Risk Analysis of Freeway Lane Closure During Peak Hour

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(This paper contains 3921 words and 8 figures and 3 tables)
ABSTRACT

This paper will examine risks associated with peak periods lane closure during construction or maintenance work on urban freeways. Generally speaking, if the Contractor is allowed greater flexibility in establishing work schedules, including the ability to work through the peak hours, a lower bid can be expected. In accordance with recently implemented policy by the Colorado Department of Transportation, if reserve capacity were available, then lane closure would be allowed. A relatively minor accident in the work zone caused substantial delays during the peak hour that virtually paralyzed traffic in the Denver Metro area. This occurrence caused re-examination of the existing lane closure policy. This paper will compare savings in the cost of construction related to allowing lane closure during peak periods with the cost of potential incident-related delays in the framework of a quantitative risk analysis.
INTRODUCTION

A lane closure decision support analysis model was developed and implemented for the Greater Denver Metropolitan Area by the Colorado Department of Transportation, Kononov et. al. (1). It was conceived as an expert system intended to improve the quality of lane closure decisions, simplify the decision making process for the end user and reduce uncertainty associated with handling traffic during construction and maintenance. It established a uniform criteria and authoritative guidance for scheduling lane closures in the metropolitan area. The lane closure strategy was conceived of as a knowledge-based expert system that can be calibrated and adapted to other metropolitan areas around the country. Development of the lane closure strategy was motivated by the need to strike appropriate balance between delays to the traveling public in the work zone and the cost of construction and maintenance. A decision support analysis system was developed based on extensive data collection and analytical procedures that estimate the queues and delays expected during lane closures. This decision support system forms the analytical framework behind the lane closure Strategy implemented by the Colorado Department of Transportation (CDOT) in the Denver Metropolitan area.

Historically, lane closure decisions were made primarily on the basis of field observations, previous experience and engineering judgment. Project-specific decisions were required to determine an appropriate lane closure schedule. This comprehensive strategy bases lane closure schedules on actual data, accounting for the spatial and temporal variations in traffic patterns that typically occur throughout a large urban area. The results of the analyses are lane closure schedules covering over 500 miles of freeway and arterial roadways and reflecting traffic operations for over 16,000 different lane closure scenarios possible in the Denver area. The schedules have been summarized in a graphical format and entered into lane closure schedule databases that may be queried by the DOT personnel to develop appropriate lane closure schedules for individual projects or maintenance operations. Figure 1 and Table 1
represent a sample of the information contained in the Lane Closure Report. This Report was also made available to the Contractor’s community to assist with planning roadwork in the Denver Metropolitan Area.

This lane closure strategy had been in effect in the Denver metropolitan area for approximately two years when a relatively minor accident in the work zone involving truck breakdown resulted in substantial delays during the peak hour, which virtually paralyzed traffic in the area. This site-specific occurrence prompted the general re-examination of the existing Region-wide lane closure strategy effecting freeways during the peak hour. Prior to this incident, lane closure during the peak hour would be allowed if reserve capacity were available. Generally speaking, if the Contractor is allowed greater flexibility in establishing work schedules, including the ability to work during the peak hours, a lower bid can be expected. This paper will compare savings in the cost of construction with the cost of potential incident-related delays in the framework of a quantitative risk analysis.

**REVIEW OF EXTANT LITERATURE**

Much has been written on the subject of work zone safety. To date, the emphasis seems to be focused on compliance with reduced speed limits in the work zones and the expected reduction in safety due to the presence of a work zone and capacity reduction in work zones.

In *Safety Implications of Freeway Work Zone Lane Closures*, Zhu and Saccomanno (2) discuss the safety implications of left lane and right lane closures. Wang et al. (3) observes that accident rates on highways are 7% to 119% higher during construction than during times without construction. Such a broad range of change in accident rates in the work zone suggests that the question is not well understood.

Huebschman, Garcia, Bullock and Abraham (4) state in *Compliance with Reduced Speed Limits in Work Zones (TRB 2004)* that accident rates increase about 30% on
interstates in work zones. The remainder of their study focused on the evaluation of a product’s effectiveness on reducing speed in the work zone.

Rister and Graves (5) conducted extensive research in estimating reasonable delay costs. They found that the various delay costs for cars used throughout the USA range from about $9/hr to about $15/hr in 1998 dollars.

Most studies seem to indicate that the introduction of work zones lead to an increase in accident rates, although this increase is highly dependent on traffic and geometric conditions, traffic control devices, and other aspects of the work zone environment. According to Venugopal and Tarko (6) the increase in crash rate at work zones may be due to several reasons including “the general disruption of traffic due to closed lanes, improper lane merging maneuvers by drivers, and inappropriate use of traffic control devices”.

