# CHAPTER 2 LITERATURE REVIEW

## 2.1 Introduction

The literature review in this chapter serves the objectives defined in Section 1.2. Because the first objective of this research is to promote HRGC safety, the safety measurements on HRGCs are reviewed first (Section 2.2). Due to the importance of HRGC safety (Section 2.2.1), usually, the HRGC safety is approached by the railroad side (Section 2.2) and the highway side (Section 2.3). To fulfill another objective of optimizing the traffic signal control, the traffic control strategies near an HRGC should be carefully examined. However, there is no reference found to directly address the highway traffic optimization incorporated with the rail operations. The closest one is the traffic control on a transit priority vehicle. Section 2.4 focuses on this special traffic control application. Additionally, the state-of-the-art Artificial Intelligence (AI) applied to traffic control is reviewed in Section 2.5. Finally, since SOURCAO is evaluated by simulation software, the review is presented in Section 2.6.

## 2.2 Highway Rail Grade Crossing Safety

After the importance of HRGC research is reviewed in Section 2.2.1, the next section (Section 2.2.2) describes the regression model to approximate HRGC accidents. Section 2.2.3 introduces another grade crossing safety model: Signal Detection Theory. Section 2.2.4 presents the worldwide views of grade crossing safety. Section 2.2.5 demonstrates the HST development in the USA. Section 2.2.6 shows the HST safety improvements by different protection measurements. Section 2.2.7 introduces the next generation of HST and Section 2.2.8 briefs Positive Train Control (PTC). Section 2.2.9 shows a PTC demonstration project. Finally, the summary is discussed in Section 2.2.10.

### *2.2.1 The Importance and the Need of Highway Rail Grade Crossing Research*

Promoting HRGC safety is one of the United States' priority transportation goals. The acknowledgment of this goal was triggered by a series of serious accidents. On October 25, 1995, for example, a collision shocked the entire nation. A train hit a school bus in Fox River Grove, Illinois. Seven students died, and twenty students were injured. The National Transportation Safety Board (1996) determined two causes of the collision:

> *the Illinois Department of Transportation to recognize the short queuing area on northbound Algonquin Road and to take corrective action; and the Illinois Department of Transportation to recognize the insufficient time of the green signal indication for vehicles on northbound Algonquin Road before the arrival of a train at the crossing.*

Another example: A freight train struck a school bus at a grade crossing, killed two children and injured four people on March 10, 1998(CNN 1998).

Both accidents were highly preventable. The coordination of highway traffic control and railroad traffic was demonstrated effectively to prevent those accidents (FRA 1998). Due to the important nature of grade crossing safety, the research directions are addressed in *Safety of Highway-Railroad Grade Crossings: Research Needs Workshop* (FRA 1995). The participants explored the research needs to achieve at least a fifty-percent reduction in accidents and fatalities at HRGCs over the next ten years. Five topics are identified from ninety-two research needs:

- Crossing Improvement (Engineering) Program (CIP)
- Data (D)
- Enforcement (E)
- Driver Education (DE)
- Human Factor (HF)

The top twenty out of the ninety-two projects are listed in Table 2-1, which is summarized in Table 2-2. Those two tables could direct the future safety research on HRGCs. The highway traffic signal control ranks as the number one priority in the experts' view, as shown in Table 2-1.

Table 2-1 Identified Research Needs by Priority

| Priority | Title |
|---|---|
| 1/CIP | Highway Traffic Control Engineering: Technology Transfer |
| 2/CIP | Low-Cost Alternatives to Conventional Warning Devices |
| 3/CIP | Proper Warning Rime With Credibility |
| 4/D | Data Requirements for Highway-Rail Grade Crossing Safety |
| 5/HF | Factors Affecting Credibility of Grade Crossing Warning Devices |
| 6/CIP | Four Quadrant Gates System |
| 7/HF | Effective of Low Cost Countermeasures for Passive Crossings |
| 8/HF | Effects of Sight Distance on Driver Behavior |
| 9/E | Photo Enforcement |
| 10/HF | Applicability of Highway Traffic Control Devices at Railroad Crossings |
| 11/CIP | Intelligent Highway Rail Intersection |
| 12/D | Update Crossing Inventory and Includes Sight Distance Data Collection |
| 13/CIP | Highway Median barriers |
| 14/CIP | Advanced Warning Messages |
| 15/DE | Deterring Educational Target Audiences |
| 16/E | Training and Middle Policies |
| 17/HF | Unique Advance Warning Signs for Active & Passive Crossings |
| 18/HF | Causal Analysis of Accidents Involving Grade Crossings |
| 19/CIP | Standard Crossingbuck Applications |
| 20/CIP | Proposed National Warrants for Selection of Warning Devices |

Table 2-2 Summary of Research Needs

| Abbreviation | Name | Number of Projects in Top 20 |
|---|---|---|
| CIP | Crossing Improvement (Engineering) Program | 9 |
| D | Data | 2 |
| E | Enforcement | 2 |
| HF | Human Factor | 6 |
| DE | Driver (Public) Education | 1 |

### *2.2.2 The Corridor Risk Assessment Model and Grade Crossing Risk Predication Model*

In the past, researchers in the Accident Prevention Division, National Volpe National Transportation Systems Center and Arthur D. Little, Inc. focused on the impacts of HRGCs to the safety of corridors (Volpe National Transportation Systems Center 1997). They decomposed the corridor accidents into different accident scenarios and types; HRGC was one of the scenarios under the studies. Factors contributing to the accidents were identified and were used as the reference variables in the regression model.

Those regression models could be established in a linear or an exponential density function. The model, Corridor Risks Assessment Model (CRAM), was based on the assumption that the number of accidents, *N*, in any time interval *t* (year) was a random variable with Poisson probability mass function $p_N$:

$$p_N(n/y,t) = \frac{(yt)n}{n!} e^{-yt} \tag{2-1}$$

Where

$n$ is the number of the accidents;

$p$ is the Poisson probability mass function in a given time interval $t$;

$y$ is the accident occurrence rate (number of accident/year), which can be linear or exponential function.

$$y = f(x) = \sum a_i x_i \tag{2-2}$$

Where

$x_i$ is the reference variable;

$a_i$ is the regression parameter and could be obtained by maximizing the likelihood function (2-1).

Beyond modeling the risk, they also used the above model to assess the accident avoidance with the implementation of some new techniques, for example, PTC. Experts first created a new scenario with PTC, then identified the accidents that are preventable under PTC. Those accidents in the new scenario were excluded from regressions so that two scenarios could be compared. For example, in the New York Empire Corridor Case Study (Mironer 1997), the risk was defined as:

(Accident/Crossing) • (Fatality/Accident)=(Fatality/Crossing)

The accident/crossing was regressed by the reference variables including crossing type, highway traffic, highway type and lanes, main tracks, train movements and train speed. The fatality/accident (severity) was well defined as *train into highway vehicle* and *highway vehicle into train*. Those two categories were decomposed into auto, truck and truck-trailer accidents. Furthermore, accident scenarios of derailment, no derailment and additional train severity were utilized to describe the decomposition. Details of the severity curves for each scenario were presented.

For the highway vehicle, it was assumed that the severity was independent of train speed (constant) if the speed was greater than 112 km/h (70 MPH). The accident data from 1975 to 1995 (Up to 112 km/h or 70 MPH) were used to develop the severity curves. While focused on the train severity, the curves were based on a conservative engineering analysis shown in Figure 2-1.

