

A Simulation of the Factors Relevant in the Transition of Traffic States Upon Approach to a Work Zone

Jonathan Daniel Lanctot

Robert Batson, Ph.D.,
Professor of Civil, Construction,
and Environmental Engineering

Abstract

The current research builds upon a previous study (Lanctot and Batson, 2008) which analyzed the methodology behind the Oklahoma Department of Transportation's Traffic Queuing Highway spreadsheet to identify factors relevant to traffic flow. The current study extends that work by examining the transition of traffic states upon approach to a highway work zone. The mathematical models previously investigated were utilized to create a simulation model which better corresponds to real-world highway data by incorporating more complex driving behaviors not present in deterministic models.

Rather than continue to use previous empirical methodologies to generate models that correspond to traffic patterns in highway work zones, we decided to take a different approach to the problem of estimating this traffic. We ask the question, *what factors are relevant to the creation of work zone queues?* This, in effect, takes the problem in reverse: rather than empirically looking at the phenomenon of traffic queues, we would like to simulate the conditions which cause these queues and learn how these variables interact. We hope that by using this innovative approach, we can begin to simulate traffic queues with more accuracy and a better understanding of how they form, thus leading to models which state departments of transportation can use to better determine their needs.

Review of Literature

The design characteristics of our project were based on the identification of well-researched variables specific to traffic simulation. Research has identified characteristics of work zones which have an impact on the overall design of a work zone and, furthermore, its capacity to accept traffic. Overall project characteristics, travel and traffic characteristics, work zone design and safety issues, and temporary traffic control strategies are all factors which affect the scope and design of a work zone roadway project (Federal Highway Administration Office of Operation 2006), while work zone lane closure configuration, intensity and location of work, percentage of heavy vehicles, driver characteristics, entrance ramp locations and volumes, grade of lane closure, duration of work, weather conditions, work time, and location of merge point and enforcement are variables which directly affect work zone capacity (The Smart Work Zone Deployment Initiative, The Midwest Transportation Consortium, The US DOT University Transportation Center for Federal Region 7 2005). In a perfect theoretical model, all these characteristics would be measured and present; however—as is the case in most engineering endeavors—care must be taken to balance the economics of the overall project. Thus, an engineer must prioritize which characteristics are most important to the project at hand and how to budget time between project theory, planning, and execution using knowledge, experience, and judgment.

Simulation methods were further researched during the project. Seven types of work zone traffic analysis tools are enumerated in various sources of literature, and three simulation methods are of great interest (Federal Highway Administration Office of Operation 2006).

Macroscopic simulation models are based on deterministic methodology and analyze the interactions between traffic networks. These methods are best applied when analyzing a specific section of a traffic network and do not include individual or unique elements of driver behavior, thus the method's "macroscopic" designation. The determining factor in a macroscopic simulation's accuracy is the accuracy of its traffic capacity information. Deterministic models are unable to relate variable and probabilistic phenomena within a work zone environment because of their reliance on fixed data (The Smart Work Zone Deployment Initiative, The Midwest Transportation Consortium, The US DOT University Transportation Center for Federal Region 7 2005).

Microscopic simulation models take the problem in reverse: individual driver behaviors and driver logic are placed on a more complex and detailed traffic network, leading to a much more probabilistic method of

analyzing work zone closures (Federal Highway Administration Office of Operation 2006). These detailed analysis techniques require massive amounts of computing power, simulation design, and execution time in comparison to simpler macroscopic simulation techniques. In addition, some microscopic simulation models are not scaled for a work zone traffic environment, leading to inaccurate results. However, as compared to the deterministic modeling employed in macroscopic simulation models, microscopic simulation models offer a more accurate representation of work zone traffic patterns and queuing lengths (The Smart Work Zone Deployment Initiative, The Midwest Transportation Consortium, The US DOT University Transportation Center for Federal Region 7 2005).

Mesoscopic simulation models offer a middle ground between macroscopic and microscopic simulation techniques. These models offer the deterministic traffic network common to macroscopic simulation models while providing the probabilistic distribution of traffic and driver logic found in microscopic simulation techniques. In addition, modeling software which employs these techniques does not require the computing power or design time required by more detailed microscopic simulation models. The result is a combination of deterministic traffic networks with probabilistic distributions of traffic and the addition of driver logic in one package (Federal Highway Administration Office of Operation 2006).

