

Traffic Control Management Through Construction Zones

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As I-70 construction activities in Colorado's Glenwood Canyon intensified, it became increasingly clear that traditional approaches to construction traffic control could neither efficiently nor safely accommodate existing traffic volumes under the number of active construction projects that would be required to complete the canyon project on schedule. In 1984 and early 1985, traffic-handling conditions had deteriorated to the point where total loss of control was imminent and there was growing public dissatisfaction with the frequently unnecessary and indiscriminate delays. In response, the Colorado Department of Highways (CDOH) authorized its management consultant, Daniel, Mann, Johnson, & Mendenhall (DMJM), to conduct a comprehensive analysis of traffic operations and safety throughout the canyon. The comprehensive study addressed many issues and suggested an innovative approach for handling traffic that would minimize delays, decrease the potential for a complete stoppage in the canyon, and allow control to be regained. Key elements of the proposed traffic management plan included a pilot-car operation, a sophisticated communications network, a systems approach to coordinating all flagging operations, and an umbrella contract that would combine all traffic control functions in the canyon under one separate authority. CDOH authorized a test of the pilot-car operation in late April 1985, which was to continue for an indefinite period of time. Operating through three active construction projects, with combined project limits of 3.6 mi, the pilot-car operation was highly successful and the benefits became immediately obvious. Because the test was conducted initially during a month with a relatively low traffic volume, it was necessary to gain a complete understanding of the dynamics of the pilot-car operation in order to assess its ability to cope with peak summer traffic volumes. Consequently, during the initial test and in subsequent periods, a large amount of operational data was collected. After data reduction and analysis, a complete understanding was gained of the traffic flow characteristics through the construction zones.

As I-70 construction activities intensified in Colorado's Glenwood Canyon, it became increasingly clear that traditional approaches to construction traffic control could neither efficiently nor safely accommodate existing traffic volumes under the number of active construction projects that would be required to complete the canyon project on schedule. The need for an overall coordinated traffic management plan had been discussed for several years. However, in 1984 and early 1985, traffic-handling conditions had deteriorated to the point where total loss of control was imminent and there was growing

public dissatisfaction with the frequently unnecessary and indiscriminate delays. In response, the Colorado Department of Highways (CDOH) authorized its management consultant, Daniel, Mann, Johnson, & Mendenhall (DMJM), to conduct a comprehensive analysis of traffic operations and safety throughout the canyon. The resultant report (1) was submitted to CDOH early in 1985.

The comprehensive study addressed many issues and suggested an innovative approach for handling traffic that would minimize delay, decrease the potential for a complete stoppage in the canyon, and allow control to be regained. Key elements of the proposed traffic management plan included

- A pilot-car operation (PCO),
- A sophisticated communications network,
- A systems approach to coordinating all flagging operations, and
- An umbrella contract that would combine all traffic control functions in the canyon under one separate authority.

CDOH authorized a test of the PCO to proceed in late April 1985 and to continue for an indefinite period of time. Operating through three active construction projects with combined project limits of 3.6 mi, the PCO was successful and the benefits became obvious immediately. The chaotic operational conditions existing before the test were highly variable and unfortunately did not allow for the collection of a statistically valid sample of data. Consequently, a quantitative assessment of the impact of the PCO on previous conditions was not possible. However, a qualitative review revealed that travel time through the construction zone was significantly reduced, overall delay was significantly reduced, motorists were stopped less frequently (usually only once), emergency trips through the canyon were more efficiently accommodated, public response was quite favorable, and contractors' operations benefited significantly in numerous ways.

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- Delay
- Travel time
- Headway

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- Discharge time
- Queue length
- Approach volume

In this paper the current operation is discussed, the findings of the operational analysis are presented, and the basis for further refinements aimed at accommodating increased traffic volumes is provided.

PILOT-CAR OPERATION

The PCO requires the establishment of two control points at either end of the controlled section. At those points, controllers hold queues until the opposing queues negotiate the canyon and pass the control point. Once that has occurred, the stopped queue is released and led through the canyon by Pilot Car A. A trailing pilot car, designated Pilot Car B, ensures that vehicles do not straggle or stop and advises the operator of Pilot Car A when gaps develop in the queue that warrant a reduction in speed to reduce the gaps. Pilot Car B also has the responsibility of "fitting in" the contractors' equipment at the end of a queue. Under field conditions, it was determined that the vehicle used as Pilot Car A in one direction would become Pilot Car B for the movement in the opposite direction. This practice evolved when it became apparent that considerable efficiency results from having Pilot Car A proceed past the control point to the end of the stopped queue, turn around, and take up position as the trailing pilot car. Similarly, when Pilot Car B reaches the control point, it can easily turn around, take up position at the head of the stopped queue, and almost immediately lead off as the new Pilot Car A.

