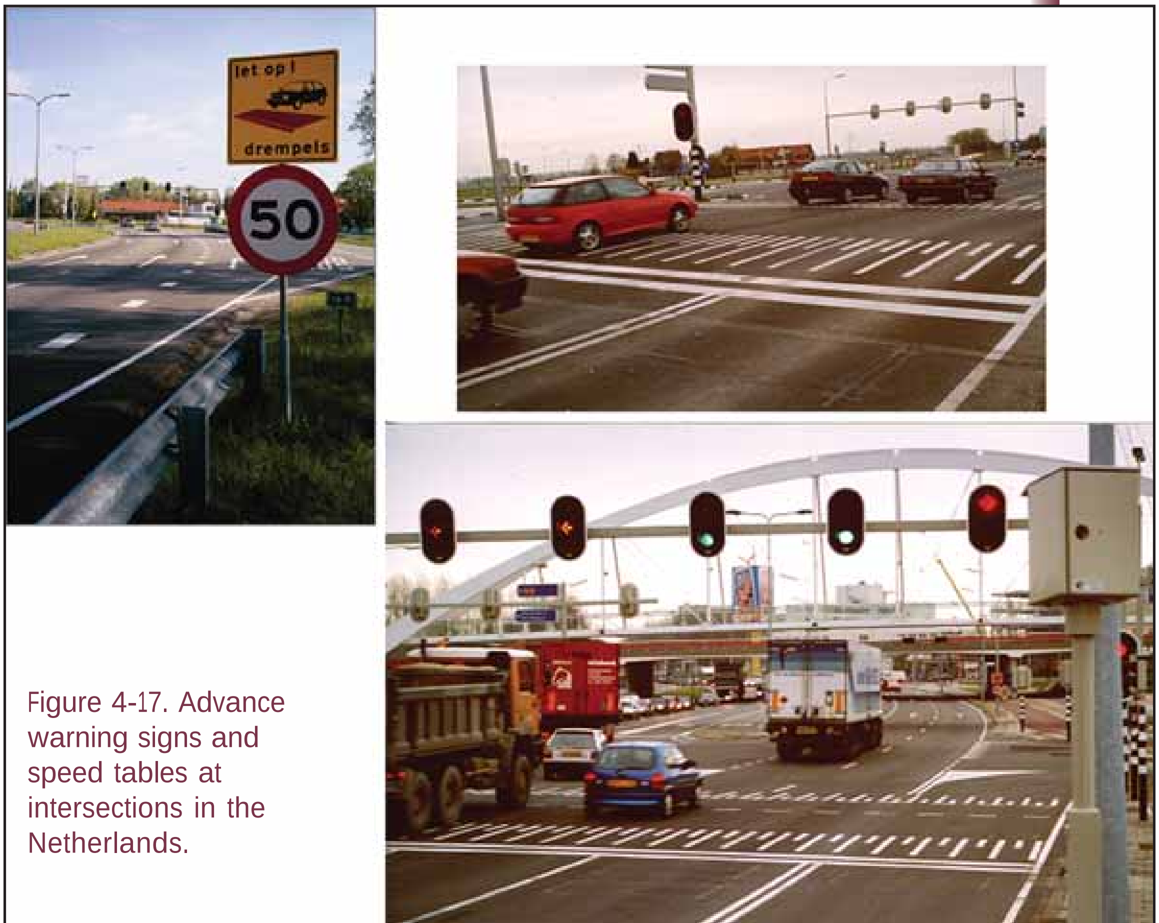


Figure 4-17. Advance warning signs and speed tables at intersections in the Netherlands.

Bicycles are used extensively as regular transportation in the Netherlands, and bicyclists' impact on intersection safety and operation is a primary consideration. The Dutch strive to eliminate conflicts between motorized and nonmotorized traffic (e.g., protected-only phasing) and to reduce wait times for nonmotorized traffic. Most serious pedestrian and bicyclist accidents are a result of crossing against a red signal. To minimize the likelihood of nonmotorized traffic crossing against the red phase, the Dutch have implemented several strategies:

- Short cycle lengths to minimize wait time for nonmotorized traffic
- Nearside bicycle and pedestrian signals (Figure 4-18)
- Supplementary signing to warn motorists of a pedestrian crossing (Figure 4-19)
- LED lights in the pavement[16]
- Countdown clocks
- Egg timer countdown indicators
- Grade-separated crossings

Figure 4-18. Nearside bicycle signals In the Netherlands.

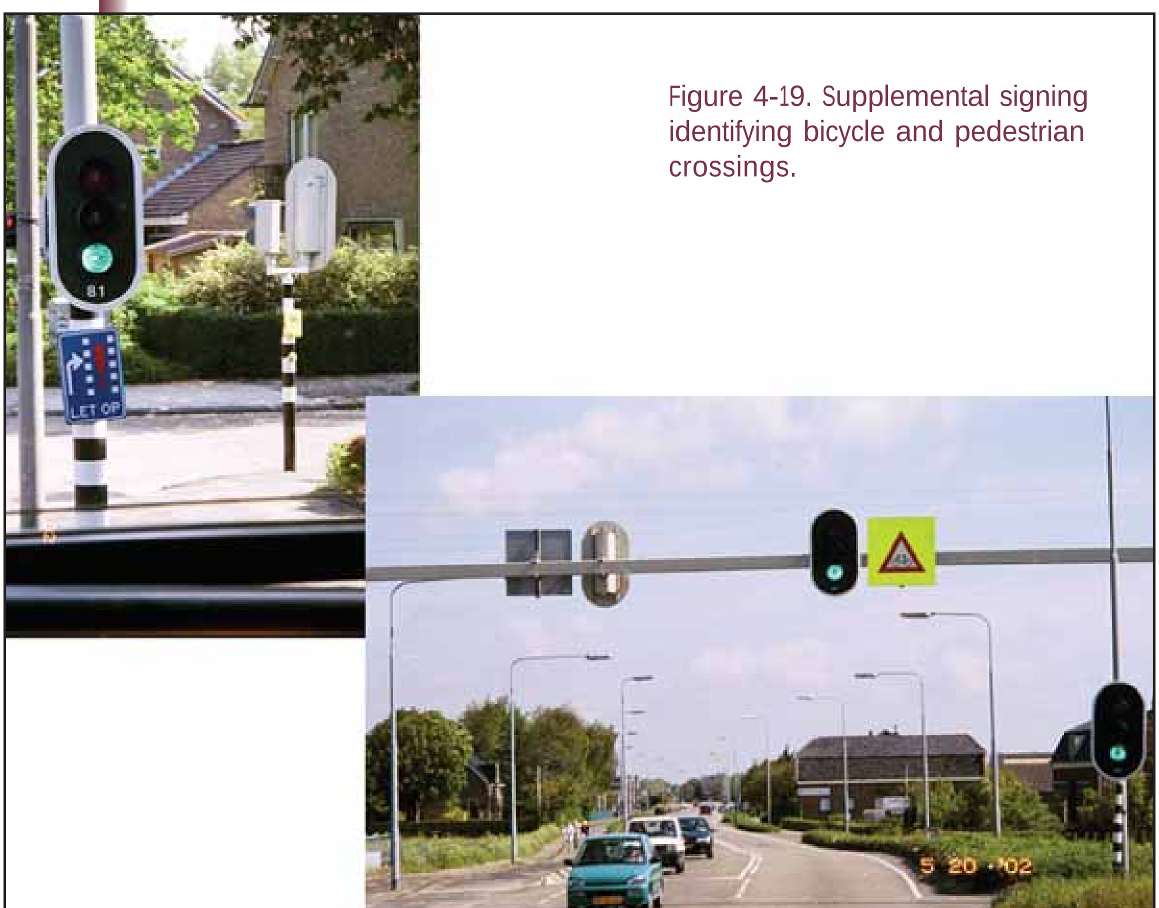


Figure 4-19. Supplemental signing identifying bicycle and pedestrian crossings.

Countdown Timers

Countdown timers appear to be an effective way of providing positive reinforcement to nonmotorized traffic that the pedestrian timing button has been activated and the signal is operating properly. Several devices are used to convey this message to pedestrians and bicyclists. One is a round countdown signal with 31 lights mounted next to the bicycle indicator (Figure 4-20). At the beginning of the red phase, all 31 lights on the signal are lit. As the green phase approaches, the lights darken one by one to let the cyclist know how much longer until the green phase is activated. A similar indicator surrounds the pedestrian push button (Figure 4-21). The yellow lights surrounding the push button are darkened to let pedestrians know when the wait is ending.

Figure 4-20. Countdown indicator for bicycle crossing.

Figure 4-21. Pedestrian countdown indicator on push button.

Most signals in the Netherlands are traffic actuated, and the signal timings vary for each cycle. The rate at which the individual lights go dark varies and is synchronized to the signal timing and operation. The timer starts by calculating the maximum wait times. If a signal group does not get a call for green, the timer accelerates, and when the last light goes out, the signal turns green. Studies have shown the following:

- Red-light running by bicyclists has dropped 25 to 30 percent.
- Sixty percent of users believe the wait time is shorter.
- Eighty-six percent of users understand the meaning of the wait-time indicator.
- Seventy-eight percent of users find the information useful.

Other timers being tested are a digital hourglass timer on the pedestrian signal pole and pavement lights installed in the crosswalk.

Bicycle Turn Lanes

At signalized intersections, separate lanes are striped for left- and right-turning bicyclists. Signs are posted to alert drivers to the presence of turning bicycles (Figures 4-12 and 4-20).

UNITED KINGDOM

Photo Enforcement Equipment

Enforcement cameras were first introduced in the United Kingdom in 1991. A number of research studies have proven their effectiveness in reducing traffic accidents.[17]

An August 2001 study and report prepared for the Department of Transport examined the effectiveness of the cameras and the issue of cost recovery on a pilot basis.[18] The study found that sites with cameras had an average of 35 percent fewer accidents and 47 percent fewer fatalities and serious injuries. A number of sites indicated that camera enforcement was particularly successful in reducing accidents between vehicles and vulnerable road users (i.e., pedestrians, particularly children). The study included a public opinion poll that found that the public was generally supportive and that the number of requests for additional cameras substantially exceeded the number of complaints about their operation.

The use of speed and red light cameras in the United Kingdom is covered by cost recovery partnerships in which fine income is retained to fund installing, maintaining, and operating cameras and processing sanctions (fixed penalty notices). To qualify for a cost recovery partnership, cameras must be sited according to rules, which include requirements that cameras have a highly visible yellow reflective cover and that the routes on which they operate be signed.

The following is a summary of the rules and framework for pilot study locations:

- Pilot projects should be coordinated among the local highway authorities, courts, and police.
- Only the cost of the enforcing speed and red-light cameras should be considered an allowable expense.
- No organization should be allowed to make a profit from photo enforcement (i.e., any surplus or fine income over costs incurred should be returned to the treasury).
- All cameras should be located in high-accident locations with a history of speed-related crashes.
- Speed surveys should be conducted before camera installation to prove that speeding is a problem at each site.
- At the end of the year, partnerships should be subject to a full audit by the district auditor, and failure to receive a clean audit would result in removal of the privilege to retain the funds.

