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Greater Yellowstone Rural ITS Project

Work Order II-2D AVI at Yellowstone National Park Entrances

Prepared for

MONTANA DEPARTMENT OF TRANSPORTATION

And

U.S. DEPARTMENT OF TRANSPORTATION,
FEDERAL HIGHWAY ADMINISTRATION

In cooperation with

DEPARTMENT OF THE INTERIOR, YELLOWSTONE NATIONAL PARK

Prepared by

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Bozeman, Montana

April 2004

IMPLEMENTATION STATEMENT

This study is sponsored by the U.S. Department of Transportation, Federal Highway Administration in cooperation with the Montana Department of Transportation, the Wyoming Department of Transportation, the Idaho Transportation Department, and the Yellowstone National Park. The major objective of this document is to summarize GYRITS Work Order II-2D, Evaluation of Automated Vehicle Identification System in Yellowstone National Park.

DISCLAIMER

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ACKNOWLEDGEMENTS

Grateful appreciation is extended to the U.S. Department of Transportation, Federal Highway Administration; Montana Department of Transportation; Idaho Transportation Department; Wyoming Department of Transportation; Yellowstone National Park; other partner agencies and the Greater Yellowstone Rural ITS Project Steering Committee members. Special thanks to those individuals who assisted with the development of this report including but not limited to Bose Sadagoparamanujam (WTI), Simon Poole (WTI), Trevor Iman (WTI), Tammy Wert (YNP), Mike Angermeier (YNP), John Sacklin (YNP), Rick McAdam (YNP), Julie Hannaford (YNP), Bundy Phillips (YNP), and Duane L. Bennett (Kanawha Scales).

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1 INTRODUCTION

1.1 Purpose and Scope of Report

The Western Transportation Institute prepared this report as part of Work Order II-2D Automated Vehicle Identification (AVI) at Yellowstone National Park (YNP) Entrance Stations. AVI technology was installed and tested at the North Entrance (near Gardiner) and the Northeast Entrance (near Cooke city) of YNP. There are tentative plans to expand the system to other entrance stations. This report summarizes the evaluation of the effectiveness of the AVI System at the initial deployment sites.

This report includes a description of the GYRITS Project, a description of the AVI system, an overview of the challenges and issues, and analysis of the benefits.

1.2 Description of the GYRITS Corridor

The Greater Yellowstone Rural ITS Project (GYRITS Project) was initiated to move rural ITS forward by demonstrating and evaluating ITS in a rural environment. GYRITS began in January 1997 with a Congressional Earmark to fund (1) the development of a Regional ITS Strategic Deployment Plan, (2) the implementation of "early winner" projects, and (3) the development of supporting documentation. In February 2000, a strategic plan was completed that included stakeholder input, GYRITS organizational structure, regional architecture, legacy systems, and candidate projects. The AVI System at the Yellowstone National Park entrances was one of the candidate projects selected for implementation.

The Greater Yellowstone Rural Intelligent Transportation System Priority Corridor is a 200-mile long, 100-mile wide, heavily utilized rural transportation corridor between Bozeman, Montana and Idaho Falls, Idaho (Figure 1). This corridor includes:

- three states: Montana, Idaho and Wyoming;
- two national parks: Yellowstone (YNP) and Grand Teton GTNP; and
- a variety of transportation facilities ranging from Interstate freeway to low-volume, two-lane rural highways.

Primary transportation facilities include:

- Interstate 90/15 from Bozeman, Montana to Idaho Falls, Idaho through Butte, Montana;
- U.S. Highway 191/20 from Bozeman, Montana to Idaho Falls, Idaho; and
- U.S. Highway 89/26 from Livingston, Montana through Jackson, Wyoming to Idaho Falls, Idaho.

Additional highways added to the corridor at the March 1998 Steering Committee meeting include:

- Highway 212 from Red Lodge, Montana, through Cooke City, Montana and into Yellowstone National Park;
- Highway 14 from Cody, Wyoming, through the east entrance of Yellowstone National Park and into the Park interior; and Highway 31 from Swan Valley Idaho, over Teton Pass to Jackson, Wyoming.

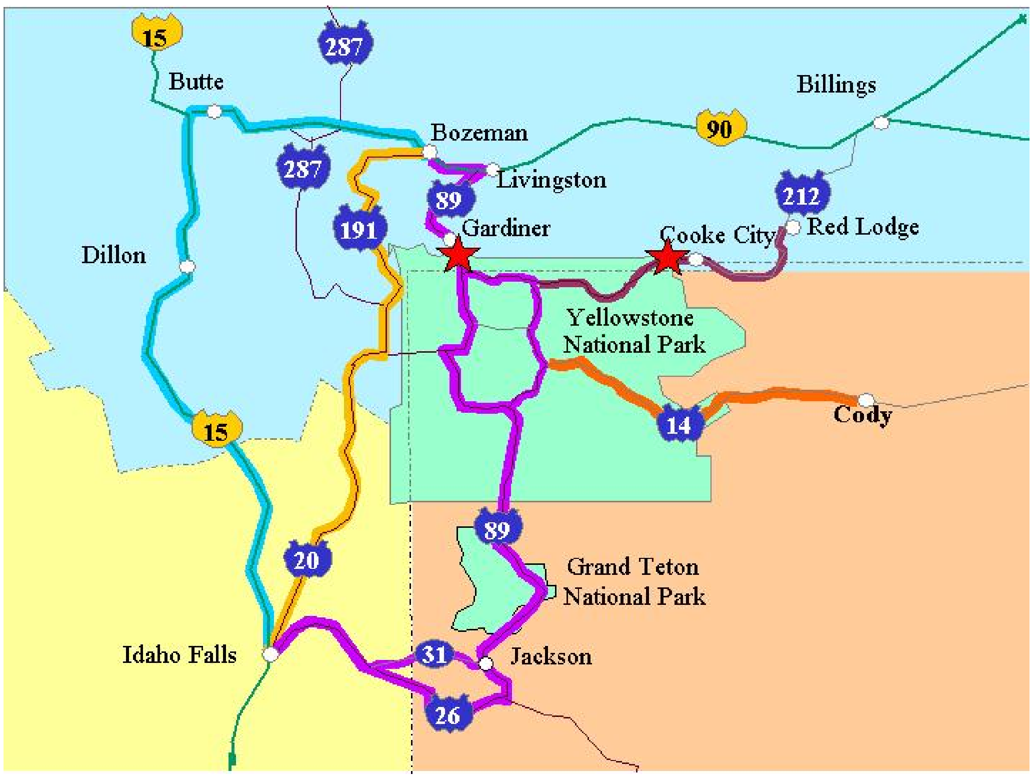

Figure 1: GYRITS Study Area

These routes represent vital transportation links for the economy and well being of the three-state area of Montana, Wyoming and Idaho. They also serve the recreational and resource needs of a growing number of individuals seeking to utilize the Greater Yellowstone ecosystem and Grand Teton National Park. The national importance of the corridor is further emphasized by its function as the connector for the trucking industry between the upper Midwest markets along Interstate 90 and the Intermountain and Southwest markets accessible by Interstate 15.

Because this report addresses AVI deployed only in YNP, it will focus on the YNP portion of the GYRITS Study Area, in particular Highways 89 and 212 at the North and Northeast Entrances to YNP.

2 ENTRANCE STATION OPERATING PROCEDURES

There are five main entrances to Yellowstone National Park (North, Northeast, East, South and West). As shown in Figure 1 the system was installed at the North Entrance (near Gardiner) and the Northeast Entrance (near Cooke City). In order to effectively describe the AVI deployments in Yellowstone one must first understand the architecture of the existing entrance gates. This section includes a description of the entrance station procedures prior to the AVI deployments and a detailed description of each entrance station.

2.1 Entrance Station Process Prior to AVI

Each entrance station is unique in regards to physical configuration. However, the purpose and operating procedures remain the same across all gates. The purpose of all entrance stations is to sell passes, check pass holders before re-entry, and provide up-to-date park information. Visitors entering the park receive a newspaper containing information regarding safety, facility availability, and park regulations. It is imperative from a safety and liability standpoint that all YNP patrons receive the safety information contained in the newspaper.

Most gates are closed to cars during winter months. The West entrance, for example typically closes from early November to mid-April (it is still open to snowmobiles and snow-coaches during these times). The North and Northeast Entrances are open year round in order to allow access for visitors, employees and Cooke City residents. Employees living in Gardiner can access Park headquarters located in Mammoth by using the North Entrance. Cooke City residents use the road between the North and Northeast Entrance to access services in winter, because. Highway 212 between Cooke City and Red Lodge is closed.