The current study examined a conclusion found in our literature review: “the capacity of work zones is governed by the efficiency of drivers to converge into the through lanes at the merge point” (The Smart Work Zone Deployment Initiative, The Midwest Transportation Consortium, The US DOT University Transportation Center for Federal Region 7 2005). Supporting this conclusion using a probabilistic mesoscopic simulation model became the focus of our research.

Research Questions and Hypothesis

Does encouraging lane merging before a work zone increase the efficiency of the work zone’s capacity, leading to a more efficient traffic flow?

Does lane merging before a work zone enable traffic to flow through the work zone more efficiently? In effect, does lane merging increase the work zone’s throughput? Does this conclusion hold for deterministic models? Probabilistic models? How can we incorporate or test this logic using other simulation methods? Ultimately, how can we increase the capacities of work zones through greater efficiency?

How can state departments of transportation and their contractors mitigate the creation of work zone queues?

Ultimately, can we control relevant variables to reduce the costs to contractors, state departments of transportation, and—most importantly—the general public? What measures can be taken to reduce traffic queues in work zones? These questions will contextualize the impact of our research into a wider framework which others may utilize in their projects, possibly in the form of general guidelines for parties involved in work zones.

We are seeking to test the hypothesis that “the capacity of work zones is governed by the efficiency of drivers to converge into the through lanes at the merge point” (The Smart Work Zone Deployment Initiative, The Midwest Transportation Consortium, The US DOT University Transportation Center for Federal Region 7 2005). Assuming this is the case, we should find that a work zone’s queue should dissipate when drivers are given the ability to choose to merge before a work zone occurs. The deterministic or probabilistic characteristics of the simulation model should not affect these conclusions, but if they do, the probabilistic model should give us more accurate traffic simulations.

Methodology

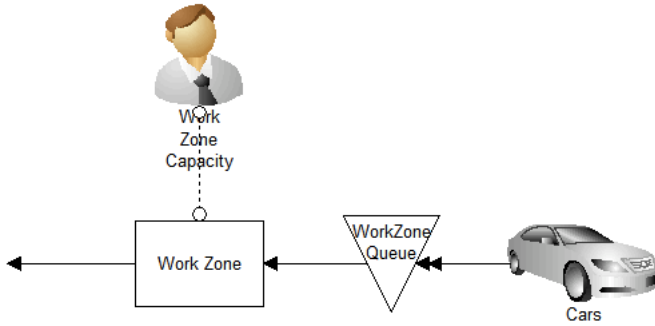
We used ProcessModel software to simulate the deterministic model researched in our previous study (Lanctot and Batson 2008). We identified and simulated four critical traffic situations:

1. Deterministic Arrivals with No Transition Zone
2. Probabilistic Arrivals with No Transition Zone
3. Deterministic Arrivals with Transition Zone
4. Probabilistic Arrivals with Transition Zone

One of the significant limitations of our previous research (Lanctot and Batson 2008) was the reliance on solely deterministic methods, which employ a constant arrival rate. In the current study, we created a simulation model which accepts both deterministic and probabilistic methods for traffic flow. For the latter, we selected a Poisson distribution, which yields an average arrival rate by oscillating the instantaneous arrival rate over time.

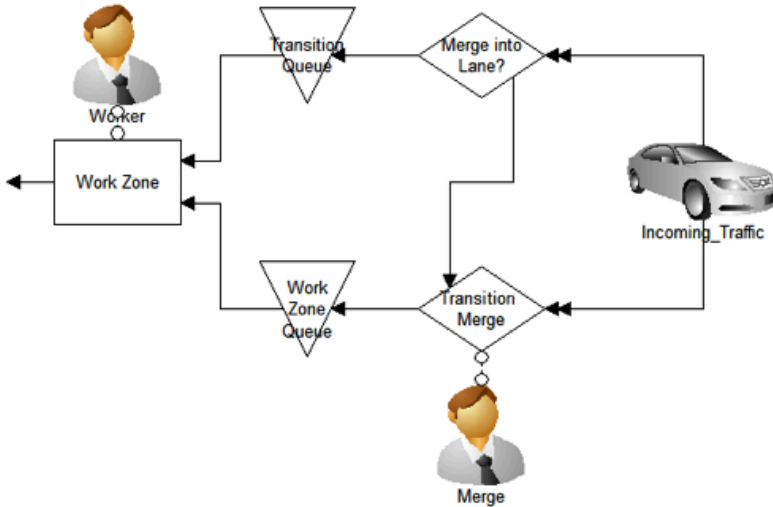
The “Transition Zone” portion of our model consisted of two factors: driver logic, which allowed for drivers to choose when to merge into a lane of traffic, and programming, which delayed all drivers when a driver merges at the work zone entrance. For this explanation, it may help to see the simulated model itself in Figure 1.