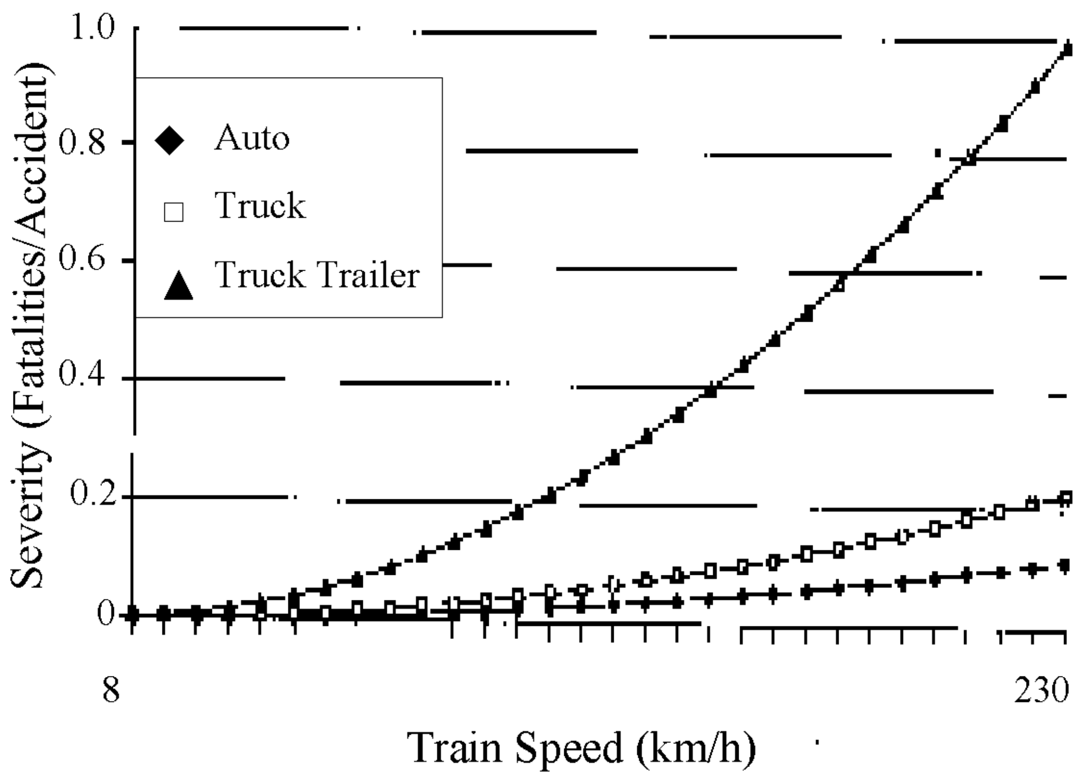


Figure 2-1 Train Speed and Accident Severity

With the improvement of signals, crashworthiness and track quality and with the increase of rail traffic, they assessed the risk on HST from New York to Boston, a section of the Northeast Corridor, where there were 14 HRGCs. Research in the Volpe Research Center concluded a risk reduction from 0.28 to 0.26 train in accidents per million train-miles on the Northeast Corridor, although the risk at an HRGC would be doubled due to HRGC accidents (0.018:0.042). They assumed there were no improvements of HRGC (Arthur D. Little, Inc. 1994 and 1997).

The obvious limitation to that model is the limitation of regression model and the lack of high-speed HRGC accident data. Usually the patterns from regressions based on low speed data do not well represent the higher speed patterns.

### *2.2.3 Signal Detection Theory*

Raslear (1997) suggested a Signal Detection Theory (SDT) to model a driver's behavior at an HRGC. In SDT, the motorist at an HRGC was analogous to the situation of an attempt to detect a signal in a background of noise. The driver made the decisions to stop based on the critical difference between signal and noise. The outcomes of the above decision were listed in Table 2-3.

Table 2-3 The Outcomes of Decision at HRGC

| State of the world | Decision | |
|---|---|---|
| | Yes, Stop | No, don't stop |
| Train is too close | Void stop | Accident |
| Train is not too close, or no train in vicinity | False stop | Correct crossing |

The detectability (2-3) was defined as the perception difference between average of signal and noise, divided by the standard deviations (the deviation of noise and signal was assumed the same). The detectability (2-3) could be replaced by (2-4).

$$d' = \frac{m_s - m_n}{s} = z_{VS} - z_{FS} \qquad (2\text{-}3)$$

Where

$m_s$ is the mean of standard signal;

$m_n$ is the mean of the noise signal;

$s$ is the common standard deviation;

$z_{VS}$ is the score for valid stop in Table 2-3;

$z_{FS}$ is the score for false stop in Table 2-3.

$$d' = \frac{m\left(T_C^* - T_S^*\right)}{s\,\sqrt{\left(T_C^*\right)^2 - \left(T_S^*\right)^2}}$$

(2-4)

Where

$T_C^*$ and $T_S^*$ are the judging time to cross the railroad and to stop before the crossing respectively.

### *2.2.4 Safety of Highway-Railroad Grade Crossings*

Battelle Inc. prepared three volumes of the reports about worldwide HRGC safety (Luedeke 1996) for the FRA under contract to the Volpe National Transportation Center. The reports were like compendiums, in which worldwide HRGC facilities, operation practices, signal controls, warning devices, barrier and various equipment manufactures were collected and compared.

### *2.2.5 High Speed Rail Development*

The corridors shown on the map (Figure 2-2) serve as the illustrative case studies as required by the Intermodal Surface Transportation Efficiency Act of 1991 (FRA 1997). The Act required the US DOT to identify the Commercial Feasibility Study of High Speed Ground Transportation (CFS). Except for the Northeast Corridor, there is at least one HRGC in any CFS corridor. HRGCs greatly challenge the future of HST safety.

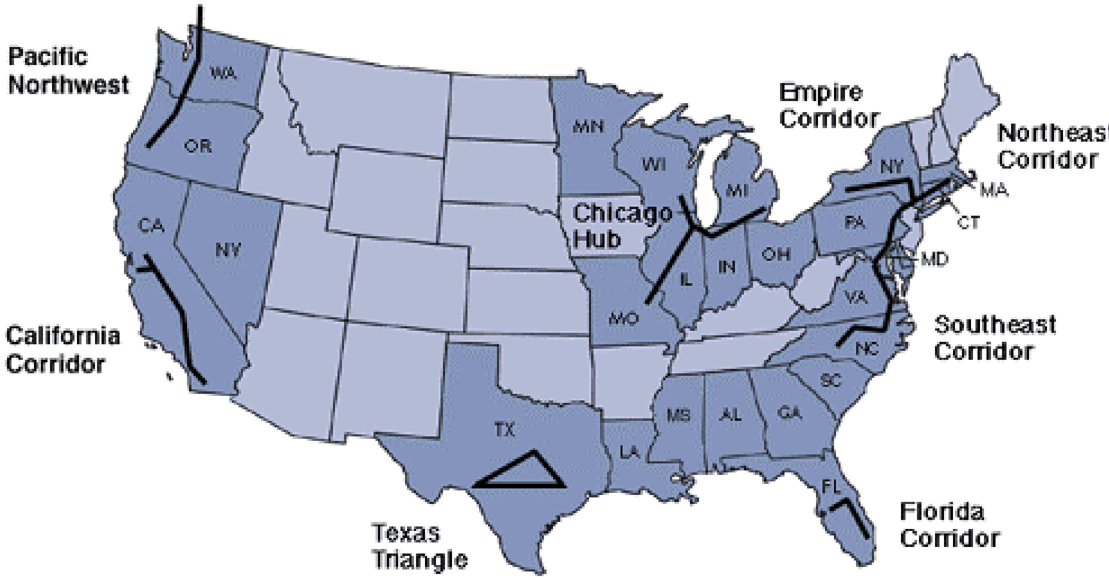


Figure 2-2 High Speed Corridors

- Existed (Speed 110 m/h or 180km/h)
  - Northeast (Boston-New York-Washington DC)
  - Empire (New York-Albany-Buffalo)
- 1010 Corridors
  - California (Bay Area-Los Angles-San Diego)
  - Chicago Hub (Detroit-Chicago, Chicago-St. Louis)
  - Florida (Miami-Orlando-Tampa)
  - Pacific Northwest (Eugene-Portland-Seattle-Vancouver)
  - Southeast (Washington-Richmond-Charlotte)
  - Texas Triangle

### *2.2.6 High Speed Guided Transportation Safety*

In the reports (FRA 1994), safety-related issues associated with passenger trains at a higher speed were reviewed. The examined corridors were supposed to have significant commuter and intercity passenger traffic as well as dense freight operations.

HRGC safety is one of six scenarios. Obstacle detectors and four-quadrant gates were assumed installed for HRGC safety improvement.

They roughly estimated that the obstacle detectors could avoid 80-90% of 22% or 19% of the HRGC accidents. Table 2-4 shows the estimated benefits to install 2-quadrant gates, lights and bells in all gates. From Table 2-4, the installation of four-quadrant gate could reduce 57% of accidents, and the two measurements (obstacle detectors plus 4-quadrant gate) could reduce 65% of HRGC accidents.