Each entrance station is staffed from approximately 6 AM to 12 AM daily during the summer with hours adjusted by season.

YNP provides patrons with multiple options for pass purchase upon entering the park. Additionally, special entry permits are provided for employees and other residential, commercial, and business travelers who enter the park on a regular basis. A description of all passes and their respective prices is shown below in Table 1.

Table 1: Park Pass Types

Pass Type	Cost	Description	Duration
Private Non-Commercial	$20.00	Receipt	7 day
Individual Motorcycle	$15.00	Receipt	7 day
Single Entity (foot, bike etc)	$10.00	Receipt	7 day
Annual Area Permit for YNP and Grand Teton NP	$40.00	Card	1 year from purchase date
Golden Eagle Pass (all parks)	$50.00	Card	1 year from purchase date
Golden Age Passport (all parks, US Citizens over 62)	$10.00	Card	Lifetime
Golden Access (all parks, disabled individuals)	Free	Card	Lifetime
Permanent Employees	N/A	Sticker	Variable
Seasonal Employees	N/A	Sticker	Variable
Residents	N/A	Sticker	Variable
Contractors	N/A	Red or White card	Variable
Park Vendors	N/A	Black text on blue card	Variable
Commercial Vendors	N/A	Sheet	Variable

2.2 Characteristics of Individual Entrance Stations

2.2.1 North Entrance Station (Gardiner)

Traffic entering the park through the North Entrance approaches on the southbound lane of US Highway 89/26 out of Livingston, Montana. A separate vendor road merges into the northbound lane approximately 100 feet north of the entrance gate. Approximately 75 feet north of the gate, the southbound lane splits into two lanes, with the right lane signed for employees and the left for visitors. Figure 2 shows the North Entrance station.

Figure 2: Long Queue at North Entrance

Additionally, traffic exits the park using a single lane. The entrance station itself is a modern (circa 1990) log building positioned such that both entrance lanes pass the window on one side and the exit lane on the other. A closer view of the North Entrance is shown in Figure 3.

Figure 3: North Entrance

The procedures followed for gate operations are relatively simple; however, high traffic volumes during peak months require the use of alternate procedures for mitigating congestion. Therefore, two sets of procedures are followed according to the level of traffic volume.

When the queue is short (traffic in the left lane does not extend past the junction between the vendor road and US 89/26), the left entrance lane (hereon referred to as Lane 1) is allocated to visitors. Traffic in Lane 1 proceeds to the service window and either purchases a pass or shows a pre-paid pass for verification. Park employees, park vendors, commercial traffic, contractors, government vehicles, and Cooke City residents with an entrance sticker or valid pass proceed to the right lane (hereon referred to as Lane 2). Once at the gate the vehicle must wait for the gate attendant's approval, usually denoted by a wave of the hand before entering the park. The lane configuration can be seen in Figure 4. When the queue is long, many employees will attempt to avoid being stuck in the single lane by using the vendor road.

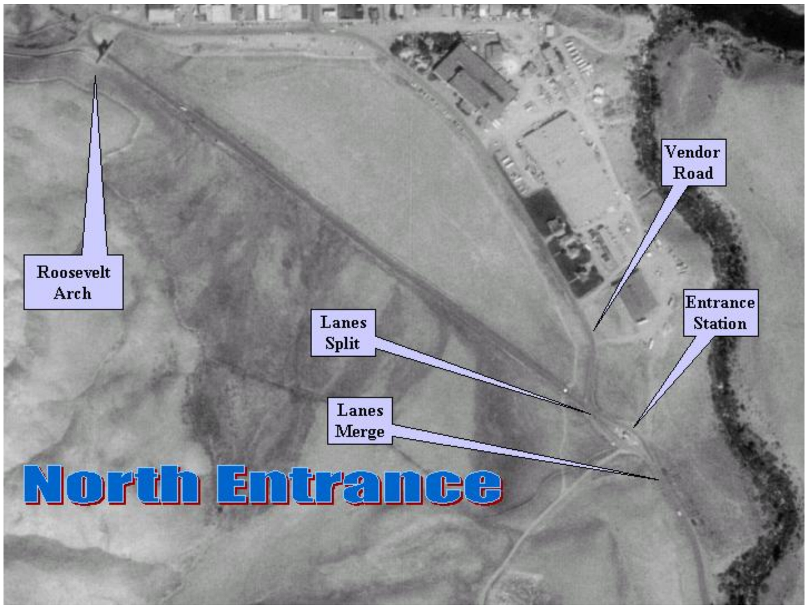

Figure 4: Aerial View of North Entrance

In the event that traffic in the left lane extends past the vendor access road for a prolonged period, a ranger goes out to the congested junction and directs traffic so that visitors with a pre-paid pass may also use Lane 2. The objective of this strategy is to better utilize the capacity of the outer lane and reduce the overall queue length. In this case the traffic volume of the outer lane increases, but the queue length does not grow substantially. From multiple days of observation it was determined that without this ranger intervention, the queue length might otherwise extend one third of the distance to Roosevelt Arch.

2.2.2 Northeast Entrance Station (Cooke City)

Traffic entering the park through the Northeast Entrance approaches on the westbound lane of US Highway 212 out of Red Lodge, Montana. Both the westbound (entrance side) and eastbound (exit side) lanes divide into two lanes approximately 100 ft. in advance of the entrance gate. The Northeast Entrance gate is a historic log structure with a low overhang that encloses the inner lane on both the entrance and exit sides of the gate. Due to the nature of this structure, the inside lane cannot accommodate larger vehicles such as recreational vehicles or large trucks. As such, large vehicles are directed to the outside lane. Figure 5 is a picture of the Northeast gate showing the lane configuration (as seen entering the Park) and historic structure.

Figure 5: Northeast Entrance Lane Configuration

The physical setup of the gate is such that lane allocation similar to the North Entrance is not possible. Vehicles approach the gate and divide into the appropriate lane according to size. If the vehicle has a valid pass the gate attendant waives the vehicle through with little delay. If the vehicle does not have a park furnished sticker or pre-paid pass, the vehicle must stop and buy a pass before proceeding. Large vehicles in the outer lane that need to purchase a pass must park and approach the window on foot. Figure 6 shows the lane signing for low and high clearance vehicles.

Figure 6: Lane Singing for North Entrance

2.2.3 West Entrance Station

Although not part of the initial deployment, the West Entrance has the highest traffic and is considered as a potential site for future expansion of the system. Traffic entering the park through the West entrance approaches in the eastbound lane of US Highway 20 out of West Yellowstone, Montana. The West entrance is equipped with four entrance lanes due to the high traffic volume. There are three permanent gate booths available to service entering traffic. At least one of the three permanent lanes is open all day, with others opening as volumes increase. The right-most lane *(Facing East)* is reserved as an express lane, and is opened by a ranger when the volumes are highest. A picture of the West gate lane configuration as seen entering the Park is provided below in Figure 7.

Figure 7: West Entrance

3 SYSTEM DESCRIPTION

The AVI system installed in Yellowstone National Park is a modification of the automatic toll collection systems seen in many urban areas. This section will provide a detailed description of the setup and configuration of the AVI installations at the North and Northeast Entrance gates.

The systems include vehicle tags, entrance equipment, and a main server, each of which are described in detail below. The systems were designed and implemented by Kanawha Scales and Systems Inc. of Poca, West Virginia.

3.1 Vehicle Tags

The vehicle tags are the Amtech AT5102 models shown in Figure 8. They are attached to the rearview mirror using Velcro adhesive strips to allow for removal and verification at gates without operational AVI. For cars and pickup trucks, tags are installed on the center of the windshield behind the rear-view mirror. For busses and large trucks, tags are attached to the lower middle portion of the windshield. 2000 tags were provided by the vendor with the initial system. Additional tags can be purchased for approximately $20.00. Approximately 400 tags were distributed to permanent employees and concessionaires by the spring of 2003.

Figure 8: Vehicle Tag

3.2 Entrance Equipment

This section briefly describes the physical equipment and hardware used by the AVI system at each site. At the North Entrance, only the right lane is AVI equipped. The AVI components at the North Entrance include two vehicle detector loops, an AVI antenna, a red/green traffic signal, battery backup system, a Pentium computer, and a push button to manually control the signal. The Northeast Entrance has two lanes equipped for AVI and has in addition two vehicle detector loops, an AVI antenna, and a red/green traffic signal. The general lane configuration of the AVI system at the North and Northeast Entrance stations is shown below in Figure 9.