Pavement Edge Markings

Pedestrian and bicycle safety is a significant issue at signalized intersections. To increase driver awareness on the approaches to a pedestrian crossing, straight pavement edge markings change to zigzag lines (Figure 4-22). In addition, the U.K. highway code forbids drivers from parking or passing another vehicle within the zigzag zone (typically 16 meters plus the crossing width plus 16 meters) to address sight distance being blocked and to prevent one driver from passing another that may have stopped to yield to a pedestrian.

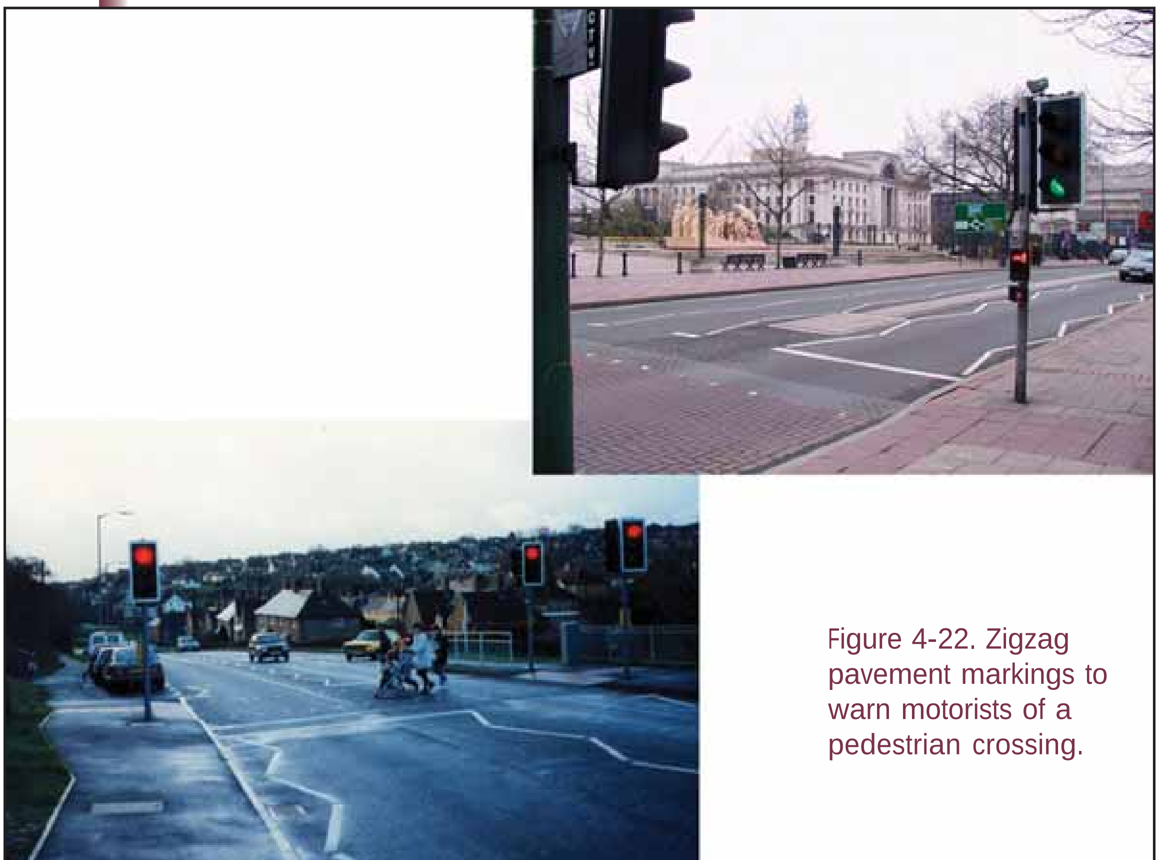


Figure 4-22. Zigzag pavement markings to warn motorists of a pedestrian crossing.

PUFFIN Crossings

The United Kingdom has developed a number of innovative signalized pedestrian crossings that rely on the latest detector technology to improve safety and traffic operations. The PUFFIN crossing uses pedestrian detectors to automatically vary the length of the pedestrian phase, giving pedestrians the time needed to cross (Figures 4-23 and 4-24).

Figure 4-23. PUFFIN crossing in the United Kingdom.

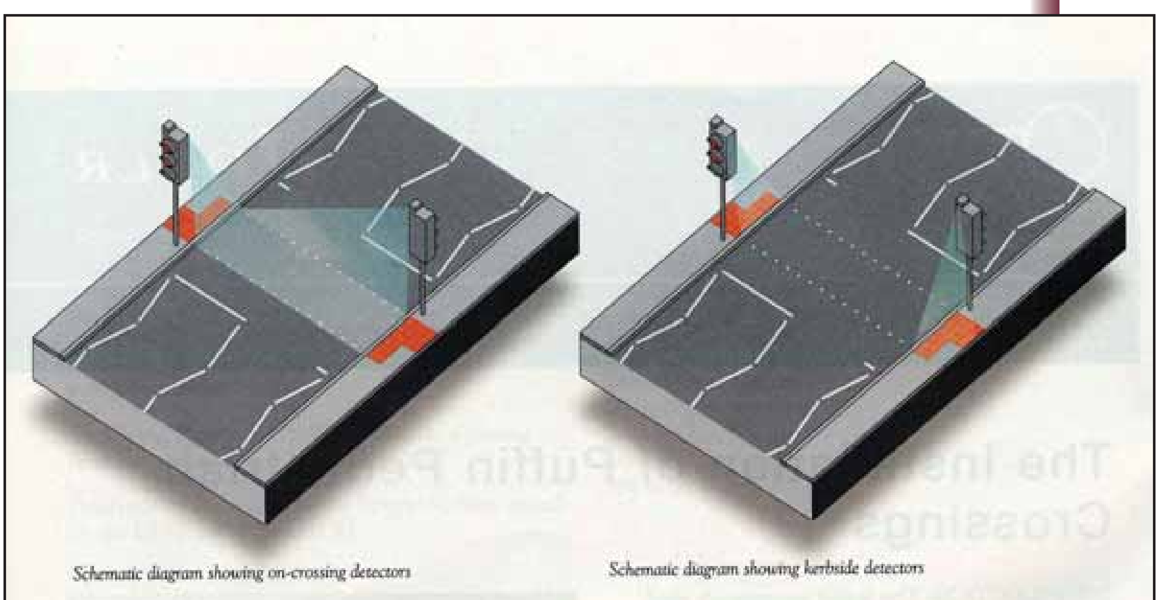


Figure 4-24. Schematic layout of a PUFFIN crossing in the United Kingdom.

Pedestrian poles placed on the near side of the road replace farside signals. On receiving a pedestrian call from a push button, the controller checks the curbside presence detector. If a pedestrian is present, the pedestrian phase is called and a light is illuminated, informing the pedestrian of the call. If the output of the curbside presence detector disappears (the pedestrian has crossed on red) the pedestrian phase call is canceled. When the pedestrian phase is started, the green walking man appears on a nearside signal. Pedestrians within the crosswalk are monitored by the crossing detectors and given sufficient time to cross the roadway. After the green man is extinguished, the red man is illuminated, signaling to pedestrians that they should not begin crossing. Maximum allowable crossing times are preset for each site. If the maximum allowable crossing times are exceeded, vehicular traffic is given a red/amber, then green signal. On divided roadways with a median, PUFFINs are often operated as two separate crossings with a staggered median that forces pedestrians to turn and face oncoming vehicular traffic (Figure 4-25).

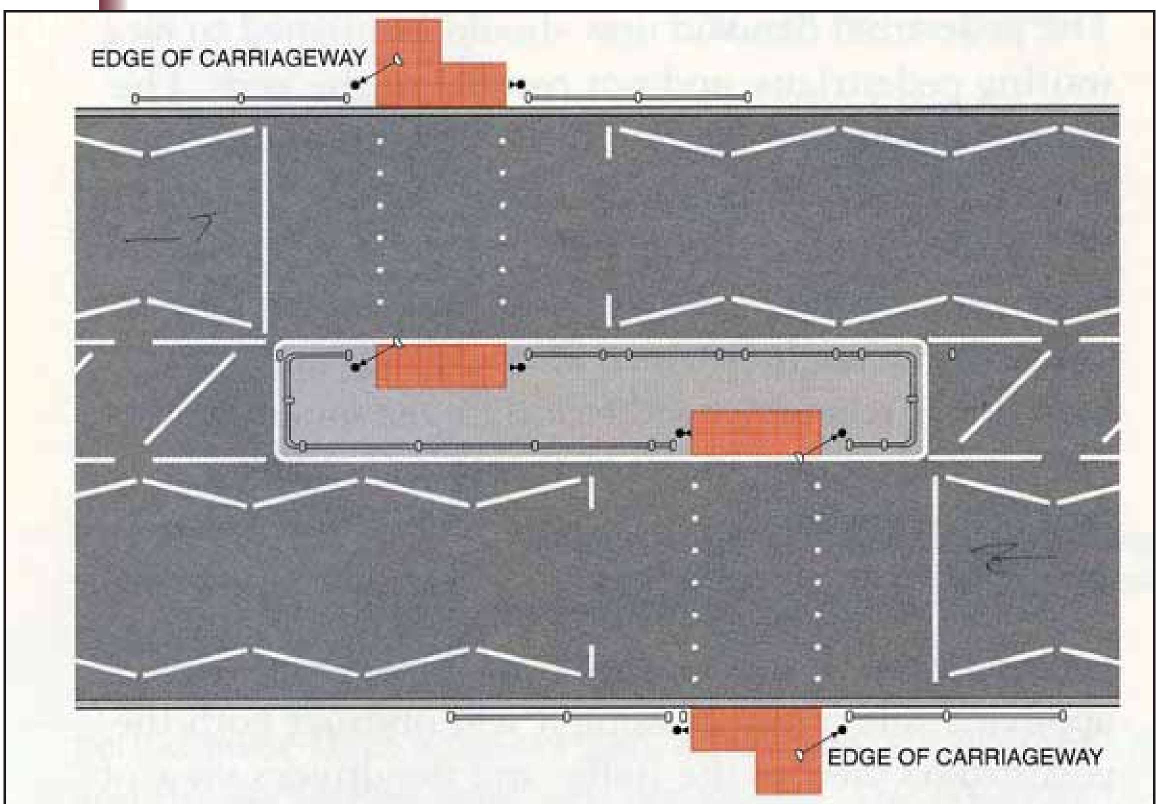


Figure 4-25. Schematic layout for a staggered PUFFIN crossing in the United Kingdom.

Some benefits of PUFFIN crossings include the following:

- Pedestrian signals are simplified (no flashing green man).
- Vehicle delays are reduced (if the pedestrian crosses during the red phase after having pushed the pedestrian button, the pedestrian call is canceled).
- Visibility problems are eliminated (nearside signals are used).

PUFFIN technology is also being applied to shared bicycle-pedestrian crossings (e.g., TOUCAN) and equestrian crossings.

Yellow Box Junctions

High-volume, congested intersections are striped with yellow crosshatches (Figure 4-26). Drivers can be cited for entering the intersection and stopping in the crosshatched area because the exit lanes are blocked by stationary vehicles, although under some circumstances (crosshatched area is blocked by opposing vehicles turning right) drivers are allowed to enter the area.