Figure 1. No Transition Zone Model



The simulation without a transition zone (“No Transition Zone”) simply allows cars to enter the work zone queue without any driver logic or decisions to be made. From there, they pass through the work zone and out of the simulation as space becomes available.

Figure 2. Transition Zone Model



With a transition zone, however (“Transition Zone”), drivers arrive in one of two lanes. In the lane that passes through the work zone, drivers proceed as before through the work zone. However, drivers in the lane which merges into the work zone face a decision: should they merge into the lane before the work zone occurs (“Merge into Lane?”) or should they drive until their lane ends (“Transition Queue”), and wait for someone from the Work Zone Queue to allow them to merge into the Work Zone?

Drivers who merge before the work zone occurs flow through the work zone faster than drivers who choose to stay in their lane until they are physically forced to merge.

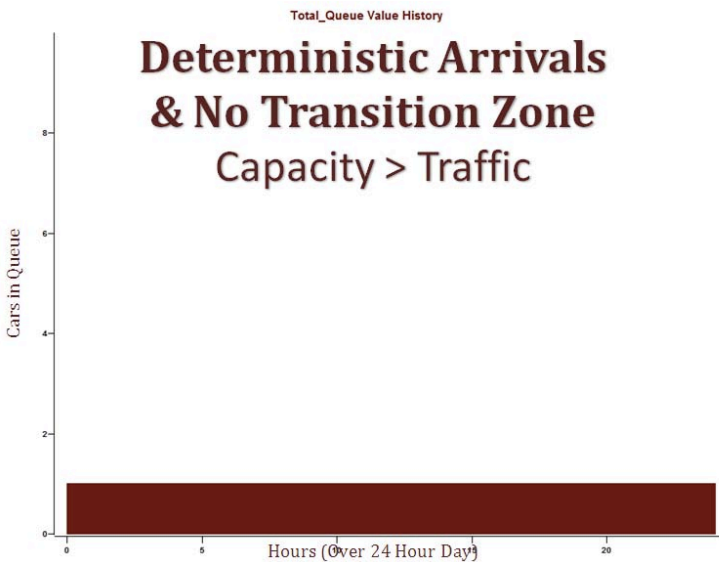
Data collection consisted of a simple counter that counted the incoming and outgoing cars in each physical part of the model. In models without a transition queue, the counter counted all cars caught within the “Work Zone Queue.” In models with a transition queue, three counters counted cars--within the “Work Zone Queue,” the “Transition Queue,” and both the “Work Zone Queue” and “Transition Queue” (that is, the sum of cars within both queues).

Results and Discussion

Analysis

Deterministic models, as studied previously, followed the same traffic pattern as before (Lanctot and Batson, 2008), while probabilistic models yielded new results. We will analyze each case separately.

Figure 3. Deterministic Arrivals with No Transition Zone, Work Zone Capacity greater than Incoming Traffic

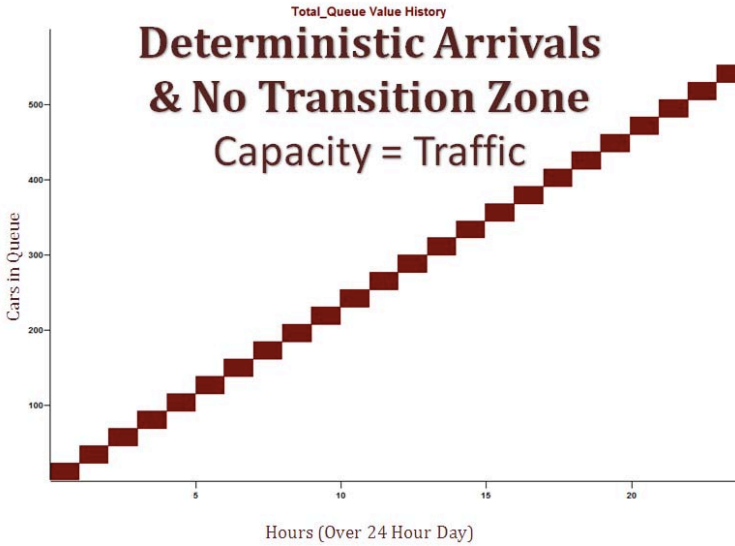


Simulation Parameters 22 cars/hr arriving, 23 cars/hr capacity, over 24 hrs¹

¹ Yields similar results for 120 hrs, or one work week.