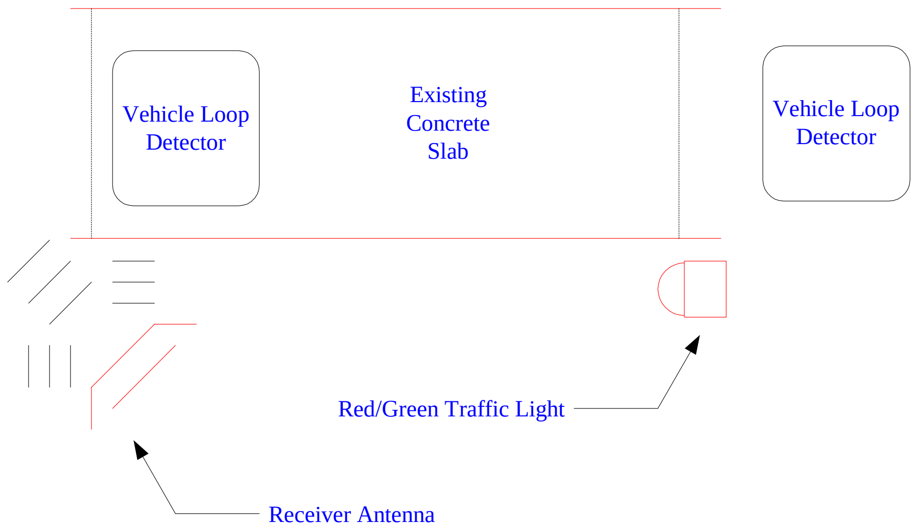

Figure 9: AVI Lane Configuration (Source: Kanawha Scales)

The general equipment layout for both the North and Northeast Entrance gates is provided in Figure 10 below.

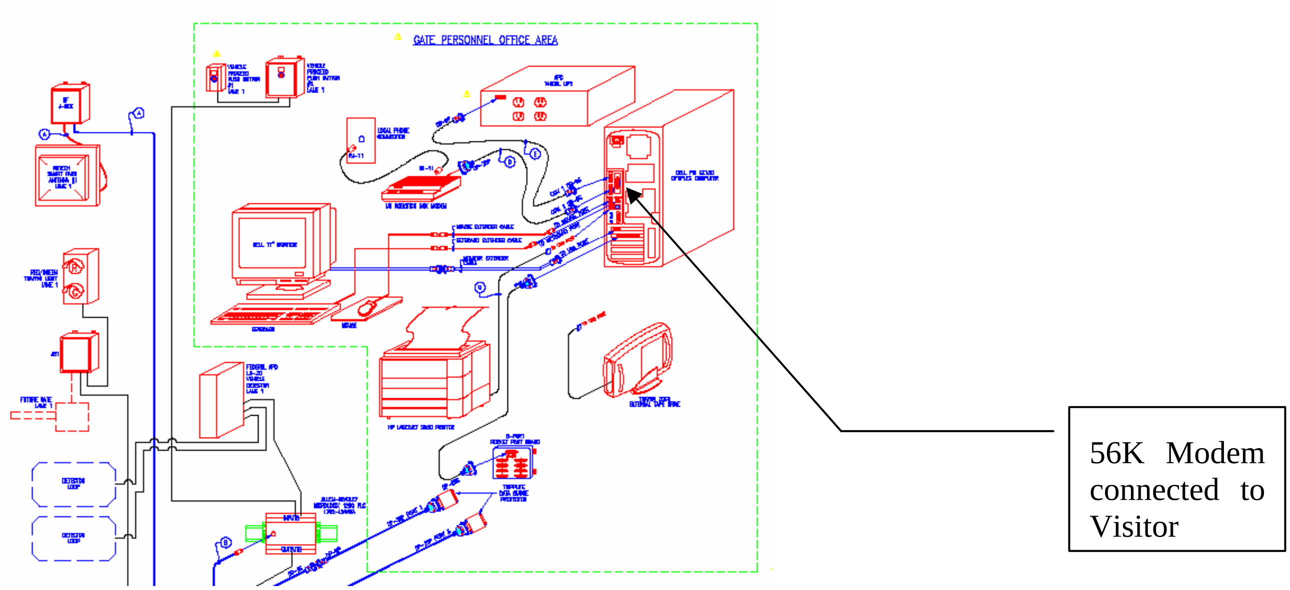

Figure 10: General Equipment Layout (Source: Kanawha Scales)

The AVI antenna and detector loops will determine if a vehicle (1) has a valid tag, (2) has no tag or an invalid tag, or (3) drives through the system without permission. The process for each of the three vehicle types is described below.

Valid Tag

1. The vehicle passes the AVI antenna with a valid tag
2. The computer processes the tag information
3. The computer verifies and logs a valid tag
4. When the vehicle crosses the first loop, the signal will turn to green
5. When the vehicle crosses the second loop the signal will turn back to red

No/Invalid Tag

1. The vehicle crosses the AVI antenna and first loop
2. The signal will remain red
3. A "presence" sound will alert the attendant that someone requires attention in the AVI lane
4. After the attendant has attended to the vehicle he/she will use the push button, shown in Figure 11, to change the signal to green
5. The computer logs a "no tag" vehicle entering
6. When the vehicle crosses the second loop the signal will turn back to red

Figure 11: Manual Sign Control

Violator

1. The vehicle crosses the AVI antenna and first loop
2. The signal will remain red
3. A "presence" sound will alert the attendant that someone requires attention in the AVI lane
4. The vehicle does not stop at the red light
5. When the vehicle crosses the second loop a different sound will alert the attendant of the violation
6. The computer will signal the Reliable Security camera system to record the violating vehicle
7. The computer logs a violator

If there are malfunctions, the attendant can reset the system by pressing and holding the manual signal control button for 10 seconds. The attendant can also use the computer to change from "active" mode described above to "inactive solid green" or "inactive flashing green." In inactive mode the system ignores traffic and the signal is either continuously green or flashing green (indicating proceed slowly).

In order to meld with the historic and natural setting of the YNP entrances, the antenna and signal, shown in Figure 12, are brown. Additionally, the system was configured for an addition of a gate arm, should YNP determine the need for one as part of the AVI system.

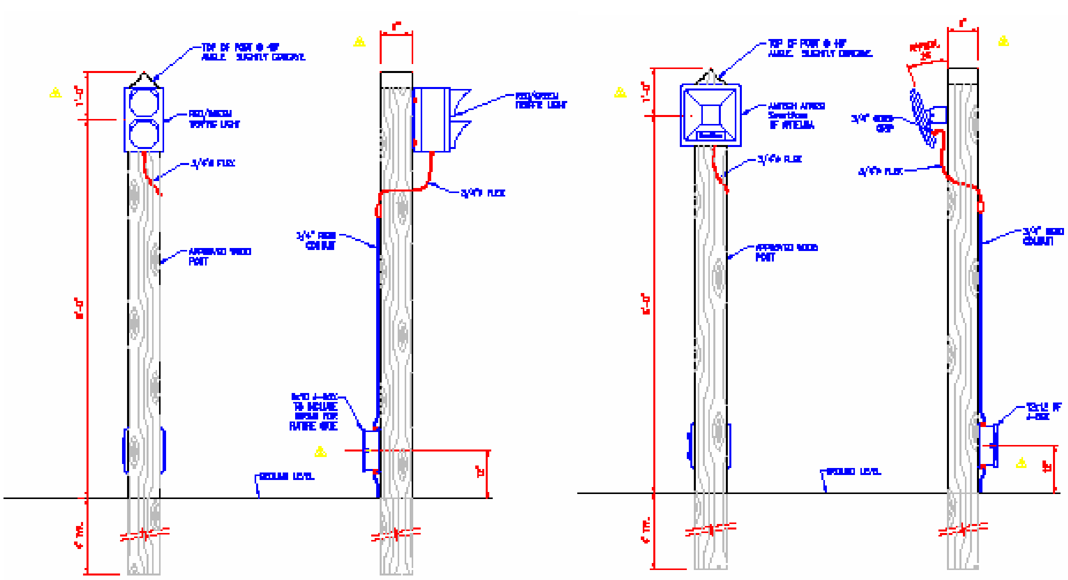

Figure 12: Traffic Signal and Antenna (Source: Kanawha Scales)

At the North Entrance, the right entrance lane (previously designated "employees only") is now "employee and AVI user only." Because of the unique layout at the Northeast Entrance, both entrance lanes are equipped with AVI. Therefore, an AVI user can either use the left (regular) or right (oversized vehicles) lane.

3.3 Main Server, Communications and Software

As shown previously in Figure 10 (AVI equipment layout), each entrance station computer is connected via modem to the main server located at YNP Headquarters at Mammoth. The main server coordinates with the entrance station computers to update changes to the user database, and store data logged by the AVI computer. The software allows YNP personnel to enter, edit, or delete user accounts. The main server will update the entrance computers. The main server is designed for easy expansion of the system to all five entrances.