Figure 4-26. Yellow crosshatched intersection in the United Kingdom.

Guide Signs at Restricted Turns

Signs are posted before locations where turns are restricted to tell drivers how to use other routes to reach their intended destination (Figure 4-27).

Figure 4-27. Restricted-turn sign.

chapter five
INNOVATIVE GEOMETRIC DESIGNS

SWEDEN

The Swedish intersection safety program is focused more on controlling driver behavior through the use of technology such as LHOVRA than through design, but a number of safety-driven intersection design practices, many of which are dictated through design codes and statutes, do exist:

- At speeds greater than 70 kilometers per hour, exclusive turn lanes and protected phasing must be provided. At speeds between 50 and 70 kilometers per hour, shared lane use and permitted phasing is optional.
- At speeds equal to or greater than 90 kilometers per hour, acceleration lanes are provided for free-flow right turns.
- At intersections where pedestrian activity is heavy, a tight turning radius is used to slow motorists through the turn.

GERMANY

Raised Medians

The team identified several geometric design practices intended to enhance pedestrian safety at signalized intersections. If a pedestrian crossing crosses more than two lanes, then a protective raised median is provided to function as a "refuge" area (Figure 5 1). The median must be at least 2 meters wide. This practice applies to both signalized and unsignalized intersections. In addition, pedestrian crossings are sometimes staggered within the median area to force pedestrians to turn and face oncoming traffic before continuing across the street (Figure 5-2).

Figure 5-1. Pedestrian refuge island in Germany.

Figure 5-2. Staggered pedestrian crossing in Germany.

Separate Stop Lines for Motor Vehicles and Bicycles

Bicyclist visibility and safety is enhanced through placement of separate stop lines for motorists and bicyclists. Where a bike lane runs parallel to a signalized intersection's approach lane, the stop line for the bicycle lane is placed closer to the intersection, and motorized vehicle traffic is forced to stop behind the bicyclist. This design practice enhances bicyclists' visibility and particularly helps reduce conflicts between right-turning vehicles and bicycles.

Bollards

Germany also uses special bollards, or series of short posts set at regular intervals, to delineate pavement areas to prohibit vehicles from parking too close to intersections and blocking the view of a pedestrian or bicyclist crossing the intersecting street.

Left-Turn Lanes

For safety reasons, left-turn lanes with protected phasing are used at high-volume and high-speed locations. According to several members of the host delegation, the use of two phased signals (particularly in rural areas) without left-turn lanes provides little or no safety benefit over an unsignalized intersection, so the use of left-turn lanes with protected phasing is highly encouraged. If dual left-turn lanes are used, then a protected phase must be provided for the motorized traffic and for the conflicting pedestrian-bicycle traffic.

Roundabouts

Roundabouts are used on a limited basis as an alternative to signalized intersections. Single-lane roundabouts are preferred, and multilane approaches and configurations are strongly discouraged. The Germans have found that roundabouts tend to reduce overall intersection delay and are most effective when approach volumes are balanced among all approaches. The Germans have developed a mini-roundabout for use in low-speed urban conditions. The inner radius is 13 to 25 meters and it has a single 4-to-4.5-meter lane. A raised (no more than 10 centimeter) island with a 4-meter radius is constructed in the center of the mini-roundabout. Mini-roundabouts have been shown to reduce accidents by 60 percent over the use of signalized intersections.

Nearside Signals

Nearside signals are preferred to minimize the number of vehicles stopping beyond the stop-bar and blocking pedestrian/bicycle crossings.

THE NETHERLANDS

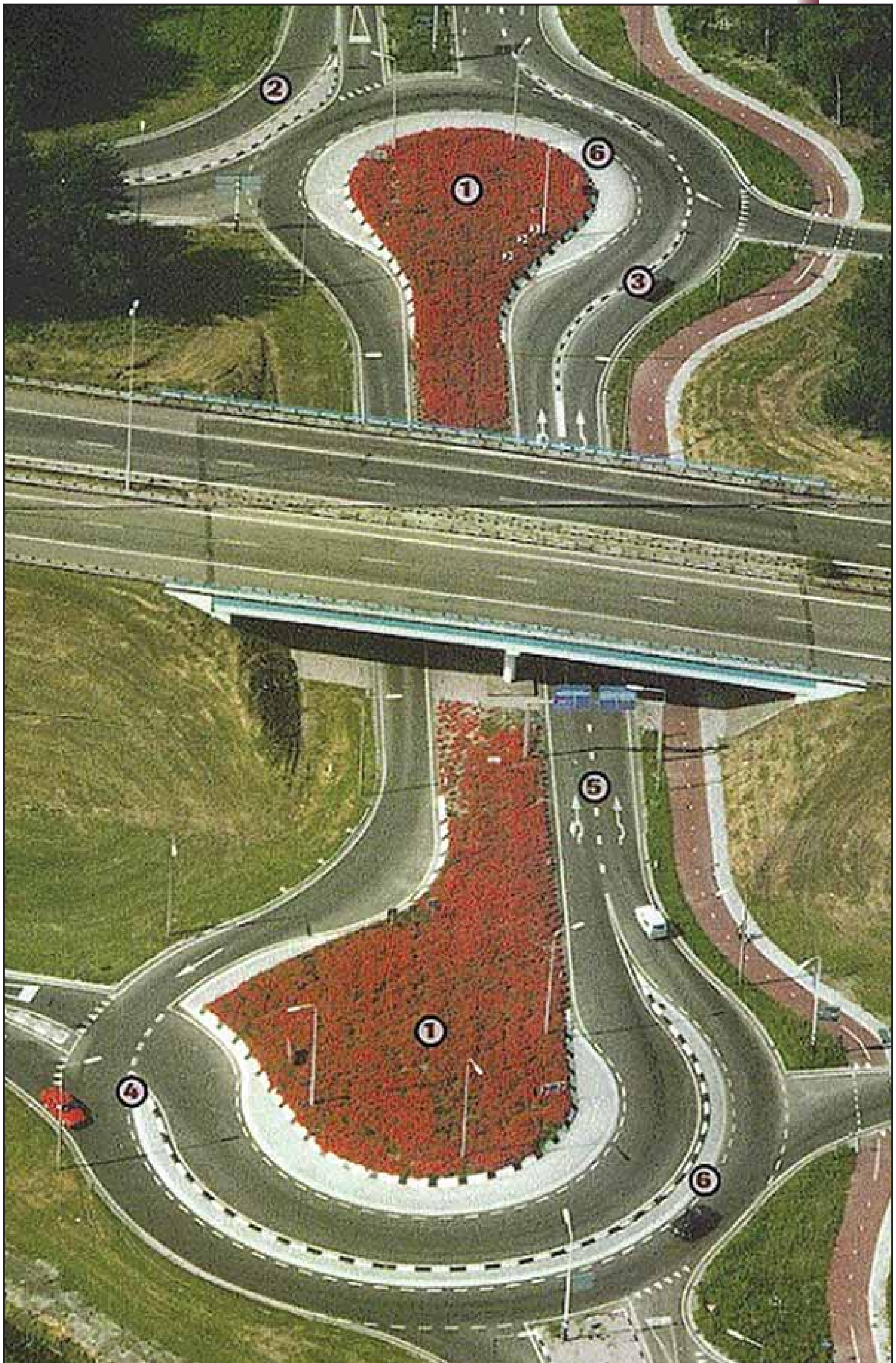
Roundabouts

Where practical and feasible, the Dutch have converted signalized intersections to roundabouts (about 6 percent in the last three to four years). A conversion to roundabouts is considered when serious signalized intersection accidents cannot be controlled by other means. They have successfully used both single-lane and dual-lane roundabouts, and studies have shown a 60 percent increase in intersection safety performance.

The Dutch have developed computer programs to predict capacities, queue lengths, and delays at roundabouts, comparable to the ARCADY software program used in the United Kingdom. The Dutch recognize that a single roundabout design will not fit all situations. To achieve the best results, they have developed and implemented several different roundabout designs to address variable conditions.

The dog bone roundabout configuration is successful at diamond-interchange intersections. In Figure 5-3, the interior of the roundabout is closed, and parallel roadways are used between the ramp terminals. The team visited a dog bone roundabout in operation. The interchange, located in an industrial area, carried a significant volume of heavy truck traffic. Based on field observations, this configuration operated very well.

Figure 5-3. Dog bone roundabout in the Netherlands.



The turbo roundabout, a modification of a standard dual-lane roundabout, is used in the Netherlands to eliminate weaving conflicts found in standard multilane roundabouts (Figure 5-4). This low-speed configuration also has been found to allow a higher capacity than the standard two-lane roundabout. While a standard roundabout has 16 potential conflict points, the turbo roundabout has 10. In either case, the conflict points are low speed, and the resulting accidents are typically less severe than those at signalized intersections (Figure 5-5).