Table 2-4 Benefits of Applying Existing Warning Systems to all Crossings

| Existing Warning System | Installation (%) | Accidents (%) | Benefit of Improvement | Accident Distribution After Improvement |
|---|---|---|---|---|
| 2-Quadrant Gates | 37 | 40 | - | 40 |
| Active Warning (lights, bells) | 19 | 28 | 69% reduction | 9 |
| Passive (cross bucks) | 44 | 32 | 83% | 5 |
| Total | 100 | 100 | | 54 |

### *2.2.7 Next Generation High Speed Rail Technology Development*

As indicated in Table 2-5, HRGCs on corridors with a higher speed train (128–200 km/h, or 80-125 mph) might not be eliminated. Those existing HRGCs challenge high-speed safety. The FRA sets the HRGC risk in 2000 as (FRA 1997):

- Train Control System provides location and speed to activate grade crossing warning;
- Onboard warring systems check if the crossing is clear after it is closed.

The identified techniques to mitigate the risk include advanced train control system (e.g. PTC), four-quadrant gate and movable barriers.

Table 2-5 Grade Crossing Signal/Control Requirements from the FRA's Action Plan (Luedeke 1996)

| Train Speed | | Public Grade Crossing | Private Grade Crossing |
|---|---|---|---|
| km/h | Mph | | |
| 128-176 | 80-110 | Use constant warning time equipment. | Deactivate normal activated (close/ lowered) barriers for a period of time sufficient for the user to negotiate grade crossing. |
| 176-200 | 110-125 | Notify approaching trains of warning device or barrier failure or an intruding vehicle in the sufficient time for the train to stop short of grade crossing without resorting to emergency brakes. | Interlock barrier system operations with the train signal/control system; barriers are unlocked (released) by a railroad dispatcher. |
| >200 | >125 | No grade crossing permitted. | |

### *2.2.8 Positive Train Control and Its Demonstration Project*

There are several types of railroad traffic control systems in the US. The railroad traffic control system, automatic block signals (ABS), track warrant and train order (timetable) are operated throughout the US railroads (FRA 1994).

In railroad traffic control system, the dispatcher at the control center controls the signal indication to the movement of train. While in ABS, the signal indication is actuated by a train through the track circuits. In the last one, dispatcher issues mandatory order (track warrants) to establish limits of train movement via radio communication or other means.

The recent advance in the train control system is PTC, which integrates the Global Positioning System (GPS), data communication and computer techniques to ensure the safety movement of the trains. The features of PTC include constantly monitoring the position of the train, dynamic blocking, digital communication and the adaptive braking algorithm. The central objectives of PTC are collision prevention, speed control and protection of roadway work or on-track equipment. Figure 2-3 illustrates an example of this scenario. Table 2-6 summarizes the PTC projects in the US.

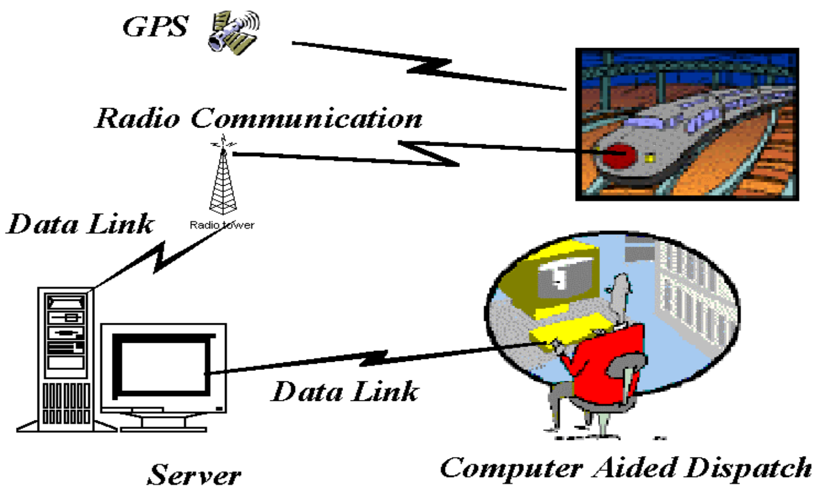


Figure 2-3 PTC Architecture

Table 2-6 A Summary on PTC Projects (Gallamore 1998)

| | Location System | Block Flexibility | Braking Algorithm | Wayside-Train Communications | Architecture |
|---|---|---|---|---|---|
| UP-BNSF PTS/PTC | GPS/DGPS Inertial Multi-sensor Kalman Filter | Dynamic Moving Block | Consist /Track Database-Adaptive | 900 MHz & 160 MHZ | Open |
| Harmon-Amtrak ICCS | GPS/DGPS | Fixed Wayside Dependent | Discrete Tables (Fixed) | 900 MHz | Proprietary |
| IL-CANAC-Arinc | Transponder | Dynamic Moving Block | Consist /Track Database-Adaptive | 900 MHz | Open |

PTC makes HRGCs safer. The train location data can be extended from GPS to HRGCs, actuate the gate and provide highway drivers with the train arrival information through various media like a Variable Message Sign. At the same time, the situation at HRGC is sent back to computer-aided dispatcher in a railroad operation center and/or be directly sent back to the train. PTC automatically generates an appropriate command (for example, to stop the train in case any hazardous situation on an HRGC is detected.) to improve HRGC safety.

### *2.2.9 Amtrak/Michigan ICCS Demonstration Project*

In the traditional train control system, the train and the control center exchange information only when a train passes a fixed point, usually a beacon (e.g. ABS). In ICCS, this updating happens in every 6 seconds. (If the speed of train is 130-180 km/h or 80-110 mph, the distance between two consecutive pulls is 200-300 m.) Afterwards, it provides a near-constant monitoring of the movement of the train (Heggestad 1996).

Before a train arrives in a public HRGC (usually 3 to 5 km), the train initiates a radio contact and waits for the HRGC’s reply. If the locomotive's on-board computer receives the confirmation, it calculates the actuating distance and sends the arrival information to the HRGC. The train would be forced to slow down or to stop if there is a slow/stop control request from the HRGC computer or no reply at all. Therefore, the safety of the HRGC is better secured.

### *2.2.10 Summary*

The literature review finds two models to estimate grade crossing safety: the regression model and the signal detection model. A workshop in directing HRGC safety research identified “Highway Traffic Control Engineering” as the number one priority to improve grade crossing safety. Three volumes of grade crossing compendiums include worldwide HRGC facilities, operation practices, and signal controls, warning devices, barrier and various equipment manufactures. One research indicates that the fatalities of passengers on the train increase parabolically with the speed of the train if a grade crossing collision happens. Special attentions have been paid to review HST related grade crossing safety. First, HST development in USA is summarized. Next, a document that estimates the accident rate by different grade crossing protections is presented. Finally, high-tech solutions to grade crossing safety and the related demonstration projects (PTC) are reviewed.

It is inferred from the literature review in this section that there is no simulation tool to evaluate grade crossing safety. The new generation of train control (e.g. PTC) could provide the necessary information flow and communication link to better coordinate traffic signals with railroad operations.

## 2.3 Highway Traffic Control near Highway Rail Grade Crossing

On the highway side, traffic signals and warning devices are used to incorporate railroad grade crossing operations. After the general requirements of grade crossing safety are introduced (Section 2.3.1), the traffic signals and the warning devices at a grade crossing are described in Section 2.3.2. In Section 2.3.3, the Technical Working Group (TWG)'s recommendations are presented since the group thoroughly examined grade crossing safety and traffic signal preemption practices. Section 2.3.4 introduces ITE's recommendations to address questions arisen by TWG. After that, the most recent and most comprehensive re-examination of warning devices at grade crossings and traffic signals near grade crossings are summarized in Section 2.3.5. Section 2.3.6 illustrates a traffic engineer's view about the current grade crossing safety and traffic signals. Section 2.3.7 explains a new preemption algorithm. Section 2.3.8 summarizes the National Architecture of ITS to HRGC. The review of the US's efforts to combat HRGC safety in terms of ITS applications is briefed in Section 2.3.9. Finally, an ITS application to HRGC is shown in Section 2.3.10.

