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1. INTRODUCTION

1.1 Background

The initial development of the National Intelligent Transportation System (ITS) Architecture was completed in July 1996. Leading up to this milestone was an intensive 33 month effort consisting of two phases and involving broad participation by public sector, industry, and academic stakeholders. The end-result of this effort was a single national ITS architecture which reflects this broad consensus input. This baseline architecture provides a structure through which the 29 ITS user services identified in the National Program Plan can be delivered throughout the United States. The architecture and analyses presented in the separate Communications Document deliverable were developed to support the original 29 user services.

More recently, a 30th user service has been developed that identifies the needs for Highway-Rail Intersections (HRI) under the guidance of the Federal Railroad Administration (FRA) and the US DOT ITS Joint Program Office (JPO). The JPO tasked the two architecture teams, headed by Rockwell International and Lockheed Martin, to modify the national architecture to include this new user service. This addendum provides a review and focused presentation of the elements of the communications architecture and communications analyses which apply to this additional user service.

1.2 Relationship to other Documents

This Communications Document addendum is one of a series of reports documenting the National ITS Architecture. In general, sufficient background information has been provided within this addendum so that it may be used without reference to the other reports. The interested reader may refer to these additional reports for more comprehensive treatment of the elements of the overall national architecture documentation that provide a context for this report. Several of the reports that are most pertinent to the subject matter of this document are briefly described in the following paragraphs.

The *Logical Architecture* provides a functional view of all user services, including the HRI user service. It defines the functions that support each user service and all of the information flows that connect these functions. The information flows are source requirements for the communications architecture that is defined in this addendum. The Logical Architecture consists of three volumes that include diagrams that identify all functions and relationships, process specifications that define the functional requirements in detail, and a data dictionary that fully defines all of the information flows.

The *Physical Architecture* collects related logical architecture functions together into subsystems. It defines a set of architecture flows that show all of the data that passes between the subsystems and the special characteristics and constraints associated with each interface. This definition of subsystem connectivity is the basis for the communications architecture.

The *Communications Document* presents a thorough analysis of the communications elements of the National Architecture that support 29 user services. Beginning with the communications requirements associated with the architecture flows, data loading analysis, communications technology surveys, and a detailed simulation of one candidate wireless communications technology is provided. This addendum extends the communications document by focusing on the impacts to the communication architecture and communication analysis associated with the HRI user service.

1.3 Organization of this Addendum

This addendum consists of five major sections that define the communications architecture that supports the HRI user service and provides selected communications analyses related to this user service.

Following this introduction, section 2 provides a focused presentation of the elements of the physical architecture that support the HRI user service. This is the one place in the National Architecture documentation that provides such a focused treatment of the architecture definition for HRI with some supporting information regarding its derivation.

Section 3 maps the HRI architecture definition to an updated communications architecture. All architecture flows which were defined to support HRI are mapped to this updated communications architecture. Only the elements of the communications architecture that were updated to support HRI are presented. Refer to the Communications Document for a comprehensive treatment of the entire Communications Architecture.

Section 4 provides a qualitative assessment of the data loading requirements imposed by the HRI user service. This assessment is based on the information flows defined in the logical architecture coupled with anevaluatory design and implementation scenario that is consistent with those used as a basis for the companion Cost Analysis Addendum that is published under separate cover.

Section 5 provides a brief review of some of the communications technologies that will support HRI. This section is an excerpt of a more comprehensive technology assessment section that is included in the Communications Document.

2. HRI PHYSICAL ARCHITECTURE

The National ITS Architecture is composed of separate Transportation Layer and Communication Layer domains. The Transportation Layer elements involved in the HRI user service include field equipment at the highway-rail intersection, the management center equipment that operates and monitors the field equipment, and the trains and highway vehicles that are managed by the HRI User Service. The architectural requirements for these transportation elements are documented under separate cover in the Physical Architecture document. The communications layer identifies the general framework for interconnecting the Transportation Layer elements and also includes supporting communications technology and data loading implications for the user services. The communication layer elements for the HRI user service is the focus for this addendum. In order to provide context for the communications discussion, an overview of the overall architecture for HRI is provided in this section.

Figure 1 is a high-level depiction of the transportation elements required for the HRI user service and their general connectivity. It shows equipment and interfaces traditionally operated by the railroads as well as equipment under the jurisdiction of state and local transportation agencies and key interfaces between highway and railroad assets that may be implemented to support HRI improvements. Table 1 expands on the figure by providing a brief overview of each of the interconnections.

