fice of University Research, UMTA. The views expressed are ours and reflect neither the opinions nor policies of UMTA.

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New Jersey Turnpike Automatic Traffic Surveillance and Control System Performance Observation

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The New Jersey Turnpike Authority's Automatic Traffic Surveillance and Control system became fully operational in January 1976. The system has proven to be an effective tool for managing traffic flow on the New Jersey Turnpike's most heavily traveled section. Motorists are provided with a diversion capability to the least-congested roadway by means of changeable message signs. The paper describes the unique roadway configuration covered by the system as well as the traffic parameters that dictate sign changes. Traffic flow affected by the system during the afternoon and evening peak hours of two high-volume traffic days was evaluated. Automatic sign changes, the magnitude of traffic parameters that caused the sign changes, and the number of vehicles diverted during these two days are described in this paper.

The New Jersey Turnpike Authority's Automatic Traffic Surveillance and Control (ATSC) system was installed and made operational in January 1976. This system was originally conceived and developed prior to and during the widening of the northern 36 miles of the New Jersey Turnpike in the latter part of the 1960s. Its purpose is to completely automate traffic control on the 12-lane section of the New Jersey Turnpike that extends 36 miles from central New Jersey to the George Washington Bridge approaches. The ATSC system provides traffic surveillance and control based on traffic data received from the field. The traffic parameters obtained from the computer are occupancy, average running speed, volume, unused capacity, and vehicle classification. These parameters are collected by means of 850 loop detectors imbedded in the pavement of all roadway components of the 36-mile network.

The traffic data collected are transmitted via buried cable to two front-end processors that process and compress the raw data and, in turn, transmit the refined data to a main computer for further analysis and action, if necessary. This main operating computer is a Digital Equipment

Corporation PDP 11-40. The traffic control is implemented by this main computer through use of traffic control strategies and accompanying algorithms programmed therein that react to the data collected and, by remote control, operate various changeable message directional signs, variable message speed limit signs, and hazard warning signs installed at key locations throughout the 36-mile section.

The purpose of this paper is to examine the performance of the ATSC system during peak-period travel times. A comprehensive description of the system can be found elsewhere (1). The ATSC system has saved motorists from delays by means of diversion. The diversion capability is due to the unique design of the roadway in the most northerly 36 miles.

The two parameters obtained directly from the field that dictate sign changes are occupancy, used for the purpose of incident detection, and unused capacity, used for balancing traffic on two parallel roadways. The occupancy parameter is defined as that portion of time, in percent, that vehicles occupy a loop detector during 1 min. For example, if vehicles occupy the loop detector for 6 s during a 1-min interval, the occupancy is 10 percent. The unused capacity parameter is a measurement that takes into consideration existing hourly equivalent volume based on 1-min measurements and the capacity of the roadway. Unused capacity is defined as the capacity of the roadway minus the hourly equivalent volume. Normally the capacity of the roadway is set at 1800 equivalent vehicles/h per lane. However, in some locations a roadway-capacity adjustment is made to achieve proper sign changes. For example, in the area near interchange 14, where considerable merging and diverging maneuvers take place, the capacity of the roadway is set at 1500 vehicles/h per lane. The hourly equivalent volume is the volume per minute multiplied by 60. Vehicle classifications are done by means of the measurement of vehicles over a loop trap configuration. A vehicle length threshold of 23 ft was found to give excellent results. Passenger car equivalency of 2.5 for each commercial vehicle was found to be most effective, based on observations of sign changes triggered after using passenger car equivalency between 1.8 and 2.8

The advantage of using the occupancy parameter for monitoring quality of flow is that this parameter can be measured directly in the field, by using pulse lengths transmitted directly from the detectors. The percentage of occupancy, based on 1-min measurement, is equal to

$$Q = 100[(T_1 + \ldots T_n)/60] \tag{1}$$

where

Q = percentage occupancy during a specific minute,
T_1 = first pulse length(s) during the specific minute, and
T_n = last pulse length(s) during the specific minute.

The ATSC system also provides average running speed per minute at each loop detector site. The average running speed is used only for monitoring the motorist's compliance in certain sections where the speed limit is reduced. Figure 1 indicates the relationship between percentage occupancy and average running speed. This information was obtained from various ATSC system computer printouts that showed percentage occupancy and average running speed for the same period. Figure 1 also contains level-of-service indicators. Table 1 shows level-of-service A-F as it related to occupancy and average running speed. The relation between the average running speed and the level of service was taken from a Transportation Research Board circular (2, Table 2.1, p. 168).