In a purely deterministic model, if incoming traffic is less than the processing capacity of the work zone, there will be no work zone queue. This is a logical conclusion in both theory and practice, and follows from previous research. (These results also follow for work zones with a transition queue; for brevity, those graphs are not presented.)

Figure 4. Deterministic Arrivals with No Transition Zone, Work Zone Capacity equal to Incoming Traffic

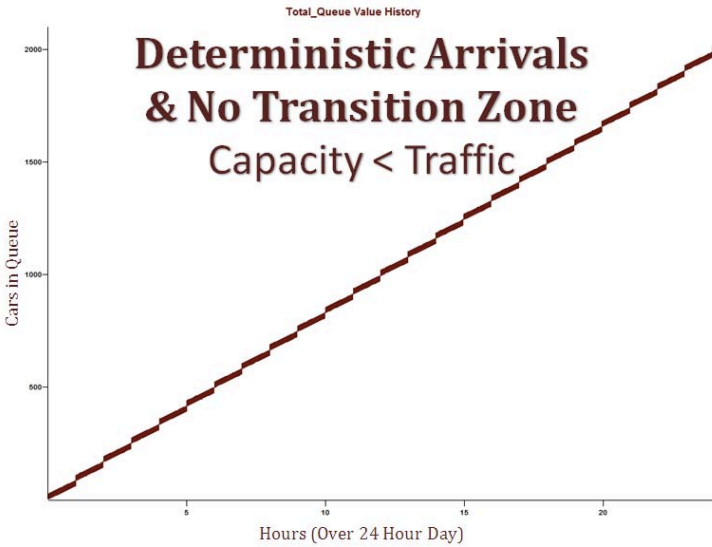


Simulation Parameters 23 cars/hr arriving, 23 cars/hr capacity, over 24 hrs²

Given the same number of cars both entering and exiting the model at the same time, one would assume that there would be no queue forming at all. In a deterministic world, this would be true: the capacity of the work zone subtracted from the number of cars arriving leaves zero cars in queue. However, we begin to see the advantages of using a simulated model in Figure 4: we have built-in inefficiency due to the model's simulated nature; thus, cars do not simply flow steadily through the work zone. Over time, they slowly build a queue in linear fashion that does not dissipate, since all variables in the model are constant over time.

² Yields similar results for 120 hrs, or one work week.

Figure 5. Deterministic Arrivals with No Transition Zone, Work Zone Capacity less than Incoming Traffic



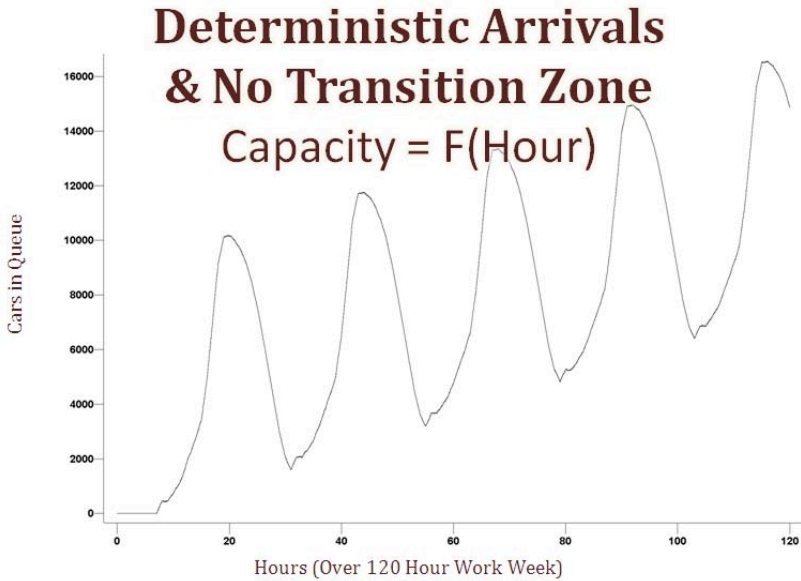
Simulation Parameters 24 cars/hr arriving, 23 cars/hr capacity, over 24 hrs