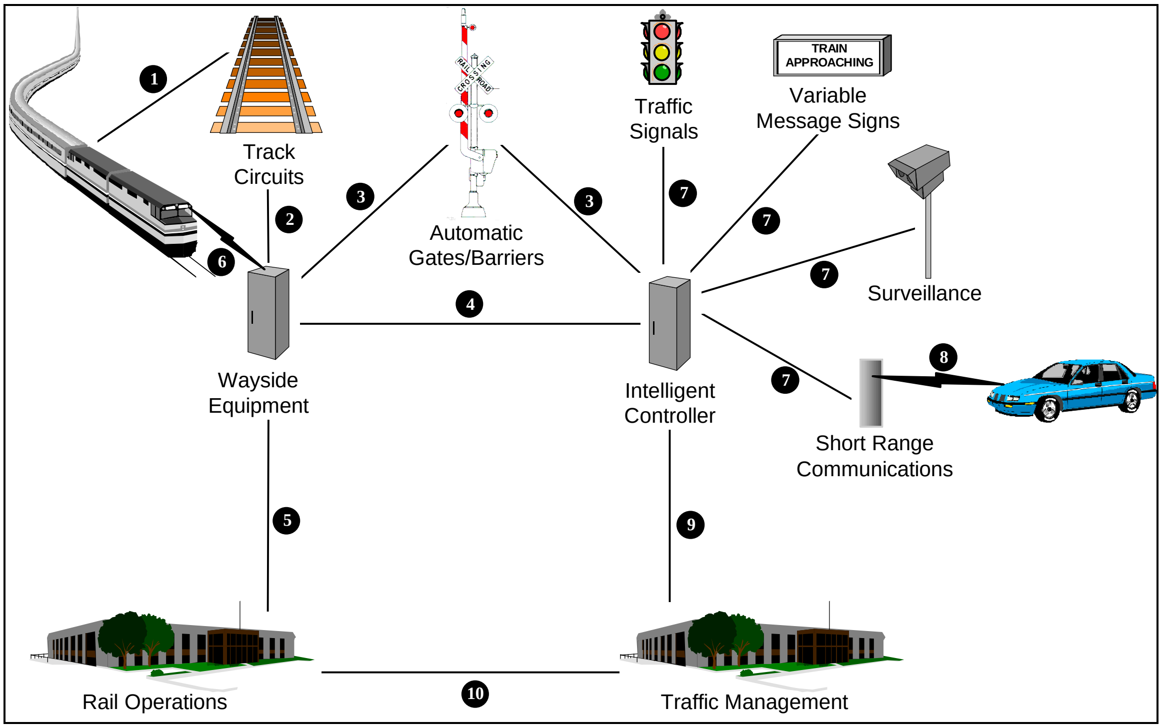

Figure 1: HRI Elements and Interconnects

Table 1: HRI Interconnects Overview

	Type	Purpose	Variations
1	Physical	Detect train presence, speed, acceleration	Track circuits are the most common mechanism; other technologies may also be applied.
2	Wireline Discrete	Fail-safe discrete representation of train activity at the intersection	Characteristics will be a function of the surveillance technology and wayside equipment requirements.
3	Wireline Discrete	Fail-safe discrete activation of signals/gates at the grade crossing	Railroad grade crossing devices are 12 volt systems. Highway-highway intersection devices are 110 volt systems.
4	Wireline Discrete or Data	Communicate train presence from wayside equipment that is aware of train activity to roadside equipment that manages highway traffic. The purpose today is to allow control strategies at adjacent highway-highway intersections to adapt to HRI closures. The same interface could be used to notify roadside equipment to activate signals/gates and other traffic management devices at the grade crossing in other implementations.	Several variations may be implemented in different scenarios andtimeframes. Near term implementations pass a discrete signal indicating that the grade crossing is closed ("Interconnect") or warning that the crossing will be closed in a short time ("Preemption"). This basic connectivity may be expanded to a data interface providing more detailed information on expected closure times, duration, and train activity.

	Type	Purpose	Variations
5	Wireline Data	Monitoring and control of wayside equipment. Represents the railroads wireline network providing connectivity to wireless base stations, switches, signals, gates and other networked railroad assets.	Network characteristics will be different for different railroads.
6	Wireless Data	Communications with the train is an alternative method for monitoring train position/speed and deriving HRI closure requirements. Communications to the train enables early warning of potential intersection hazards.	Communications from the train back to a control center (Rail Operations) prior to HRI activation vs. Short range communications to wayside equipment which locally determines HRI closure requirements.
7	Wireline Discrete or Data	Local monitoring and control of traffic surveillance and traffic control devices enabling monitoring and management of highway traffic in the vicinity of HRIs.	Intelligent devices require data interfaces to support programming and status monitoring. Basic signals require only discrete voltage inputs.
8	Wireless Data	Direct provision of HRI status data to in-vehicle devices. Data may be provided as informational displays to the driver, used to provide safety warnings to the driver, or used as an input to vehicle control systems.	Content and timing requirements for the interface vary with intended in-vehicle application.
9	Wireline Data	Central monitoring and control of highway traffic surveillance and control devices.	Many different protocols currently implemented. Potentially significant future migration to NTCIP as a standard for this interface.
10	Wireline Data	Sharing of HRI status and closure schedules between highway management and rail management systems	Shared data may be limited to as-needed communication of detected equipment failures affecting HRI communications or extended to more regular communication of real-time information enabling HRI closure forecasts.

Figure 2 identifies the mapping between the HRI elements and the Physical Architecture subsystems and interconnects. As can be seen, the physical architecture aggregates roadside surveillance, controller, and device equipment associated with HRI into the roadway subsystem. This approach is consistent with the approach for highway-highway intersection equipment in recognition of the high degree of potential commonality between this equipment. Similarly, the Wayside Equipment terminator encapsulates the wireless interface to the train as well as the other interrelated wayside surveillance and control equipment that are the exclusive domain of the operating railroad/rail agency. This general approach, to refrain from specification of internal railroad requirements within the National ITS Architecture, also resulted in identification of Rail Operations as a terminator. This mapping focuses the National Architecture specifications on those interfaces which span agency and public/private boundaries.

Consistent with the Transportation Layer Definition, the communication layer focus is on the interagency interfaces identified as #4 (Roadway - Wayside Equipment) and #10 (Rail Operations - Traffic Management) as well as the existing National Architecture interfaces that are also necessary to support HRI user service requirements (#8 Roadway - Vehicle and #9 Traffic Management - Roadway).

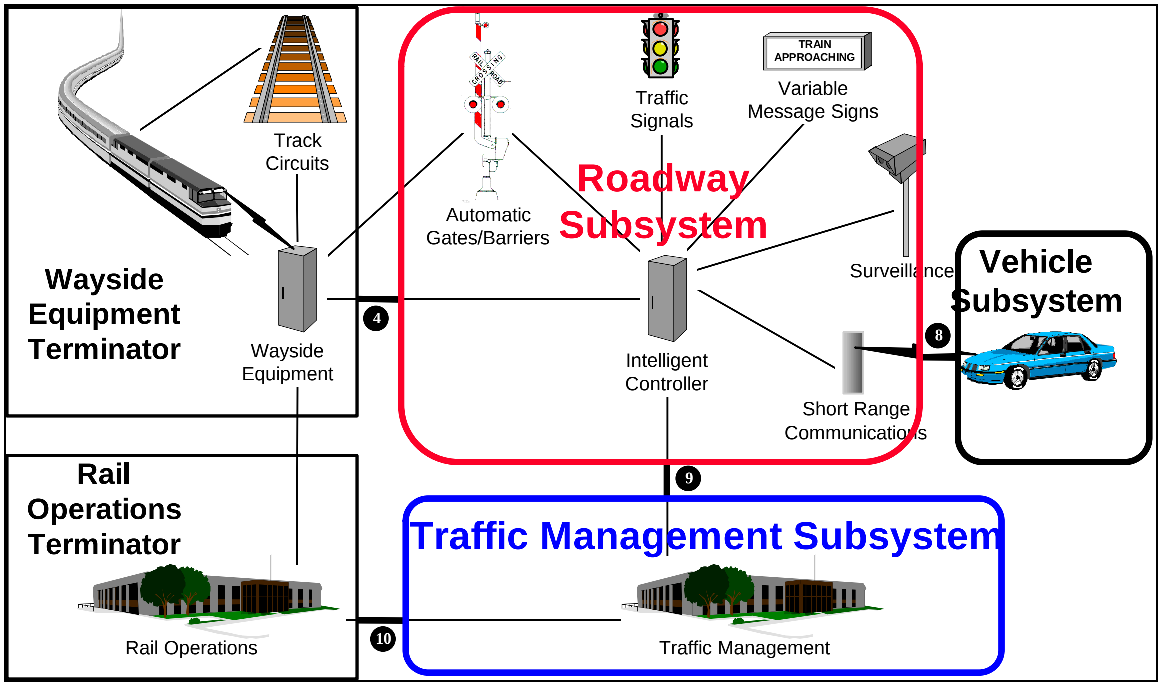

Figure 2: Physical Architecture Mapping

3. Communications Architecture Support For HRI

3.1 Approach

The Communications Architecture defined in the Communications Document is in most ways robust enough to address the communication requirement posed by the HRI User Service. The existing architecture was evaluated and refined following the same general approach used for developing the architecture. The figure describing the communications architecture development approach presented in chapter 2 of the Communications Document is reiterated in figure 3 with annotations highlighting the areas in which the HRI user service has impact. These new or changed communications architecture products are presented in this section.

