Costs and Benefits of Vision-Based, Wide-Area Detection in Freeway Applications

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Wide-area detection systems (WADS) through video image processing is gaining worldwide acceptance as a proven technology for IVHS, as well as a preferred emerging technology for replacing loops in many practical situations. This technology has been tested and validated in many real-life applications. The advantages and sophistication of WADS are easily realized at intersections where the large number of detectors and need for wide-area measurements lead to up-front cost justification; this is not so obvious on freeways because of sparse detection and current lack of widespread WADS applications. In this article, a direct comparison of loops versus WADS is made, assuming that WADS is only being used as a direct replacement of loops. Even when ignoring intangible benefits, it is demonstrated that when an economic analysis is performed, WADS can be substantially more cost effective than loops. Intangible benefits include stopped vehicle and incident detectors, automatic extraction of measures of effectiveness and performance measurement, wide-area detection, continuous visual performance verification, accurate speed measurement through vehicle tracking, surveillance at minimal incremental cost, and others.

The need for advanced traffic detection devices that reduce installation and maintenance costs while extracting more traffic flow measurements has lead to the development of machine vision wide-area detection systems (WADS). Machine vision provides "above road" detection and wide-area measurements that replace many conventional inductive loop detectors. Lane closure costs for loop installation and maintenance are effectively eliminated. In addition, the detection performance is easily verified and detectors are easy to reconfigure interactively.

The Autoscope WADS, selected for this cost comparison, has been installed in over 400 sites in North America, Europe, and Asia for both freeway and intersection applications. Although reliability and performance have been assessed through various installations and studies (*1–4*), cost effectiveness on freeways has not been documented. The objective of this paper is to present benefit and cost results based on data collected on a typical freeway detection installation in Minnesota, which is actually unfavorable to WADS because it only requires sparse detection for only two main-line lanes in each direction and on ramps. Furthermore, the installation was intended only for conventional electronic surveillance and ramp metering; as such, only volume and time occupancy are currently measured so that the detector stations consist of single loops rather than the loop pairs that are usually required for speed measurement. In spite of this, the comparison results are very favorable for video detection because they indicate that Autoscope was cost effective even without accounting for many of its intangible benefits. The Minnesota Department of Transportation (Mn/DOT), which funded this project, provided all the data associated with the actual costs of a recently instrumented section of Trunk Highway 36 in Minnesota in which the loops were installed. They also provided up-to-date infrastructure costs associated with loops and video detection and specified the three alternative design options associated with the video. In this article, the overall project objectives and functional specifications of the machine vision device used are presented. This is followed by a description of the site selected for the cost study, the methodology and assumptions, the benefits of the WADS system considered, and the results of the economic analysis.

BACKGROUND

One of the primary objectives of the project completed for Mn/DOT was to compare costs and benefits of video versus conventional loop detection for operational deployment on freeways. The replacement of current loop functionality was a primary requirement. However, the functional capabilities of the Autoscope WADS used in this cost-benefit study exceeded the capabilities of the loop detector alternative against which it was compared. In addition to the individual detections, volume counts, and time-occupancy provided by the loops, the video detection system provides wide-area detection and speed, as well as vehicle length measurements. Furthermore, it classifies vehicles based on vehicle length. These measurements are simultaneously accumulated into time intervals ranging from 10 sec to 1 hr and are made available to the user via serial communications. In addition to these parameters, space mean speed, space occupancy, density, average time-headway per lane, and user-defined level of service congestion grades are generated. Detector outputs can be combined using logical "or," "and," or "nand" operations and can be delayed or extended for user-defined times. These last functions are particularly useful for complex applications, such as adaptive intersection or ramp control based on wide-area detection and reporting alarms for incidents.

Recently, an incident detection algorithm was added to the processor itself. This follows a natural trend to distribute processing within a traffic management system and reduce communication bandwidth requirements. It also allows the algorithm to use data that otherwise might not be available to a central traffic detector server.

TEST SITE AND DESIGN ALTERNATIVES

The site selected for the cost-benefit study was a 4.7-km (2.8-mi) section of Trunk Highway 36 north of St. Paul where a conventional loop detection system and three closed-circuit television (CCTV) surveillance cameras were installed as part of a state construction

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project completed in the fall of 1993. This portion of freeway has two main-line lanes in each direction and five interchanges as shown in Figure 1. As built, there are six detector stations in each main-line direction, a detection station on north- and southbound Snelling Avenue, and detection on all 24 adjoining ramps. Each lane or ramp detector consists of a single loop detector, as shown in the Figure 1, for providing only volume and time-occupancy information.