### *2.3.1 General Requirements of Traffic Control and Warning Time*

At the HRGCs, where the speed of a train is over 32km/h (20 mph), the required minimum constant time of flashing lights is 20 seconds (FHWA 1988 and 1997). Under the GUIDANCE title, the proposed amendments to the manual of Universal Traffic Control Devices (FHWA 1997) state:

> *When roadway-rail intersection with an active traffic control system is located within 60m (200 feet) of an intersection or mid-block location controlled by a traffic signal, the traffic control signal should be provided with preemption in accordance with Section 4D-13. Coordination with the roadway-rail intersection warning system should be considered for traffic control signals located more than 60m (200feet) from the crossing. Factors should include motor vehicle traffic volumes, approach speeds and queue lengths.*

The FRA regulations address required minimum warning time in Title 49 CFR, Part 234.225. Under "Activation of Warning System", it states:

> *A highway/rail grade crossing warning system shall be maintained to activate in accordance with the design of the warning system, but in no event shall it provide less than 20 seconds warning time before the grade crossing is occupied by rail traffic.*

49 CFR Part 234.223 states:

> *Each gate arm shall start its downward motion not less than three seconds after flashing lights begin to operate and shall assume the horizontal position at least five seconds before the arrival of any train at the crossing.*

The American Association of Railroads, in its Recommended Practices: Part 3.3.10, Recommended Instructions for Calculating Approach Warning Times for Railroad Activated Highway Grade Crossing Warning Devices Minimum Warning Time, states:

> *Warning devices shall operate for a minimum of 20 seconds before a train enters the crossing.*

The Federal Highway Administration Railroad/Highway Grade Crossing Handbook states (FHWA 1986, 126):

> *On tracks where trains operate at speeds of 20 mph or higher, the circuit controlling the automatic flashing light signals shall provide for a minimum operation of 20 seconds before the arrival of any train. This 20-second warning time is a MINIMUM.*

### ***2.3.2 Warning Time at HRGCs with Active Traffic Control***

Several papers were published to evaluate the constant warning time together with the highway traffic signals (Bowman and McCarthy 1986, Richards 1990 and 1991, Heathington 1990).

Richards et al at the University of Tennessee conducted the most extensive research about the warning time at active crossings in the late 1980s. They divided the research into several individual tasks:

- Review of relevant literature, including a survey of warning time and practices in foreign countries;
- Assessment of the critical time for large trucks to start up and clear tracks after a full stop;
- Driver behavior at active crossings with regards to warning time;
- Driver expectancies and tolerance levels (human factor laboratory study).

The experimental data in field tests included HRGC clearance time, exposure time and the percentage of drivers who arrived at the crossing without stopping after the warning started. In addition, a description of crossing violation and a delay model was given. In the model, a train was generated according to rail traffic first. A random warning time was assigned to the train. Then, the highway vehicular traffic was allocated from the input traffic volume. The model predicted if the driver would stop or not according to the field experiment data. Delays could be accumulated from those stopped vehicles. Finally, they presented the guideline for waiting time selection.

### *2.3.3 Technical Working Group's Recommendations*

In response to the Fox River crash in October 1995, the Secretary of Transportation formed the Task Force of Highway-Rail Crossing Safety. It is intended to examine factors that might have contributed to the crash and other factors that might have been overlooked while drafting the DOT's action plan. The formation of the Technical Working Group to review the existing standards and guidelines was one of the task force's recommendations (Alroth 1997). The followings are some of the related recommendations from the TWG:

- Twenty Second Minimum Warning Time

The TWG recommends practitioners continue to use the 20-second minimum warning time as a minimum. Additional time is added as determined by American Association of Railroad (AAR)'s Signal Manual, FHWA's research, and site specific studies. The TWG recommends additional study to provide a procedure to determine the optimum safe warning time for the HRGCs. The procedure must take into consideration that excessive time could encourage gate runners.

- Interconnect Signals

The TWG recommends practitioners use guidance found in ITE, *Preemption of Traffic Signals at or Near Railroad Grade Crossings with Active Warning Devices* or other current research findings, when planning and designing preemption systems. The TWG recommends practitioners consider interconnecting existing traffic signals to the HRGCs: when traffic queues have recently backed up to the crossing during congested traffic period; when railroad warning devices and highway traffic controls are added or revised; and when tracks are close to a parallel highway. The TWG recommends that the FHWA examine and evaluate a new Manual on Uniform Traffic Control Devices (MUTCD) traffic signal warning, based on the preemption requirements with the nearby railroad warning devices.

- Types of Preemption

The TWG recommends, in the next revision of *Railroad-Highway Grade Crossing Handbook*, the FHWA provide additional detailed guidance on how to evaluate and design a cost-effective and safe preemption system, based on site conditions. The TWG recommends that the FHWA add general guidance on the types and the design of preemption to MUTCD. The TWG recommends that experimentation and evaluation be conducted to determine the effectiveness of a sign to warn pedestrians of shortened crossing time at locations where simultaneous preemption is used.

### *2.3.4 Preemption of Traffic Signals at or near Railroad Grade Crossings with Active Warning Devices*

A recommended practice of the Institute of Transportation Engineers (ITE 1997) concentrated on three essential issues of the preemption: when to preempt, design elements and operations. The ITE identified that those issues were

> *very complex and must be designed and operated for a specific location, often with the unique condition. With the extremely large number of variables involved, it is difficult, within the professional volunteer membership of this committee to simply quantify time and distance components.*

- When to Preempt:

Highway traffic queues have the potential for extending across nearby rail crossings. Alternatively, the traffic backed up from a nearby downstream railroad grade crossing could interfere with the signalized highway intersections.

- Design Elements:

Interconnecting distance: in order to determine which signals need to be interconnected, an unusual 15-minute peak period flow rate is suggested to do the queue study. When there is no enough space to hold the large number of vehicles, the pre-signal is advocated. The 20-second minimum time for the railroad circuit to activate the warning devices prior to train arrival may not be enough. Engineering study is recommended to determine the minimum time.

- Operation and maintenance

### *2.3.5 Traffic Signal Operations near Highway Rail Grade Crossings*

Sponsored by TRB, the synthesis document (Korve 1999) is the most recent and most comprehensive review of the traffic signal practices and devices near HRGCs. It detailed three parts: grade crossing warning devices, highway traffic signal preemption near HRGCs and the interconnection of warning devices and highway traffic signal to the railroad circuits. Noticeably, the synthesis presented how to calculate the advanced warning time and identifies new concepts to improve both safety and mobility at HRGCs:

- Advanced train detection;
- Pre-signal to control traffic entering grade crossing;
- Further research to develop a consistent set of preemption sequence.

The synthesis further concluded that coordination was one of the most important activities to improve HRGC safety. The survey in the synthesis study indicated the importance of responsible agency corporations and the joint inspections. Additionally, the TWG recommendations (Section 2.3.3) and the ITE's practices (Section 2.3.4) were recommended for practice use.

### *2.3.6 Signal Preemption Problem and Accident on HRGCs*

Hintersteiner (1997) identified two critical issues for the HRGC roadway design: Storage Length and Traffic Signal Preemption Operations. After analyzing the related regulations and the vehicle operations, the preemption problem of the traffic controllers was addressed: for both the NEMA and 170 controllers, the preemption call would not be executed unless the clearance time ended. That is, for example, if there was a pedestrian coming from another direction, the train preemption call would be unable to start immediately until the pedestrian cleared and the other call ended. Due to the above reasons, Hintersteiner pointed out that two HRGC accidents, including the Fox River accident, were the direct result of the above traffic signal conflict.

### *2.3.7 Enhanced Algorithm for Railroad Preemption of Traffic Signals*

The authors (Venglar, Jacobson and Engelbrecht 2000) developed an algorithm shown in Figure 2-4 to replace traditional preemption logic. Simulation software (PedSIM and TexSIM) was executed to evaluate the algorithm on a signal grade crossing intersection and on a signal highway intersection. The objective was to develop a phase plan to smoothly transfer between the preemption phase and other phases in order to avoid the sudden curtailing of some phases (like the pedestrian phase). In the test cases, delay reductions of 1.7 percent and 1.3 percent were achieved.