As shown in the figure, the basic Communications Services Hierarchy and Network Reference Model established for the first 29 user services is equally applicable to the HRI user service. The wireline (*w)* and wireless interfaces (*u1, u2)* identified in the Network Reference Model support the interagency connectivity and information distribution requirements for HRI. Similarly, the basic interactive and distribution communication services are inclusive and cover all communication service categories applicable to HRI.

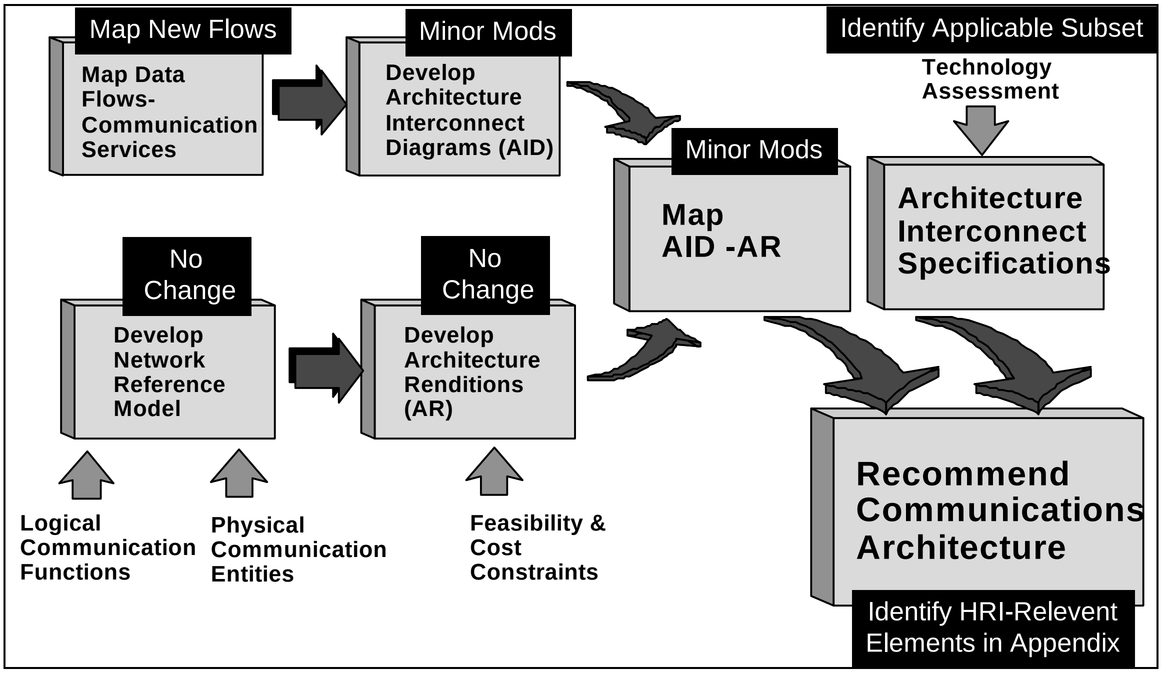

Figure 3: HRI Modifications to Communications Architecture

3.2 HRI-Specific Communications Architecture Elements

3.2.1 HRI Data Flow Mapping

Both the Logical and Physical Architectures are sources for data flow definitions that can be allocated and assessed in the communications architecture and analysis. The Physical Architecture defines architecture flows which show the major information transfer requirements for each subsystem. The Logical Architecture provides a more detailed presentation of the individual data flow components which are allocated to, and define, the architecture flows in the Physical Architecture. The Communications Layer maps the Logical Architecture Data Flows to Interconnects and Communications Services. Table 2 provides this mapping for the HRI-Specific data flows. Note that there are many other data flows that may also convey HRI-relevant information (e.g., the Roadway-Vehicle flows supporting in-vehicle signing, the Traffic Management Subsystem -Information Service Provider flows providing broad area distribution of HRI events). These flows, which have application beyond the HRI user service, are defined in section 4 of the Communications Document.

Table 2: New HRI Flow Mapping

Source	Destination	Architecture Flow	Logical Data Flow	Interconnects	Comm Service
Rail Operations	Traffic Management	railroad advisories	fro_incident_notification	w	c, m
Rail Operations	Traffic Management	railroad schedules	fro_maintenance_schedules	w	c, m
Rail Operations	Traffic Management	railroad schedules	fro_train_schedules	w	c, m
Roadway Subsystem	Traffic Management	hri status	hri_guidance_for_beacon_message	w	c, m
Roadway Subsystem	Traffic Management	hri status	hri_guidance_for_vms	w	c, m
Roadway Subsystem	Traffic Management	hri status	hri_status	w	c, m
Roadway Subsystem	Traffic Management	hri status	hri_traffic_data	w	c, m
Roadway Subsystem	Traffic Management	hri status	rail_operations_message	w	c, m
Roadway Subsystem	Traffic Management	hri status	traffic_management_request	w	c, m
Roadway Subsystem	Traffic Management	intersection blockage notification	hri_blockage	w	m
Roadway Subsystem	Traffic Management	intersection blockage notification	intersection_blocked	w	m
Roadway Subsystem	Wayside Equipment	hri status	twe_hri_status	w	c, m
Roadway Subsystem	Wayside Equipment	intersection blockage notification	twe_stop_highway_indication	w	m
Roadway Subsystem	Wayside Equipment	intersection blockage notification	twe_stop_train_indication	w	m
Traffic Management	Rail Operations	hri advisories	tro_equipment_status	w	c, m
Traffic Management	Rail Operations	hri advisories	tro_event_schedules	w	c, m
Traffic Management	Rail Operations	hri advisories	tro_incident_notification	w	c, m
Traffic Management	Roadway Subsystem	hri control data	indicator_sign_control_data_for_hri	w	m
Traffic Management	Roadway Subsystem	hri control data	rail_operations_advisories	w	m
Traffic Management	Roadway Subsystem	hri control data	rail_operations_device_command	w	m
Traffic Management	Roadway Subsystem	hri request	hri_traffic_surveillance	w	c, m
Traffic Management	Roadway Subsystem	hri request	ro_requests	w	c, m
Traffic Management	Roadway Subsystem	hri request	tms_requests	w	c, m
Wayside Equipment	Roadway Subsystem	arriving train information	fwe_approaching_train_announcement	w	m
Wayside Equipment	Roadway Subsystem	arriving train information	fwe_train_data	w	m
Wayside Equipment	Roadway Subsystem	track status	fwe_wayside_equipment_status	w	m