To evaluate the effect of camera placement and coverage on cost, three Autoscope deployment alternatives were chosen for comparison with the actual loop installation. Each alternative was required only to provide detection equivalent to the loops. This requirement underutilizes the WADS capabilities but was done deliberately to assess the worst-case scenario in which Autoscope is used only as a loop replacement for counting applications. Alternatives 1 and 2 use supplemental loop detection on ramps not within the camera's field of view, because only point detection was required on ramps. Alternative 3 uses machine vision exclusively for detection.

Alternative 1 was configured so that the video cameras were located in the median to provide detection for each main-line direction, as well as those ramps within the field of view. The median was as much as 23 m (75 ft) wide in some places, permitting easy access for installation and maintenance. This type of camera placement is not recommended for installations with three or more lanes in each direction when the median exceeds 5 m in width. A total of seven cameras was needed to provide detection on the six main-line stations and Snelling Avenue, as well as on 10 of the 24 ramps. A total of 14 loop detectors were used on ramps to supplement the video detection.

Alternative 2 was configured to have the video cameras located near the outside shoulder of each main-line direction, doubling the number of cameras to 14 to provide detection at all detector stations plus 14 of the 24 ramps. This is a typical camera placement with three or more lanes in each direction and a wide median greater than 5 m. As a result of the added cameras, only 10 loop detectors were used on the ramps, again to supplement the video detection.

Alternative 3 was identical to Alternative 2, except that supplemental detection on 10 ramps was accomplished with 8 additional cameras, bringing the total to 22 cameras. This alternative, therefore, used video detection exclusively throughout the entire roadway.

It should be noted that cost reductions were achieved by moving the locations of the detector stations so that cameras could view the main-line traffic plus exit and entrance ramps wherever possible, in all three alternative deployment scenarios.

METHODOLOGY AND ASSUMPTIONS

This portion of Trunk Highway 36 freeway was selected for the study primarily because current cost data was readily available for the loop detector installation, which had been completed during the 1993 construction season. Although less favorable to WADS than wider urban corridor freeways, this portion of freeway is representative of a major portion of metro area suburban freeways and highways. If the cost comparison were to be favorable on this roadway, it would certainly be even more favorable on wider roadways, consisting of three or more lanes per direction and narrower medians, simply because the wide-area detection capabilities are available at no extra cost.

The Mn/DOT Traffic Management System (TMS) plan sheets from the construction project were used for both the loop and the Autoscope installation alternatives to derive statements of estimated quantities from which the costs were calculated. In addition, because the loop installation required lane closures and were actually installed during daylight hours (9:00 to 14:30), the user delay, in vehicle hours, for main-line detector stations was computed using the KRONOS Freeway Simulation Program, which has been tested and validated for Minnesota freeways for over 10 years (*5,6*).

Ground rules for estimating costs were to include the incremental costs required to exclusively support either loop or video detection. For example, the majority of conduit was laid to support ramp