3.4 Deployment Costs

Kanawha Scales provided the equipment, installation and training for the AVI system at a cost of $289,920. YNP staff time to contract, oversee installation, receive training on the system, populate database, and distribute tags was estimated at $19,573. No new staff were hired; this is an estimate based on the number of hours existing staff worked on the project. During the road construction at the Northeast Entrance add-ons such as communications conduit, estimated at $6,920, were completed in anticipation of the AVI system.

4 CHALLENGES AND ISSUES

There were several issues and challenges that occurred during the design, installation and testing of the AVI system. These issues are discussed here.

Because the buildings are historic, approval was required from the State Historic Preservation Office (SHPO). Although this is important it delayed the installation and limited what could be done with design. The SHPO did not approve installation of a gate, although the wiring is in place. The SHPO also requires that all components blend in with the building. As a result, the size, location and color of the signal head may limit the visibility. It is possible that many vehicles did not respond to the signal possibly because they did not see it (Figure 13). Clearly aesthetics are a priority and a more visible signal may not be possible.

Figure 13: Signal and Antenna at North Entrance

Following installation, the system needed some early modifications to help it work consistently. The attendant notification sound was changed after initial complaints that it was "annoying." Initially the system also had difficulty reading tags. A different antenna was used and this seemed to improve the system. To date the system still does not read every tag.

One negative impact of the system is the encroachment of system components on the limited storage space at the entrance stations. Figure 14 shows the storage unit at the Northeast Entrance with the AVI equipment on one wall.

Figure 14: AVI Equipment at Northeast Storage Unit

5 DATA COLLECTION METHODOLOGY

This section of the report will detail the methodology employed in gathering data relating to traffic volumes, delay times and user acceptance. Specifically, data discussed includes: user surveys, historical visitation data, perceptions of traffic by Park staff, manually collected stop watch delay times and time stamp video delay times.

5.1 Definitions

Some terms commonly used in queuing analysis, and used in this report, are defined here in layman's terms.

Flow refers to the number of vehicles that pass a given point in a given time interval. It is usually expressed in vehicles per hour

An **inter-arrival time** is the length of time that passes between vehicles arriving (sometimes called headway). This is usually defined as when they arrive at the back of the queue. The average can be calculated as the inverse of the flow. This is expressed in minutes or seconds per vehicle.

A **queue** is a line of vehicles waiting to be serviced. Characteristics of the queue can be measured or estimated such as average queue length (in number of vehicles). The queue does not include the vehicle(s) being serviced.

The **service time** is the amount of time it takes for a "server" to process one vehicle. This does not include the time in the queue, only when the driver is directly interacting with the server.

Inter-arrival times and services times are commonly assumed to follow a **Poisson** or some other common **distribution**. The time (service or inter-arrival) for an individual vehicle is not constant and varies with a certain probability distribution.

The **flow time**, for the purposes of this paper, is the sum of the time in the queue and the service time.

Delay time is the amount of time waiting in the queue. For a single vehicle this can be expressed as a unit of time (minutes or seconds). For the entire entrance facility, a specific lane, or a specific user group this is expressed as vehicle-hours-per-day (other units of time can be used in place of hour or day).

5.2 User Survey

In order to determine the perceived usefulness and ease of use of the system, users were interviewed. Park employees that had been issued a pass were sent a mail back survey shown in Appendix A. Users were asked questions regarding how much time the AVI system saved them, how difficult it was to use, and the overall effectiveness. Surveys were distributed by

Yellowstone National Park. 313 surveys were returned which accounted for almost all of the surveys distributed in the spring of 2002. The type of vehicle (user) is shown in Figure 15.

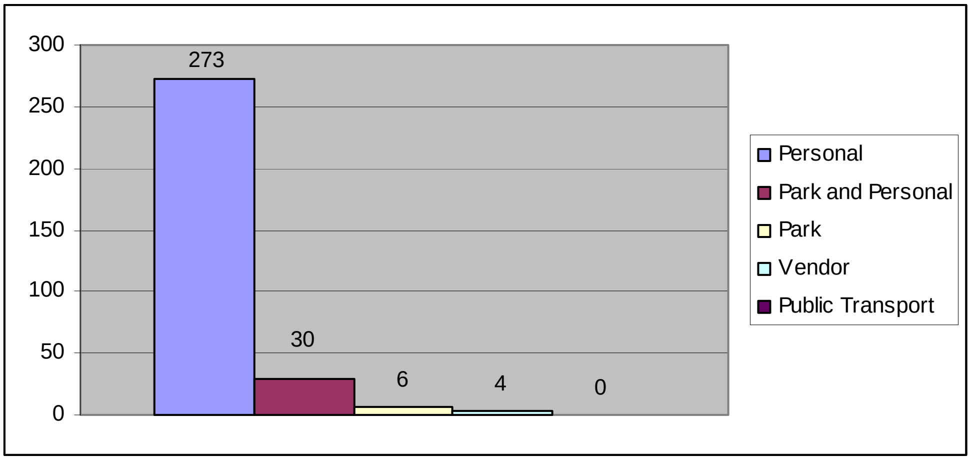

Figure 15: Survey Respondents: Type of Vehicle

The perceived time savings is shown in Figure 16 and the perceived improvement in Figure 17. There were no significant differences in the answers between the types of vehicles used or the frequency of entering the park. A majority of the users saw no time savings.

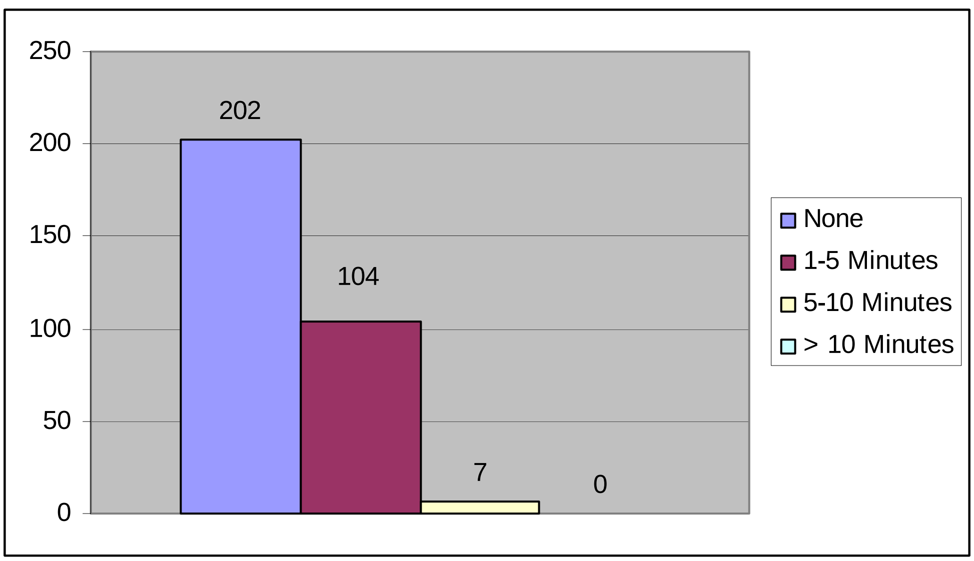

Figure 16: Perceived Time Savings

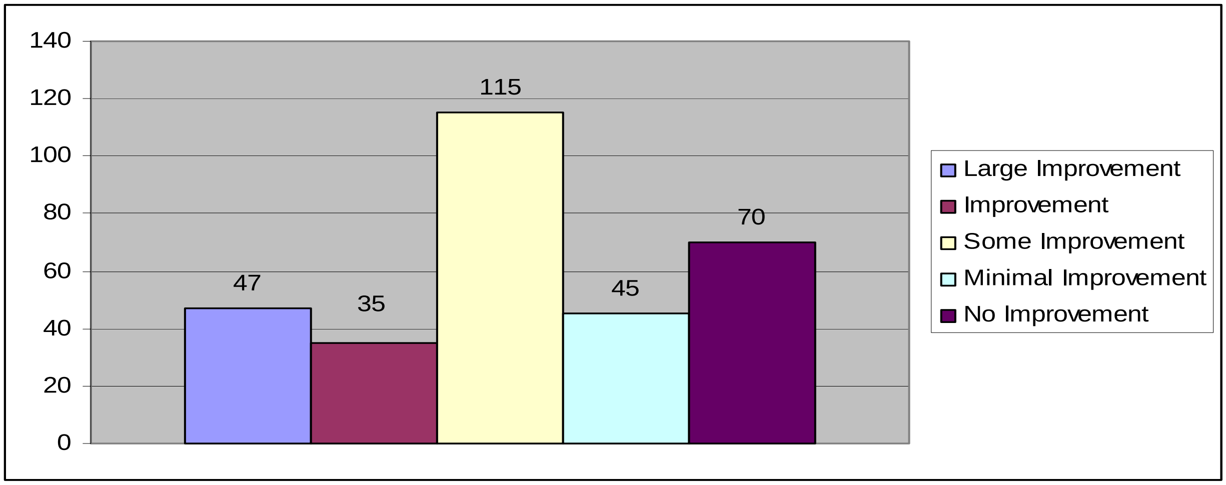

Figure 17: Perceived Improvement

287 of the 294 respondents stated the system was not difficult to use. The main complaint was that it did not always work. Some stated they would like to see the vehicle tag be smaller. It was also mentioned that the delay was primarily from not being able to get into the employee lane at the North Entrance due to the geometry.