w: wireline interconnect; m: messaging data service; c: conversational data service;

3.2.2 HRI Architecture Interconnect Diagram

Construction of an architecture interconnect diagram that supports HRI entails addition of interconnects supporting the two terminators that were added for HRI. The content of this diagram is equivalent to figure 2 where each of the numerical interface designators (e.g., 4, 8, 9, 10) are replaced with awireline or wireless designators as identified in the previous table.

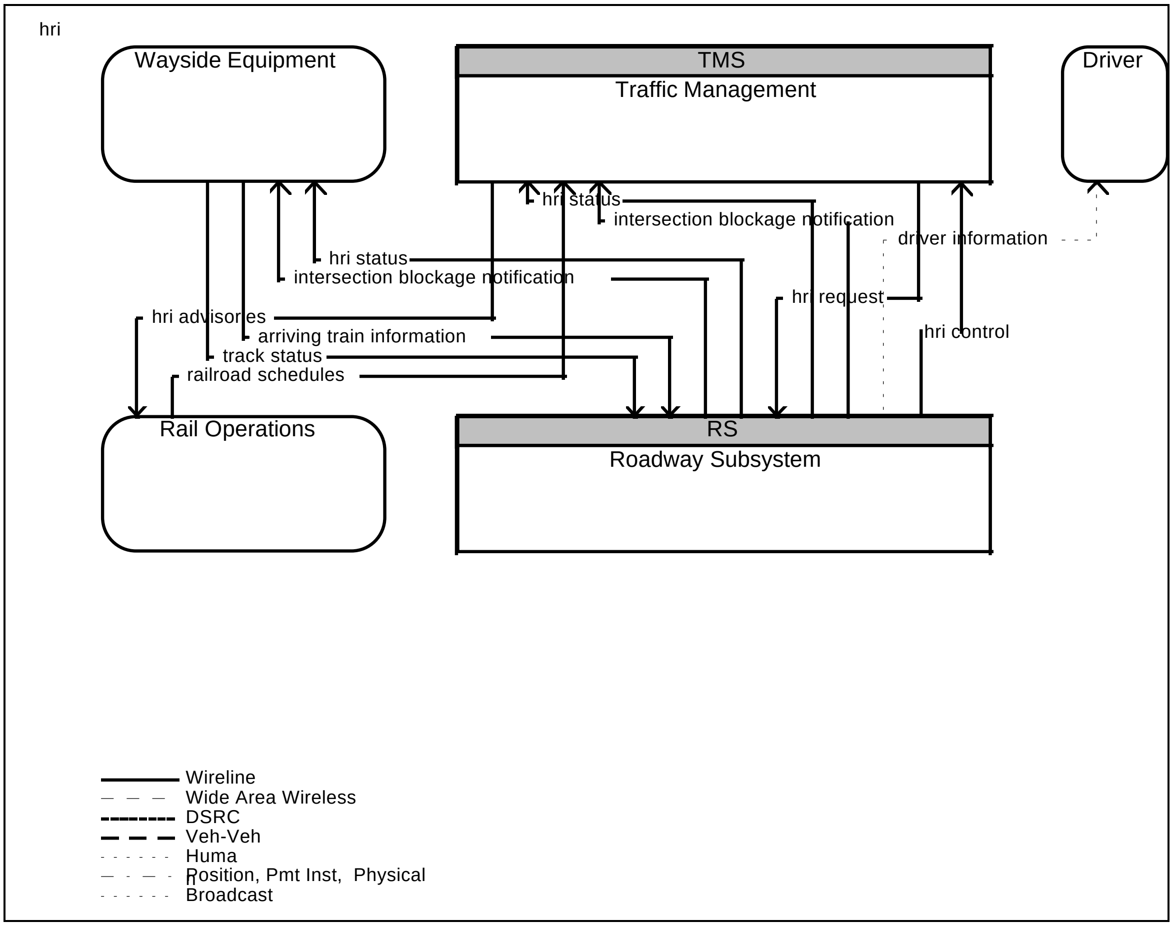

Figure 4: HRI Interconnect Diagram

4. HRI DATA LOADING ANALYSIS

4.1 Approach

A qualitative assessment of the impacts the HRI user service requirements have on the data loading analysis documented in sections 4 through 6 of this document was performed. This assessment estimates the additional loads on the existing interfaces and the overall loads for the new interfaces that would be required to support the HRI user service. While it is beyond the defined scope of the National Architecture, the likely derived impacts on the wireless interface to the train due to the HRI communications defined in the architecture is also briefly assessed.

4.2 Source Data

The new HRI messages in the architecture definition are confined to wireline interconnects between Rail Operations, the Traffic Management Subsystem, the Roadway Subsystem, and Wayside Equipment. As in the original data loading analysis discussed in sections 4-6 of the Communications Document, the wireline data loading results are derived directly from aggregation of size estimates in the Logical Architecture based on communication user populations consistent with those used in the cost analysis. These user populations and penetration factors for the three time frames and scenarios is depicted in table 3.

Specific size estimates for each logical data flow as extracted from the logical architecture are presented in table 4. The expressions that are used for some of the size estimates in the logical architecture are reconciled for each data flow in the final column of this table. Where the parameter values vary across time frames and scenarios, the values associated with the urban, 20 year scenario were used. As can be seen from the table, none of the messages identified for HRI are anticipated to be very large. The largest HRI-specific message ("railroad schedules") conveys anticipated crossing closure schedules for a particular region.

Table 5 identifies the frequency estimates associated with each of the HRI specific data flows as extracted from the Logical Architecture data dictionary.