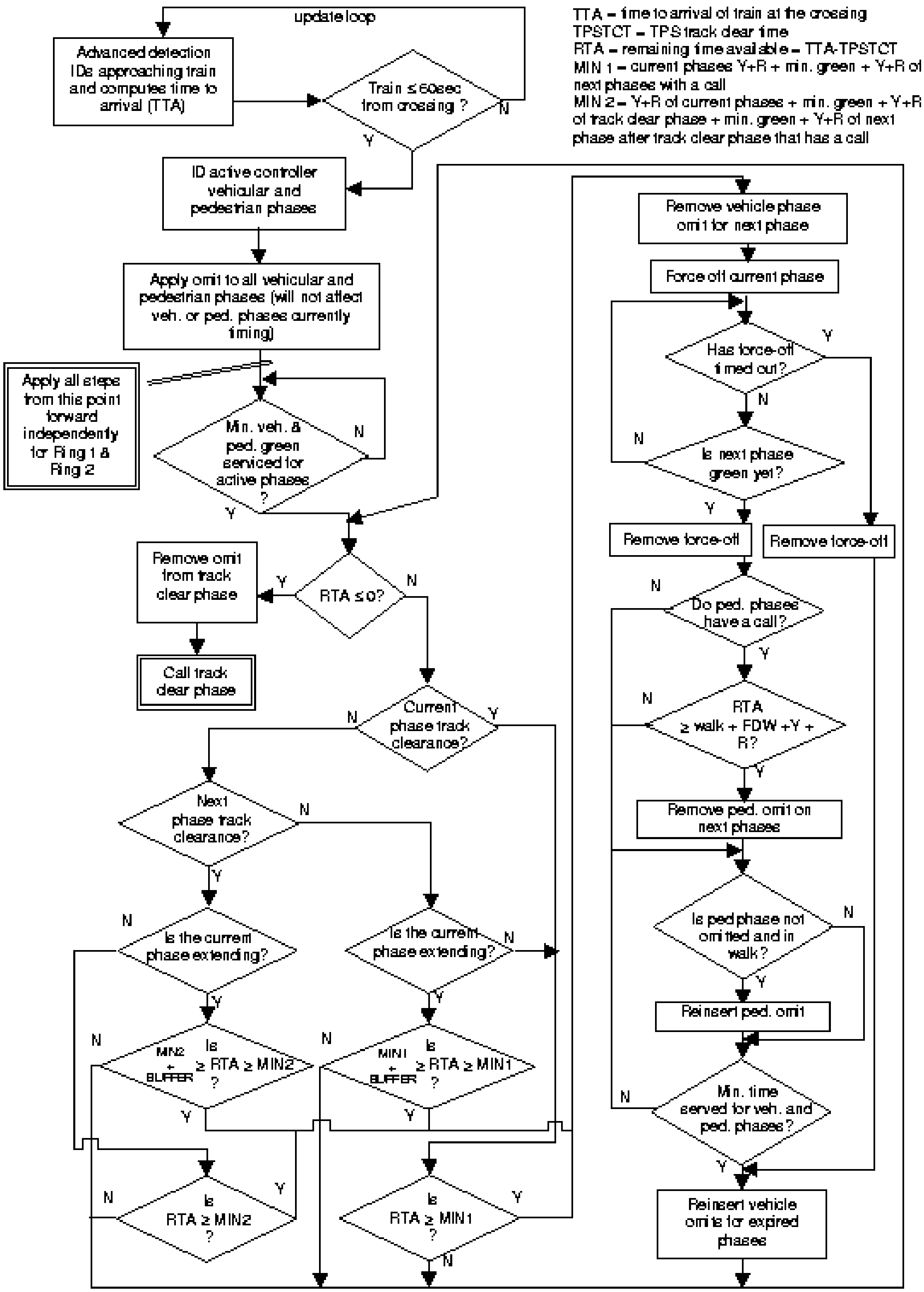


Figure 2-4 TPC Logic

### *2.3.8 The National Architecture for Intelligent Transportation System*

The National Architecture for ITS (NAITS) (*US DOT 1999)* identified the Highway Railroad Intersection (HRI) as one of thirty ITS user services. The physical, logical and communication structures of the HRI are defined in the NAITS. The physical model is shown in Figure 2-5.

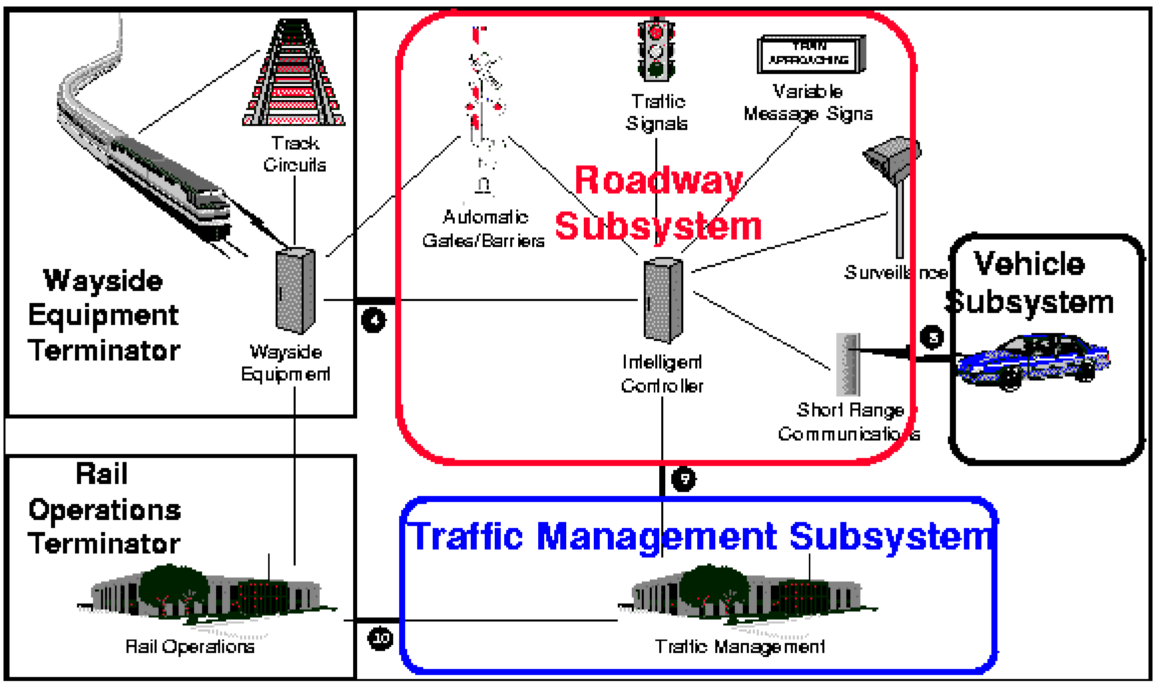


Figure 2-5 NAITS Physical Architecture for HRGC

The logical model defined the functions or process specifications that were required to perform ITS user services. Those functions were depicted using data flow diagram (DFD). A simplified top level diagram is shown in Figure 2-6. The DFDs in the logical architecture could be used as a guide and standard interface to deploy ITS programs. Table 2-7 summarizes market packages, subsystems and equipment packages related to the HRGC safety.