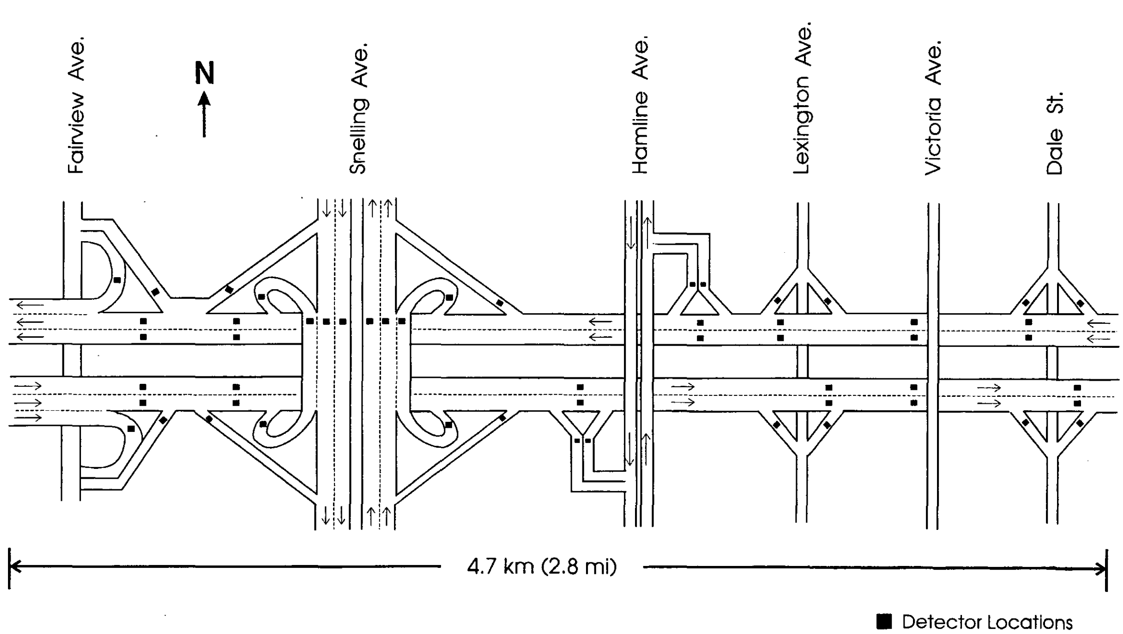


FIGURE 1 Section of Trunk Highway 36 used for detection cost comparison.

meters; therefore, estimated quantities did not include that conduit because it had the capacity to carry lead-in wire for loops and power lines and video cable for cameras. It was clear from the TMS plan sheets that the loops were laid out to maximize the usage of ramp meter conduit in order to minimize total construction costs. In turn, this same consideration was used when camera locations were selected.

Following standard Mn/DOT procedures, all linear quantities measured from the plan sheets were increased by 4 percent to account for grade changes. As a spot check, the total measured length of loop detector lead-in wire was compared and agreed to within 1 percent of original Mn/DOT estimates made before construction.

It was further agreed to use pricing and engineering practices that were used for this specific 1993 construction project. Therefore, all loop and WADS costs are in 1993 dollars. The only significant change in engineering practice is that trenched conduit for camera video and power was required to be rigid steel conduit in 1993, whereas today it is standard practice to use nonmetallic conduit, which is 60 percent lower in price. As a result, the total system costs would be reduced by $3,300 for Autoscope Alternative 1 and by $5,000 for Autoscope Alternatives 2 and 3.

Primary components of the loop detectors are the loop itself, lead-in wire, detector amplifier cards, input files to hold the amplifier cards, and the 170 controllers which processed and transmitted the detection data back to the central Traffic Management Center (TMC). However, the 170 controllers, except for the Victoria Avenue station, were used for ramp control and their cost was not included as part of any detection system. If no ramp control were present, the cost of the loop installation would be increased by the cost of the 170 processors. Each furnished and installed loop cost $560, two conductor No. 14 lead-in wire cost $2.07/m ($0.63/ft), and the four-channel inductive loop detector amplifiers were $153 each.

Primary components of the WADS system are the cameras, including fixed focal length lens, enclosure, and mounting brackets; the WADS processors; and video coaxial cable and power to the camera. The average price of the camera system and the WADS processor used was $7,000 per camera in 1993, in spite of the anticipated price drop as the technology became widespread. The price of the RG-11 coaxial video cable was $2.46/m ($0.75/ft), and the three-conductor No. 10 wires for power were $3.28/m ($1.00/ft).

Note that all prices for loop and video detection components include materials and labor to install. Traffic control costs, which are typically 3 percent of Mn/DOT project costs, were estimated to be $40 per loop, by simply taking 3 percent of the total system cost and dividing by the number of loops. Although no lane closures are required for the WADS alternatives, traffic control costs were nevertheless added to the total system costs. These costs were arbitrarily chosen as $20 per camera, one-half of the traffic control cost per loop, as a conservative estimate.

Finally, the indirect user cost because of lane closures was estimated by multiplying user delay in vehicle hours by a user cost in dollars per vehicle hour. A delay cost of $10.65 per vehicle hour was derived from (*7*), which quoted an FHWA study that used $8.42 per vehicle hour because of lost time and wasted fuel in 1987. This number was increased to $10.65 by assuming an inflation rate of 4 percent per year.

The University of Minnesota Center for Transportation Studies provided assistance in estimating the delay in vehicle hours because of lane closures required to install loops. The roadway geometry and loop detector locations were measured from the plan sheets. Actual traffic demand data from a typical construction day was used for the KRONOS freeway simulation. A day with fair weather and typical roadway volumes was chosen, and then traffic data was extracted from the TMCs detector data base collected by these same loops, which had been installed 6 months earlier. The loops were actually installed between 9:00 hr and 14:30 hr, and the contractor was required to close a minimum of 370 m (1200 ft) of lane upstream of the saw cut for the loop. It typically takes 2 hr per loop installation. A simulation lane closure schedule was set up to complete a full installation in one lane of roadway. It should be noted that because of simulation program constraints, the length of lane closure was limited from 60 m to 245 m (200 ft to 800 ft), in all but one case, instead of the 370 m required. Therefore, the simulation can be expected to underestimate the delay.