The larger messages identified in table 4 are all anticipated to be relatively infrequent messages (i.e., one per day or one per hour) as can be seen from table 5. A range of data loading estimates for various scenarios may be calculated from the input data in tables 3 through 5. The overall data loads associated with the new HRI data flows would be relatively modest for each of the identified scenarios based on the assumptions and estimates identified in these tables.

4.3 Assessment

The findings are consistent with that for the other 29 user services; the wireline interfaces can readily accommodate the relatively modest additional loads levied by these future HRI systems. This overall finding must be caveated by the many design assumptions it incorporates. For instance, grade crossing surveillance can be accomplished in many different ways, each with vastly different data loading implications. As in the data loading analysis in the Communications Document, assumptions regarding the number of CCTV cameras, video encoding standards, and desired image quality swamp the other wireline data requirements.

Table 3: Highway-Rail Intersection Related Scenario Population and Penetration Estimates

EV_Parameters -- Relevant to HRI		Urbansville			Thruville			Mountainville		
Phase II Source Parameters	**Basis**	**5 yr**	**10 yr**	**20 yr**	**5 yr**	**10 yr**	**20 yr**	**5 yr**	**10 yr**	**20 yr**
Centers										
Traffic_Management_Centers	NAR Ev Design	2	3	5	1	1	2	0	0	0
Roadway Characteristics										
Std_Speed_HRIs	10% of Intersections; 50% for Rural	256	256	256	104	104	104	10	10	10
High_Speed_HRIs	10% of Std_Speed	26	26	26	10	10	10	1	1	1
CMS for HRI	40% of SSR + All HSR	128	128	128	52	52	52	5	5	5
In-Vehicle Signing Beacons for HRI	25% of SSR + All HSR	90	90	90	36	36	36	4	4	4

Urbansville		Urban-EVD -- Relevant to HRI		Phase II Penetrations						Evaluatory Design Quantities Summary					
Subsystem	**EP ID**	**Equipment Package**	**Source Parameters**	**5 yr Low**	**5 yr High**	**10 yr Low**	**10 yr High**	**20 yr Low**	**20 yr High**	**5 yr Low**	**5 yr High**	**10 yr Low**	**10 yr High**	**20 yr Low**	**20 yr High**
TMS	TMS18	HRI Traffic Management	TMCs	0%	0%	33%	66%	60%	100%	0	0	1	2	3	5
TMS	TMS19	Rail Operations Coordination	TMCs	0%	0%	33%	66%	60%	100%	0	0	1	2	3	5
RS	RS15	Standard Speed Rail Crossing	Std_Speed_HRIs	0%	0%	33%	66%	60%	100%	0	0	84	169	154	256
RS	RS16	High Speed Rail Crossing	High_Speed_HRIs	0%	0%	33%	66%	60%	100%	0	0	8	17	15	26
RS	RS7a	Roadway In-Vehicle Signing -- Additional for HRI	In-Vehicle Signing Beacons for HRI	0%	0%	33%	66%	60%	100%	0	0	30	59	54	90
RS	RS14a	Roadway Traffic Information Dissemination -- Additional for HRI	CMS for HRI	0%	0%	33%	66%	60%	100%	0	0	42	84	77	128

Thruville		InterUrban-EVD -- Relevant to HRI		Phase II Penetrations						Evaluatory Design Quantities Summary					
Subsystem	**EP ID**	**Equipment Package**	**Source Parameters**	**5 yr Low**	**5 yr High**	**10 yr Low**	**10 yr High**	**20 yr Low**	**20 yr High**	**5 yr Low**	**5 yr High**	**10 yr Low**	**10 yr High**	**20 yr Low**	**20 yr High**
TMS	TMS18	HRI Traffic Management	TMCs	0%	0%	30%	60%	60%	100%	0	0	0	1	1	2
TMS	TMS19	Rail Operations Coordination	TMCs	0%	0%	30%	60%	60%	100%	0	0	0	1	1	2
RS	RS15	Standard Speed Rail Crossing	Std_Speed_HRIs	0%	0%	30%	60%	60%	100%	0	0	31	62	62	104
RS	RS16	High Speed Rail Crossing	High_Speed_HRIs	0%	0%	30%	60%	60%	100%	0	0	3	6	6	10
RS	RS7a	Roadway In-Vehicle Signing -- Additional for HRI	In-Vehicle Signing Beacons for HRI	0%	0%	30%	60%	60%	100%	0	0	11	22	22	36
RS	RS14a	Roadway Traffic Information Dissemination -- Additional for HRI	CMS for HRI	0%	0%	30%	60%	60%	100%	0	0	16	31	31	52

Mountainville		Rural-EVD -- Relevant to HRI		Phase II Penetrations						Evaluatory Design Quantities Summary					
Subsystem	**EP ID**	**Equipment Package**	**Source Parameters**	**5 yr Low**	**5 yr High**	**10 yr Low**	**10 yr High**	**20 yr Low**	**20 yr High**	**5 yr Low**	**5 yr High**	**10 yr Low**	**10 yr High**	**20 yr Low**	**20 yr High**
TMS	TMS18	HRI Traffic Management	TMCs (incl virtual TMC)	0%	0%	0%	0%	0%	0%	0	0	0	0	0	0
TMS	TMS19	Rail Operations Coordination	TMCs (incl virtual TMC)	0%	0%	0%	0%	0%	0%	0	0	0	0	0	0
RS	RS15	Standard Speed Rail Crossing	Std_Speed_HRIs	0%	0%	30%	60%	60%	100%	0	0	3	6	6	10
RS	RS16	High Speed Rail Crossing	High_Speed_HRIs	0%	0%	30%	60%	60%	100%	0	0	0	1	1	1
RS	RS7a	Roadway In-Vehicle Signing -- Additional for HRI	In-Vehicle Signing Beacons for HRI	0%	0%	30%	60%	60%	100%	0	0	1	2	2	4
RS	RS14a	Roadway Traffic Information Dissemination -- Additional for HRI	CMS for HRI	0%	0%	30%	60%	60%	100%	0	0	2	3	3	5