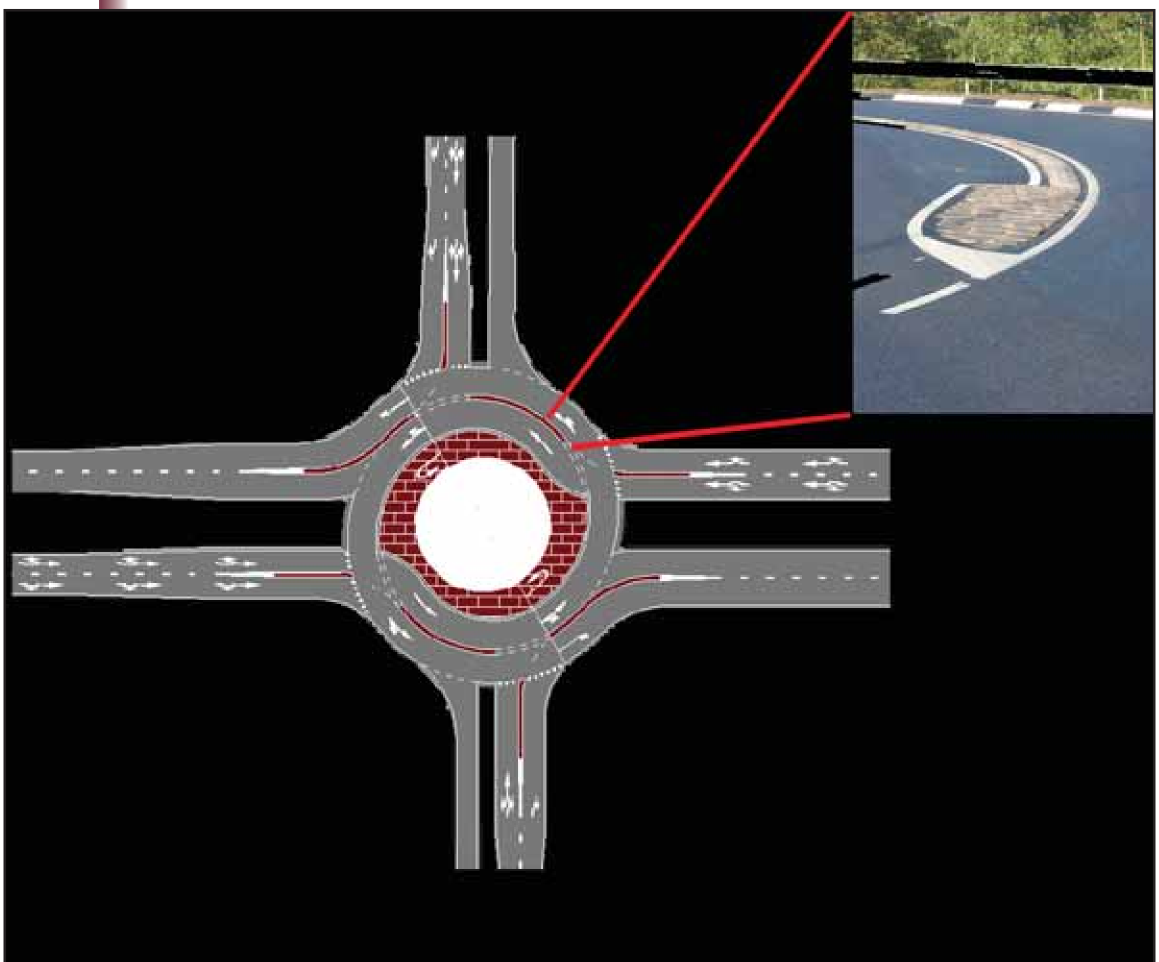
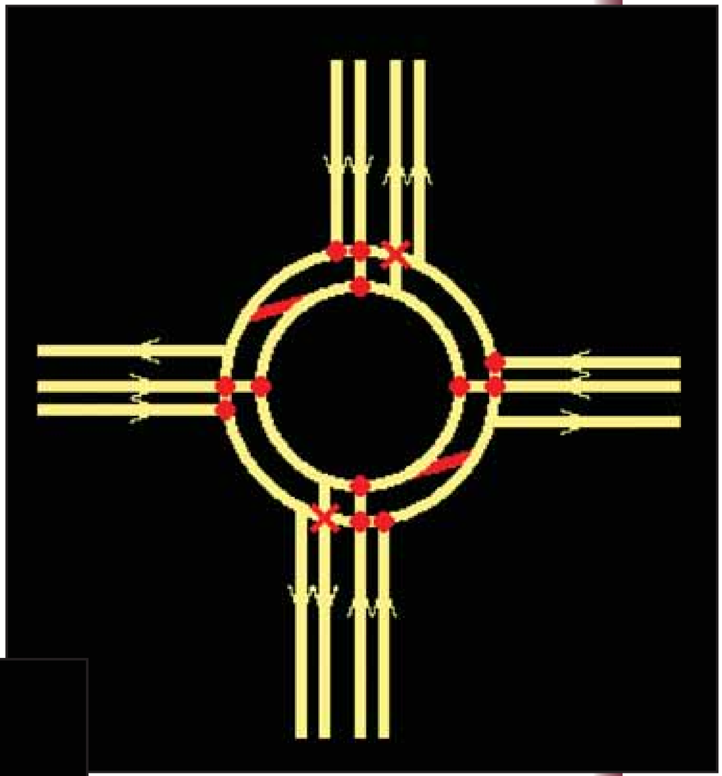
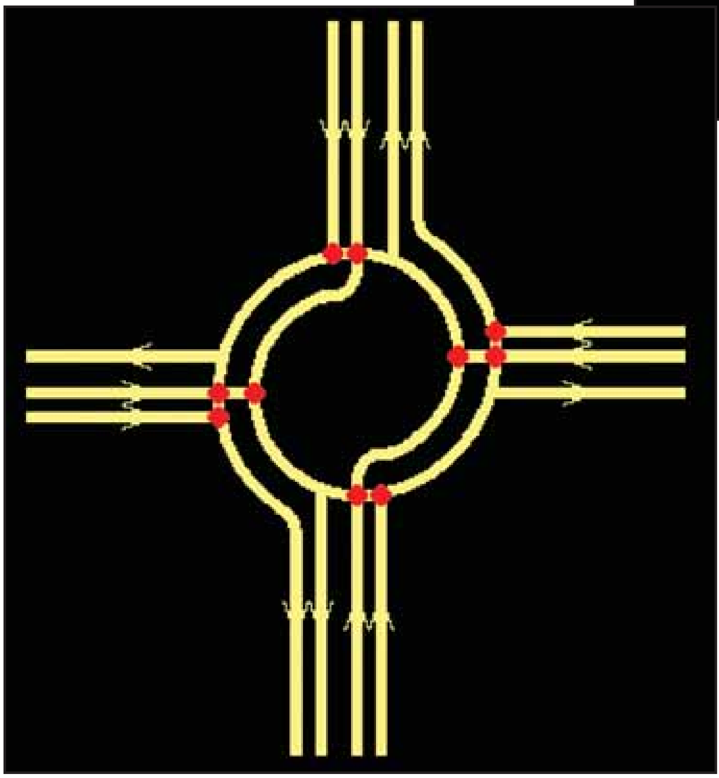


Figure 5-4. Turbo roundabout configuration in the Netherlands.

Figures 5-5. Comparison of conflict points between traditional and turbo roundabouts.



Traditional



Turbo

Roundabouts limit the ability to control traffic flow and maintain platoons in a network. Typically, upstream and downstream signals are used to control and meter traffic flow and improve the efficiency of the roundabout and the overall traffic network. Pedestrian and bicycle safety issues at roundabouts are addressed by providing clearly delineated bicycle and pedestrian crossings (Figure 5-6).

Figure 5-6. Delineated bicycle and pedestrian paths at roundabouts in the Netherlands.

Speed Tables

A method to control speed at higher-speed signalized intersections is the use of speed tables placed just inside the stop bar. Speed tables are designed to be comfortably traversed at the posted speed limit. If a vehicle is traveling above the speed limit, the driver feels the effect of the "bump." The team saw an interesting version of this approach at a signalized intersection where only the right turn lane had a speed table. The purpose was to slow vehicles turning right to improve safety for pedestrians and bicyclists crossing the intersected street (Figure 5 7).

Figures 5-7. Speed table in right-turn lane.

UNITED KINGDOM

Primary guidelines for geometric design at intersections are in two documents prepared by the U.K. Highways Agency: “Design Standards for Signal Controlled Junctions” (document TD 50/99) and “Layout of Large Signal Controlled Junctions” (document TD89/02).

ARCADY

Roundabouts are used extensively in the United Kingdom. Urban and suburban roundabouts that carry high traffic volumes are commonly signalized to improve safety, capacity, and flow. TRL has developed a software program, known as ARCADY, to predict capacities, queue lengths, and delays at roundabouts. ARCADY is used as an aid in designing new roundabouts, as well as in assessing the effects of modifying existing designs. ARCADY is also capable of accident prediction for various types of roundabout designs.

The British have developed several complex signalized roundabouts. One design, called a through-about or hamburger, takes the major through movement through the center of the roundabout and eliminates that heavy movement from the circulatory roadway (Figure 5-8). All turners use the roundabout, and signals separate them from through traffic when they reach that point.

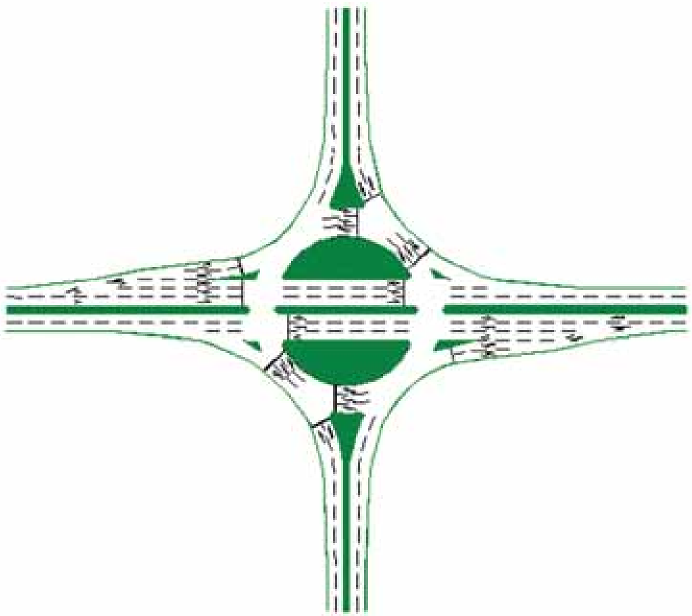


Figure 5-8. Schematic layout of a through-about intersection.

Another design, known as the double through-about or the hot cross bun, takes both through movements through the center of the roundabout, while turns remain on the roundabout's circular portion (Figure 5-9). These designs primarily address capacity increases. Anecdotal evidence suggests that they do not affect safety significantly, and it is clear that these designs are operationally complicated and require significant design study before they are implemented. Clearly, as these roundabout designs become more complex, it becomes imperative that their traffic signals remain properly synchronized.

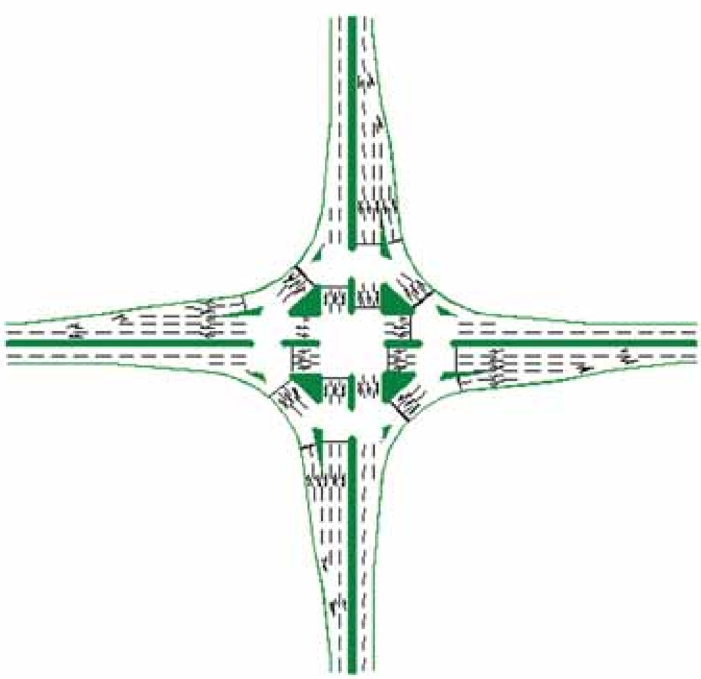


Figure 5-9. Schematic layout of a double through-about intersection.

A first-of-its-kind, high-capacity intersection is scheduled to begin construction in the United Kingdom in 2002 (Figure 5-10). The design displaces right turns (equivalent to left turns in the United States) to cross the conflicting through movement far before the intersection, allowing intersection control to be simplified from four phases to two. Intersection simulations indicate that the design will improve efficiency by 20 to 30 percent. Five of these intersections have been built in Mexico, and one has been constructed in Quebec.