The congestion-producing incident is detected by means of a mathematical formula that takes into consideration the percentage occupancy at an upstream and downstream loop detector. This mathematical formula is composed of the following:

$$\text{Occupancy upstream} - \text{occupancy downstream} > 10 \text{ percent} \tag{2a}$$

$$100 \text{ percent}[(\text{occupancy upstream} - \text{occupancy downstream}) \div \text{occupancy upstream}] > 50 \text{ percent} \tag{2b}$$

Equation 2b ensures that the ATSC system would not consider an incident when the roadway is heavily congested. For example, if the upstream detector indicates an occupancy of 53 percent and the downstream detector indicates an occupancy of 30 percent, Equation 2b is not satisfied. However, when the two conditions are satisfied, an incident alarm will sound off. Then, the computer will make appropriate sign changes that result in the diversion of traffic from the incident area. Traffic diversion will also occur when the unused capacity on the three-lane roadway section is less than 500 equivalent vehicles, provided that the parallel roadway is capable of accommodating the diverted traffic. The computer can determine the effect of the diverted traffic prior to the actual sign change. The projection is done by using historical traffic data that are stored in the computer. An example of actual sign changes triggered as a result of occupancy and unused capacity is described in the last part of this paper.

ROADWAY SECTION

For the purpose of explaining the action taken by the ATSC system, a brief explanation of the area is given. As previously indicated, the ATSC system covers 36 miles between the area near interchange 9 (milepost 82) and its northern terminus at US-46 (milepost 118). The area between mileposts 82 and 106 is known as the dual-dual roadway. This section is composed of two separate three-lane parallel roadways that are separated by a median barrier. Under normal conditions, all trucks and buses that enter the dual-dual roadway must use the outer roadway. Passenger cars, on the other hand, can use either the outer or the inner roadways. The area between mileposts 106 and 118 is composed of two separate roadways, which are known as the easterly and westerly roadways. All vehicles are allowed to use either roadway. The easterly roadway primarily services traffic to and from the Lincoln Tunnel (interchanges 16E and 17) and the westerly roadway primarily services through traffic on Interstate 95 to and from the George Washington Bridge (interchange 18W). Figure 2 shows the area of the New Jersey Turnpike covered by the ATSC system. Tables 2 and 3 show the 28 locations where the changeable message signs are located at points where traffic can be diverted to a desired roadway on both the northbound and the southbound directions, respectively.

EXAMPLES OF TRAFFIC DIVERSION

The following section describes an actual traffic diversion executed during two peak travel days. A search of the records indicates that the effectiveness of the ATSC system's performance can best be described by examining the following two days: Wednesday, November 23, 1977, the Wednesday preceding

Figure 1. Average running speed versus percentage occupancy by level of service.