Work zones seem to be especially difficult for trucks due to their dimensions and operating characteristics. Benekohal and Shim (7) surveyed 930 truck drivers and found that 90% of those surveyed considered traveling through work zones to be more hazardous than traveling through road sections not affected by construction. Safety in work zones continues to remain a high-priority issue for highway agencies partly due to the limited understanding of the causes of the crashes. According to the National Work Zone Safety Information Clearinghouse, in one year, work zones in this country are associated with more than 700 fatalities, 24,000 injury crashes, and 52,000 property damage-only crashes, and the estimated cost of these crashes exceed $4 billion per year. One could argue that the work zones are likely to increase in number due to the emphasis on repair and reconstruction. Hence, it can be expected that the number of accidents in work zone will increase correspondingly.

Traffic control devices found to reduce the frequency of crashes in the work zone. For example, Garber and Srinivasan (8) found that variable message signs with radar could reduce the possibility of speeding at work zones, and hence reduce the frequency / severity of crashes. In another study, orange rumble strips due to their high visibility
were found to have a significant effect on vehicle speeds, see Meyer (9). However, in some cases, these traffic devices may themselves be a safety hazard to drivers, passengers, and the workers, and need to be studied carefully, see Bligh (11) and Bryden (10). Rear-end crashes have consistently been the most predominant type of crashes. This has been found to be true to for work-zones as well. Between 30 and 40% of crashes at work zones are rear-end crashes, Wang et al., (3). Very few published studies have analyzed the causes and the factors associated with rear-end crashes in work zones. One possible reason is the lack of detailed data. According to the study by the FHWA (12) based on data from Illinois, Maine and Michigan the percentage of work zone accidents involving a rear-end collision was significantly higher than that of non-work zone accidents. This may suggest that speed differential among vehicles traveling through work zones may be a primary contributor to work zone accidents. It was also found from all three States’ distributions that the percentage of sideswipe collisions in work zones is higher than the percentage of sideswipe collisions in non-work zones. Many work zones typically include narrower lanes and shoulder/lane closures, which increase the chance of lane-change maneuvers. This may account for the difference in the percentage of sideswipe accidents.

Questions still remain regarding the safety of work zones. It is believed that major obstacles to answering these questions are: (1) the lack of quality data related to the characteristics and conditions existing at the time of the accident, and (2) the lack of reliable work zone inventories. Past studies about work zone safety were mostly based on limited data. Very few studies attempted to explicitly consider exposure to work zone activities or to develop work zone accident rates that account for differences in exposure. A key need is to determine an appropriate exposure measure to calculate the work zone crash rate.

It seems that the prevailing majority opinion among researchers of work zone safety is that the phenomenon of accident occurrence in the work zone is complex, dependent on many factors and not well understood.
RISK ANALYSIS-ANALYTICAL FRAMEWORK

This study will accept uncertainty related to increase of work zone related accidents and still provide decision support analysis for freeway lane closure during peak hour. This methodology will assist transportation professionals with lane closure decision-making in the climate of uncertainty, by estimating accident risk and resulting delays. Crash cost (i.e., property damage only, injury, fatality) will not be explicitly considered in this study. Considering that work zone crashes have a higher percentage of rear-end crashes, one could argue that work zone crashes are less severe. However, at the same time, work zones may include crashes between vehicles and workers and between vehicles and fixed objects, which can be quite severe. With this in mind, we feel that the overall crash costs will remain relatively stable and will not influence the final outcome of the risk analysis. Accident risk will be first assessed using Safety Performance Functions (SPF) calibrated for conditions without lane closure. Then, appropriate adjustments will be made for an accident frequency increase in the work zone. Use of Safety Performance Functions into road safety analysis was introduced by Hauer and Persaud (13). Safety Performance Functions in essence are accident prediction models, which generally relate traffic exposure measured in AADT to safety measured in the number of accidents over a unit of time. A great deal of substantive and comprehensive work in the area of accident modeling was undertaken by Miaou and Lum (14), Hauer and Persaud (13) and Hauer (15). Details concerning dataset preparation and model fitting for the development of the Safety Performance Functions (SPF) are described by Kononov and Allery (16). The model parameters are estimated by the maximum-likelihood method in the Generalized Linear Modeling (GLM) framework using a dataset containing 14 years of accident data. To estimate expected accident frequency during peak hour, we will make use of the SPF calibrated specifically for urban freeways.

The case history presented in this paper to illustrate risk analysis methodology involves a highway improvement project on an existing Urban 6-Lane Freeway in the Denver Metro area. By consulting the SPF calibrated by the Colorado Department of Transportation (CDOT) specifically for the 6-Lane Urban Freeways, it was found that
37.4 accidents per mile per year might be expected for an Average Daily Traffic (ADT) of 100,000 vehicles. The SPF used is shown on Figure 2. An ADT of 100,000 vehicles per day existing within project limits on this 6-lane facility suggests some reserve capacity. This availability makes this segment a candidate for a lane closure consideration during the peak period. The question we will now explore in detail can be formulated as follows: Does the cost savings and expediency of construction outweigh delays related to an accident in the work zone during peak period traffic?