As with Figure 4, the conclusion presented here is one that is both logical and obvious: when the work zone capacity is less than the number of cars arriving each hour, the work zone queue will never dissipate and will grow over time in a linear fashion. While this graph looks similar to Figure 4, one must be aware of the scale of the ordinate: there are four times as many cars in the queue at the end of the day in Figure 5. (For the sake of brevity, this simple case will not be presented for the “Transition Zone” model.)

To finalize the transition from a theoretical model to a usable, simulated environment, we needed to create a test case that would work in our new model and in the model previously tested. Similar results between models would confirm the underlying methodology of our newly constructed model, and any computational differences would merit further study.

³ Yields similar results for 120 hrs

Figure 6. Deterministic Arrivals with No Transition Zone, OKDOT Spreadsheet Model Case

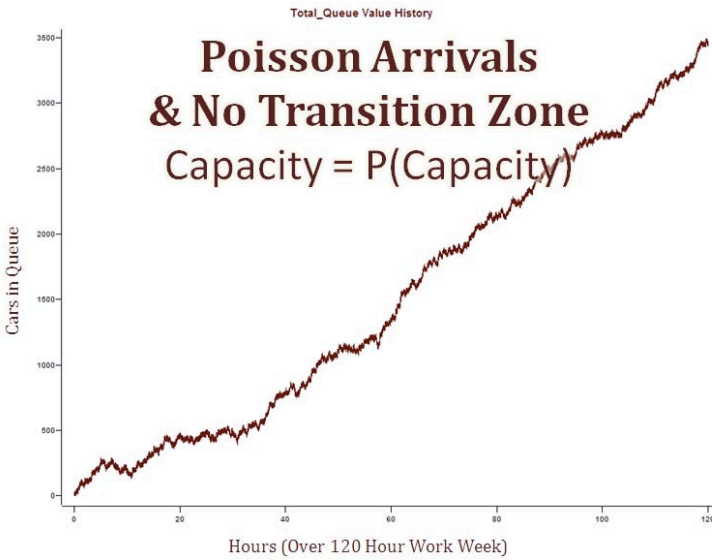


For one 24-hour period, the OKDOT spreadsheet model and our simulation model matched results nearly one-to-one on an hour-by-hour basis, forming the same queue in both models each hour. However, one of the limitations of the OKDOT model is its inability to run concurrent days—that is, it can only run one 24-hour cycle of data. When we run our simulated model over 120 hours (one work week) we find that, over a 24-hour period, the OKDOT deterministic model would develop a queue that would not dissipate (Lanctot and Batson, 2008).

Using these data, we surmised that there must be some incorrect assumption found within the OKDOT model, and, after a great deal of searching, we found that the OKDOT model assumes that any traffic queue at 3:50 a.m. automatically dissipates to zero. This, in fact, is the starting point for the model's calculations and explains the discrepancy between the two models.

After recreating our deterministic model in a simulated environment, we began to experiment with probabilistic arrivals. We wondered if the deterministic conclusion would hold in the case of Work Zone Capacity equal to Incoming Traffic if we used a Poisson Distribution for incoming traffic. That is to say, on average, the Work Zone Capacity would be equal to the Incoming Traffic, but, on an hour-by-hour basis, the incoming traffic would vary according to Poisson Distribution.