The controlled section was divided into 10 equal segments, with signs installed to clearly identify the checkpoints. As a queue proceeds through the canyon, Pilot Cars A and B report their location by radio each time they reach a checkpoint. In this manner, all individuals in the radio network clearly understand the location of the head and the tail of the queue as it proceeds through the canyon. The pilot-car operators also record their departure and arrival times as they cross the respective checkpoints.

Communications

Because of the terrain constraints on radio transmissions, it was decided to equip all members of the PCO with UHF radios. Radios were also supplied to each project traffic control supervisor (TCS), because it is essential that they know exactly where and in what direction the queues are moving. In communicating with their individual project flaggers, the TCSs use UHF radios, but on different frequencies from those used in the PCO. Selected CDOH project personnel have had their state radios modified to be capable of receiving and transmitting over the PCO radio network.

Flagging

The implementation of the PCO required a complete reversal in the role and duties of the project flaggers. Before the PCO, flaggers and TCSs were controlling traffic to provide for the passage of construction equipment and the performance of

some construction tasks. In effect, the public was at the mercy of the flagging personnel on each project that they passed through. Because there was no coordination between projects, the public was simply forced to work its way through the canyon from project to project. In effect, motorists were faced with running a gauntlet each time they traversed the canyon. Driver expectancy was continually violated and motorists had to respond to a bewildering array of varying conditions. Uniformity of controls and procedures was almost totally absent. It was not uncommon to see contractors' equipment intermixed with the traffic stream. The potential for a disastrous emergency situation was becoming ever more apparent.

Under the PCO, the role of the project flagger is to control contractors' equipment, not the public. Flaggers are stationed at points of contractor equipment operation to control their entry onto the highway and ensure a clear passage for the arriving queue.

Staffing

The following is a listing of the key parties involved in the PCO and a description of their responsibilities:

1. Colorado Department of Highways
 - a. Overall administration of the program
 - b. Evaluation of the program's success
 - c. Enforcement of regulations governing the operation
2. Daniel, Mann, Johnson, & Mendenhall
 - a. Assistance in implementing the program
 - b. Expert advice to CDOH
 - c. Monitoring of operations and analysis of findings
3. Traffic coordinator (TC)
 - a. Overall coordination of all participants
 - b. Management of emergencies as well as priority delivery of construction materials
 - c. Placement and removal of cones, folding and unfolding of traffic signs
 - d. Maintenance of all equipment used by pilot-car operators and pilot-car controllers
 - e. Maintenance of official diary
 - f. Maintenance of daily dialogue with project TCSs
4. Project traffic control supervisor
 - a. Supervision and direction of project flaggers
 - b. Maintenance of project flaggers' equipment
 - c. Coordination of individual contractor's operation through TC
5. Pilot-car operator
 - a. Guidance of traffic through one-way zone
 - b. Reporting on position of traffic queue
 - c. Assurance of compliance with no-stopping and no-passing requirements
6. Pilot-car controller
 - a. Control of traffic approaching one-way zone
 - b. Provision of advance warning at rear of queue
 - c. Management of lead pilot car based on instructions from TC
7. Project flagger
 - a. Direction of contractor equipment operators
 - b. Communication with project TCSs

Equipment

The pilot cars used in the test operation were actually mini-pickup trucks equipped with manual transmissions. Four pickups were originally acquired: two for the actual PCO, one for the TC, and one as a spare. They have proved to be durable under the stress of operating some 200 mi a day. However, this use equates to some 50,000 mi/year. Because of the intensive use, rotation of the four vehicles is necessary to avoid premature aging of half the fleet. Also, experience has shown that in the future, vehicles for this operation should be equipped with automatic transmissions. The pilot-car operators are burdened with numerous duties as they traverse the canyon. In addition to the obvious requirements for judgment, attentiveness, and the ability to operate the vehicle, the operators are continually using the radio to report arrival times at checkpoints, to coordinate the smooth movement of contractor equipment that needs to move with the queue, and to maintain the maximum density attainable in a given queue. For these reasons, the additional burden of operating the manual transmission is an unnecessary distraction.