5.3 Historical Visitation Data

Visitation patterns and growth trend data were required in order to establish appropriate data collection timeframes. For the purpose of this study it was determined that collection timeframes must coincide with peak volume periods. Therefore, historical visitation data was required as a benchmark. The following sections describe the sources of the historical data.

The Visitor Services Office (VSO) of Yellowstone National Parks keeps statistics on the number and type of visitors entering the park. These statistics are recorded at the entrance gates using the gate's cash registers. Daily and monthly totals were collected from 1997-1999 for the North, Northeast, and West entrances. The Annual totals for 1997-1999 are provided below in Table 2 for the North, Northeast and West entrance gates, respectively.

Table 2: Annual Total of Entrances (Three Gates Only)

Entrance Gate	1997	1998	1999
North	167,753	176,496	185,730
Northeast	78,652	54,886	66,551
West	323,124	394,945	354,382
Total	569,529	626,327	606,663

To identify the peak time periods for data collection, the data from 1999 was analyzed on a monthly basis for each entrance. Figure 18 and Figure 19 summarize the aggregate data for the North and Northeast entrances, respectively.

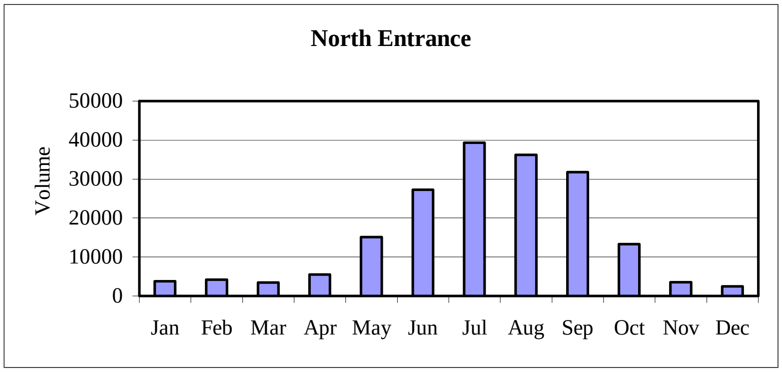

Figure 18: Monthly Volumes at North Entrance

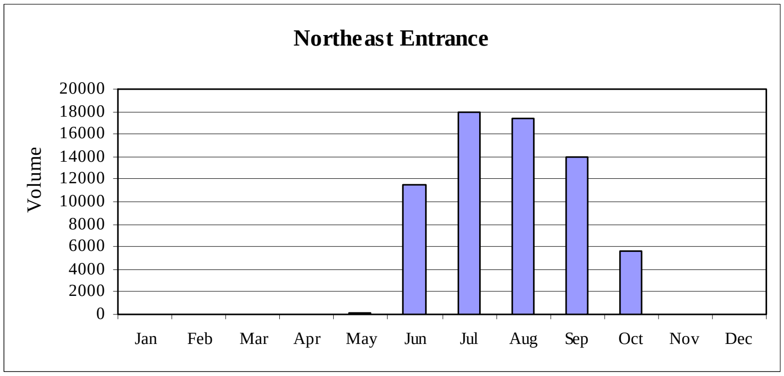

Figure 19: Monthly Volumes at Northeast Entrance

From the graphs displayed above, one can see that the entrance gates displayed similar visitation patterns throughout the summer of 1999, with peak periods occurring from early July to August. With this information, the evaluation team could select data collection dates within the peak timeframe, assuming that visitation patterns do not fluctuate drastically from year to year.

Typical of most places, traffic continues to increase as shown in Figure 20. Although there has been a leveling off in recent years, this is likely due to recent economic and social factors. Visitation will likely continue to increase.

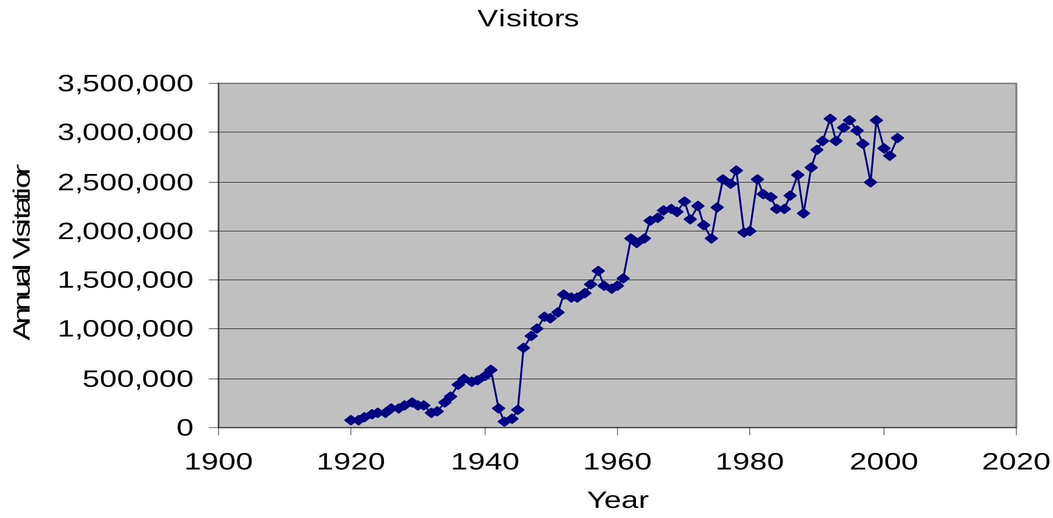

Figure 20: Annual Park Visitation

5.4 Vehicle Volumes from Staff Interviews

In order to prepare an evaluation technique, entrance station personnel were interviewed to obtain estimates of the maximum expected delay, typical timeframes of the maximum queue and its respective length, and current methods employed to mitigate congestion. The ranger in charge of each gate provided the relevant information.

Ranger Rick McAdam provided pertinent information on the North Entrance gate. From this interview, the following pieces of information were gathered:

- A queue typically forms beginning at 9AM and is fairly constant through 1PM.
- Employees constitute a large portion of the traffic during this time frame
- Approximately 5-10% of the gate's traffic uses the outside lane (for employees)
- The convergence of an upstream vendor road causes traffic congestion.

Ranger Bundy Phillips provided similar information concerning the Northeast Entrance gate.

- A queue typically forms from 10 AM through 4 PM.
- This queue forms so late in the morning due to the long travel time on the Beartooth Highway.
- The maximum probable queue at the northeast lane is approximately 15 vehicles long.

Ranger Julie Hannaford provided similar information concerning the West entrance to the Park.

- The longer queues usually are present from 7:30 AM through 1:30 PM. In an effort to combat this problem, the entrance gate was built four lanes wide.
- A ranger operates the express lane when volumes are highest (approximately 9:00AM-11:00AM).
- By utilizing this four-lane operation, the queue lengths are limited to approximately 20 vehicle maximums.

5.5 Preliminary Delay Times

Using the information provided above, the evaluation team developed a strategy for collecting the following data for each vehicle at all three entrances.

- Arrival Time – time when a vehicle comes to within one vehicle length of the standing queue or the gate entrance
- Process Time – difference between the gate arrival and departure times.
- Pass Type

Using custom made data collection sheets; the evaluators recorded the time each vehicle entered and left the queue as defined above. The upstream data collectors recorded vehicle make, class, color and time entering queue. The downstream data collectors recorded vehicle make, class, color, entrance sticker type, and time leaving the queue. This technique was employed due to the speed and volume of traffic flowing through the gate. A schedule of the data collection times and dates is provided below in Table 3.