The decision making process, and the consequences of each possibility, of whether or not to allow lane closures for construction during the peak period, can be illustrated using the framework of a decision tree, presented on Figure 3.

The challenge then becomes to populate each branch of the decision tree with realistic values. From the scope of work of the highway project in our case history, we ascertained that a job time frame includes 60 days of lane closure and a closure length of 1.0 mile. Given ADT of 100,000 expected frequency of 37.4 accidents per mile per year attained from the Urban 6-Lane Freeway SPF graph translates into accident expectancy of 6.1 through completion of the 60-day job.

Since this analysis is primarily concerned with accident occurrences during the peak period, a 10-year query of the CDOT accident database shows the distribution of accidents presented on Figure 4 for Denver Metro area freeways on weekdays.

Using these numbers, we can then calculate the number of expected accidents in our 60-day job site during the peak period to be about 2.1. An illustration of this calculation is shown below:

\[ E = \mu \frac{J}{365} \left( \frac{W_p}{W_p + W_o} \right) \]
\( \mu \) = Average accident frequency per mile per year from applicable SPF for a work zone that has a specific ADT and length

\( J \) = Length of job in days

\( W_p \) = Average number of weekday peak period accidents

\( W_o \) = Average number of weekday off-peak accidents

\( E \) = Expected accidents in the work zone during the peak period

Since it has been shown that accident patterns closely fit a Poisson process, we can then determine the chances of at least one (one or more) accident occurring in the work zone area during the peak period.

Since experiencing at least one accident is complementary to experiencing zero accidents, the expression is:

\[
P(X \geq 1) = 1 - P[X = 0]
\]

or in terms of our example,

\[
P_r[X = 0] = \frac{2.1^0 e^{-2.1}}{0!} = 0.122
\]

then,

\[
1 - 0.122 = 87.6\%
\]

So the odds of observing 1 or more accident during the peak hour in the project area without construction is 87.6%. However, to account for historical increases of accident probability due to the presence of a work zone, we will increase the chances of an accident occurring. While there is some uncertainty related to this question, we will use an estimate developed by Huebschman et al. (4) of 30%, which we consider conservative. Thus the expression becomes:
\[ P(X = 0) = p(0.21 \times 1.3) = \frac{(2.1 \times 1.3)^0}{0!} e^{(-2.1 \times 1.3)} = 0.065 \]

then,

\[ 1 - 0.065 = 93.5\% \]

The odds of observing 1 or more accident in our work zone during construction in the weekday AM and PM peak hour periods are 93.5\%, which means that not observing an accident is highly unlikely. The decision tree for our example can then be updated (Figure 5) to reflect the chances of accidents occurring under Poisson assumption.

What now remains is determination of the consequences of the decision to allow lane closure on a 60-day project. Research shows that average delay costs range from about $10 to about $20 per vehicle-hour in 2004 dollars, for the purposes of our example analysis, a delay cost of $15/vehicle-hour will be used for all delayed vehicles.

The next variable to consider is the number of vehicles that may be impacted by an accident during the peak hour in the work zone. The map on the following page shows the approximate location of the accident referred to earlier that recently occurred on I-76 during the PM peak in Denver. This accident effectively closed I-76, and thus can be used as an illustration of what would occur if an accident occurred in a work zone during the peak hour. The outlined area on the map approximates the extent of backups on other freeways and highways affected by the closure of I-76. The area shown is a combination of known backups that occurred during the incident in some areas and estimations of backups in other areas.

From the scaled map, it was determined that about 23 miles of backups occurred during this incident. With 3 lanes of travel affected, and an assumed 25 ft. of length per vehicle, this equates to about 15,000 delayed vehicles. This figure does not account for delay on minor streets, but it may overestimate delayed vehicles on the highway since it counts delayed vehicles in both directions. Given the uncertainty in estimating the
overall number of vehicles delayed, we will conduct sensitivity analysis for a range of
delayed traffic from 5,000 to 25,000 vehicles.

Using the range we have now established, we tabulated the results of the 2-way
sensitivity analysis in table 2 below. The analysis relates costs associated with a series
of delays with the number of vehicles affected.

Each value was calculated using the following formula:
(number affected) X (cost of delay) X (length of delay)
or, for the first cell in our example (rounded down to nearest 1,000 to be conservative),
(5,000 vehicles) X ($15/hour) X (10/60 hours) = $12,000

We will use $112,000 as an average estimate of the delay cost associated with one
accident.