Folding signs and portable sign brackets were fabricated by CDOH personnel for the tailgates of both pickups that read Pilot Car/Follow Me. The signs are closed when a vehicle is operating as Pilot Car B and opened when its role changes to that of Pilot Car A.

A sequence of warning signs was installed at the approach to each checkpoint to alert motorists of the PCO. Within the controlled section, equally spaced (0.36-mi) No Stopping signs were installed on either side of the road. On top of each signpost, normal street name sign brackets hold black-on-yellow checkpoint numerals, to which the pilot car operators refer when announcing their position.

OPERATIONAL CHARACTERISTICS

Once the coordinated PCO was implemented, it became immediately apparent that there was an improvement in the quality of service to the traveling public. To quantify the results of the operation and develop a basis for predicting when traffic flow conditions could not be accommodated by the PCO, a comprehensive data collection and recording program was begun during the first week of the operation. Concurrently, a computerized queuing model was run in an attempt to determine whether traffic characteristics in the canyon could be predicted according to traditional queuing theory. The data collection program was designed to be carried out periodically throughout the year so that the effects of varying traffic volumes could be analyzed.

The types of data collected included the following:

- Traffic approach volumes—Manual counts along with vehicle classifications were made in order to obtain the arrival rates of vehicles throughout the time period of the PCO. The counts were taken at distances sufficiently removed from the construction so that the random-arrival pattern of vehicles was not affected.
- Travel times—The travel time of each queue was calculated on the basis of the pilot-car operators' radio transmissions of departure and arrival times at the respective checkpoints.

- Discharge and passage times—The elapsed time for each queue of traffic to pass a given point was determined by radio transmission and was used along with queue volumes to determine vehicle densities and headways.

- Queue volumes—The number of vehicles in each queue was recorded manually at a point midway through the controlled section.

With the collected data, it was possible to calculate the speed of each queue, the average speeds of all vehicles, the average delay times for vehicles in each queue, and the overall average delay times per day for each direction. The information presented in this paper is based on data recorded between 7:00 a.m. and 5:00 p.m. on April 24 and 25, 1985, and on June 3 and 4, 1985.

Observations

The information gathered in the field was tabulated in a computer spreadsheet program from which it was then reduced to give the various calculated traffic parameters. The key operational parameters are summarized in Table 1.

TABLE 1 SUMMARY OF OPERATIONAL PARAMETERS

Parameter	April	June	Percent Change
Combined approach volume (vph)	3,402	4,114	+21
Combined queue volume (vph)	3,169	3,839	+21
Average queue volume (vph)	80	96	+20
Average no. of queues per day	35	40	N/A
Average speed (mph)	25.2	26.9	7
Average delays (min)	12.7	12.4	-2.5
Headway (sec)	4.44	4.10	-8
Travel time (min)	8	8	N/A
Passage time (min)	5.15	6.21	+20

The difference between the combined approach volume and that actually carried in the queues was attributable to the high number of construction-related vehicles that either did not go as far as the location of the PCO or were allowed to bypass a stopped queue and therefore were not counted. The average number of vehicles per queue increased 20 percent, which was consistent with the overall traffic volume increases. It was found, in fact, that the length of the queue was directly proportional to the amount of approach traffic.

Although average speeds increased 7 percent from April to June, it could not be assumed that speeds would continue to increase in direct relationship to increases in traffic volumes. The lower average speeds in April were mostly attributable to the novelty of the PCO and are evidence of the motorists', as well as contractors', lack of familiarity with this type of operation. Observations indicated that the average travel time through the one-way section and the average speed stabilized at about 8 min and 27 mph, respectively. It is unlikely that these two parameters will change significantly from this point on (unless, of course, the length of the one-way section is changed).

The 2.5 percent reduction in average delay time was attributable to the improved efficiency of the operation and must not be interpreted as a trend. In fact, as traffic volumes increase

substantially (without considering unusual events), delays can be expected to increase accordingly.

The headway is the calculated time difference between adjacent vehicles passing a given point. The 8 percent reduction in headway was related to the improved efficiency and confidence level. Again, it is not expected that headway will decrease significantly, because of the level of activity in the construction zone, the traffic mix, and the "interest factor."

Passage time—the time required for the entire queue to pass a given point—was recorded at three locations: the beginning and mid- and endpoints. The passage times given in Table 1 were taken at the endpoint, which was found to be the critical, and therefore the most meaningful, location.