An estimated two-lane roadway capacity of 4,800 vehicles per hour and constricted capacity of 1,500 vehicles per hour with one lane closed were specified for the simulation. The capacity was estimated using measured data from all main-line detectors and the constricted capacity reduction of 68 percent was extrapolated from the *Traffic Engineering Handbook* (*7*), which provides the capacity reduction that results from lane closures on a typical freeway.

The simulation results are shown in Table 1 for a baseline run with no lane closures and the three simulator construction runs. The delay is accumulated only for vehicle speeds below 64 kph (40 mph). A total delay of 3,853 vehicle hours resulted for one lane of closure to install loops. This delay was multiplied by four to obtain a total estimate of 15,400 vehicle hours of delay for the entire four-lane roadway. A total estimate of 34,000 L (9,000 gal) of extra fuel was similarly obtained. The $10.65 per vehicle hour delay includes the cost of extra fuel and lost time. The resulting user cost because of delay is $164,000. Note that this is not a direct cost paid by the department, but an estimate of an indirect cost borne by the users of the road. This cost could be reduced by installing loops at night, with modest increases in the direct costs of installation. However, the objective of this comparison was to compare with an actual loop installation that occurred during daytime hours using the provided "furnished and installed" prices, which were for daytime work and not nighttime.

Finally, to allow extrapolated comparison with wider roadways, the cost of adding loop detection for an additional one lane in each direction was computed from which total system costs for three and four lane highways could be derived. The user-delay costs for these wider roadways would likely be greater as volumes also increased, however such increases were not considered in this study, and the same value of $164,000 in user-delay costs was conservatively used for these wider roadway estimates.

Mn/DOT had two system design requests that significantly impacted total system costs that are not included as part of the system costs because they were not considered necessary to provide detection capability functionally equivalent to loops. However, it is worthwhile to discuss these design requests, the reasons for the requests, and the incremental impact on WADS system costs. The first request arose from Mn/DOT's desire to take advantage of a key Autoscope benefit, the capability to verify detector performance as well as video quality, remotely. To realize this benefit, they requested that the video transmission from the camera to the WADS processor use an existing multimode fiber-optic line to transmit the video from the field cabinet to a regional TMS shelter where the WADS processors could be located. In turn, the outputs of the multicamera WADS processors could be selected for transmission on

TABLE 1 KRONOS Simulation Results for Installation of Six Loops in One Lane of Westbound Trunk Highway 36

Length of Roadway: 5624m (18,450 ft)
Time of Simulation: 8:00 A.M. to 3:00 P.M. each day
Lane Closures Permitted from 9:00 A.M. to 2:30 P.M.

Lane Closure Per Loop:
2 hours required
60m to 245m (200 - 1200 ft of lane closed)

Simulation Run	Total Travel Vehicle-Km (vehicle-mile)	Travel Time (vehicle-hr)	Ave. Speed Km/hr (mph)	Delay* (vehicle-hr)	Fuel Liter (gal.)
BASELINE (no lanes closed)	91,732 (57,000)	918	100.0 (62.1)	0	13,601 (3,593)
CONSTRUCTION Day #1	88,232 (54,825)	2,071	42.7 (26.5)	1,014	14,842 (3,921)
CONSTRUCTION Day #2	95,648 (59,433)	3,805	25.1 (15.6)	2,583	20,149 (5,323)
CONSTRUCTION Day #3	93,204 (57,914)	1,225	76.1 (47.3)	256	14,316 (3,782)

* Delay computed only for vehicle speeds under 64 Km/hr (40 mph)

the single-mode, fiber-optic line back to the TMC. This would permit detector layout, performance verification, additional surveillance, and video quality monitoring to be performed from a central location, thereby reducing maintenance costs incurred by trips to the field to troubleshoot system operation.

The incremental cost to realize this benefit consists of multimode fiber-optic transmitters and receivers, a length of fiber-optic line to splice into the fiber-optic backbone, and a splice vault in which to place and protect the splice. The basic costs for each WADS system does not include this cost, because loops do not provide this capability and the comparison would be unfair; however, this feature will be discussed in the benefits-costs comparison discussion. The basic cost for each system does include the cost of coaxial cable runs from the cameras to the WADS processor in the field cabinets.