Table 3: Data Collection Times and Dates

Entrance	**North**		**Northeast**		**West**	
Dates	7/31/00	8/1/00	8/15/00	8/16/00	7/27/00	7/28/00
Time of Day	7:30 AM - 3:30 PM	7:30 AM - 2:30 PM	8:00 AM - 4:00 PM	8:00 AM - 2:00 PM	7:15 AM - 4:00 PM	7:15 AM - 2:00 PM

Each vehicle was recorded twice, upon entering and leaving the queue. Therefore, it was necessary to match the two data records in order to calculate each vehicle's delay time. Due to error in identifying and recording vehicle characteristics, a decision logic sequence was developed to match upstream and downstream records. If the vehicles match was not clear, it was left out of further calculations.

After matching and evaluating the data, it was apparent that a large portion of the data was missing a required field, was inaccurate or could not be matched. The North Entrance was used to provide an estimate of the error in the data, where the error % is calculated as follows:

$$Error\% = \left(\frac{Invalid\ \mathrm{Re}cords}{Valid\ \mathrm{Re}cords} \right) x100$$

Table 4: Estimate of Error in Data

	July 31, 2000	August 1, 2000	% Error
Valid Records	1021	1034	2055
Invalid Records	240	179	419
% Error	24%	17%	**20%**

The results of this data collection effort are still reported here for information purposes. However, due to the error, they are not used in the Queuing analysis. The data collection errors were resolved as discussed in the next section.

The North Entrance had an average flow time of 2.59 minutes with a maximum and minimum of 14.48 minutes and 0.02 minutes respectively. Table 5 below displays a detailed assessment of the values for both July 31st and August 1st of 2000, and is followed by Figure 21 displaying the distribution of flow times.

Table 5: North Entrance Flow Times

Flow Time Summary for all Vehicles on July 31 and Aug 1, 2000						
	Avg Flow Time		**Max Flow Time**		**Min Flow Time**	
Date	*seconds*	*minutes*	*seconds*	*minutes*	*seconds*	*minutes*
31-Jul-00	147.38	2.46	869.00	14.48	1.00	0.02
1-Aug-00	164.75	2.75	755.00	12.58	1.00	0.02
Overall Avg Flow Time	155.46	***2.59***	869.00	14.48	1.00	0.02

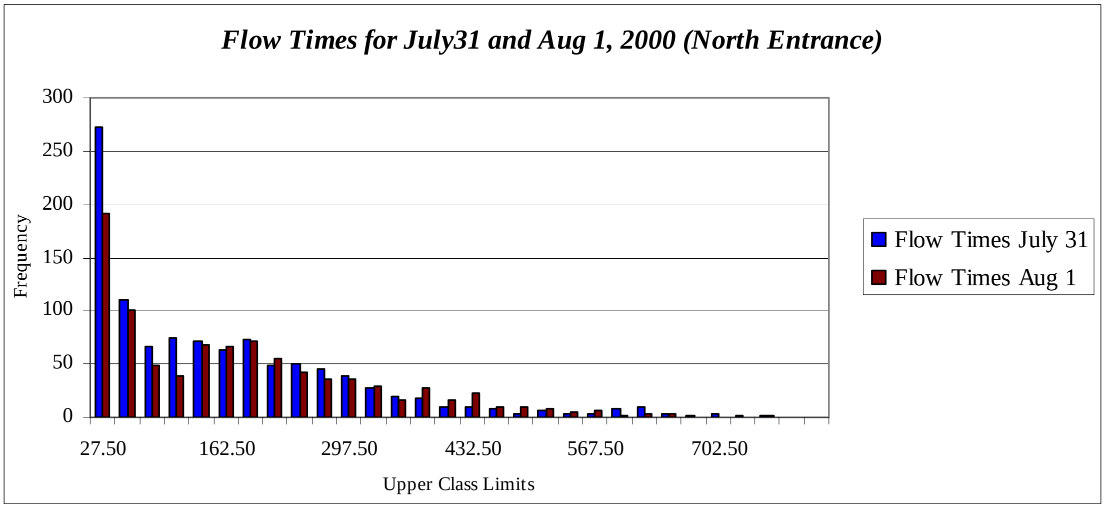

Figure 21: Histogram of Flow Times at North Entrance

The Northeast Entrance had an average flow time of 1.55 minutes with a max and min of 12.75 minutes and 0.02 minutes respectively. Table 6 displays a detailed assessment of the values for both August 15th and 16th of 2000, and is followed by Figure 22 displaying the distribution of flow times.

Table 6: Northeast Entrance Flow Times

Flow Time Summary for all Vehicles on Aug 15 and Aug 16, 2000 (Northeast)						
	Avg Flow Time		**Max Flow Time**		**Min Flow Time**	
Date	*seconds*	*minutes*	*seconds*	*minutes*	*seconds*	*minutes*
31-Jul-00	90.45	1.51	396.00	6.60	1.00	0.02
1-Aug-00	97.33	1.62	765.00	12.75	2.00	0.03
Overall Avg Flow Time	93.01	***1.55***	765.00	12.75	1.00	0.02

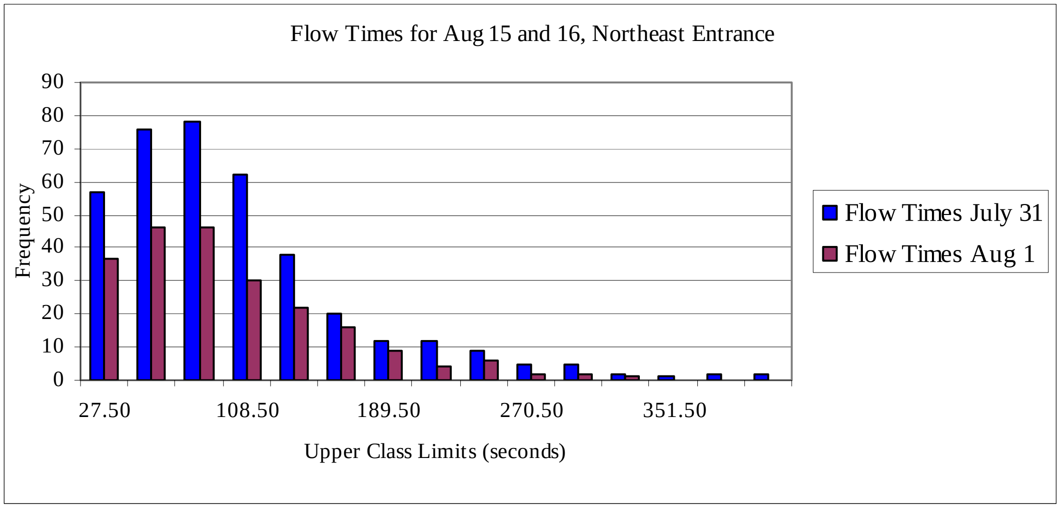

Figure 22: Histogram of Flow Times at Northeast Entrance

5.6 Revised Delay Times

To resolve the previous problem, time stamped video was used. The traffic volume data was collected at the North and Northeast Entrances. The data was collected for north gate on 7-30-02 and 7-31-02 and northeast gate on 8-14-02 and 8-15-02. Twenty-four hour data collection was not feasible due to lighting. The data collection efforts were concentrated to times when a measurable queue was present (i.e. 7 AM to 3 PM).

Similar to the previous effort, the evaluators recorded some vehicle characteristics, the time each vehicle entered and left the queue, and the vehicle pass type. At the same time a time stamped video recorded all the vehicles. The video was used to obtain accurate times for each vehicle. The following pass types categories were used:

- Permanent Employees – P-EMP
- Seasonal Employees – S-EMP
- Cooke City Residents – RES
- Contractors – CONT
- Vendors to the park – VEND
- Commercial Vendors – COMM
- Government Vehicles – GOV
- Park Visitors – VISITOR
    - Purchasing pass – NP
    - Season pass – PASS
    - Receipts -RECEIPT

From the data collected the number of arrivals, inter-arrival time, process time and flow time were found for each type of pass. The total vehicles (for the two, 8 hour periods on consecutive days) are shown in Table 7 and Table 8.

Table 7: Two-Day Totals for North Entrance

Pass Type	Entrances	Total Delay	Avg. Delay
REC	549	11:39:41	0:01:16
PASS	676	14:04:10	0:01:15
NP	545	12:29:50	0:01:23
P-EMP	446	0:12:49	0:00:02
S-EMP	212	0:07:01	0:00:02
VEND	60	0:10:27	0:00:10
CONT	30	1:20:53	0:02:42
COMV	4	0:00:59	0:00:15
GOV	72	0:02:36	0:00:02
RES	117	0:01:45	0:00:01
MISC	11	0:09:08	0:00:50
Total	2722	40:19:19	0:00:53

Table 8: Two-Day Totals for Northeast Entrance

Pass Type	Entrances	Total Delay	Avg. Delay
REC	114	1:06:34	0:00:35
PASS	255	3:25:17	0:00:48
NP	276	4:26:17	0:00:58
P-EMP	12	0:13:02	0:01:00
S-EMP	11	0:10:46	0:00:59
VEND	15	0:00:56	0:00:04
CONT	13	0:11:46	0:00:54
COMV	0	na	na
GOV	24	0:10:28	0:00:26
RES	15	0:11:14	0:00:45
MISC	0	na	na
Total	736	9:56:20	00:00:49

The Northeast Entrance had low volumes with comparatively little delay. For this reason the queuing model discussed in the next section was only completed for the North Entrance. For this analysis we reduced the data to best-fit distributions for inter-arrival times.