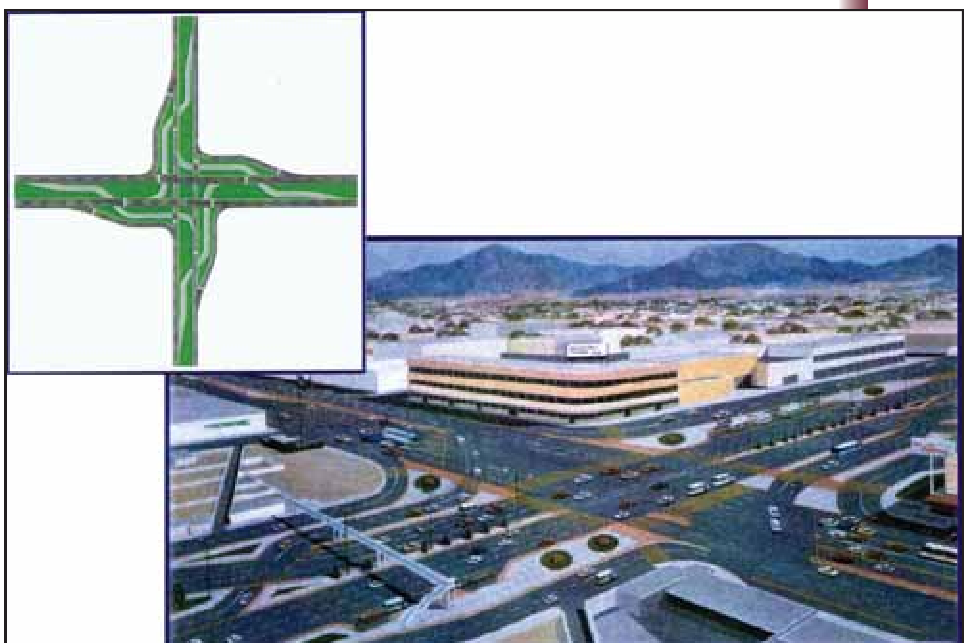


Figure 5-10. Schematic of a high-capacity intersection.

chapter six
PROCESSES AND PROCEDURES FOR PROBLEM IDENTIFICATION

SWEDEN

SNRA, local transportation agencies, and police collaborate on reviewing accident statistics to identify problems at, study, and develop solutions for high-accident locations.

GERMANY

In Germany, high-crash locations are identified by traffic safety commissions (known as the KEBU in Frankfurt), which typically use the frequency and type of accidents at an intersection to identify a high-crash location, or "black spot." Threshold values for the number of crashes of a similar type must be met before a location can be considered a high-crash site. In Frankfurt, an intersection with five or more accidents of the same type in one year is considered a black spot and must be addressed by the traffic safety commission. Frankfurt does not consider exposure (accident rates) in black spot identification, but some cities in Germany are beginning to rely on accident rates to help identify black spots.

The federal government provides funds for training opportunities and design/countermeasure guidelines for traffic safety commissions. Site-specific safety solutions and countermeasures are developed on the basis of site-specific engineering studies. Traffic safety commissions are responsible for monitoring and ensuring the effectiveness of safety improvements.

THE NETHERLANDS

Safety goals in the Netherlands are established at a national level and driven by the principles of sustainable safety. The national government covers 50 percent of the cost of safety efforts at provincial, metropolitan, and local levels.

Development of sustainable safety goals and principles has led the Dutch to adopt a systematic approach to roadway safety. The three primary principles of sustainable safety are functional use, homogeneous use, and predictable use. In 1997, the Dutch began implementing phase I of the sustainable safety plan—classifying their entire roadway network. The network was divided into three types: national and regional freeways, regional and district distributors, and urban and rural access roads. Once a road has been identified by type, officials make sure it meets its classification requirements. This systematic approach to making form follow function has provided safety improvements on roadways and at signalized intersections.

Specific intersection-related safety problems are identified through a review of accident records in coordination with local law enforcement agencies. In addition, the Dutch use their extensive network of loop detectors to help target potential speed-related and red-light-running safety problems. Once an accident problem is identified, an engineering study is performed to evaluate appropriate safety improvements. Guidance on specific safety strategies is provided in the suite of handbooks prepared by CROW. A wide array of traffic safety improvements is typically considered, but the primary focus is to reduce severity of accidents through the speed reduction measures identified in previous chapters.

UNITED KINGDOM

As in other countries the team visited, responsibility for identifying black spots in the United Kingdom lies primarily with local highway authorities working in conjunction with police agencies. TRL developed software to help identify black spots and overall trends in highway safety. The microprocessor accident analysis package (MAAP) is built on a relational database that can be customized for a user's particular needs. The tool includes geographic information system (GIS) software to help target high-accident locations and provides the user with a range of tools for identifying and analyzing problems and isolating common features among accidents (Figure 6-1). One program feature the team found particularly useful is the stick diagram, a tabular diagram that provides a graphical summary of accident statistics at a given location (Figure 6-2).[19] The diagram lists all significant characteristics of each crash (night-day, wet-dry, hour of crash, etc.), allowing analysts to identify crash-causing trends easily.

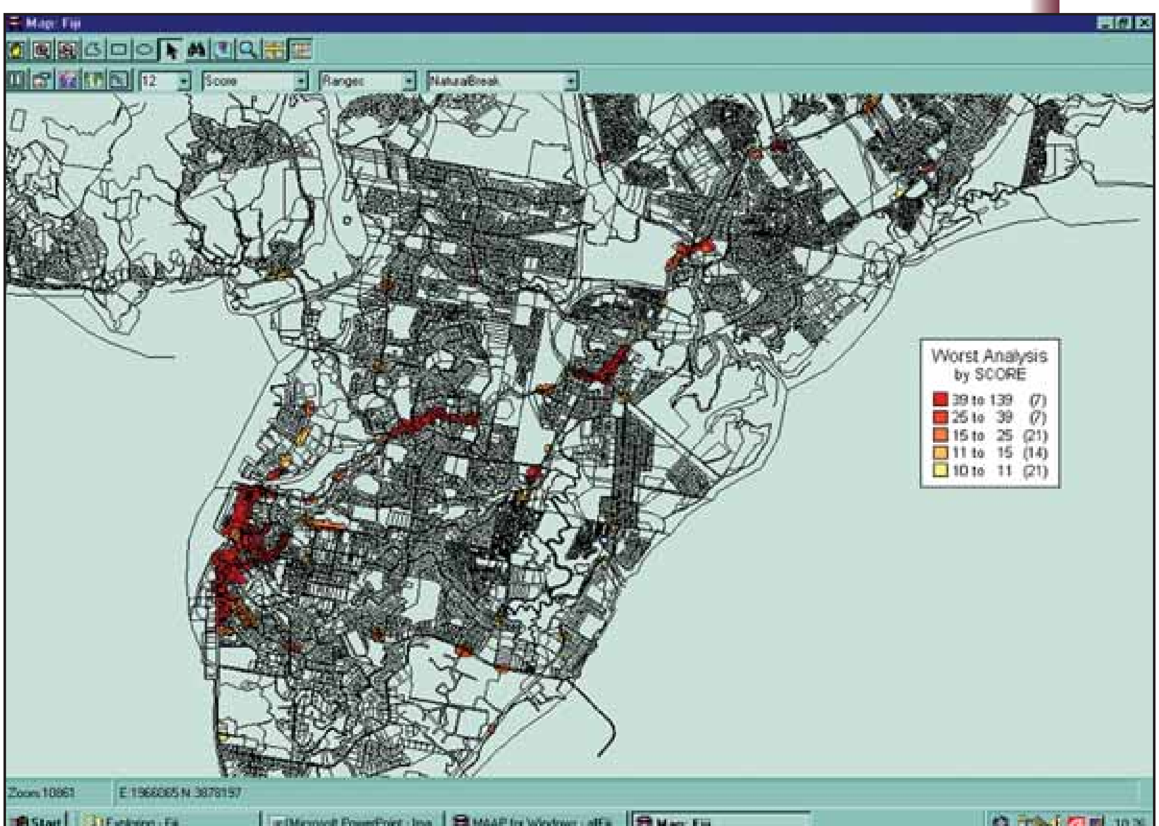


Figure 6-1. MAAP GIS-based software to target high-accident locations.

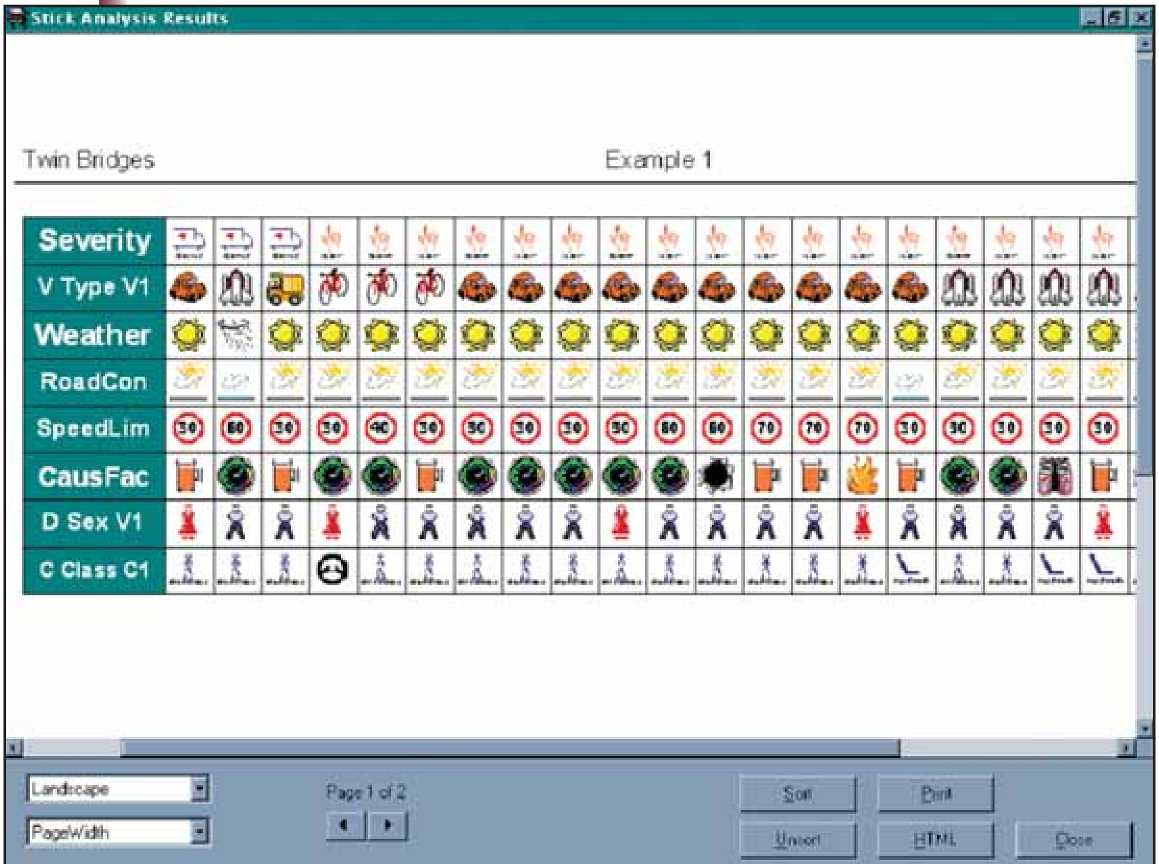


Figure 6-2. MAAP stick diagram used to graphically summarize accident statistics.