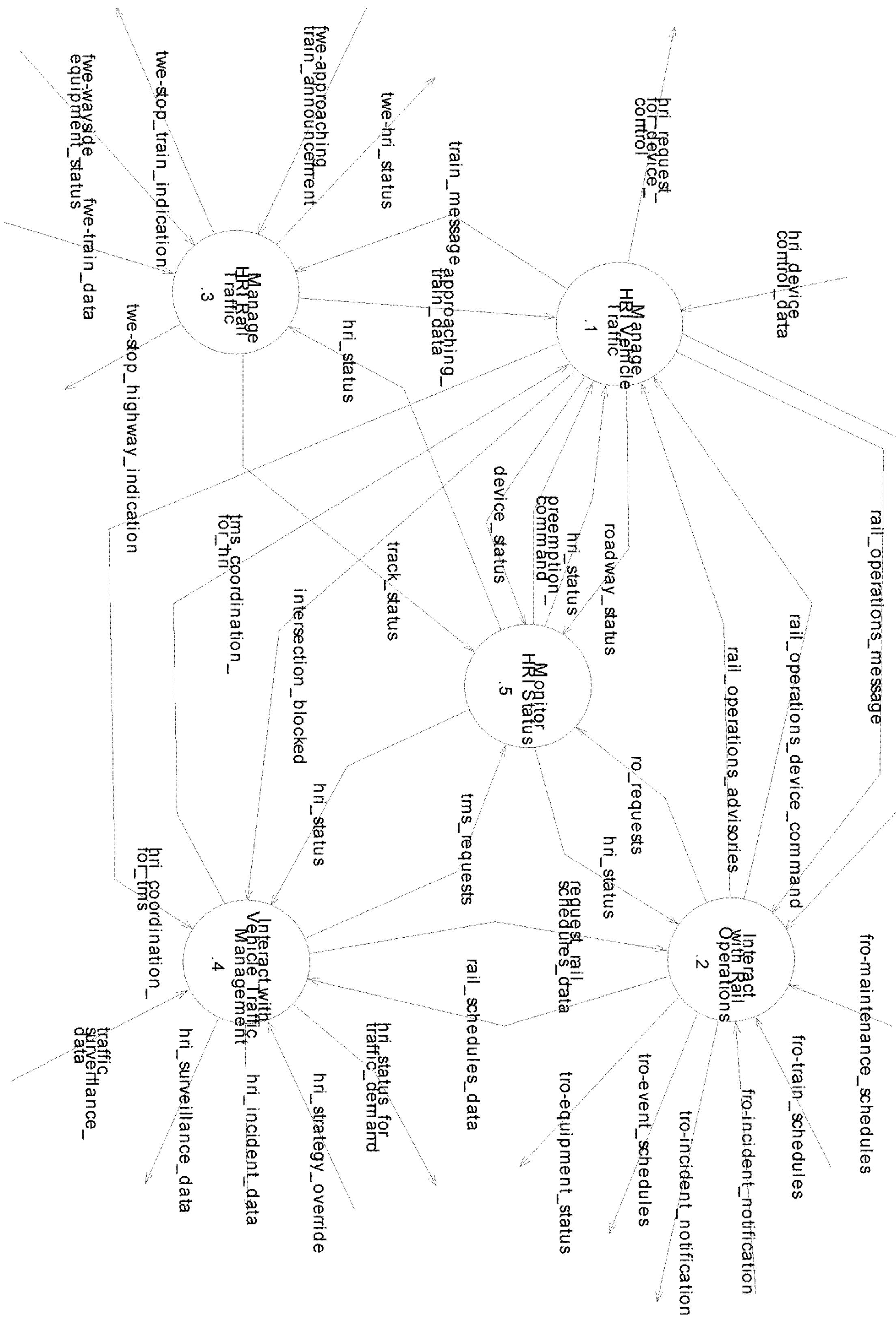


Figure 2-6 NAITS Logical Architecture for HRGC

Table 2-7 The Market Packages and Equipment Packages

| Market Package | Market Package Name | Sub-system | Equipment Package Name |
|---|---|---|---|
| ATIS9 | In Vehicle Signing | TMS | TMC Input to In-Vehicle Signing |
| | | RS | Roadway In-Vehicle Signing |
| | | VS | In-Vehicle Signing |
| ATMS03 | Surface Street Control | TMS | Traffic Maintenance |
| | | TMS | TMC Basic Signal Control |
| | | RS | Roadway Signal Controls |
| ATMS06 | Traffic Information Dissemination | RS | Roadway Traffic Information Dissemination |
| | | TMS | TMS Traffic Information Dissemination |
| ATMS13 | Standard Railroad Grade Crossing | RS | Standard Rail Crossing |
| | | TMS | HRI Traffic Management |
| ATMS14 | Advanced Railroad Grade Crossing | RS | Advanced Rail Crossing |
| | | TMS | HRI Traffic Management |
| ATMS15 | Railroad Operation Coordination | TMS | Rail Operation Coordination |
| AVSS10 | Intersection Collision Avoidance | RS | Roadway Intersection Collision System |
| | | VS | Vehicle Intersection Control |

### *2.3.9 ITS Applications to Railroad Crossing Safety*

Gribbon (1998) summarized some US activities on ITS applications to the HRGC safety. In the summary, the highlighted project includes:

- Los Angles automatic enforcement of gates (A law enforcement project of lowering gate running)
- Vehicle Proximity Alert System (VPAS)

  VPAS is a special device installed on vehicle to catch the broadcasting of the incoming the train arrival information.

- Long Island, New York

  The details are described in Section 2.3.10.
- Minnesota Guidestar

  A similar device like VPAS is being developed.
- Positive Train Separation (PTS)

  Application of GPS to PTS and traffic management are built.
- Gary-Chicago-Milwaukee ITS Priority Corridor

  The in-vehicle warning system developed in the project is similar to the VPAS and those in the Minnesota Guidestar.

### *2.3.10 Long Island Rail Road Intermodal Control System*

Comparing with most HRGCs, the priorities of the vehicles in Long Island project were arranged in following direction: (GRS 1997; Glens 1997; English 1999; Hoveskeland 1999; Twombly 1999; Allen and Alam 1999)

- Highway Emergency Vehicles — HIGH
- Trains (Commuter)
- Highway Vehicles — LOW

That is, if a highway emergency vehicle occupies the grade crossing, the HRGC sent a message to the train via radio communication to stop the train. The acknowledgment indication was provided at the crossing when priority is granted to the priority highway vehicle.

If there was no presence of the highway emergency vehicle in the HRGC, all highway vehicles yielded the right of way to the train. A uniform time warning of 30 seconds was provided to the motorists. When the train stopped at the station near the HRGC, the gate was deactivated and remained open to the highway traffic.

Stalled vehicle detection was another feature of the system. This information was forwarded to the train to adjust the speed of the train or to stop it. With the installation of Intelligent Grade Crossing Control, the gate-up time was increased; therefore, highway travel time was down and safety was improved.

### *2.3.11 Summary*

Almost all of the related documents showed that the interconnection and the coordination between railroad and highway traffic signals are critical to grade crossing safety. Those documents suggested the 20-second advanced warning time and 60m interconnection distance to be calibrated according to local conditions (Sections 2.3.3-2.3.6). The literature review exposed that a computer-based decision-support tool was needed to design the preemption to evaluate the MOEs of preemption and to assist engineers with the preemption design. The ITS application to a grade crossing provided us with necessary information flow and communication link to better coordinate traffic signals with railroad operations.

## 2.4 Traffic Signal Optimal Control with Priority Vehicles

Rather than searching the endless amount of documents on traffic control, the purpose of this section is to review the selected traffic control strategies that may fit HRGC highway traffic. There is no reference found to directly address the traffic signal optimization incorporated with the railroad operations. The closest one is the transit priority vehicle traffic control. The focus of this section is on the special traffic control application.

Traffic signal optimization can be classified as off-line and on-line, actuated and pre-timed for a network, for an arterial and an isolated intersection. Some of the algorithms are tested extensively while others are examined under a simulation environment. Chapter 3 of the Traffic Control Systems Handbook (FHWA 1996) provided a comprehensive description of various traffic control strategies. The first two subsections described general guidance of priority control. Other sections summarized the features of some selected priority control algorithms.

### *2.4.1 The National Architecture for ITS*

A DOT document (1998) presented the first time guidance to apply the NAITS to the traffic control, in which two methods for a county-wide traffic control with transit priority coordination were described.

The first one involved a center-to-center approach. The transit center tracked the location of the priority vehicles and sent back the message to the traffic management center, where traffic signals were controlled. An algorithm took account of the transit information and made a real-time change of the traffic signals in favor of the priority transit vehicle operations.

The second approach was a coordinated approach. Transit vehicles directly communicated to the local traffic controller. The document also described a sample solution to the planning and design of the control system, a cost analysis and the other practical issues in general.

### *2.4.2 Traffic Control System Handbook*

The signal priority system (FHWA 1996) was classified into the following subsections.

#### *2.4.2.1 Conditional signal priority*

If the transit vehicle could effectively use the green phases, following control strategies could be considered:

- Phase/green extension
- Phase earlier start and red truncation
- Red interrupt or special phase
- Phase suppression/skipping
- Compensation
- Window stretching

#### *2.4.2.2 Signal timing plan priority*

Signal timing plans were generated in favor of transit buses. TRANSYT 7F was given as an example to implement the strategy.

### *2.4.3 SCOOT*

Version 3 of SCOOT (Bretherton 1995) was extended to accommodate active priority to buses. The extensions of green phases and recall strategies were embedded in the normal control. In the extension mode, the buses were granted the green phase extension. In the recall mode, the current stage might terminate earlier, and the succeeding stages were called earlier to yield the right of way to buses. To determine whether the recall or extension was permitted, the degree of saturation (DOS) was used. It was recommended that the DOS was set to 1.1 for priority extension and 0.95 for recalls. The simulation and the field test in London showed the effectiveness of the algorithm.

### *2.4.4 The Signal Priority Procedure for Optimization Model*

The traffic signal optimization with transit priority was classified into cyclic and acyclic (Conrad 1998, Yagar and Han 1995). For example, cycle length and its split algorithms were embedded into SCOOT and SCAT models.

The acyclic algorithms usually discarded the traditional concepts like cycle length, split and offset. A phase plan was a sequence of the switch points, representing the start of a new phase plan. The objective of minimizing the overall delays was based on continuos traffic conditions updated in a time horizon about two-minute long. Usually, only the first 3-5 seconds were implemented, and the rest was updated according to the traffic condition. Some acyclic examples were Signal Priority Procedure for Optimization Model (SPPORT), UTOPIA and OPAC.