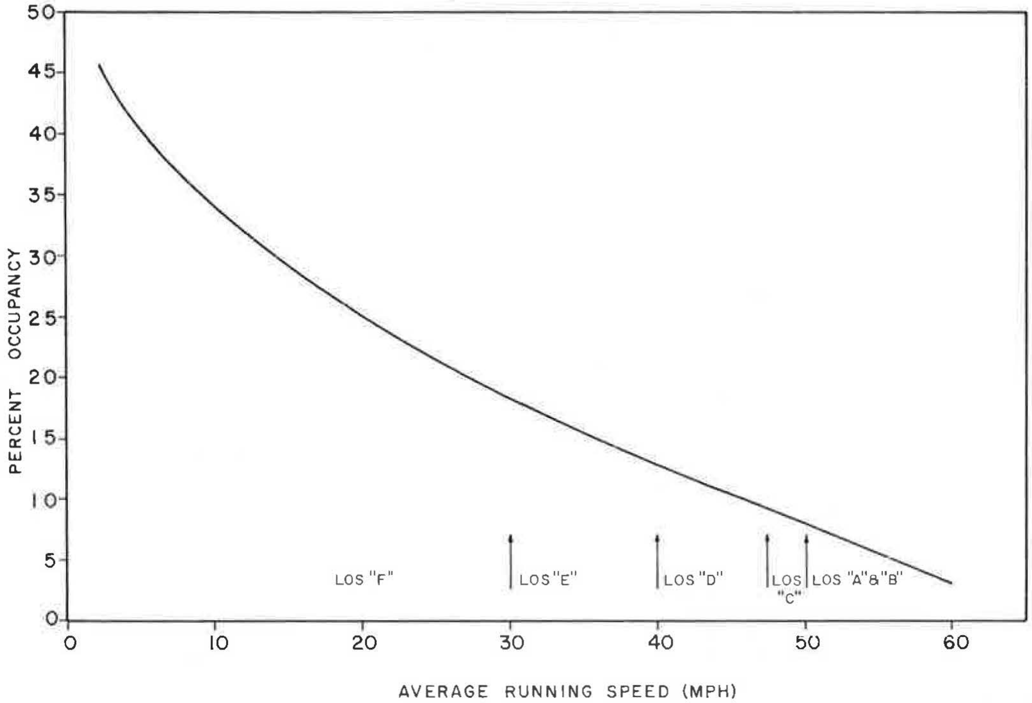

Table 1. Level of service descriptions.

Level of Service	Traffic Flow Description	Average Running Speed (mph)	Occupancy (%)
A	Free flow	>50	0-12
B	Free flow	>50	0-12
C	Stable flow	48-50	12-14
D	Approaching unstable flow	40-48	14-16
E[a]	Unstable flow, capacity	30-40	16-20
F	Forced flow	<30	≥20

[a]Capacity occurs when average running speed is equal to 30 mph and percentage occupancy is equal to 20 percent.

the Thanksgiving holiday, and Friday, June 23, 1978. These two days were selected because they represent days on which sign changes took place to a large extent due to heavy traffic flow. On Wednesday, November 23, 1977, most of the traffic consisted of long-distance holiday travelers. Traffic on the second day consisted primarily of travelers to summer resorts located in New Jersey. On both days commuter traffic was also a significant factor. The total traffic on the New Jersey Turnpike during November 23, 1977, was 438 485 and on June 23, 1978, it was 450 623. This traffic volume can be compared with the 1977 average annual daily traffic (AADT) of 311 408 vehicles and the 1978 AADT of 330 473 vehicles. On November 23, 1977, sign changes were due to congestion that resulted from accidents and heavy traffic flow. On the other hand, on June 23, 1978, sign changes were due to congestion that resulted from heavy traffic flow only. For the purpose of simplifying the description of the ATSC system's performance, the following roadway designations are used:

SNO--outer roadway, northbound;
NSO--outer roadway, southbound;
SNI--inner roadway, northbound;
NSI--inner roadway, southbound;
SNE--easterly roadway, northbound;
NSE--easterly roadway, southbound;
SNW--westerly roadway, northbound; and
NSW--westerly roadway, southbound.

The first letter of the designation signifies the direction from which traffic is coming; the second letter signifies the direction of traffic flow, and the third letter describes the roadway. These roadway designations are also used by operating personnel, which includes State Police, emergency vehicle operators, and the New Jersey Turnpike Authority Operations Center's dispatchers.

November 23, 1977

The following is a description of sign changes and traffic characteristics for vehicular flow on the New Jersey Turnpike that took place on November 23, 1977, between 3:25 and 6:00 p.m., the time when all signs returned to normal.

At 3:25 p.m., an accident occurred at milepost 110 SNW. This location is about 1 mile north of interchange 15W. The accident resulted in blockage of the left and center lanes. An occupancy reading of 24 percent was detected at a loop detector located just south of the accident. On the other hand, the downstream detector north of the accident indicated a reading of 5 percent. Since the congestion criteria for an incident detection was met, an alarm was sounded to indicate to the operator that an incident had just occurred.

At this point, the changeable message signs located at the SNO and SNI roadways about 1 mile north of interchange 14 displayed the message ALL TRAFFIC to direct traffic to the SNE roadway. The message to the SNW roadway from the SNO and SNI roadways displayed the message EXIT 15W ONLY. These message displays were mandatory rather than advisory. In addition, the computer displayed a 35 mph speed limit message at milepost 109 SNW and 45 mph at milepost 107 SNW. The computer also activated the speed warning signs at these locations to read REDUCE SPEED AHEAD--CONGESTION. On the verification

Figure 2. Area on New Jersey Turnpike covered by ATSC system, mileposts 82-118.