Table 4: Highway-Rail Intersection Related Data Flow Size Estimates

Source	Data	Architecture Flow	Logical Data Flow	Size Expressions	Sizes (Bytes)
Rail Operations	Traffic Management	railroad advisories	fro_incident_notification	=1024	1024
Rail Operations	Traffic Management	railroad schedules	fro_train_schedules	=HRI_EVENTS_PER_DAY*(crossing_id+tr ain_id+crossing_close_time+train_arrival_ me)	187500
Rail Operations	Traffic Management	railroad schedules	fro_maintenance_schedules	=HRI_MAINT_PER_DAY*(crossing_id+cr ssing_close_time+crossing_close_duratio +1024)	52
Roadway Subsystem	Traffic Management	hri status	hri_guidance_for_beacon_message	=3	3
Roadway Subsystem	Traffic Management	hri status	hri_guidance_for_vms	=3	3
Roadway Subsystem	Traffic Management	hri status	hri_status	=hri_state+hri_closure_data_response	1152
Roadway Subsystem	Traffic Management	hri status	hri_traffic_data	=128	128
Roadway Subsystem	Traffic Management	hri status	rail_operations_message	=128	128
Roadway Subsystem	Traffic Management	hri status	traffic_management_request	=128	128
Roadway Subsystem	Traffic Management	intersection blockage notification	hri_blockage	=16	16
Roadway Subsystem	Traffic Management	intersection blockage notification	intersection_blocked	=16	16
Roadway Subsystem	Wayside Equipment	hri status	twe_hri_status	=1	1
Roadway Subsystem	Wayside Equipment	intersection blockage notification	twe_stop_train_indication	=1	1
Roadway Subsystem	Wayside Equipment	intersection blockage notification	twe_stop_highway_indication	=1	1
Traffic Management	Rail Operations	hri advisories	tro_equipment_status	=128	128
Traffic Management	Rail Operations	hri advisories	tro_incident_notification	=1024	1024
Traffic Management	Rail Operations	hri advisories	tro_event_schedules	=1024	1024
Traffic Management	Roadway Subsystem	hri control data	indicator_sign_control_data_for_hri	=list_size+GRADE_CROSSINGS*(crossin g_id+hri_sign_control_data)	701
Traffic Management	Roadway Subsystem	hri control data	rail_operations_advisories	=128	128
Traffic Management	Roadway Subsystem	hri control data	rail_operations_device_command	=128	128
Traffic Management	Roadway Subsystem	hri request	hri_traffic_surveillance	=256	256
Traffic Management	Roadway Subsystem	hri request	ro_requests	=128	128
Traffic Management	Roadway Subsystem	hri request	tms_requests	=128	128
Wayside Equipment	Roadway Subsystem	arriving train information	fwe_train_data	=train_id+train_speed+train_length+train_ rival_time	19
Wayside Equipment	Roadway Subsystem	arriving train information	fwe_approaching_train_announcement	=2	2
Wayside Equipment	Roadway Subsystem	track status	fwe_wayside_equipment_status	=1	1

Table 5: Highway-Rail Intersection Related Data Flow Frequencies

Source	Destination	Architecture Flow	Logical Data Flow	Freq. Expression (1 = Once Per Second)	Frequency
Rail Operations	Traffic Management	railroad advisories	fro_incident_notification	1/DAY	1/86400
Rail Operations	Traffic Management	railroad schedules	fro_maintenance_schedules	1/DAY	1/86400
Rail Operations	Traffic Management	railroad schedules	fro_train_schedules	1/DAY	1/86400
Roadway Subsystem	Traffic Management	hri status	hri_status	=ro_requests+tms_requests	1/3600+1/860
Roadway Subsystem	Traffic Management	hri status	hri_traffic_data	=event_notice	188/86400
Roadway Subsystem	Traffic Management	hri status	traffic_management_request	=1/HOUR	1/3600
Roadway Subsystem	Traffic Management	hri status	hri_guidance_for_beacon_message	=hazard_condition	1
Roadway Subsystem	Traffic Management	hri status	hri_guidance_for_vms	=hri_advisory	1
Roadway Subsystem	Traffic Management	hri status	rail_operations_message	=current_hri_state	1
Roadway Subsystem	Traffic Management	intersection blockage	intersection_blocked	=hri_hazard	1
Roadway Subsystem	Traffic Management	intersection blockage	hri_blockage	=current_hri_state	1
Roadway Subsystem	Wayside Equipment	hri status	twe_hri_status	=fwe_approaching_train_announcement	188/86400
Roadway Subsystem	Wayside Equipment	intersection blockage	twe_stop_train_indication	=fwe_approaching_train_announcement	188/86400
Roadway Subsystem	Wayside Equipment	intersection blockage	twe_stop_highway_indication	=fwe_approaching_train_announcement	188/86400
Traffic Management	Rail Operations	hri advisories	tro_event_schedules	=1/DAY	1/86400
Traffic Management	Rail Operations	hri advisories	tro_equipment_status	=1/DAY	1/86400
Traffic Management	Rail Operations	hri advisories	tro_incident_notification	=1/DAY	1/86400
Traffic Management	Roadway Subsystem	hri control data	rail_operations_advisories	=1/DAY	1/86400
Traffic Management	Roadway Subsystem	hri control data	rail_operations_device_command	=1/DAY	1/86400
Traffic Management	Roadway Subsystem	hri control data	indicator_sign_control_data_for_hri	=1	1
Traffic Management	Roadway Subsystem	hri request	hri_traffic_surveillance	=1/HOUR	1/3600
Traffic Management	Roadway Subsystem	hri request	ro_requests	=1/DAY	1/86400
Traffic Management	Roadway Subsystem	hri request	tms_requests	=1/HOUR	1/3600
Wayside Equipment	Roadway Subsystem	arriving train information	fwe_train_data	= DAILY_TRAINS/DAY	188/86400
Wayside Equipment	Roadway Subsystem	arriving train information	fwe_approaching_train_announcement	=DAILY_TRAINS/DAY	188/86400
Wayside Equipment	Roadway Subsystem	track status	fwe_wayside_equipment_status	=1	1

Wireline bandwidth is plentiful, and inexpensive when compared to the wireless communications interfaces. The wireless interface to the train, while not specified by the architecture, may be considered to be the most sensitive to projected data loading increases for advanced HRI implementations which include train notification. For instance, current data communications systems may supports only 100 bits per second per train in a worst case scenario. Efficiently managing this bandwidth is a key concern and overall data loading analysis for this interface is an on-going railroad activity as new systems are deployed that require data communications. To support these analyses, the messages that are provided to the wayside equipment that have potential implications for train communications may be considered separately.

An intuitive assessment indicates that HRI communications requirements to the train as identified in the user service are not likely to be a driving factor. Forward channel communications to the train is limited to emergency notification of blockage. By making the simplifying assumption that these warning systems are at every HRI and work perfectly (e.g., false alarm rate =zero), then the number of messages generated per year across the nation would be equal to the number of accidents at grade crossings which was approximately 5000 (excludes light rail) in 1993. While a false alarm rate of zero is an unreasonable expectation, it is unlikely that these systems will be fielded if the false alarm rate is significant due to the expense and risk to the railroad associated with the unscheduled full stops that these false alarms could initiate. At a false alarm rate that will be acceptable to the railroads, the data loading associated with these systems will be nominal. Of course, implementations which provide a positive proceed indication to the train prior to each HRI would incur much higher data loads. Such implementations would also have a higher false alarm rate but would be consistent with fail-safe design practices.