Figure 7. Poisson Arrivals with No Transition Zone, Work Zone Capacity equal to Poisson Distribution



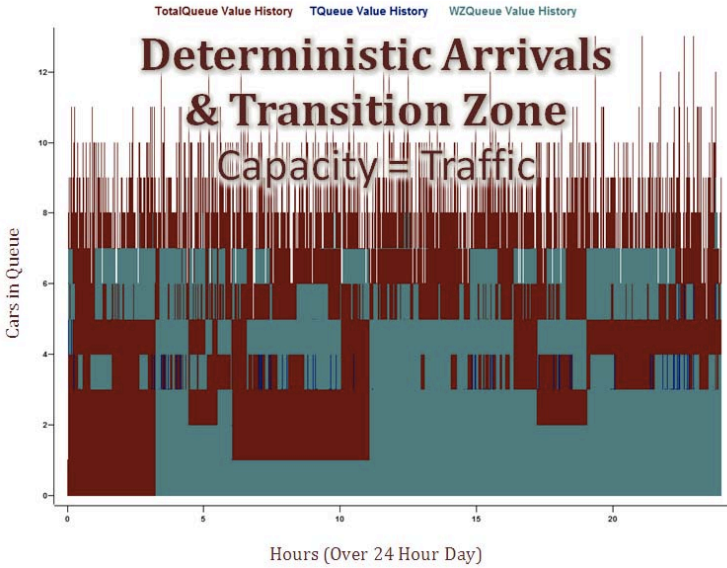
Simulation Parameters P(23) cars/hr arriving, 23 cars/hr capacity, over 120 hrs⁴

We found that a similar number of cars were trapped in the queue whether deterministic or probabilistic methods were used. In Figure 7, we find the same “linear” growth in queue as seen in deterministic models. Even with a variance in car arrivals, there is no change in the work capacity of the work zone.

Giving drivers the ability to organize before the introduction of a work zone revealed a compelling finding, as illustrated below in Figure 8: drivers are able to pass through the work zone without creating a significant work zone queue.

⁴ Yields similar results for 24 hrs.

Figure 8. Deterministic Arrivals with Transition Zone, Work Zone Capacity equal to Incoming Traffic



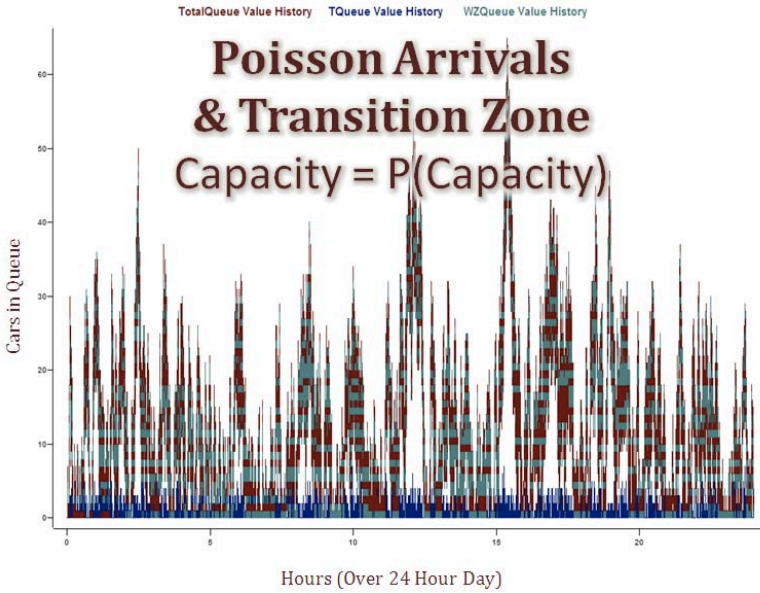
Simulation Parameters 23 cars/hr arriving, 23 cars/hr capacity, over 24 hrs.⁵

This lane-merging effect maximizes the work zone’s capacity, thereby increasing its efficiency and allowing more drivers to flow through the zone without stopping. This outcome was not present in either the deterministic or probabilistic models, and is the direct result of the introduction of driver-based behaviors within our simulation.

Given that transition zones can maximize the efficiency of work zone capacities, we return to the probabilistic case to confirm this outcome with more realistic arrivals.

⁵ Yields similar results for 120 hrs.

Figure 9. Poisson Arrivals with No Transition Zone, Work Zone Capacity equal to Poisson Distribution



Simulation Parameters P(23) cars/hr arriving, 23 cars/hr capacity, over 24 hrs.⁶

As one can see from Figure 9, we retain the ebb and flow of the work zone queue, which dissipates several times throughout the day. Due to probabilistic arrivals, there are times when the queue spikes to larger numbers, but this is also followed by times when the queue is relatively short.