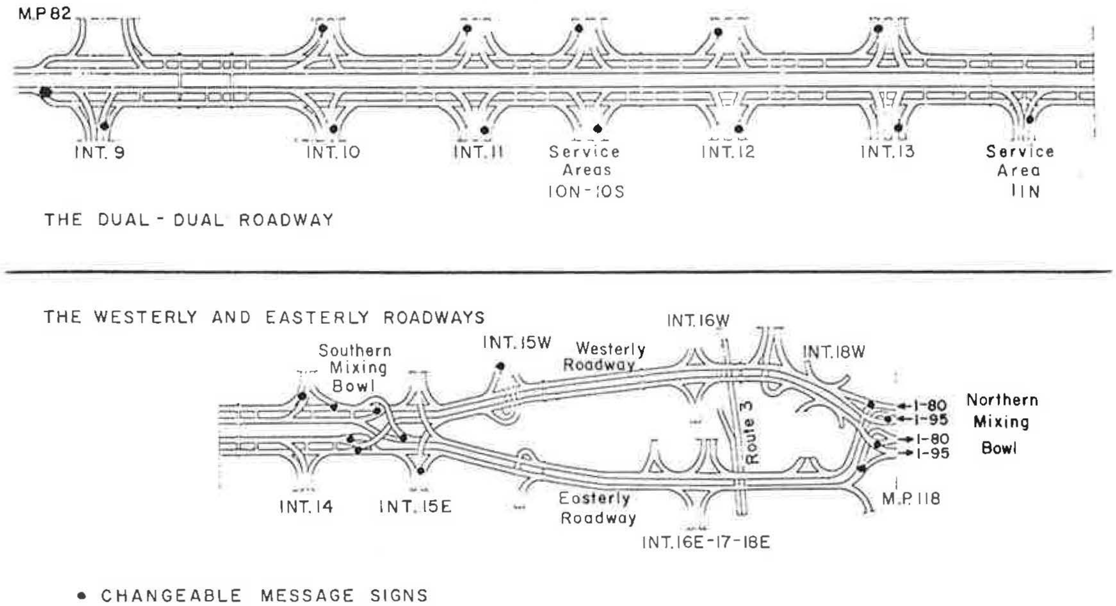

Table 2. Location of entry points where northbound traffic can be diverted.

Location of Entry	Milepost	Diversion Capability
Dual-Dual Roadway		
Mainline split	82	Outer or inner roadway
Interchange 9	83	Outer or inner roadway
Interchange 10	88	Outer or inner roadway
Interchange 11	91	Outer or inner roadway
Service area 10N	93	Outer or inner roadway
Interchange 12	96	Outer or inner roadway
Interchange 13	100	Outer or inner roadway
Service area 11N	102	Outer or inner roadway
Interchange 14	105	All traffic to outer roadway, no diversion capability
Easterly and Westerly Roadway		
Main line, southern mixing bowl	106	Easterly or westerly roadway
Interchange 15E[a]	107	Easterly or westerly roadway
Interchange 15W[b]	109	Westerly or easterly roadway
Interchange 16W[b]	112	Westerly roadway (normal message) or easterly road via NJ-3 eastbound to interchange 17
Interchange 17[a]	112	Easterly roadway (normal message) or westerly roadway via NJ-3 westbound to interchange 16W
Main line, northern mixing bowl	117	I-80 westbound or US-46 westbound, I-95 eastbound or US-46 eastbound

[a]Located on easterly roadway. [b]Located on westerly roadway.

Table 3. Location of entry points where southbound traffic can be diverted.

Location of Entry	Milepost	Diversion Capability
Easterly and Westerly Roadway		
Mainline from I-80 and U-46, northern mixing bowl	117	Easterly or westerly roadway
Mainline from I-95, northern mixing bowl bowl	117	Easterly or westerly roadway
Service area 13	116	Easterly or westerly roadway
Interchange 16W[a]	112	Westerly roadway (normal message) or easterly roadway via NJ-3 eastbound to Interchange 16E
Dual-Dual Roadway		
Mainline, southern mixing bowl	106	Outer or inner roadway from easterly roadway
Mainline, southern mixing bowl	106	Outer or inner roadway from westerly roadway
Interchange 14	105	Outer or inner roadway
Interchange 13	100	Outer or inner roadway
Interchange 12	96	Outer or inner roadway
Service area 10S	93	Outer or inner roadway
Interchange 11	91	Outer or inner roadway
Interchange 10	88	Outer or inner roadway
Interchange 16E[b]	112	Easterly roadway (normal message) or westerly roadway via NJ-3 westbound interchange 16W

[a]Located on westerly roadway. [b]Located on easterly roadway.

of an accident, the word ACCIDENT was added to the speed warning sign.