Unusual Events

The information contained in Table 1 was utilized in preparing the derivation of the DMJM projection model (available from the authors). It should be noted that the discussions pertaining to the operational parameters are based on "normal" operations; that is, they do not take into account unscheduled or unusual events, such as those that have already occurred on several occasions during the PCO. For example, a natural rockfall occurred on June 5, 1985, in the vicinity of a stopped queue, resulting in vehicle damage and bodily injury. This necessitated stopping all traffic in the canyon until the emergency was cleared. There have been several instances in which rock cuts resulted in unusually larger-than-expected volumes of material landing on the road, which also required temporary closing of the canyon.

These events are unusual, yet they can be expected to occur periodically for some time to come. The possible responses to these events have been discussed elsewhere (1). The frequent passage of an emergency vehicle through the canyon in response to some need outside the canyon has become almost routine. These events have been successfully handled through the coordinated communications network. Although all vehicular movement in the canyon is temporarily halted to allow passage of the emergency vehicle, these stoppages are short enough not to adversely affect the PCO.

Coordination with Other Projects

The PCO as described encompasses several projects at the west end of Glenwood Canyon. There is additional construction activity several miles to the east of this operation that also requires frequent traffic stoppages. Although it is impractical to include the eastern area as part of the PCO, the importance of coordinating these traffic stoppages with the PCO cannot be overstated. The effects that uncoordinated traffic control on the east end project can have on the PCO, or vice versa, can be dramatic and very detrimental to achieving the goal of minimal delay to motorists.

Because the foregoing phenomenon is difficult to quantify in understandable terms, it is best shown graphically. Figure 1 shows a plot of actual westbound approach volumes by time of day superimposed on a plot of westbound queue volumes corresponding to the same period of time. It is readily apparent that the queue volumes do not follow the more orderly arrival pattern of approach traffic unimpeded by construction. The

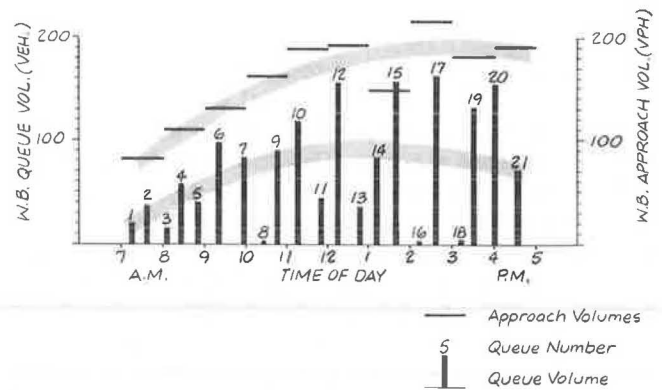


FIGURE 1 Westbound approach and queue volumes, Glenwood Canyon pilot-car operation, April 24, 1985.

alternating high and low queue volumes clearly illustrate the regulated but uncoordinated release of westbound traffic from the east-end project. By contrast, Figure 2 shows the same type of information for the eastbound direction in which the queue traffic has not been subjected to previous construction-related stoppages. Figure 2 shows what the westbound plot could, and should, look like if the east-end traffic stoppages and releases were fully coordinated with the PCO. In both Figures 1 and 2, the bands of shading show the general variation of approach volumes and queue volumes throughout the day. Note the parallel relationship between approach volumes and queue volumes, which clearly substantiates the correlation between the two.

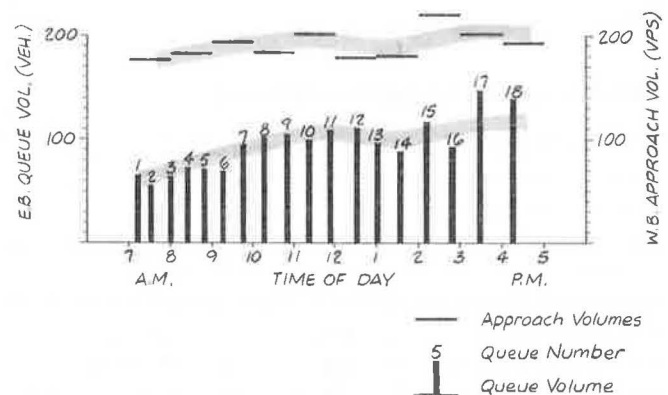


FIGURE 2 Eastbound approach and queue volumes, Glenwood Canyon pilot-car operation, April 25, 1985.