Conclusions

Deterministic and probabilistic models yield similar results in similar microscopic situations

While we have not shown this to be true in all situations, we have found that in simulated models featuring work zones there is no significant difference between building a deterministic model or probabilistic model which calculates the number of cars that will find themselves in a queue. Both situations tend to produce similar results; thus, the required energy to convert deterministic models to probabilistic ones is, more than likely, not going to change the results calculated.

⁶ Yields similar results for 120 hrs.

Deterministic models do not accurately represent driving behaviors such as lane merging in microscopic situations such as work zones

While the deterministic model has proven itself when compared to probabilistic models, we have found that changing driving behaviors and adding driver logic to these models creates very different results, leading us to conclude that these driver-based behaviors are not well represented in deterministic models. Because of a work zone's microscopic properties, the individual characteristics of the roadway, signage, weather conditions, and driver behaviors all play a greater role in determining how drivers navigate the work zone versus the deterministic models we studied. While deterministic models are better for calculating large networks of highways where these behaviors will average themselves out over a long period of driving time, these models cannot reproduce accurate work zone traffic flows, due to this lack of information.

Merging drivers before a work zone maximizes the work zone's capacity

Finally—getting back to the overall purpose of our research—the best thing drivers can do to avoid work zone traffic delays is to cooperate with one another to merge before the occurrence of a work zone, thereby maximizing its capacity and leading to shorter work zone queues and overall traffic delays. This can be accomplished via signage which alerts drivers to the presence of a work zone with sufficient time, telling drivers which lanes are open and closed before the work zone is in visible range, and encouraging drivers to work together to navigate work zones without stopping. We encourage DOTs to enforce guidelines which will enact these changes and contractors to provide accurate information to drivers.

Further Research

Due to time constraints, we were able to simulate only the simplest of cases. How can we extend the models we have to include factors such as weather and individual driver behaviors? Do driver behaviors affect the results of simulation models more so than external factors, such as weather and work zone activity? How should engineers prioritize their model development in the future?

While we have outlined some improvements that can be made to maximize traffic flow on approach to work zones, we have yet to investigate the cost and benefits to using these methods. Is it reasonable for engineers to run multiple analysis tools for each work zone? How can we best quantify

the benefits of using a microscopic simulation method when the requirements over macroscopic methods are so much larger? Engineering judgment must always guide such a decision, so research into qualifying these gains in terms of time, money, and safety would be valuable. Modulating variables such as project size, duration, and budget would help make these gains more meaningful as well.

Finally, what can we further do to encourage drivers to merge before work zones? While perfect information is a good goal, how much of this information is received by drivers, and how does a work zone's unique characteristics change this receipt of information? What prevents drivers from accepting or acting on this information? Can law enforcement or other agencies encourage drivers to merge in some way? What other driver psychology is related to this issue, and how does it shape what DOTs and contractors can do for work zones?

Works Cited

- Batson. *Tentative Project Plan for ALDOT Project "Work Zone Lane Closure Analysis Model."* Tuscaloosa: The University of Alabama, 2007.
- Batson, Ray, Turner, and Cui. *Work Zone Lane Closure Analysis Model.* Research Proposal, Tuscaloosa: The University of Alabama, 2007.
- Benekohal, Kaja-Mohideen, and Chitturi. *Evaluation of Construction Work Zone Operational Issues: Capacity, Queue, and Delay.* Final Report, Urbana-Champaign: The University of Illinois, 2003.
- Federal Highway Administration Office of Operation. *Work Zone Impact Assessment: An Approach to Assess and Manage Work Zone Safety and Mobility Impacts of Road Projects.* US DOT, 2006.
- Garber and Hoel. *Traffic and Highway Engineering.* Florence: Thomson Learning, 2003.
- Lanctot and Batson. *Traffic Queuing at Highway Work Zones: Accuracy and Improvements Needed in Spreadsheet-based Predictive Models.* Final Report, Tuscaloosa: The University of Alabama, 2008.

Maze, Schrock, and Kamyab. "Capacity of Freeway Work Zone Lane Closures." *Mid-Continent Transportation Symposium*. 2000. 178-183.

The Smart Work Zone Deployment Initiative, The Midwest Transportation Consortium, The US DOT University Transportation Center for Federal Region 7. *Synthesis of Procedures to Forecast and Monitor Work Zone Safety and Mobility Impacts*. Ames: Iowa State University, 2005.

Transportation Research Board. *Highway Capacity Manual*. Washington: National Research Council, 1994.