5. COMMUNICATION TECHNOLOGIES REVIEW

This section contains a broad review of the various communication technologies that may be used to satisfy the HRI user service communications requirements. The communications technology review is limited to wireline technologies to be consistent with the HRI interfaces identified in the architecture definition. Of course, wireless technologies may also be viable alternatives for communication with widely distributed field equipment at the wayside and roadside. Indeed, most highly distributed system implementations will include both wireline and wireless components in the overall communications solution. This section includes applicable excerpts from the more comprehensive wireline technology survey contained in the Communications Document. Also refer to the Communications Document for wireless technology surveys.

A range of communications technologies will support the interconnects and data flows identified to support the HRI user service. Basic implementations of the Wayside Equipment to Roadway Subsystem interface require only a point to point wireline connection providing a discrete voltage that notifies the roadway subsystem of pending HRI activity. More sophisticated network solutions become attractive for the communications between the Roadway Subsystem and Traffic Management Subsystem. Finally, the peer-to-peer communications requirements associated with the Traffic Management Subsystem to Rail Operations interface recommend a third set of communications options.

The intent of this section is solely to provide the reader with a characterization of today's candidate technologies that is as complete as possible, and also to offer a glimpse into the systems that loom on the horizon. Hopefully, this section will provide the implementors with a broad perspective of existing technologies. However, this section does not constitute in any way a technology study for any particular scenario. In particular, it does not account for any political, institutional, jurisdictional, budgetary or other similar constraints.

5.1 Wireline Communications

Wireline network options include the use of private networks, public shared networks, or a mixture of the two. Examples of private network technologies are twisted pair cables, FDDI over fiber optic rings, SONET fiber optic networks, and ATM over SONET networks. Examples of public shared network options are the leasing of telephone company-offered services such as leased analog lines, frame relay, ISDN, metropolitan ethernet, and Internet. A third wireline network option is that of a mixed network, where existing communications infrastructure can be utilized to the greatest extent possible, and possibly upgraded to carry any increased data load. The addition of CCTV in particular can overload the backbone of an existing network.

The decision to specify a private network is probably not motivated by technological reasons because the desired data bandwidth can be supplied through the use of public shared networks. Public shared networks have many other advantages such as cost sharing and risk reduction. It is certain that in the time frames studied that one or more local carriers can provide a network connectivity to fulfill the HRI communications requirements.

The reasons for building a private network have more to do with requirements/preference for a network built to the exact specifications of the user, and with matching the funding mechanism. If one-time capital funding is more easily obtained than monthly lease fees, then a private network appears as the best choice. In any case, there will still be an ongoing maintenance cost.

The active participation of the owners of the roadway right of ways in partnership with one or more commercial carriers may be a means of having a private network built for the ITS infrastructure at little or no cost to the local agency. In exchange for the use of the rights of way, the carriers would provide a portion of the network capacity for ITS use, and much of the maintenance cost. Bartering of railroad right-of-way offers similarly attractive options to the railroad operator.

For the purposes of the communication analysis, the owner of the network is not an issue, nor is the exact technology used on each link an issue. The candidate network technologies studied included those that are standardized (or will be in the time frames of interest) and are available in commercial quantities. The choice of a network technology for a deployed network must be based on the specific details of the infrastructure assets deployed in the specific metropolitan area. Any conclusions drawn in this analysis should not be generalized to every deployment area.

5.1.1 Candidate Wireline Technologies

The candidate network technologies discussed below are chosen from standardized network technologies because they consist of components available from multiple vendors. There are no added development costs, they are compatible with public shared networks, and they have been tested in various environmental conditions. The candidate private network technologies studied here include Ethernet, Fiber Distributed Data Interface (FDDI), Synchronous Optical NETwork (SONET), and Asynchronous Transfer Mode (ATM).

In addition to the network technologies listed above, the use of twisted-pair copper lines for the lowest level in a network is considered as a cost saving means of transmission. This allows the reuse of existing twisted-pair infrastructure. For new construction, the cost of fiber with optical transceivers is close to the cost of twisted pairs with modems.

Ethernet is a network technology based on a bus, primarily used in local area networks. The data rate is typically 10Mbps, and the transmission media is coaxial cable. Access is controlled by a media access protocol (MAC) incorporating a Carrier Sensing Multiple Access with Collision Detection (CSMA/CD) scheme. The access protocols cannot accommodate networks covering a large area efficiently. To cover a metropolitan area the network must be broken down into many smaller LAN areas, which are then linked together using high-speed links. The CCTV camera load in any reasonable area would probably exceed the data capacity of ethernet, so a separate network would be required to carry the video data.

FDDI is a LAN-based network technology using a fiber optic transmission medium. It can support a data rate of 100 Mbps, and a total network cable length of 100 km. Up to 500 stations can be linked on a single network. Although a logical ring network topology is required, FDDI can support both star and ring physical topologies. Access to the ring is controlled by a token-passing scheme: A station must wait for a token before transmitting, each station repeats any frames received downstream to the next station, and if the destination address on a frame matches the station address, it is copied into the station's buffer and a reception indicator is set in the frame status field of the message which continues downstream. The message continues downstream through the network to the originating station which then removes the message from the network. An enhancement to FDDI was standardized as FDDI II, which provides a circuit mode of operation. It allocates time slots of FDDI to isochronous channels. Up to sixteen, 1.144 Mbps channels can be allocated, with a 1 Mbps channel remaining for a token channel. Using this standard would allow constant-rate data from CCTV cameras to be transmitted on the isochronous channels with the remaining time slots available for the asynchronous (packet) data from intersection controllers and sensors.