For certain pass types the average flow rates will be different during different times of the day. The first step is to segregate the data for each pass type into different daily time segments. If a t-value of more than two (2) cannot be found it was not segregated (a t-value of greater than 1.96 means we are 95% confident the different time segments have different averages). For the North Entrance the time segregations are shown in Table 9.

Table 9: Time Splits

Pass Type	Start Time	End Time	flow (veh/hr)	t-test
NP-1	7:00:00	8:00:00	7.50	2.78
NP-2	8:00:00	10:40:00	32.44	3.49
NP-3	10:40:00	11:40:00	54.50	-3.22
NP-4	11:40:00	15:00:00	36.75	
PASS-1	7:00:00	8:20:00	30.38	3.44
PASS-2	8:20:00	10:30:00	63.92	-6.77
PASS-3	10:30:00	15:00:00	35.11	
RECIEPT-1	7:00:00	8:50:00	36.82	2.26
RECIEPT-2	8:50:00	9:50:00	55.50	-2.18
RECIEPT-3	9:50:00	11:30:00	40.50	-3.76
RECIEPT-4	11:30:00	15:00:00	23.57	
Pemp-1	7:00:00	7:40:00	58.50	4.19
Pemp-2	7:40:00	8:00:00	133.50	-3.21
Pemp-3	8:00:00	8:20:00	57.00	-3.60
Pemp-4	8:20:00	9:20:00	32.50	-5.23
Pemp-5	9:20:00	15:00:00	15.35	
Semp-1	7:00:00	7:40:00	13.50	2.27
Semp-2	7:40:00	8:00:00	49.50	-6.61
Semp-3	8:00:00	15:00:00	11.29	
VEND	7:00:00	15:00:00	3.63	
CONT	7:00:00	15:00:00	1.88	
GOV	7:00:00	15:00:00	4.50	
COMM	7:00:00	15:00:00	0.25	
RES	7:00:00	15:00:00	0.38	
MISC	7:00:00	15:00:00	0.69	

The next step was to find a feasible distribution to represent the inter-arrival times for each of the pass-time elements in Table 9. Poisson is a distribution is commonly used for traffic flow. It is beneficial since it only uses the average inter-arrival time as the only variable (not the variance or other variables). Because of this, assumptions can be made about future increases in traffic flows for various pass types without the need to make assumptions about the future variance. As an alternative, a Gamma distribution can be used in place of Poisson where a shape factor is used to increase or decrease the tails for a better fit. A gamma distribution with a shape factor of 1 is equivalent to a Poisson distribution. Figure 23 shows an example of the probability density function for the raw data, a Poisson distribution and a Gamma distribution for one of the pass-time groups.

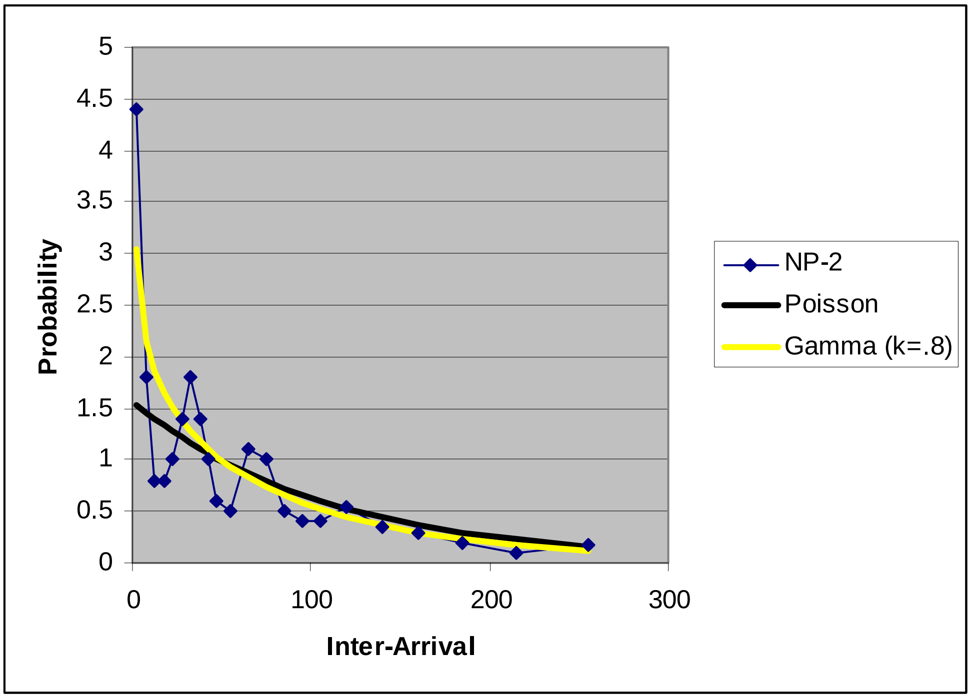

Figure 23: Probability Density Functions

Table 10 summarizes the results of the Chi Squared goodness of fit analysis. Some pass-time groups had too small of a sample size to yield any statistically significant results. These groups will have minimal impact on the total delay by their very virtue of having very low flows. These are assumed to be Poisson distributed. The second permanent employee time group (PEMP-2) did not meet the requirement, but was close. The shape factors in Table 10 and the flow rates in Table 9 will be used for the queuing analysis.

Table 10: Best Fit Distributions for Inter-Arrival Times

Pass Type	Shape Factor	k	x ^2	Acceptable x^2
NP-1	1	Small Dataset Assume Poisson		
NP-2	0.8	22	26.28	33.92
NP-3	1	16	18.21	26.30
NP-4	1	30	41.39	43.77
PASS-1	1	13	9.32	22.36
PASS-2	0.9	11	18.45	19.67
PASS-3	0.9	16	26.02	26.30
RECIEPT-1	0.8	19	21.76	30.14
RECIEPT-2	1	15	16.83	25.00
RECIEPT-3	1	19	29.95	30.14
RECIEPT-4	1	23	22.72	35.17
PEMP-1	1	9	8.03	16.92
PEMP-2	1	12	21.85	21.03
PEMP-3	1	5	1.82	11.07
PEMP-4	1	9	7.38	16.92
PEMP-5	1	25	16.1	37.65
SEMP-1	1	Small Dataset Assume Poisson		
SEMP-2	1	4	0.58	9.49
SEMP-3	1	23	23.06	35.17
VEND	1	9	4.62	16.92
CONT	1	4	1.96	9.49
GOV	1	9	6.74	16.92
COMM	1	Small Dataset Assume Poisson		
RES	1	Small Dataset Assume Poisson		
MISC	1	Small Dataset Assume Poisson		

The service times for each pass type were also determined. These are shown in Table 11 for the North Entrance. Unlike the inter-arrival, the service times are assumed not to vary with the time of day. The service times for visitors are larger due to the fact that attendants spend more time with visitors explaining the details of the park and safety precautions. The longest time was for visitors with no pass (NP), likely due to the extra time needed for purchasing a pass. No feasible distribution type was found for the service times, so the existing distribution was used. In other words, for the queuing model even if the vehicle flows are changed (i.e., increased based on future predictions) the service times will not change. A vehicle in the model is randomly assigned one of the measured service times from the base data with the same pass type.

Table 11: Average Service Times for North Entrance

Pass Type	Average Service Time (s)
COMV	23
CONT	16
GOV	08
MISC	11
NP	51
PASS	24
P-EMP	15
REC	16
RES	17
S-EMP	13
VEND	12

5.6.1 Flow Times for AVI Users

The video data was collected prior to the AVI installation. For the queuing model, the evaluation team needed a service time distribution for AVI users. The service time of AVI users was collected manually with a stopwatch. The data was collected from 7-9:30 AM on a weekday. The service time for the 84 vehicles with AVI tags were consistently about 1 second. For the model, AVI users are assigned a service time of one second.

Additionally during the period of this data collection approximately 50% of the entering vendors (VEND) and 15% of permanent employees (PEMP) had AVI tags. These proportions are used as the “current” scenario (discussed later).