The second request was that each camera be mounted on separate, specially designed CCTV poles. These innovative "crank-down" poles were designed to support much heavier CCTV surveillance cameras with full pan-tilt and zoom capability and washer-wiper systems, to minimize movement from wind and vibration, and to enable maintenance crews easy access to the CCTV camera system without the services of a bucket truck. Additionally, the poles can be located in places that bucket trucks cannot reach. The incremental cost of these benefits will likewise be discussed in the comparison discussion.

COST AND BENEFIT COMPARISON

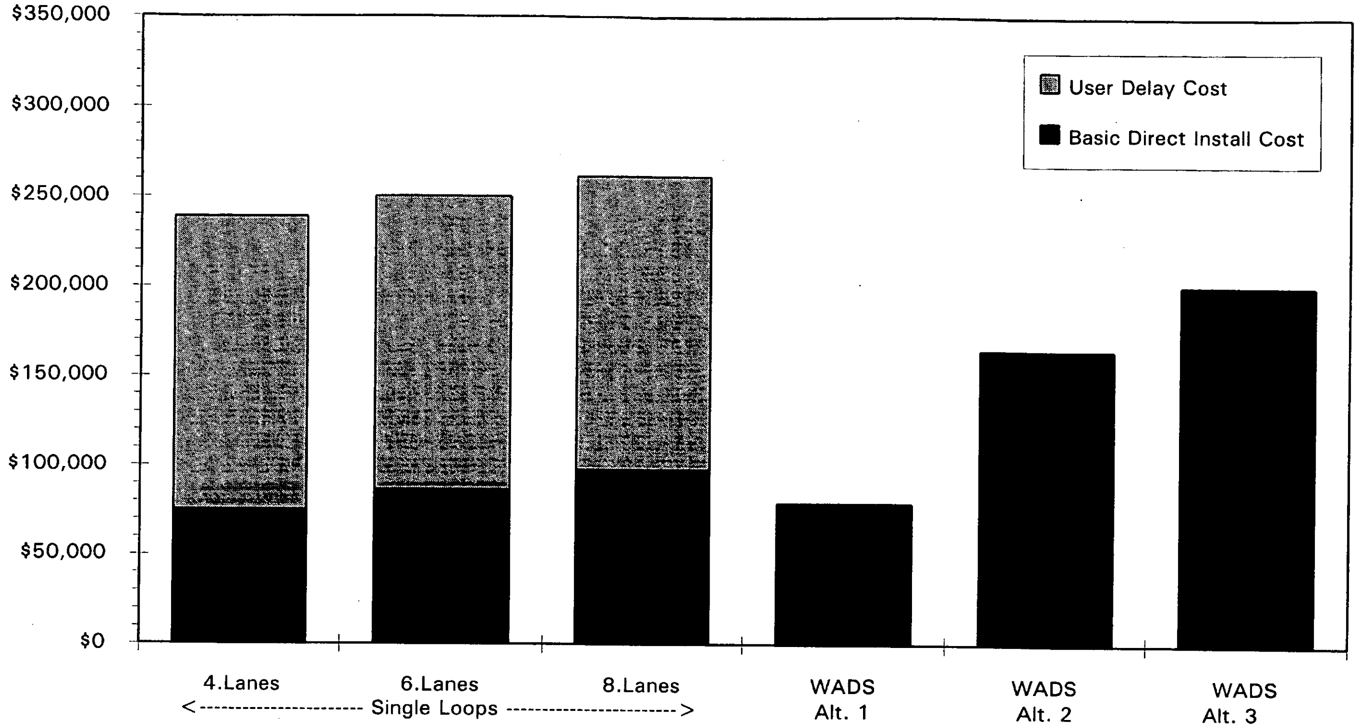
The total system costs are shown in Figure 2 for the loop (four lanes) and CCTV surveillance systems per TMS plan sheets, for the loop installation extrapolation to six and eight lanes, and for all three Autoscope alternatives. Note that the WADS cost is the same for four-, six-, and eight-lane roadway options. The indirect user-delay costs because of main-line lane closures required by the loop installation have been distinguished from the basic out-of-pocket direct costs of installation. The user-delay costs resulting from loop installation ramp closures were not taken into account in this study because of the lack of sufficient diversion information and the limited budget for the study.