TRL has developed a software package that can be used to evaluate safety trade-offs in the design and operation of signalized intersections. The software can be applied to new designs and used to evaluate current conditions and proposed improvements. Optimized signal capacity and delay (OSCADY) software is used primarily for capacity calculations, queue lengths, and delay at isolated signalized intersections. In addition, the software has accident-prediction capabilities for low-speed (30 miles per hour or less) urban intersections. The data required for accident prediction is vehicle and pedestrian flow, length of pedestrian crossing, geometric characteristics, and signal timing plan. With this information, the software will estimate expected accident characteristics. The software's model relies on the large amounts of empirical accident data collected in the United Kingdom, so it is not likely to produce reliable results for conditions in the United States.

chapter seven
LOW-COST SAFETY IMPROVEMENTS

SWEDEN

In their meetings with the scanning team, the Swedish hosts discussed a number of intersection safety improvements. To avoid eliminating any potential safety improvements, the team chose to include some treatments that might be considered high-cost safety improvements in the following list:

- Prohibit right turns on red, particularly at intersections with significant pedestrian and bicycle traffic.
- Use 100-second-maximum cycle lengths to improve pedestrian, bicycle, and motorist compliance with the red phase.
- Use a pocket transmitter to extend a signal's green time for school groups or other special users. This approach could be used to comply with Americans with Disabilities Act requirements without providing unnecessarily long pedestrian clearance intervals when they are not needed.
- Provide audible pedestrian-crossing signals to reinforce visual signals and address the needs of the hearing impaired.
- Adopt intersection design and operational concepts based on approach speeds. For example, all signalized intersections with an approach speed limit greater than 70 kilometers per hour should be provided with exclusive turn lanes and perhaps have protected-only phasing for left and right turns.
- Implement the LHOVRA system at isolated high-speed intersections where safety problems have been demonstrated and signal synchronization is not a concern.

GERMANY

The German hosts presented several intersection safety improvements. To avoid eliminating any potential safety improvements, the team chose to identify the following safety improvements regardless of their costs:

- Determine clearance intervals based on conflict points and approach speeds. Doing so can be incorporated into design or signal-timing modifications inexpensively.
- Develop and implement multidisciplinary (enforcement, education, and engineering) traffic safety commissions to identify, study, and recommend improvements at high-accident locations. The success of these commissions requires adequate training and/or traffic safety background for members and a strong leadership committed to improving traffic safety.
- Publicly identify high-accident intersections through distinctive signing (similar to the curve warning sign).

- Consider prohibiting left turns at congested intersections and instead install signing to reroute traffic to make three right turns.
- Install "please wait" signals at pedestrian crossings to indicate that the pedestrian button has been activated.
- Complete detailed, well-documented phasing and timing plans to ensure that change intervals can accommodate vehicles approaching the intersection. Such plans would ensure that motorists could stop with a reasonable deceleration rate or proceed and clear potentially conflicting traffic safely.
- Perform safety audits as part of regular design and evaluation of high-accident locations.
- Install photo enforcement equipment at high-crash locations. The German approach is to reduce motorists' speed on intersection approaches to minimize the consequences of potential conflicts.
- Enhance intersection pavement markings for bicycle and pedestrian crossings. (Members of the German delegation disagreed about the effectiveness of additional pavement markings. One school of thought says the most effective way to improve nonmotorized safety is to provide protected phasing for pedestrian and bicycle traffic.)
- Develop speed-related (rather than traffic volume-related) warrants for exclusive left-turn lanes and protected phasing requirements.
- Eliminate right turns on red, particularly when pedestrian crossings are present.
- Install pedestrian fences, or staggered crossings, so that pedestrians must turn when crossing a street and face oncoming traffic.

THE NETHERLANDS

The team identified a number of low-cost improvements the Dutch implement to make signalized intersections safer. Many are aimed at improving the safety of pedestrians and bicyclists, since walking and biking are such significant means of travel, particularly in urban areas. Low-cost safety improvements include the following:

- Limit maximum cycle lengths to 90 to 120 seconds to minimize delay and maximize compliance. In the case of actuation and demand control, cycle lengths are substantially shorter. Shorter cycle lengths tend to reduce the level of red-light running of both motorized and nonmotorized traffic.
- Consider the effects of placing signal heads on the near side of the intersection so crossroad drivers cannot anticipate the end of a conflicting phase and pedestrian walkways are kept clear.
- Suggest protected left-turn phasing, which may be helpful when opposing vehicle approach speeds are in excess of 50 kilometers per hour.

- Target traffic law enforcement and automated enforcement actions based on speed and red-light-running violations at high-accident locations. Dutch officials strongly emphasized the importance of a coordinated public awareness program in conjunction with an automated enforcement program.
- Provide countdown clocks at pedestrian and bicycle crossings.
- Consider the use of large signal back plates to increase visibility.
- Provide dynamic, radar-controlled speed signs at high-speed intersections.
- Provide speed tables on intersection approaches to control speed.
- Consider using punitive signalization ("cut-off" signals) to reduce high speed. If a vehicle is detected traveling more than 10 miles per hour over the posted speed limit, the signal changes to red before the vehicle enters the dilemma zone.
- Develop a multidisciplinary (enforcement, citizens, universities, etc.) task force to target high-accident locations and the driver behavior associated with severe intersection accidents.
- To the extent possible, provide consistency in intersection design and operation to minimize driver confusion.

UNITED KINGDOM

The team observed a number of low-cost safety improvements in the United Kingdom:

- Use short cycle lengths to encourage driver and pedestrian compliance with signal controls.
- Provide dilemma zone protection through appropriate detector placement and settings for speeds greater than 35 miles per hour.
- Deploy PUFFIN and TOUCAN technologies where pedestrian and bicycle traffic is present.
- Provide zigzag pavement markings at lane edges approaching pedestrian crossings.
- Use the speed discrimination and extension (SDE) strategy on high-speed approaches to vary green extension and minimize vehicles caught in the dilemma zone.
- Use speed and red-light-running cameras where accidents are related to such violations.
- Use road safety audits at preliminary design, final design, implementation, and follow-up levels.
- Install high-friction surfaces in the dilemma zone at high-speed intersections.

- Install offset crosswalks with staggered crossings to force pedestrians to face oncoming traffic.

chapter eight
RESEARCH ON SIGNALIZED INTERSECTION SAFETY

SWEDEN

MATRIX

Sweden is using real-time traffic models to optimize signal timings in their network. MATRIX is a real-time traffic automation system that uses a generic information and control platform. Traffic information collected from road network sensors feeds into MATRIX so that traffic signal timing plans can be managed in a demand-responsive manner.

The strategy is to compare real-time traffic data with origin/destination and assignment estimation and adjust signal timings to compensate for this variance in traffic demand. This strategy is being implemented using technology developed in Turin, Italy, and the system is still under development.[20]

SuperLHOVRA

Sweden is in the process of improving LHOVRA with SuperLHOVRA. The focus of SuperLHOVRA is heavy vehicles, which safety studies have confirmed are disproportionately involved in right-angle crashes. The system detects heavy vehicles 250 meters and 130 meters from an intersection, measures speed and vehicle length, and adjusts signal timings to reduce the likelihood of red-light running. The system has been installed at four locations, resulting in a 90 percent reduction in heavy truck red-light running. Because this system requires a large number of loop detectors, which are often unreliable, researchers are looking into cheaper, more reliable detection techniques.[21]

GERMANY

The Federal Highway Research Institute (BAST) is conducting or overseeing nearly 300 highway-related research projects. Its budget is about EUR 30 million per year. Fifty percent of the budget is spent on research projects, including about EUR 4 million on safety. BAST identified seven projects that address issues raised by the team:

- Right turn on red with green arrow (1996-1999)
- Tolerance toward traffic detection systems for vehicle-actuated control methods (1997- 1999)
- Standardization and modular design for traffic engineering–based problems at signalized intersections, including evaluation of the use of standardized controllers (1998)
- Examination of the effectiveness of interventions at existing traffic lights (1995-2000)

- Acceleration of public transport under special consideration for cyclists and pedestrians (ongoing)
- Standardization of interfaces for traffic lights (ongoing)
- Assurance of traffic light quality (ongoing)

THE NETHERLANDS

The team identified a number of research efforts focused on signalized intersection safety. Dutch research shows that photo enforcement can effectively encourage user compliance and reduce vehicle speed and red-light-running violations. The Dutch are just beginning a research program with SWOV (a scientific safety board[22]) to determine the effect photo enforcement has had on actual safety performance metrics, such as reducing the number and severity of accidents.[23]

Pedestrian crossing during the red phase is an important concern in the Netherlands. The Dutch have developed several techniques to minimize this behavior. They are testing and researching additional strategies and techniques to further improve nonmotorized motorists' compliance with red signals. Several ongoing research projects involve the use of video detection to identify waiting pedestrians or bicyclists and LED countdown sensors in the pavement.

The use of dynamic, hydraulic speed bumps is being studied in the Netherlands. The height of the speed bump can be varied, depending on the speed of the approaching vehicle.

In addition, CROW is developing guidelines for pedestrians and bicycles on roundabouts.[24] The Transport Research Centre [25] from the Ministry of Transport, Public Works, and Water Management is engaged in a number of research projects:

- Use of rescue services to improve highway safety
- Railway crossings
- Roadway work zones
- Information signs and stations

UNITED KINGDOM

TRL, in partnership with the Department for Transport, the Highways Agency, and other transportation agencies in the United Kingdom, is involved in a number of research projects focusing on signalized intersection safety.

The Department for Transport is working on three research projects in 2002 and 2003:

- Effects of traffic signal strategies on the safety of vulnerable road users
- Safety effects of bus priority schemes
- Assessment of the casualty reduction performance of local highway authorities

The United Kingdom is researching new technologies to improve detection capabilities used in PUFFIN and TOUCAN crossings.

chapter nine
RECOMMENDATIONS AND IMPLEMENTATION PLANS

The team met several times during the scan to discuss observations and findings. Each member provided a list of recommendation ideas. Through group discussion, team members combined these ideas and distilled them into the following list of team recommendations. The team also discussed preliminary implementation ideas, and the team's final implementation strategy will be reflected in the scan technology implementation plan (STIP). In addition, many individual team members observed innovative processes and techniques of personal or professional interest to them, and those implementation ideas are captured in the additional recommendations section.

PRIMARY RECOMMENDATIONS

1. **Develop a model photo enforcement process/program to reduce red-light running and control speed at high-accident signalized intersections.** Ken Kobetsky will serve as the team champion for this recommendation. Goals include developing best practices through which public support for photo enforcement can be enhanced (e.g., making signal timing fair to road users, making cameras readily identifiable, and ensuring that enforcement methods are not used simply to raise money). Implementation strategies include the following:

    - Obtain funds through the STIP program to develop a production report for deployment and implementation.
    - Communicate findings through transportation-related groups such as AASHTO, FHWA, and ITE.
    - Develop programs and strategies targeted toward safety organizations such as the AASHTO Standing Committee on Highway Traffic Safety, Mothers Against Drunk Driving, National Highway Traffic Safety Administration, Insurance Institute for Highway Safety, and Advocates for Highway and Auto Safety.