We have determined the mean number of accidents that will occur during the peak hour
during our example job to be 2.1 accidents, and we have shown that the increased
probability of an accident occurring in our work zone is about 30% versus when a work
zone is not present. Carrying this to the next step, we can then multiply each cell by 2.1
and by 1.3 accidents per project to determine the expected number of accidents, on
average, for the lane closure scenario. Table 3 below reflects a range of delay costs
that can be incurred throughout 60 days of project duration (rounded down to nearest
1,000 to be conservative).

This tells us that, on average, we should assume a delay cost of $305,000 for our
example job. This cost must be considered when the decision to allow a peak hour lane
closure is made.

This can then be compared to the total cost of allowing lane closure only off-peak. A
survey of area contractors and estimators shows that on average, a job can be
expected to last about 15% longer in duration when peak hour work is not allowed.
Additionally, a premium of about 15% in job cost will also be required for off peak only work. For a $1,000,000 project, this translates into a premium payment of $150,000. Considering an average cost of $112,000 in delay per accident, in concert with Poisson assumptions, our final decision tree is then reduced to figure 7.

In this example we used 30% increase in accident frequency due to construction. It is interesting to note that even if safety performance during construction does not change, which is highly improbable, the outcome of the risk analysis does not change. Figure 8 shows a reduced decision tree that reflects accident probability, which assumes that safety performance in the work zone is the same as without it.

**CONCLUSIONS**

This analysis shows that it is critical to consider the delay resulting from potential accidents, when making decisions about lane closures during peak periods on urban freeway. Establishing criteria that is based solely on available capacity is not sufficient.

It can also be seen from this analysis that the odds of an accident in the work zone occurring in the Denver metro area during a peak period closure are quite high. Thus the probability of massive backups and delays occurring at least once during a typical project requiring a lane closure are a near certain (93.5%).

The best estimate of the expected number of accidents in the work zone on the segment of road is probably its safety performance absent construction. It is generally accepted that safety performance during construction will be characterized by increased number of accidents, the magnitude of the increase, however, is uncertain. Despite this uncertainty it is possible to assess the risk of potential accidents using sensitivity analysis. The case history on this busy urban freeway illustrates that even if safety performance during construction remains the same as without it, lane closure during the peak period on an urban freeway is best avoided.
In our case example, the expected cost of delay for allowing a peak period lane closure is $305,000. In contrast, a premium of $150,000 is incurred by the DOT for allowing work only off-peak. This equates to a net overall societal disbenefits in the amount of $155,000 when work during the peak hour is allowed. From the standpoint of making policy, and considering the secondary adverse impacts, including driver frustration and negative public relations, it appears that closure during the peak period on the urban freeway should be avoided whenever possible.
REFERENCES


3. Wang, J., Hughes, W., Council, F. and Paniatti, J. Investigation of highway Work Zone Crashes; What we Know and What We don’t Know. Transportation research record 1529, TRB, national research Council, Washington, D.C., 1996


7. Benekohal, R. F. and Shim E. Illinois Department of Transportation Survey of Truck Drivers’ Opinion on Work Zone Traffic Control


11. Bligh et al., reference to be provided


### Table 1: Region 6 Lane Closure Policy

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<thead>
<tr>
<th>State Highway Number</th>
<th>Facility Name</th>
<th>Location</th>
<th>From</th>
<th>To</th>
<th>Begin of Section (MP)</th>
<th>End of Section (MP)</th>
<th>Facility Type</th>
<th>Weekday</th>
<th>Weekend Closure Window</th>
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<td>OSFA</td>
<td>6th Ave/EB</td>
<td>Billings St.</td>
<td>Airport Blvd.</td>
<td>17</td>
<td>10.19</td>
<td>12.685</td>
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<td>7:00 PM to 9:00 AM</td>
<td>6:00 PM to 11:00 AM</td>
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<td>Airport Blvd.</td>
<td>Billings St.</td>
<td>13.98</td>
<td>16.18</td>
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<td>12700</td>
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<td>Anytime</td>
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<td>12700</td>
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Schedule times shown in bold lettering represent freeway segments that must be re-opened by 7:00 PM or earlier.

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Paper revised from original submittal.
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**TABLE 2: Two-way sensitivity analysis outcomes per accident**
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<td>Dollars/Project</td>
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**TABLE 3:** Two-way sensitivity analysis outcomes with lane closure per project
Figures

Figure 1: Region 6 Lane Closure Map
Figure 2: 6-Lane Urban SPF
FIGURE 3: Decision tree-conceptual framework
FIGURE 4: Accident distribution by peak/off peak period on Denver Metro Area freeways
FIGURE 5: Decision Tree with Estimated Chance Nodes
FIGURE 6: Scaled Map of Incident Related Backups
FIGURE 7: Final Decision Tree
FIGURE 8: Final Decision Tree with No Reduction in Work Zone Safety