It is significant to note that when the road is resurfaced, on average every 8 years in Minnesota, that the loops must be installed again. The direct costs to replace the loops is roughly an additional 45 percent of the original direct cost. However, the user-delay cost will be incurred in full or will be even greater if road usage has increased. These additional costs do not appear in Figure 3. Elimination of significant recurring user-delay costs and recurring loop install costs are a primary benefit of the WADS alternatives.

A further breakdown of costs for the loop and WADS alternatives shown in Figure 2 is given in Table 2. Note that the user-delay cost was only computed for the freeway configuration with two lanes in each direction. A conservative value of $10.65 per vehicle hour of delay was used to convert the delay into dollars because of lane closures for loop installation. This value includes lost time and fuel costs. Values ranging from $10 to $15 per vehicle hour are commonly used to determine the cost of delay.

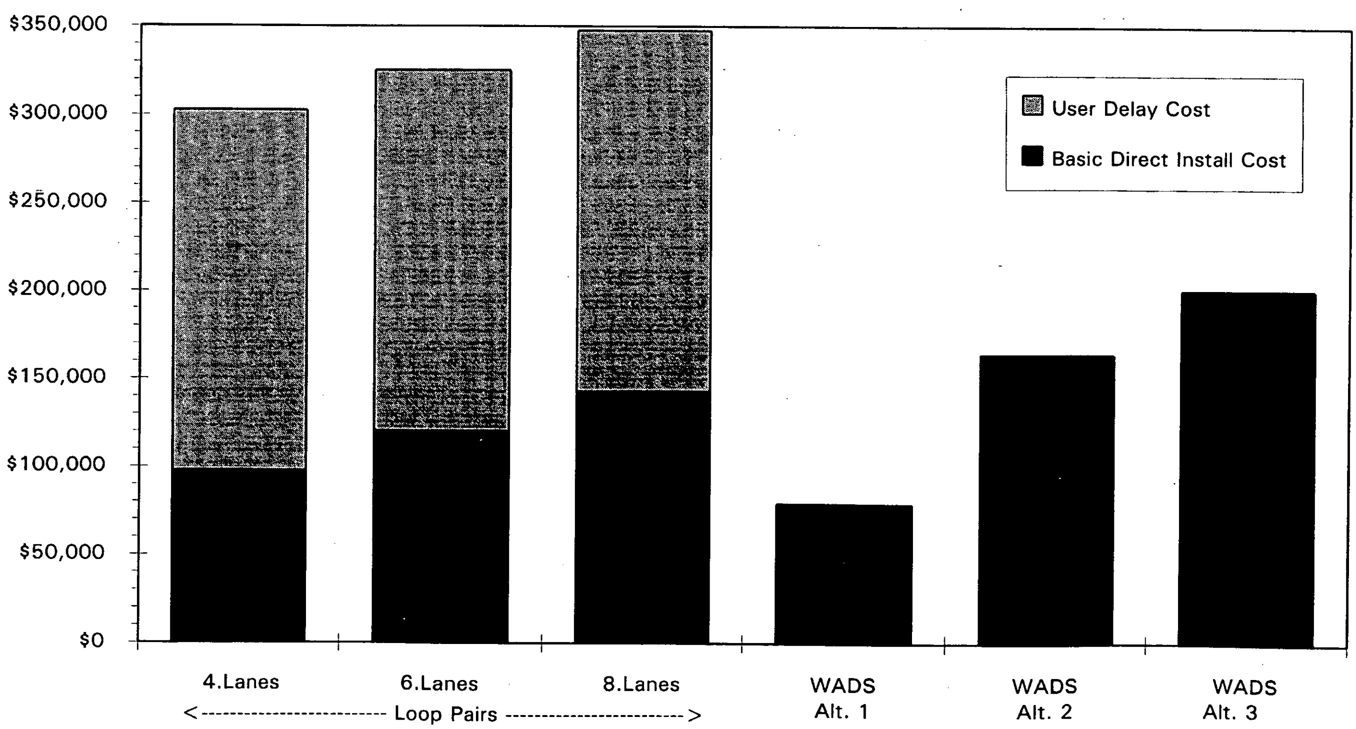
Benefit-cost ratios of 1.25 to 18.4 for the two lanes in each direction roadways were computed by dividing the incremental direct cost of the WADS installation into the WADS benefit; in this case the avoidance of delay cost because of lane closures. For example, WADS Alternative 1 cost $8,896 ($78,890 to $69,994) more than the loop direct costs. Dividing this cost into the $164,000 delay cost not incurred by the WADS system produces a benefit-cost ratio of 18.4. Note that favorable benefit-cost ratios resulted even for WADS Alternative 3, which used video detection exclusively.