The SPPORT optimizer is shown in Figure 2-7. It was designed to supply effective transit priority while still considering the other traffic. A rule-based optimization process generated a set of candidate signal timing plans at first. Different priority traffic was used to form a genetic list of rules. By applying the stochastic decision-making process, the phase plans were produced to accommodate those priority requests. After that, a user-defined objective function (by combination of the traffic delay, stops and travel time) was optimized through the generated plans.

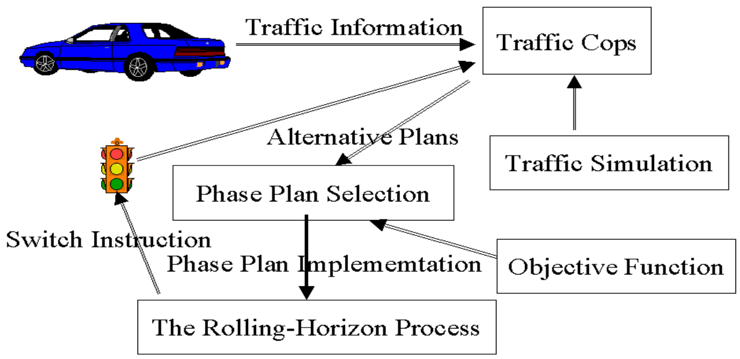


Figure 2-7 The SPPORT Optimizer

The model employed its own discrete-event-based microscopic traffic simulator to forecast the near term traffic. The difficulty of applying this model to HRGC is that, in the latter case, the time horizon is much longer.

### *2.4.5 Adaptive Signal Control with Bus-Preemption*

Chang, Vasudevan and Su (1996) discussed adding the bus-preemption factor to the isolated adaptive signal control by the cyclic approach. They calculated a Performance Index (PI), which was the combination of passenger delay, vehicle delay and schedule delays in all competing phases. The control logic is given below:

Step 1:
At time step k and phase I, compute the minimum and maximum green time;

Step 2:
Check the minimum and maximum green time:

Condition 1

If the green time is less than minimum green $G^i_{min}$, extend green. Update elapsed great time $U^i(k)$;

Condition 2

If the green time $U^i(k)$ is greater than maximum green $G^i_{max}$, green is terminated. Update $U^i(k)$ and $G^i_{min}$;

Condition 3

If neither 1 nor 2, continue step 3;

Step 3:

If no bus is present, $P^i_{lj}(k)=0$. Otherwise:

Step 4:

Compute *PI;*

Step 5:

If $PI>=0$, extend current green by another time step *T*; otherwise, the optimal decision is not favorable to the intersection and a switchover decision is taken.

They used NETSIM output data to calculate a sample. The results showed that, with the preemption, the total passenger delay defined was less than that without the preemption.

### *2.4.6 PRIMAVERA Project in England*

Priority Management for Vehicle Efficiency Environment and Road Safety (PRIMAVERA) on Arterial was a part of Driver II project in Europe. PRIMAVERA's main objectives were defined as (Montgomery and Biora 1994, 1995):

- Review state-of-the-art ATT methods for queue management, public transport priority and traffic calming on urban arterial;
- Develop integrated strategies using these methods and test them by simulation and field trials.

The literature review showed three strategies for public transport priority: priority lanes, selective detection of priority vehicles, and modification of existing signal control and gating techniques with priority for public transport. Most of these strategies had been applied as part of motorway access control, but there were a few references for the use on urban arterial.

In the PRIMAVERA, the existing real time systems SCOOT and SPOT were improved so that they could implement the new algorithms. Those models of the network were also improved to represent reality more accurately.

The public priority system is shown in Figure 2-8. When approaching the intersection, buses installed with the TIRIS transponders were identified by the reader. The time for the buses to reach the stop line was predicted and appropriate weights were adjusted. A set of policy was used by the SCOOT or SPOT optimizers in order to generate signal timing phase in favor of buses:

- To avoid an early termination of the stage which benefits the buses;
- To extend the stage which benefits the buses;
- To recall the early stage which benefits the buses.

Each of the above actions was assigned different weights at each optimization decision (which takes place 5 seconds before a phase change was due) to the merit values associated with the three courses of action. These actions were ADVANCE (bring the stage change forward by 4 seconds), STAY (leave the stage change where it is) or RETARD (put back the stage change by 4 seconds).

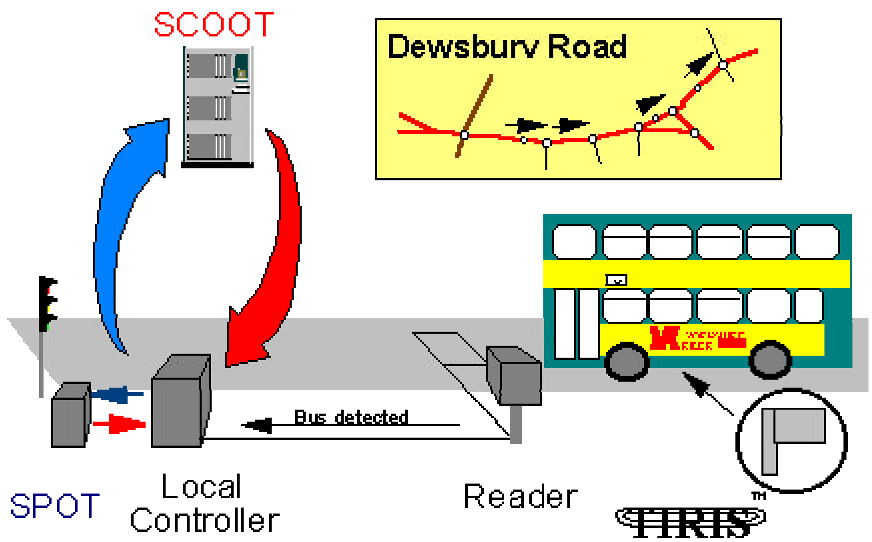


Figure 2-8 PRIMAVERA Public Transportation System Architecture

### *2.4.7 An Intelligent Bus Priority Concept*

Balke, Dodek and Urbanic (2000) proposed a method whose objectives were to provide priority without disrupting progression or significantly altering the normal sequencing and duration of the non-coordinated phases. Priority was given to those buses that were in need of priority, based on some user-defined criteria. The system architecture had four modules: (i) Arrival time prediction module, (ii) Priority Assessment Module, (iii) Strategy Selection Module, and (iv) Strategy Implementation Module. The experiments showed that there was a minimal increase to the overall system delay as long as the volume to capacity ratio was below 0.95. Priority was granted as long as the minimum green and clearance time constraints were satisfied, and none of the phases was skipped.

### *2.4.8 Dynamic Allocation of Right-of-Way for Transit Vehicles in Urban Networks*

Duerr (2000) proposed **D**ynamic **A**llocation of **R**ight-of-Way for Transit **V**ehicles **i**n Urban **N**etworks (DARVIN) for a bus priority control system. The objective is to improve bus progression in mixed traffic while optimizing overall performance of the network: travel time reduction for transit vehicles, maximum schedule adherence, and minimum disruption to general traffic. A genetic algorithm approach was used to optimize the signals by minimizing a weighted delays and stops. Experiments showed that DARVIN significantly reduced the overall passenger delays.

## 2.5 The Application of Artificial Intelligence to Traffic Control

In this section, the author searched the state-of-the-art methodologies for AI applications to traffic signal control. It is found that there is no direct application of the AI domain knowledge to traffic signal control near grade crossings. This survey serves as a tool to formulate SOURCAO.

The literature review interestingly finds that two special applications of artificial intelligence, Neural Network and Genetic Algorithm (GA), are popular. They are discussed in the following two subsections.

### *2.5.1 Neural Network*

#### *2.5.1.1 Neural Network Approach to Adaptive Traffic Control*

Spall, Chin and Smith (Spall 1996, Chin 1998 and Smith 1996) presented papers in the proceedings of several conferences. They employed a "simultaneous perturbation stochastic approximation" (SPSA) method to optimize and train the traffic signal simultaneously.

They tested the methodology in two field studies: one located in Manhattan, New York city, and the other in Montgomery, Maryland. The first test demonstrated that the fixed control had a 4.6% waiting time increase while the latter had an average of 7% loop counter increase with a 90% confidence bound equal to ±2.5%.