SONET is an optical interface standard for networks that allows inter-operability between equipment manufactured by different vendors. It defines the physical interface, optical line rates, frame format, and operations, maintenance, and provisioning overhead protocol. The base rate of transmission is 51.84 Mbps, and higher rates are allowed as multiples of the base rate. At the base rate, data are transmitted in frames of 90 by 9 bytes every 125 microseconds. Higher rates are achieved by transmitting a multiple number of these frames every 125 microseconds. The first three "columns" of the 90 by 9 byte frame are reserved for overhead data, and the rest constitute the "payload" of 50.11 Mbps. The synchronous structure and byte-interleaved structure of SONET allows easy access to lower-order signals, which allows the use of lower- cost hardware to perform add/drop, cross-connect, and other bandwidth allocation techniques, eliminating the need for back-to-back multiplexing/demultiplexing. The overhead allows remote network monitoring for fault detection, remote provisioning and reconfiguration of circuits, reducing network maintenance costs. SONET networks can be configured as point-to-point or ring networks. For fault redundancy, SONET rings are frequently configured as bi-directional rings with one-half of the network capacity reserved for transmission during a fault. In the case of a cut in the two fibers (one for each direction) between two adjacent nodes on the ring, traffic is rerouted by the nodes on either side of the break, in the direction away form the break, using the reserved excess capacity of the ring.

ATM is a packet-switching technology that routes traffic based on an address contained in the packet. Packets are statistically multiplexed through a store-and-forward network, allowing multiple data streams of various data rates to flow through the network with greater instantaneous link efficiency. The technology uses short, 53-byte fixed-length packets, called cells, allowing the integration of data streams of various rates. The short cell length limits the length of time that another cell must wait before given access to the link. Cells containing video data can be given a priority over data cells, so that continuous video streams will not be interrupted. The 53-byte cell consists of a 5-byte header and 48 bytes of user data. ATM is connection oriented, and every cell travels through the network over the same path, which is specified during call setup. The cell header then contains only the information the network nodes need to relay the cell from one node to the next through the network. ATM connections exist only as sets of routing tables stored in each switch node, based on the cell header. Each ATM switch along the route rewrites the cell header with address information to be used by the next switch node along the route. Each switch node needs to do very little to route the cell through it, reducing switching delay. ATM can be used on a variety of links, and particularly SONET links for the medium-haul lengths required in a metropolitan-area deployment. The ATM concept, being based on switches routing packets, tends to favor a star configuration with a dedicated line to each user. ATM is still in the development phase, but should be considered as one of the strongest network technology candidates for the deployment time frames being considered.

5.1.2 Candidate Wireline Topologies

The network connecting the traffic surveillance and traffic management devices near each highway-rail intersection to the TMS will typically be at least a two-level network, with the first network level connecting the devices and associated intelligent controllers to a hub and the second network level connecting each of the section's hubs to the TMS. An additional network level may be added as a set of concentrators deployed throughout the sections to concentrate data over higher-rate lines to the hub. Concentrators are applied in the network where they can be used to decrease the overall network cost.

The use of star connectivity was studied for both levels of the network. The selection of a ring or star network configuration is largely determined by the link transmission technology selected, such as private FDDI networks, and public leased twisted pairs. Examples of some of the connectivity options and their effect on the total length of links was analyzed. The results of the simulations showed clearly that the delay on any reasonably designed wireline network was completely negligible.

It is expected that a common communications network will be used to support communications requirements associated with both highway-rail intersection management and highway-highway intersection management. Even greater efficiencies associated with shared communications infrastructure may be realized if this same common network is also used to support communications between similarly located wayside equipment.

5.1.3 Public Network Usage

The candidate shared public network technologies include leased analog lines, digital leased lines, frame relay, Integrated Services Digital Network (ISDN), metropolitan ethernet, Switched Multimegabit Data Service (SMDS), and Internet.

Portions, or all, of the communications links for the architecture can be provided by shared public network technologies. The public network technologies that can be considered to fill a large subset of communications requirements, and are available in most jurisdictions are detailed in Table 4.

Metropolitan ethernet may be available in some jurisdictions as a service provided by CATV companies. This shared network is currently found in only a few metropolitan areas, but could be offered in many more in the future as CATV systems are upgraded with fiber-optic technology. This network technology is only applicable to the controller data, and cannot handle the CCTV data load.

Many jurisdictions will already have some form of communications network in place for the centralized control of intersection controllers. The architecture will allow the continued use of these networks if desired, with the lower-level twisted-pair links used for the intersection controller data. The addition of CCTV cameras brings the data rate requirement of the network up so that a high-speed network backbone is required. Concentrators can be placed in the network to multiplex the intersection controller links onto the high-speed backbone network, along with the CCTV data links.

Table 4: Widely Available Public Network Technologies

Link Technology	Analog leased lines	Digital leased lines	Frame Relay	ISDN	SMDS
Type of service	Dedicated circuit	Dedicated circuit	Packet switched	Circuit switched and packet	Packet switched
Transmission medium	Standard telephone line	Digital facilities	standard telephone line to four-wire T1 technology	basic rate ISDN - standard telephone lines; primary rate ISDN - four-wire T1 technology	four-wire T1, and fiber optics
Data rate	up to 28.8	2.4 Kbps, 64 Kbps, fractional T!, T1 (1.5 Mbps), T3 (4.5 Mbps), DS3 (45 Mbps)	56 Kbps up to T1	Circuit switched B channel 64Kbps, packet D channel 16 Kbps; basic rate ISDN=2B+D, primary rate ISDN = 23B+D	T1, T3, SONET to 155 Mbps
Capabilities	point-to-point and multipoint	point-to-point and multipoint	Suitable for data only.	B channel well suited for CCTV which can be used intermittently, D channel for simultaneous data	Suitable for data only.
Comments	Universally available	High reliability	Fixed monthly charge based on data rate	Cost is usage dependent	Cost is usage dependent
Cost/month (rough estimate, based on undiscounted tariffs)		56 Kbps: $300/month; T1: $3.50/month/mile + $2500/month; DS3: $45/mile/month+ $16000/month	56 kbps: $175/month T1: $435/month	basic rate ISDN: $25/month + $0.57/kilopacket for data and $0.016/minute for B channel	

5.1.4 Localized Use of Internet

The Internet could also potentially provide data communications, but there are security issues in its use for many of the ITS network applications.

The Internet is a collection of networks using TCP/IP protocol (Transmission Control Protocol--TCP, and the Internet Protocol--IP). Since its introduction by the Inter Networking Working Group in 1982, it has gained tremendous attention in the network communities. (The average time between new networks connecting to the Internet was ten minutes as early as July, 1993.)

Section 7.5.2.4 investigates the feasibility of using the Internet as a communication network between the Traffic Management Subsystem and other transportation centers. This analysis is applicable to consideration for use of the Internet for the TMS to Rail Operations interface. In general, this analysis supports the intuitive assessment of many Internet users that highly variable communications delays will be experienced. Large variations in reliability (measured by packet loss statistics) were also noted. These measures should not preclude use of the Internet for non-secure communications of data where high performance and reliability are not primary considerations.