The number of detectors used for the comparison of the loop and WADS alternatives also is shown in Table 2. Note that the Autoscope processor has significant unused detection capacity for all three WADS alternatives. The unused capacity, in number of detectors, can be calculated by subtracting the number of detectors used from a potential of 25 detectors per camera. Actually, each Autoscope processor will process up to four cameras simultaneously with at least 100 detectors distributed between the cameras.



Notes: 1. WADS cost is the same for 4, 6, and 8 lane roadway options.
2. Cost of crankdown poles and pan/tilt/zoom cameras would increase WADS cost.

FIGURE 2 Total system cost comparison of WADS versus single loops.



Notes: 1. WADS cost is the same for 4, 6, and 8 lane roadway options.
2. Cost of crankdown poles and pan/tilt/zoom cameras would increase WADS cost.

FIGURE 3 Total system cost comparison of WADS versus loop pairs (for speed).

TABLE 2 Summary of Installation Cost Estimates

Brief Description	Number of Mainline Lanes Per Direction	Loop Cost	VIDS Cost	User Delay Cost*	Total System Cost	B/C	No. of Detectors	Cost Per Detector
Conventional Loops Only	2	69,994	—	164,000	233,994	—	54	4333
	3	80,812	—	164,000	244,812	—	66	3709
	4	91,630	—	164,000	255,630	—	78	3277
WADS Alternative 1 Median Cameras Supplemental loop detection on ramps	2	19,555	59,335	0	78,890	18.4	54	1461
	3	″	″	″	″	—	66	1195
	4	″	″	″	″	—	78	1011
WADS Alternative 2 Side view cameras Supplemental loop detection on ramps	2	20,930	143,478	0	164,408	1.7	54	3044
	3	″	″	″	″	2.0	66	2491
	4	″	″	″	″	2.2	78	2108
WADS Alternative 3 Side view cameras Video detection on all ramps	2	—	200,923	0	200,923	1.2	54	3720
	3	—	″	″	″	1.4	66	3044
	4	—	″	″	″	1.5	78	2576

*Use delay cost calculated only for mainline on 2 lane roadway.

Finally, to assist comparison of each alternative, the system cost has been converted to a "cost per detector" in Table 2. Note that WADS Alternative 1, in which maximal use of the wide-area capability is made by mounting the camera in the median, has the lowest cost per detector of any of the WADS alternatives, as expected, and is lower than the loop installation as well.

In the funded study, speed measurement was not a requirement because speed is not yet used in Minnesota for surveillance and control because of cost and loop maintenance considerations. Loop pairs can be located in the roadway at a known separation distance and sampled at high frequency (100 Hz) to measure the speed of vehicles passing between the loops. Although the most desirable freeway state variable to measure is density, it cannot be measured directly from point sensors, such as loops, but can be estimated from flow and space mean speed. However, it suffers from the sampling noise of the point flow measurement over time and assumes constant flow over a local region. In the absence of sensors to measure density directly, speed can very effectively be used. An important feature of speed is that it can be measured at a point and does not require many vehicles to sample accurately. As a result, rapid breakdowns in traffic can quickly be assessed to enable timely management and control decisions to be applied.

If speed is required, the benefit of WADS takes on significant value. The extra loops required for speed measurement would cause a significant increase in total cost. The added cost of extra loops was computed and is shown in Figure 3. Increases in direct cost are 30 percent, 39 percent, and 46 percent for the four-, six-, and eight-lane roadways, respectively. The user-delay costs were conservatively estimated to increase by 25 percent because of the added delay resulting from the time to install the extra loops.

As discussed in the previous section, supplemental surveillance and centralized video troubleshooting are benefits that result when the WADS system is connected to an already existing fiber-optic communications backbone. The incremental cost to add fiber-optic connections to Autoscope Alternative 1 is $22,700 and is $39,700 for both Alternatives 2 and 3. The same benefit could be accomplished with wireless video transmission alternatives in the absence of fiber-optic lines. The cost of wireless video transmission was not evaluated in this study.