The SPSA worked like this:

1. Give the initial weight;
2. Make a slight change to the weights, record the value of loss function in a certain period of time (e.g. several hours);
3. Repeat step 2 and the gradient change can be concluded;
4. Update the weights using their own gradient formation.

#### *2.5.1.2 Development of Self-Organization Traffic Control System Using Neural Network.*

Nakatsji and Kaku (1991) presented an approach to the optimal split problem of traffic signal control in two steps: the first step was to use the multilayer neural network to represent the relationship between the traffic delays and the splits of cycle. The weights were trained through back propagation in the first stage and assumed unchanged in the second stage. In the optimization stage (the second stage), there were two objectives: one was the square summation of the queue length, and the other was the performance index defined by TRANSYT. A stepwise method was applied to solve the optimal splits.

#### *2.5.1.3 Neural Signal Control System*

Hua and Faghri (1995) implemented a Kohonen network to represent the traffic signal splits under an isolated intersection. The experiment showed the algorithm was superior to the optimization mechanism in SOAP.

### ***2.5.2 Genetic Algorithm***

Noticeably, GA is successfully applied in priority signal optimization (Duerr 2000), as discussed in Section 2.4.8, and Duerr's review is not discussed in this section.

#### *2.5.2.1 Using Genetic Programming to Learn Cooperative Control Law for Networks of Traffic Signals*

Montana (1996) of BBN Systems and Technologies completed a project for the FHWA. In the project, genetic programming, a variation of a genetic algorithm, was developed to optimize cycle times, phase splits and offsets for the fixed signal control on four intersections. The GA algorithm took input from TRAF/NETSIM (an earlier generation of CORSIM), and the preliminary results were encouraging.

#### *2.5.2.2 Enhanced Genetic Algorithm for Signal Timing Optimization of Oversaturated Intersection*

The GA (Park 2000) was applied to minimize the delay function with the penalty function and maximize the throughput. In the algorithm described before, CORSIM is employed as an unbiased evaluator. The hypothesis testing indicated that GA-based strategies with average delay minimization produced a superior signal-timing plan, compared to TRANSYT-7F.

*2.5.2.3 Signal Timing Determination Using Genetic Algorithms*

Foy, Benekohal and Goldberg (1992) implemented a GA to search for an optimal solution of signal timing with the least average auto delay, which was computed from HCM.

*2.5.2.4 Evaluation of Dynamic Signal Coordination and Queue Management Strategies for Oversaturated Arterial*

Abu-Lebdeh and Benekohal (1998) defined a queue formulation to apply the GA to solve signal coordination. They recommended the algorithm to be evaluated through microscopic simulation.

### *2.5.3 Other AI Applications*

A few applications of rule-based inference to priority signal control are described in Sections 2.4.4 (Conrad 1998, Yagar and Han 1995) and 2.4.7 (Balke et al 2000). Those two papers are not discussed in this section.

*2.5.3.1 Artificial Intelligence Application to Traffic*

The book (Eds. Bielli, Ambrosino and Boero 1994) presented the current state and the future perspective of the AI approach, the application of knowledge-based systems (KBS) to traffic control, traffic management and in-vehicle intelligence.

A review of the AI applications to traffic control (Kriby and Parker 1994) revealed 127 references, including congestion control, incident detection and traffic signal design. The traffic signal design under development covered aspects of selection of alternative left turn signal phases, sequences and stages, choice between alliterative signal timing strategies for adaptive control and when to bring in remedial plans.

Ambrosino, Bielli and Boero presented an Intelligent Urban Traffic Control System (IUTCS) prototype for the DRIVE project. The knowledge representation included objective-oriented, rule-oriented and constraint-based ones. The objective-oriented one supported network structure, traffic-state and control-state representations. In traffic control, rules were provided for signal plan selections. The constraint-based knowledge was used in data analysis and in the traffic-control. The inference mechanism operated on a local level, a network level and a net hierarchy level (e.g. different zones). IUTCS had been tested in laboratory, and an on-site test was planned.

CLAIRE was another AI application in the DRIVE project, which was presented by Scemama in his paper *CLAIRE: A Content-Free AI Based Supervisor for Traffic Control*. CLAIRE was a real-time rule-based system for recognizing and managing congestion in a traffic network. An assessment of CLAIRE was presented by Dougherty, IBBEtson, Birby and Mongomery in the same book.

#### *2.5.3.2 Knowledge-Based System for Adaptive Traffic Signal Control*

Elahi, Radwan and Goul (1992) presented an expert system prototype: Signal Control at Isolated Intersection (SCII). The knowledge base was designed as “adaptive.” The knowledge base processed the historical traffic volume data by movement type on signal cycle. The effectiveness of past cycles was adapted to the new environment. The inference engine was based on LISP. The test demonstrated delay reduction on one data set by applying microscopic simulation software: TEXAS.

*2.5.3.3 Generically Adaptive Signal Control Algorithm Prototype*

Owens and Stallard introduced a rule-based approach to adaptive control. The strategy, Generically Adaptive Signal Control Algorithm Prototype (GASCAP), was centered about a sophisticated queue estimation algorithm, a set of logical rules determining the signal state for uncongested conditions, and an algorithm computing a fixed timing plan for congested conditions. Simulation results indicated that GASCAP could effectively reduce the delay and increase the throughput for a variety of network geometry and traffic conditions.

## 2.6 Traffic Simulation

The SOURCAO is evaluated in a simulated environment. It is desirable to know how the traffic simulations themselves are evaluated. Currently, a set of available software in the US is:

- NETSIM/FRESIM series: TSIS/CORSIM by the FHWA, WATSIM by KLD Associates and SimTraffic by Trafficware Corp.
- INTEGRATION by Dr. Michael Van Aerde
- PARAMICS by Quanstone, Scotland
- VISSIM by PTV Transworld AG, Germany

### *2.6.1 Assessment of Traffic Simulation Models*

Skabardonis (1999) prepared a report for the Washington State Department of Transportation. The criteria to evaluate the simulations were listed as follows:

- Model Capabilities/Features
- Modeling of Traffic Flow
- Input Data Requirements
- Output Options
- Computational Aspects
- Cost

The author recommended that, for arterial operations, CORSIM appeared to be the leading model for most scenarios involving intersection design, signal coordination schemes, and transit modeling along exclusive lanes or in mixed traffic. VISSIM was particularly useful in analyzing signal transit priority strategies, intersection layout and control (signals, stop signs and roundabouts), and effects of roadway geometry and access control.

### *2.6.2 A Comparison of the VISSIM and CORSIM Traffic Simulation Models on a Congested Network*

Loren Bloomberg and Jim Dale made the comparison through a specific engineering project. They made 10 runs and compared the results including travel time sensitivity analysis, *t*-test for travel time differences and throughput. The author suggested applying both models for the same project because of the similarity in internal modeling and program structure. They noticed that the absolute value of travel time was quite different, though it was inconclusive which model generated more reasonable travel time.

## 2.7 Summary

The literature review finds two models to estimate grade crossing safety: the regression model and the signal detection model. It is inferred from the literature review in this chapter that there does not exist microscopic simulation tool to evaluate grade crossing safety and the impacts of the new generation of train control systems (e.g. PTC) to grade crossing safety.

The experts, in a workshop in directing HRGC safety research, identified "Highway Traffic Control Engineering" as the number one priority. Almost all of the reviewed papers on highway traffic preemption showed that the interconnection and the coordination between railroad and highway traffic signals are vital to grade crossing safety. The advanced warning time and interconnection distance are suggested to be calibrated according to local conditions in the reviewed documents. The review exposes that a computer-based decision-support tool is needed to design the preemption, to evaluate the MOEs of preemption and to assist the preemption design. The application of AI to traffic signal control is concentrated on neural network and genetic algorithm without further detailed study.

Because of the HST development in the US, the fatalities of passengers on the train are found to parabolically increase with speed increase of the train. High-tech solutions to grade crossing safety are suggested and tested in the related demonstration projects (e.g. PTC). Although HST further challenged the current grade crossing safety, the new generation of train control (e.g. PTC) and ITS applications to grade crossing provide the necessary information flow and communication link to better coordinate traffic signals with railroad operations. The literature review finds no direct research on optimizing highway traffic signals incorporated with grade crossing information.

CORSIM and VISSIM are considered the most able traffic software and the leading model of representing real world traffic. Due to the cost and performance consideration, CORSIM is chosen as the simulation software to evaluate SOURCAO.