2. **Enhance dilemma-zone detection at high-speed, isolated, rural intersections using LHOVRA, MOVA, OSCADY, and other identified strategies.** Rudy Umbs will serve as the team champion for this recommendation. Implementation strategies include the following:

    - Collect site-specific information at high-accident locations.
    - Solicit team members for candidate intersections within their jurisdictions.
    - Coordinate with the National Committee on Uniform Traffic Control Devices (NCUTCD) and the AASHTO Subcommittee on Traffic Engineering and Standing Committee on Highway Traffic Safety.
    - Identify candidate locations within five months.

- Obtain full or partial funding through the STIP program.
- Bring European experts to the United States to assist in designing, implementing, and testing new technology.

3. **Develop a series of pilot projects to control speed through intersections using a combination of practices observed in Europe.** Techniques include geometrics (lane width and speed tables), pavement markings, automated photo enforcement, and adjustable message signs. Rick Collins will serve as the team champion for this recommendation. Implementation strategies include the following:

    - Compile best-practice information from Sweden and the Netherlands to develop a best-practices guide.
    - Identify candidate locations for test implementation.
    - Bring European experts to the United States to assist in designing and implementing speed-reduction strategies.
    - Work with FHWA to fund a synthesis project to develop a best-practice plan and identify demonstration projects.

4. **Promote roundabouts as alternatives to signalized intersections as a way to manage the consequences of collisions (severity versus frequency).** Phil Clark will serve as the team champion for this recommendation. Implementation strategies include the following:

    - Work with European experts to develop guidelines for converting signals to roundabouts in the United States.
    - Develop seminars and training courses, including operational and geometric computer simulation (similar to ARCADY) instruction for highway designers.
    - Develop a process and tools, including operational and geometric computer simulation packages, to assist designers and highway agencies in conveying the advantages to the public.

5. **Develop guidelines and identify pilot projects to enhance pedestrian safety at signalized intersections in the United States.** Guidelines will focus on applying strategies such as PUFFIN and TOUCAN crossings, countdown indicators, and audible pedestrian signals. Nazir Lalani will serve as the team champion for this recommendation. Implementation strategies include the following:

    - Coordinate with the NCHRP pedestrian signal project.
    - Develop a toolbox to identify best practices.
    - Work with the AASHTO task force to incorporate some of the geometric design applications observed during the visit.
    - Coordinate with user groups such as the American Disability Association.

- Coordinate with NCUTCD.
- Identify feasible locations to pilot test various strategies.

ADDITIONAL RECOMMENDATIONS

In addition to the primary team recommendations, several team members have identified practices or programs that relate to their specific areas of expertise. The following is a summary of individual recommendations:

Table 2. Additional Recommendations

Category	Recommendations	Implementation Strategy	Team Contact
Signing/marking	Introduce wider pavement markings in the United States.	Introduce these concepts as optional in the markings chapter of the FHWA Manual on Uniform Traffic Control Devices (MUTCD).	Steve Van Winkle, svanwinkle@ci.peoria.il.us
Phasing/operations/ detection	Adopt traffic signal operational policies restricting left turns to protected-only operation on high-speed (45 mph or higher) roads.	Draft proposed text for amendment to MUTCD and submit to NCUTCD for consideration. Present rationale and encourage adoption of such policies by committees of TRB and ITE.	Robert Seyfried, r-seyfried@northwestern.edu
	Test modification of the LHOVRA concept using extension of red clearance interval to accommodate vehicles in the dilemma zone at the expiration of the green interval because of a max out.	Determine whether available hardware and software can provide the desired logic and operation. Identify two test locations for pilot implementation.Report findings at TRB and/or ITE meetings.	Robert Seyfried, r-seyfried@northwestern.edu
	Require a standard yellow interval for all U.S. traffic signals. Additional clearance time needed would be accommodated in all-red interval.		Steve Van Winkle, svanwinkle@ci.peoria.il.us
Pedestrians/bicycles	Use countdown indicators to provide feedback to pedestrians and bicyclists.	Investigate the operation of Dutch signal installations.Pilot test operation at two locations and identify changes in pedestrian and bicyclist behavior and degree of understanding. Draft text for proposed amendments to MUTCD.Report findings to TRB/ITE.	Robert Seyfried, rseyfried@northwestern.edu
	Test a modified PUFFIN pedestrian signal in the United States.		Steve Van Winkle, svanwinkle@ci.peoria.il.us
Other	Incorporate promising strategies into the implementation guides for the AASHTO/ NCHRP Strategic Highway Safety Plan.	Prepare implementation guides for 13 emphasis areas of the Strategic Highway Safety Plan. Promising strategies and examples will be incorporated into multiple guides as appropriate.	Kevin Slack, kslack@ch2m.com

appendix a
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BIOGRAPHIC SKETCHES

Gene K. Fong (co-chair) is the director of Field Services–East for the Federal Highway Administration (FHWA) in Baltimore, Maryland. Fong oversees the Federal-aid Highway Program in 14 eastern States and the Eastern Resource Center offices. His emphasis includes providing strategic leadership in enhancing intermodal and interagency cooperation and coordination to advance FHWA and U.S. Department of Transportation (DOT) initiatives, including support for the

DOT and FHWA goal to continually improve highway safety. In the past, he served as the division administrator in Washington State and assistant division administrator in New York State. Fong has a master's degree from San Jose State University. He is a licensed professional engineer in Michigan and serves on several executive leadership committees for FHWA.

James H. Kopf (co-chair) is the chief engineer and deputy executive director of the Mississippi Department of Transportation (MDOT) in Jackson, Mississippi. He is responsible for developing and executing all technical policies and procedures for MDOT. He also exercises general and technical supervision of MDOT functions. Kopf has been with MDOT for 35 years. He has a bachelor's degree in civil engineering from Mississippi State University. He is a licensed professional engineer and a licensed professional land surveyor in Mississippi. He serves on various national transportation committees, including the American Association of State Highway Officials' Standing Committee on Highways, Study Committee on Quality, Special Committee on TRAC, Standing Committee on Highway Traffic Safety, Subcommittee on Transportation Systems Management, and Transportation Research Committee. He is also a member of the National Society of Professional Engineers and Mississippi Engineering Society.

Philip J. Clark is deputy chief engineer and director of the Design Division for the New York State Department of Transportation in Albany, New York. He is responsible for oversight of transportation design activities statewide, including developing related policies, procedures, and standards. Clark has also served as director of the department's Poughkeepsie regional office, where his responsibilities included oversight of a $200 million annual capital construction program and maintenance and operation of the State transportation system in seven counties north of New York City. He is a licensed professional engineer in New York and has a bachelor's degree in civil engineering from the University of Vermont. Clark serves on the American Association of State Highway and Transportation Officials' Task Force on Geometric Design, which is responsible for preparing "A Policy on Geometric Design of Highways and Streets."

Rick Collins is the director of the Traffic Engineering Section for the Texas Department of Transportation (TxDOT) in Austin, Texas. He is responsible for developing and issuing statewide guidelines, standards, and procedures for traffic engineering features such as signs, traffic signals, and pavement markings. The Traffic Engineering Section is also responsible for the Hazard Elimination Program, a Federal safety construction program. Collins has served with TxDOT for more than 18 years and has been involved in traffic, safety, and design issues. He also has two years of design experience with a private engineering firm in Austin. He has a bachelor's degree in civil engineering from Texas A&M University and a master's degree in engineering from the University of Texas at Austin. He is a licensed professional engineer in Texas and is a member of the American Association of State Highway and Transportation Officials' Highway Subcommittee on Traffic Engineering and the Institute of Transportation Engineers.

Richard A. Cunard is the engineer of traffic and operations for the Transportation Research Board (TRB) in Washington, D.C. He is responsible for the technical activities at TRB related to traffic engineering and control, traffic operations, intelligent transportation systems (ITS), and vehicle-highway automated systems. He has authored numerous technical papers and articles on traffic control, operations, and safety issues. Cunard has served with TRB for more than 13 years and has more than 25 years of experience in traffic engineering and safety for public and private agencies. He has bachelor's and master's degrees in civil engineering from Wayne State University. He is a licensed professional engineer. Cunard is active in several national and international professional associations and societies and serves on international technical program committees in the areas of ITS, traffic control, traffic engineering, and traffic safety.

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Stephen N. Van Winkle is the public works director for the City of Peoria, Illinois, a position he has held since 1982. Among his responsibilities is management of 225 signalized intersections. Motorist and pedestrian safety are his primary goals. In the past, Van Winkle worked for the Illinois Department of Transportation, where he was involved in geometric intersection and roadway design and the application of traffic control devices. He served as the bureau chief of Traffic Engineering and Roadway Planning and Project Programming for one of Illinois' nine highway districts. Van Winkle has a bachelor's degree in civil engineering and a master's degree in highway and traffic engineering from Texas A&M University. He is a fellow of the Institute of Transportation Engineers (ITE) and has served as Illinois Section president, Urban Traffic Engineering Council chair, international director for District 4, and ITE delegation chair on the National Committee of Uniform Traffic Control Devices.

appendix b
AMPLIFYING QUESTIONS

To help clarify the scanning team's areas of interest, members have identified six topics as important categories for discussion. Team members have developed specific questions in each category to help facilitate discussions and provide additional insight into their interests in safety at signalized intersections.

A key goal of our visit is to identify readily implementable intersection-safety solutions and programs for deployment in the United States. Please focus your discussions and efforts on highly promising and implementable intersection-safety countermeasures and solutions. We are particularly interested in how you have identified and overcome implementation barriers and any special implementation needs. Please provide specific examples and documentation.

In addition to the primary topics of interest, outlined in I through VI, the panel has identified a number of general topics that pertain to several or all of the categories:

- The organization of, structure of, and responsibilities for your country's traffic signal operations and intersection safety.
- What are your country's safety priorities for pedestrians, bicyclists, and motorists, relative to providing overall mobility? How do these priorities affect your approach to intersection safety programs?
- How do legal issues or the risk of tort lawsuits influence your approach to intersection safety? To what extent do concerns about possible tort lawsuits create barriers to considering or implementing innovative safety improvements?
- How does your organization fund intersection safety-related activities?
- The panel is interested in both urban and rural signalized intersection safety, particularly safety at high-speed rural signalized intersections.
- Do you have any public educational programs that target intersection safety? If so, please provide examples (flyers, posters, television commercials, etc.). We are interested in programs targeted to all users, including drivers, pedestrians, bicyclists, school children, etc.
- What correlation have you found between the enforcement of intersection-related laws and intersection safety?

As you review the amplifying questions, please consider these general issues and their effect on your agency's approach to signalized intersection safety. Any specific examples (plans, photographs, reports, site visits) that illustrate your safety approach would be appreciated.

I. SELECTION, DESIGN, INSTALLATION, OPERATION, AND MAINTENANCE OF TRAFFIC CONTROL DEVICES AT SIGNALIZED INTERSECTIONS WITH A FOCUS ON THE SAFETY IMPLICATIONS OF EACH OF THESE ELEMENTS.

1. How does your organization use safety measures or safety-based performance indicators to justify the installation of traffic signals or improvements to signalized intersections? On which safety measures are the criteria based?

2. Under what circumstances would you not signalize an intersection? How would you address intersection safety under those circumstances?

3. Under what circumstances would you downgrade intersection control (e.g., replace a signal with stop control) to improve intersection safety?