What these figures do not show directly but illustrate by implication is the effect that the east-end project has on eastbound traffic that has just passed through the one-way section as part of a queue. This traffic should ideally not have to stop again but is frequently required to do so because of a lack of total coordination. Actual field observations have proved this to be the case. An attempt has been made to coordinate the stoppages and releases of traffic at the east end with the PCO at the west end. This has met with limited success, mainly because of the lack of a central authority over all traffic control operations in the canyon.

CONCLUSIONS AND RECOMMENDATIONS

The data collected from the PCO quantified operational parameters only under relatively low approach volume conditions. However, detailed analysis of the data resulted in a clear understanding of the dynamics of the PCO under all approach volume conditions. The empirical data were used in logical relationships of traffic flow to develop a predictive equation for determining maximum service rates under varying approach volumes. A complete description of the mathematical derivation of the equation is available from the authors.

In the early stages of implementing the PCO, there was hope that a modified signalized intersection queueing model would be capable of predicting actual operations. However, the results were disappointing. The model did not reflect actual conditions and could not be calibrated. As in so many analytical models, the assumptions required to operate it made the model incapable of duplicating field observations.

Two of the misconceptions associated with the queueing model were that breakdown would occur when the capacity of the PCO was exceeded. The model assumed that specific approach volumes would exist hour after hour and that the queue buildup would rapidly grown out of control, with queues building much faster than they could be dissipated. Phenomenal queue-length buildups of many miles were predicted at the point of breakdown.

Such, however, was not the case. Based on observed headways, travel speeds, and the control section length, the DMJM model shows that the point at which the approach volume will begin to exceed the service rate occurs at about 600 vehicles per hour (vph). This is equivalent to 2.3 queue passages/hr. However, "breakdown" (in the sense used by traffic engineers) will not occur. Even when approach volumes exceed the service rate of the system, an average of 600 vph or more will continue to flow through the canyon.

With approach volumes higher than 600 vph, the normal reaction (and the often-expressed belief) is to "cut the queues" in order to expedite vehicles through the control section. However, the analysis revealed that the key constraint to service rate is travel time. Consequently, the appropriate response to excessive queue buildup is to reduce the time lost to travel. The only practical way to do this is to reduce the number of queues per hour or, in other words, to extend the length of queues guided through the control section. For example, if only 2.0 queues are operated per hour under approach-volume conditions of 650 vph, the service rate increases to 626 vph.

Theoretically, this means that 24 vehicles would be left waiting as opposed to the 50 vehicles that would have been left waiting with 2.3-queue passages/hr. It should be noted, however, that the vehicles left waiting would have experienced only minimal delay to that point, because they would have been among the last vehicles to arrive in the waiting queue.

There are two practical procedures for regulating the number of queue passages per hour. The operation can accommodate all queued vehicles until approach volumes reach 600 vph; consequently, the procedures need only be used when approach volumes exceed that level. Because the volumes entering both ends of the canyon will not be monitored, the procedures are based on physical queue relationships with approach volumes. When approach volumes reach 600 vph, the DMJM model predicts that 259 vehicles will be in a queue and passage time plus pilot-car turnaround time will equal 18 min. Either of these two factors can therefore be used to monitor the buildup of approach volumes during the day. A distance equal to 259 queued vehicles (7,770 ft) can be marked on the roadway and monitored by the operator of Pilot Car A as it completes a passage. Similarly, a controller can time the turnaround and discharge times to determine when 18 min has elapsed.

When either of the two monitoring methods indicates that 600-vph approach volumes are being experienced, the Glenwood Canyon TC will know that a queue buildup that cannot be completely dissipated with each passage is being experienced. At that time, the number of vehicles in each queue should be increased gradually, thereby reducing the number of queues per hour, and the operator of Pilot Car A should begin reporting estimates of the number of vehicles left waiting at the beginning of each passage. Depending on the intensity of arrival rates, time of day, season of the year, and response to the reduction in queues per hour, the TC may choose to continue the PCO. On the other hand, circumstances will occasionally dictate that the PCO be placed on standby and the roadway be opened to two-way traffic until such time as arrival rates taper off to manageable levels.

REFERENCE

1. *A Report on Traffic Operations and Emergency Procedures During Construction*. Daniel, Mann, Johnson, & Mendenhall, Denver, Colo., 1985.

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