Each of the three WADS alternatives evaluated assume that existing poles or structures are available on which to mount cameras. Adding poles specifically for WADS cameras will increase the total cost. The innovative crank-down poles that were evaluated for this study cost nearly $7,000 a piece. The desire to avoid using bucket trucks for camera-pointing necessitates an additional cost of roughly $1,000 for pan-tilt and zoom capabilities. Although providing flexibility of pole placement and the potential for reduced maintenance costs, providing poles exclusively for WADS main-line cameras significantly increases costs. The incremental cost increase to add special crank-down poles and pan-tilt and zoom capabilities would be 73 percent of the total system cost for WADS Alternative 1, 62 percent for Alternative 2, and 55 percent for Alternative 3. It should be noted, however, that outside of Minnesota, no such expensive poles have been used in connection with video detection.

In addition to the benefits already discussed, there are many more that may be important to consider in a cost-benefit comparison for specific freeway projects. The benefits of WADS over loop detectors are summarized in Table 3. These benefits must be evaluated in each specific freeway project where WADS is under consideration. What is a valuable benefit to one agency may be of less value to

TABLE 3 Comparison of Video WADS versus Loops for Benefit Evaluation on Freeways

Function	WADS	Loops
Year round install, maintenance	Yes, except for underground conduit and wiring	No
Lane closures required	No, maybe shoulder	Yes
Usable during reconstruction	Yes	No
Susceptible to deterioration	No	Yes
Visual detecton monitoring	Yes	No
Reliable speed measurements	Yes	Yes, with speed trap pair
Stopped vehicle detection over wide area	Yes	Not practical
Wrong way vehicel detection	Yes	Yes with second loop
Vehicle classification	Yes, 3 classes	Yes, with speed trap pair
Spatial occupancy, density measurement	Yes	No
Queue length measurement	Yes	Yes, with added loops
Delay, extend, combine detector outputs	Yes	No
Provide MOE's, stops, delays, etc.	Yes	No
Incident detectors	Yes	Yes, if processed at central location
Visual surveillance capability	Yes	No
Off-line video processing capability	Yes	—

another. For example, an agency with no surveillance camera capabilities would benefit greatly from the surveillance available from WADS, whereas an agency with existing CCTV cameras in place, such as Mn/DOT, would, from the surveillance point of view, benefit only marginally. Using recommended mounting heights of 10 m (30 ft) or more, the top of the camera field of view can typically be set to just below the horizon to provide a surveillance view with detectors in the near field at the bottom of the field of view to maximize detection performance.

CONCLUSIONS

This study demonstrated that when user costs are taken into account, Autoscope is more cost effective than conventional loop detectors, even for sparse detection requirements on a two-lane roadway. Benefit-cost ratios ranging from 1.25 to 18.4 were obtained for three alternative Autoscope configurations on a freeway with two lanes in each direction and when speed was used for accurate assessment of traffic state. As expected, benefit-to-cost ratios are even higher when cost data is extrapolated to three and four lanes in each direction because the multiple lane detection capability of video detection and when speed is used for accurate assessment of traffic state. Although the direct cost to install conventional loops, in most cases, is less than the costs of the WADS alternatives, the total loop cost, including the indirect cost to users because delay from lane closures, is greater than the cost of all three WADS alternatives. Even though this analysis derived user-delay costs for loops installed during the day, there are many sections of roadway that cannot be installed at night without causing significant delays. Cost trade-off between nighttime and daytime loop installation were not part of this study.

Furthermore, as detection requirements grow, the cost of using conventional loop detection will increase. Although loop costs have been minimized over the last 30 years, the cost of video WADS should continue to decline as production levels increase and manufacturing costs are reduced, which will further increase the cost effectiveness for freeway applications. Finally, recurring loop replacement required by road resurfacing will lead to continued direct costs and even greater indirect user costs that only make video detection more favorable. Documented mean time between failures by the CCTV camera manufacturers is in excess of 20 years, which experience has thus far supported.

The cost effectiveness of video WADS will be driven by site- and application-specific requirements. The system planners must weigh all the costs and benefits of WADS versus conventional loop detection. The cost of installing WADS will be competitive with the cost of installing loops in most cases, except for those in which simple measurement such as volume or occupancy are required at a single or a few points, such as on a freeway ramp. Even where the cost is higher, the intangible benefits and advantages of wide-area detection can justify the additional cost.

Wide deployment of WADS will enable other IVHS traffic management technologies to take root and will eventually lead to more efficient management of traffic, saving time and money and reducing congestion and pollution levels. The development of automatic measure of effectiveness extraction; incident detection; and continuous, real-time performance monitoring that is possible with WADS will greatly aid in the evaluation of traffic management schemes.

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