4. How do signal operation policies and procedures explicitly address intersection safety (e.g., special signal timing requirements, cycle lengths, permissive versus protective left-turn phasing, number of phases, lead versus lag phasing, length of clearance interval, all-red interval, pedestrian phase, dilemma zone protection, right-turn prohibitions on red, pre-green interval, etc.)?

5. Please describe or document any policies, procedures, or special devices (including pavement markings or sensors) employed to address safety issues at signalized intersections with the following:

   - High pedestrian volume
   - Significant bicycle traffic
   - Elderly users (both drivers and pedestrians)
   - Disabled or handicapped users (including the visually impaired)

6. What traffic control devices are used to address safety issues at isolated high-speed intersections (e.g., advanced warning systems, special signal operational schemes, and special hardware)? Please discuss or provide documentation on operational and design criteria for such devices and successes of their application in improving intersection safety.

7. What types of special signal displays (e.g., left/right turn, pedestrian, bicycle, etc.) are used to improve intersection safety?

8. In what manner is safety considered in signal system coordination?

9. To what extent is maintenance considered an intersection safety issue? What is your agency's policy for signal trouble calls? Do you have a proactive bulb replacement program?

10. What training is offered in the selection, design, installation, operation, and maintenance of traffic control devices?

11. What special considerations are given to emergency preemption at signalized intersections?

12. How common are lawsuits involving traffic control devices? What kind of lawsuits?

13. What safety effects (positive or negative) have been noted in using LED signals?

II. INNOVATIVE TRAFFIC CONTROL DEVICES AT SIGNALIZED INTERSECTIONS.

1. What are some examples of innovative traffic control devices employed on or adjacent to the roadway primarily for intersection safety reasons? Examples might include the following:

   - Strobe lights to increase visibility
   - Pedestrian detectors or countdown timers
   - Advance vehicle detection
   - Video surveillance or detection

2. What circumstances have led to the installation of these innovative traffic-control devices?

3. What measurable effects have these devices had on intersection safety? Please provide examples and documentation.

4. What safety measures or procedures are used to determine if traditional traffic control solutions are ineffective and that innovative traffic control is required?

5. How are automated enforcement measures used to enforce red light running? Please describe the technology, enforcement practices, barriers to implementation, and special implementation needs. How effective has automated enforcement been in reducing intersection-related accidents?

6. How is innovative traffic control technology identified, implemented, and measured for effectiveness? What legal and/or administrative issues are encountered?

7. Please describe any innovative traffic control devices, interconnections, or special signal operational treatments used at signalized intersections near at-grade rail crossings.

8. Please describe any innovative traffic control devices used to address transit safety at signalized intersections. This includes both bus and light-rail transit.

III. INNOVATIVE GEOMETRIC DESIGNS FOR SIGNALIZED INTERSECTIONS.

1. Please describe and provide examples of innovative geometric designs developed, deployed, or in the process of being deployed to address safety problems at signalized intersections. Please provide any available supporting data or studies to verify measurable improvements.

2. Please describe any safety criteria or guidelines that address conversion of a signalized intersection to a roundabout. On what measures are such criteria

based? What are the key issues (e.g., pedestrian activity, transit activity, bicycle use, public education/awareness, vehicle design considerations, approach speed, etc.) to be considered when evaluating a roundabout versus a signalized intersection?

3. Please describe safety or other guidelines you follow to convert an at-grade intersection to a grade-separated interchange. Examples of such solutions would be appreciated. What impact do these conversions have on intersection safety?

4. What effects do auxiliary lanes have on signalized intersection safety? Please consider the following:

   - Left-/right-turn deceleration/storage lanes (length/transitions)
   - Double left-/right-turn deceleration/storage lanes
   - Right-turn acceleration lane
   - High occupancy vehicle (HOV) lanes
   - Bicycle lanes

5. What innovative design measures are used to separate pedestrians and bicycles from motorized vehicle traffic at signalized intersections?

6. What safety-based criteria or guidelines related to intersection geometric features are used?

7. Please describe and provide background on how intersection safety and operations directly influence the design process. Please discuss or describe how you choose the design of signalized intersections, addressing the following key decisions:

   - Selection of design vehicle for channelization
   - Determination of design speed
   - Selection of human factor inputs, such as pedestrian walking speed
   - Determination of need and design for left- and right-turn lanes
   - Determination of need and design for raised islands, medians, and other physical channelization
   - Determination of the number of lanes, including through lanes and turning lanes
   - Determination of appropriate lane widths

8. How are traffic-calming measures used to improve traffic safety at signalized intersections or on the approaches to signalized intersections?

9. To what extent are innovative geometric designs used to eliminate or minimize conflicting movements within an intersection? Examples include the following:

- Median U-turns
- Indirect left-turn lanes
- Left-turn acceleration lanes

Please provide examples of their implementation, special implementation needs, and barriers to implementation, particularly in circumstances where safety was an explicit consideration. What impact does the application of these innovative geometric designs have on intersection safety?

IV. PROCESSES AND PROCEDURES FOR PROBLEM IDENTIFICATION, EVALUATION, AND COUNTERMEASURE SELECTION AT SIGNALIZED INTERSECTIONS WITH SAFETY PROBLEMS.

1. What measures are used to identify and prioritize safety problems at signalized intersections? What types of data are collected and how are they used?
2. What primary considerations are used to select the appropriate safety countermeasures at signalized intersections? How are the costs of improvements compared to the benefits? How do you balance safety needs with intersection efficiency?
3. How are safety countermeasures monitored for effectiveness? How is the information compiled and made available for reference by others?
4. Please describe any governmentally (or other) mandated safety goals in your country related to intersections and signalized intersections.
5. What surrogate measures do you use for crash frequency or severity? If possible, please provide documentation and examples.
6. How are law enforcement or other agencies involved in identifying and solving safety problems at signalized intersections?
7. What reference materials/guidelines are provided to staff or local officials to aid them in evaluating their intersections for safety and choosing among appropriate improvements? How is this information disseminated?
8. How do you educate the public on safety issues and driving procedures?

V. LOW-COST SAFETY IMPROVEMENTS FOR SIGNALIZED INTERSECTIONS.

1. What are some specific examples of low-cost intersection safety improvements in operations, geometric design, enforcement, or education? What were the keys to successful implementation?
2. How do you employ left- or right-turn prohibitions as a low-cost means of addressing safety problems? Please provide information on the safety effects of these prohibitions at the intersection and along the path of diverted movements.

3. How do you incorporate law enforcement measures to improve safety at signalized intersections? Are there studies that document the effectiveness of law enforcement measures? We are interested in both conventional and automated enforcement techniques.

VI. RESEARCH PROJECTS FOCUSED ON SAFETY ISSUES AT SIGNALIZED INTERSECTIONS.

1. What ongoing research activities in your country (or elsewhere in Europe) are related to signalized intersection safety? Topics of interest include the following:
   - Surrogate measures for safety
   - Alternative geometric design solutions
   - Operational effects
   - Human factors
   - Elderly drivers
   - Disabled users
   - ITS strategies
   - Safety of pedestrians
   - Safety of bicyclists
   - Collision avoidance systems (in vehicle or road based)
   - Modeling the expected safety effects of design or operational treatments
2. What agencies or organizations sponsor, participate in, or have a strong interest in intersection safety? How do they influence and help carry out your national research agenda?
3. How are research plans and findings disseminated and implemented in your country?

appendix c
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Endnotes

1. Road Accidents, 2001 figures, Ministry of Transport, Public Works, and Water Management, Transport Research Centre (AVV), e-mail: servicedesk@avv.rws.minvewn.nl.

2. For more information, contact Govert Schermers, Ministry of Transport, Public Works, and Water Management. See Appendix C for contact information.

3. For more information about safety timing calculations, contact Joachim Bielefeld, City of Frankfurt. See Appendix C for contact information.

4. For more information about the signal maintenance program and experience with halogen bulbs in Frankfurt, contact Joachim Bielefeld, City of Frankfurt. See Appendix C for contact information.

5. Only the recommendations are available in English. The handbooks are in Dutch. For more information, contact Hillie Talens, CROW. See Appendix C for contact information.

6. For more information see: "Traffic Control in Urban Areas, a Survey Among Road Managers," A.P.M. Wilson, F. Middelham, J.W.M. Vermeul, paper published at the 10th International Conference on Road Transport Information and Control, IEE, London, April 2000, Conference Publication No. 472, or contact Frans Middelham. See Appendix C for contact details.

7. For more information about SCOOT, contact Mike Middleton, Department of Transport. See Appendix C for contact information.

8. For more information about MOVA, contact J. R. Peirce, TRL. See Appendix C for contact information.

9. For additional information about signalizing roundabouts, contact J. R. Peirce, TRL. See Appendix C for contact information.

10. Each letter of this acronym stands for an optimization, or priority, function of the system. The acronym does not translate well into English, but its letters stand for the following: L, generic priority (trucks, buses, queue, platoons); H, priority of the main road (mobility); O, incident reduction (traffic safety); V, variable yellow interval (mobility); R, red-light-running control (traffic safety); and A, minimization of green-yellow-red-green sequences (i.e., rest in red when traffic is not present).

11. A comprehensive report on developing and implementing LHOVRA is available through SNRA, "Signal Control Strategy for Isolated Intersections" (publication 1991:51E). For more information, contact Alf Peterson, SNRA. See Appendix C for contact information.

12. For more information on Stockholm's LED conversion, including conversion plans, technical specifications, warranties, and maintenance, contact Torbjörn Boivie, SNRA, or Lars Söder, City of Stockholm. See Appendix C for contact information.

13. For more information on the use of handheld transponders, contact Mats Fager, City of Stockholm. See AppendixC for contact information.

14. For more information about the public safety messages, contact Jeroen Kempen, 3VO. See Appendix C for contact information.

15. For more information about speed tables, contact Bertus Fortijn, Province Zuid-Holland. See Appendix C for contact information.

16. This has been proposed by Bo Boormans from DTV. See Appendix C for contact information.

17. These studies include the following: (1) A. Hooke, J. Knox, and D. Portas, 1996, “Cost Benefit Analysis of Traffic Lights and Speed Cameras,” Police Research Series Paper 20, Police Research Group, Home Office, London, U.K. (2) D.J. Finch, P. Kompfner, C.R. Lockwood, and G. Maycock, 1994, “Speed, Speed Limits and Accidents,” Project Report 58, Transport Research Laboratory (TRL), Crowthorne, U.K. (3) M.C. Taylor, D.A. Lynam, and A. Baruya, 2000, “The Effects of Drivers’ Speed on the Frequency of Road Accidents,” Report 421, TRL, Crowthorne, U.K.

18. For a copy of the report, contact David Williams, Department of Transport. See Appendix C for contact information.

19. For more information about the MAAP, contact J. R. Peirce, TRL. See Appendix C for contact information.

20. For more information about MATRIX, contact Torbjörn Boivie, SNRA. See Appendix C for contact information.

21. For more information about SuperLHOVRA, contact Alf Peterson, SNRA. See Appendix C for contact information.

22. For more information, see www.swov.nl.

23. For more information about the program, contact Meine van Essen, Openbaar Ministerie. See Appendix C for contact information.

24. For more information, contact Hillie Talens, CROW. See Appendix C for contact information.

25. For more information, contact Frans Middelham, AVV. See Appendix C for contact information.