During the period between 3:25 and 3:50 p.m., 1450 vehicles that normally would have used the westerly roadway were diverted to the easterly roadway, away from the accident area. Although traffic on the easterly roadway became quite heavy due to the additional traffic, it was easier to remove the vehicles that were involved in the accident more expeditiously. At 3:50 p.m. the computer changed the signs on the SNO and SNI roadways, and displayed a normal message. Note that all three lanes on the SNW roadway at the accident location were available at 3:48 p.m. At 3:50 p.m., the speed limit sign located at milepost 107 SNE displayed 45 mph and the speed limit sign at milepost 109 SNE displayed 30 mph. The location of milepost 109 SNE is about 3 miles south of interchange 16E.

At 4:00 p.m., the computer displayed a message to divert all northbound traffic at interchange 15E to the westerly roadway. During the 15-min display of this message, about 250 vehicles were diverted from interchange 15E to the westerly roadway, thus the load on the easterly roadway was eased. At 4:30 p.m., the occupancy on the SNW roadway was 24 percent, and on the SNE roadway the occupancy was 16 percent. During the period between 4:30 and 5:35 p.m. several sign changes took place, which lasted no more than 10 min at a time. These sign changes resulted in a diversion of 1300 vehicles. At 4:30

p.m., the speed limit on the SNE roadway was back to 55 mph; at 5:05 p.m., the speed limit at milepost 107 SNW was returned to 55 mph; and at 6:00 p.m. the speed limit sign at milepost 109 SNW was back to 55 mph. In addition, all changeable message signs were back to normal at 6:00 p.m.

During the period between 3:25 and 6:00 p.m., all speed limit adjustments, as well as diversionary sign displays, were done automatically by the computer. However, these sign changes were carefully monitored by traffic engineers and Operations Center personnel. An examination of the ATSC computer printout information indicated that the level of service attained on both the SNW and SNE roadways at 6:30 p.m. could not have been attained prior to 8:00 p.m. without the availability of the ATSC system.

June 23, 1978

Another example of traffic diversion occurred on Friday, June 23, 1978. The diversion on this date occurred primarily on the southbound roadways. Traffic from the NSW and NSE roadways traveled through the southern mixing bowl to the NSO and NSI roadways. The normal signing directs all buses and trucks and all vehicles destined to interchange 14 from the NSW and NSE roadways to use the NSO roadway. On the other hand, passenger cars from the NSW and NSE roadways can use either the NSI or NSO roadways.

On Friday, June 23, 1978, due to traffic volume, sign changes were made to direct the southbound traffic from the NSW and NSE roadways and from interchange 14 southbound. At 3:30 p.m. all NSE roadway traffic was diverted to the NSI roadway. The reason for this change was based on unused capacity figures. The unused capacity on the NSO roadway was 0. The NSI roadway had an unused capacity of 2260 equivalent vehicles. During this period the occupancy in the area between the southern mixing bowl southbound and interchange 13 on the NSI roadway was 9 percent. The occupancy at the same location on the NSO roadway was 12 percent.

At 5:00 p.m. the changeable message signs from the NSE roadway were back to normal. All NSW traffic was directed to the NSI roadway. During this period the unused capacity on the NSO roadway was 0 and the unused capacity on the NSI roadway was 1580 vehicles. The occupancy during this period was 10 percent on the NSI roadway between the southern mixing bowl and interchange 13 and 12 percent in the same location on the NSO roadway. At 5:10 p.m. all traffic from the NSE roadway was directed to the NSI roadway. Between 5:20 and 5:30 p.m. all traffic from the NSE roadway was directed to the NSO roadway. From 5:30 to 5:40 p.m. all traffic from the NSE roadway was diverted again to the NSI roadway and traffic from interchange 14 was diverted to the NSO roadway. At 5:30 p.m. the unused capacity in the area between the southern mixing bowl and interchange 13 was 900 on the NSI roadway and 1400 at the same location on the NSO roadway. At 5:40 p.m. all changeable message signs and all speed limit signs were returned to normal. An examination of the ATSC system computer printouts indicated that about 50 min of delay time were saved by motorists who were traveling southbound from the easterly and westerly roadways.

CONCLUSIONS

The New Jersey Turnpike Authority's ATSC system has proved to be an effective tool for traffic management. Comparison of operational experience before and after the installation of the ATSC system indicates an improvement in traffic flow on the New Jersey Turnpike, especially during times of peak travel demand. Without the system, proper accommodation would have been difficult for the 15 percent growth in traffic on the northern 36 miles of the New Jersey Turnpike that occurred between 1976 and 1979. The system has provided motorists with an effectively used roadway network and authority personnel with a valuable tool for providing optimum service to the traveling motorist in terms of rapid incident detection, rapid response time, and alleviation of congestion.

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