5.7 Queuing Model for North Entrance

Arrival and service times were created based on the pass-time group distributions described in the previous sections. The bypass lane from the vendor facilities is disregarded for the queuing model. Vehicles will use either lane one or lane two. Vehicles using lane two cannot move to lane two until they pass the “split point”. The value of the split point in reality is about 10 vehicles back from the entrance station. This value was calibrated so the total delay matched that of the base year data. The calibrated value was 15 vehicles to the split point. It is probably longer due to the fact that employees often use the vendor service road to bypass the lane 1 queue.

The value of the split point was also used as the trigger for the second server (see the section on entrance operating procedures). If the queue is longer than the split point (i.e. 15 vehicles) than a person will presort vehicles such that anyone with a pass that would normally use lane one could now use lane two. The following lane use rules apply to the various pass types:

- Can only use lane 1: NP
- Can only use lane 2: PEMP, SEMP, VEND, CONT, GOV, COMM, RES, MISC

- Can only use lane 1 unless a second server: PASS, RECIEPT

The lane assignment is generally true in real operating situations. However, occasionally those in the lane 2 group will use lane 1.

After the model was calibrated several scenarios were created. There were three growth scenarios modeled with each of four different AVI use scenarios for a total of 12 different scenarios.

- Growth Scenarios
    - Base Year: Traffic flows matched that of the baseline data collected.
    - 10% Growth: Flows for all pass-time groups increase by 10% of base year.
    - 50% Growth: Flows for all pass-time groups increase by 50% of base year.
- AVI use Scenarios
    - No AVI: No vehicles are equipped with AVI.
    - Current: 50% of “VEND” pass types and 15% of “PEMP” pass types are randomly assigned to have AVI and a 1 second service time.
    - All PEMP: 50% of “VEND” pass types and 100% of “PEMP” pass types are randomly assigned to have AVI and a 1 second service time.
    - 20% Pass: AVI use includes Current scenario (50% VEND, 15% PEMP) and 20% annual pass-holders (“PASS”).

For each scenario the simulation was run 5 times and an average taken for the total delay found. The results are shown in Table 12. The average queue length throughout the day was also determined as shown in Table 13.

Table 12: Total Delay (veh-hr/dy hh:mm:ss)

Growth \ AVI Use	No AVI	Current	All PEMP	20% PASS
Base Year	35:55:29	35:37:37	35:16:37	29:30:45
10%	49:18:52	49:18:31	48:37:35	41:12:17
50%	91:54:45	89:16:54	86:25:00	79:10:16

Table 13: Queue Length (vehicles)

Growth \ AVI Use	No AVI	Current	All PEMP	20% PASS
Base Year	4.5	4.5	4.4	3.7
10%	6.2	6.2	6.1	5.1
50%	12.4	12.0	11.7	10.7

There is minimal delay savings when part or all of the permanent employees use AVI. This is not surprising since employees already have very low service times. There could be an impact if annual pass holders were added to the system. Notice that the impact of AVI participation increases as the total flow increases.

The model shows a more than doubling of total delay with a 50% increase in traffic flow. Delay at the North Entrance will likely get much worse than it currently is. However, it is important to keep in mind that the 91 plus hours of delay in the 50% growth – no AVI scenario amounts to 2 minutes 40 seconds per vehicles, which could be considered very reasonable. Also, the model is calibrated on the base year data. As with any model, the further from the base year, the less accurate it becomes.

5.7.1 Limitations of the Queueing Model

The queuing model is only an estimation of reality and has several limitations. Some of the assumptions and limitations are discussed here. Future improvements to the model could resolve these limitations.

- In the model service times were not affected by time of day or length of the queue. In reality visitors and attendants are likely to spend longer exchanging information and visiting if there is not a line of cars waiting. The extreme values of service times (i.e., 45 minutes) were not used by the model. In reality these extreme service times occurred when there was no queue and caused no delay. In initial runs of the model these long service times occurred when there was a queue and caused considerable delay.

- The vendor access road was not modeled due to the complexity it added. The model could be improved to allow for probability of vehicles to use this short cut depending on their knowledge of the area and length of queue.

- The model does not include erratic human behavior such as using the inappropriate lane, vehicle break downs, people stopping to take a picture, people cutting in line, etc.

5.8 Summary of Benefits

The USDOT suggests the value of travel time is $10.17 per vehicle per hour[1]. The North gate has high traffic volumes for approximately three months out of the year. These estimates assume only three months per year of heavy traffic, and that the AVI system functions without any major overhaul requirements for five years. Using the No AVI option as the base of comparison, travel time savings for five years (assuming only three months per year of heavy traffic) are shown in Table 14.

[1] USDOT Departmental Guidance for Valuation of Travel Time in Economic Analysis [Memorandum], April 9, 1997

Table 14: Value of Five Year Travel Time Savings

Growth \ AVI Use	Current	All PEMP	20% PASS
Base Year	$1,090.22	$2,371.64	$23,476.43
10%	$21.36	$2,519.11	$29,691.32
50%	$9,632.01	$20,121.35	$46,648.77

Clearly even if traffic flows increase significantly and the system is expanded to annual pass-holders, travel time savings alone is not enough to warrant the costs of the system. However, other less quantifiable benefits include:

- Enhanced staff capabilities from dual use of AVI computers
- Public relations value of improved service
- Freeing time of entrance staff to focus on assisting non-AVI users

The reduction in service time is not included in the delay time savings. Patrons using AVI would likely not have long service times when using the traditional method of showing a pass.

6 SUMMARY AND CONCLUSIONS

The AVI system was installed at the North and Northeast Entrance and was operational by Spring 2003. Although these gates do not have the highest flow of vehicles, they were selected to test the system since a considerable number of employees use these entrances.

Two day totals for the Northeast Entrance measured 740 vehicles and almost 10 hours of delay. Because of the small amount of delay at the Northeast gate, it was not modeled beyond this initial measurement. The two-day totals for the North Entrance measured 2700 entrances and over 40 hours of vehicle delay. The entrance was modeled based on these data and showed no significant reduction in delay times with AVI as it is currently used. However if traffic increased and the system was expanded to include annual pass holders a delay savings of 10 hours per day could be realized.

The geometries at the North and Northeast Entrances limit the effectiveness of such a system. The North Entrance has a single lane until approximately 75 feet from the entrance station. So vehicles cannot use the AVI lane if the queue extends beyond this point unless they use the vendor access road. At the Northeast Entrance both AVI lanes could potentially be held up with non-AVI users since they are both mixed use.

Strong consideration should be given to expansion of the system to the West entrance, which has the highest flows. The West entrance does not have the geometric constraints that hindered the effectiveness of the system at the North and Northeast Entrance.

To maximize effectiveness at the West Entrance, it would be advisable to conduct a similar modeling effort prior to installing any system, and to ensure that reliability issues have been addressed.

7 REFERENCE

USDOT Departmental Guidance for Valuation of Travel Time in Economic Analysis [Memorandum], April 9, 1997

8 APPENDIX A: USER SURVEY

Yellowstone National Park
Automated Vehicle Identification System (AVI)

USER SURVEY

1 Please specify where you have used the AVI system? ***(Check only one)***

- ❑ North Park Entrance (Gardiner)
- ❑ Northeast Entrance (Cooke City)
- ❑ Both North and Northeast entrances

2 What type of vehicle(s) have you used with the AVI system? ***(Check all that apply)***

- ❑ Personal Vehicle
- ❑ Park Vehicle
- ❑ Vendor Vehicle e.g., corporate delivery truck
- ❑ Public Vehicle e.g., bus or other means

3 How often do you enter the Park in an average week? ***(Check only one)***

- ❑ Less than one
- ❑ 1 - 4
- ❑ 5 - 14
- ❑ 15 – 30
- ❑ More than 30

4 How much time do you feel the AVI system saves you each time you enter the Park? ***(Check only one)***

- ❑ I have not noticed a difference in wait time
- ❑ 1 – 5 min.
- ❑ 5 – 10 min.
- ❑ More than 10 min.

5 Please compare the AVI system to traditional park methods. ***(Check only one)***

Large Improvement		Some Improvement		No Improvement
☐	☐	☐	☐	☐

6 Please rate how <u>difficult</u> you feel the AVI system is to use. ***(Check only one)***

Very Difficult		Moderately Difficult		Not Difficult
☐	☐	☐	☐	☐

7 Please rate the overall <u>effectiveness</u> of the AVI system. ***(Check only one)***

Very Effective		Moderately Effective		Not Effective
☐	☐	☐	☐	☐

General Comments/Suggestions: ______________________________

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THANK YOU FOR YOUR PARTICIPATION!