Construction Alternative Screening with Regional Travel Demand Model

By:
Marty Milkovits (Corresponding Author)
Cambridge Systematics, Inc.
100 CambridgePark Drive, Suite 400
Cambridge, MA 02140
Phone: (617) 354-0167;
Fax : (617) 354-1542
e-mail : mmilkovits@camsys.com

Dan Tempesta
Cambridge Systematics, Inc.
100 CambridgePark Drive, Suite 400
Cambridge, MA 02140
Phone: (617) 354-0167;
Fax : (617) 354-1542
e-mail : dtempesta@camsys.com

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ABSTRACT
Major roadway construction projects often have multiple construction alternatives representing different trade-offs between construction duration, construction cost, and user delay. A model can be useful to gain insight into traffic operations and delays for each construction alternative. The obvious impact of construction is on the path choice or en-route decisions: travelers will choose a different path to avoid the construction area. But, large-scale construction projects may also impact pre-trip decisions. However, it is not reasonable to assume that travelers will necessarily respond to a construction project in the same manner as a permanent network change, such as the change in the network once the construction is complete.

This paper proposes a hybrid application of a regional travel demand model to more reasonably represent traveler behavior during construction. Also, the benefits and limitations of using static assignment to evaluate construction alternatives are described and a process to develop total user costs for each construction alternative is presented. This approach is implemented using the regional travel demand model for Minneapolis / St. Paul to evaluate construction alternatives for a series of related projects on I-35E north of St. Paul. The methods described in this paper are appropriate for initial construction alternative screening activities that may leverage the static assignment results on their own as well as for activities that will represent the construction alternatives in a microsimulation model.
INTRODUCTION
Construction projects must balance user impacts with construction efficiency. User impacts may be severe when construction is on a key corridor serving an urban area. One approach to speed construction is to close the entire roadway and allow for full construction flexibility; however the benefit of reduced construction duration and cost may not outweigh the user impacts. Previous examples of construction with full closure have occurred after an unplanned incident forces the road to be completely shutdown, thus allowing unfettered reconstruction. A planned closure can be a politically charged decision and the advantages over other potential construction alternatives must be justified.

Models are a useful and accepted way to quantify user impacts. The type of model required depends on the nature of the construction project, the level of specificity of the construction alternative, available data, and the decision time frame. This paper focuses on the evaluation of high-level construction alternatives to reduce unnecessary detailed mitigation planning and lessen the burden on the local planning agency. In these situations, a regional travel demand model can be an appropriate tool.

Regional travel demand models are usually designed to produce the “average weekday” travel conditions assuming network equilibrium. Therefore, these models are appropriate for large-scale, longer-term projects where pre-trip traveler behavior may change due to construction. However, the modeler should consider that the construction network state is temporary and a regional model calibrated to forecast changes based on long-term network states may be too sensitive. Another point to consider is that the static assignment component of a regional model has limitations, but it can yield useful information for higher level analysis.

This paper discusses how each aspect of a typical regional travel demand model might be sensitive to construction alternatives and proposes a hybrid application of a model. The change in operating costs (VMT) and delays (VHT) from a hybrid travel demand model application are used to assess and compare construction alternatives in Minnesota.

WORK ZONE MODELING
There are a variety of construction projects that would benefit from modeling to gain insight into the user response and costs. This paper focuses on long-term, major construction projects. Under a long-term project, it is not unreasonable to assume that the network will reach equilibrium, i.e. where no user could change their decision and experience a lower cost. If equilibrium cannot be reasonably assumed, then a static assignment model is not appropriate. Alternatively, if the construction is extensive enough that users may shift destination, mode or time, re-applying a 4-step or activity-based model is warranted. These conditions are likely where a major roadway is closed as part of construction.

This section reviews the two main approaches to modeling a work zone: microsimulation / dynamic traffic assignment and static assignment as part of a regional travel demand model. Finally, the extensions to modeling with a regional travel demand model that are proposed in this paper are introduced.

Work Zone modeling with Microsimulation / Dynamic Traffic Assignment (DTA)
The DTA Traffic Analysis Toolbox Volume 2 includes “Work zone impacts and construction diversion” in the list of projects for which DTA would be an appropriate tool. However, the Analysis Toolbox also explains that these models require a more detailed level of data specificity to build the model (e.g. signal timings) and to calibrate (e.g. counts, speeds and congestion levels at sub-hour frequency). Moreover, operational models are less readily updated as the construction alternative evolves and may still require a regional travel demand model to generate trip table inputs.

The conclusions of this paper are still relevant when a microsimulation model is feasible and appropriate. Even if there are adequate time and resources to develop and calibrate a microsimulation model, the trip tables from a regional model are useful, if not necessary. The development of those trip tables needs to consider the expected response of each of the long-term demand models to the construction activity.
Work Zone modeling with a regional travel demand model and static assignment
The Primer for Dynamic Traffic Assignment summarizes the limitations of static assignment as related to the use of a Volume Delay Function (VDF), which does not provide for spillbacks, different lane performance, or merging and weaving behavior (3). Therefore, a static assignment model will not be sensitive to detailed work zone plans. However, the advantage of a static assignment model is that these details do not need to be rendered to operate the model, which allows for faster modeling of large areas.

If, as in the application presented in this paper, time constraints and data availability restrict the use of a microsimulation or DTA model, a static assignment model can provide valuable insights. The FHWA traffic analysis toolbox for work zone modeling gives two main advantages of using a travel demand model for work zone planning: 1) most metropolitan areas already have a calibrated regional travel demand model; and 2) the model can predict wide-area traffic redistribution (4).

Sinha et al. applied a regional travel demand model to evaluate the INDOT Hyperfix Project (5). The INDOT Hyperfix involved closing a high volume downtown artery in Indianapolis to speed the construction. Regional model results were used to examine changes in VHT under two construction alternatives: partial closure and full closure “hyperfix”. The daily user delay, calculated as change in VHT from base to each construction alternative, was multiplied by construction duration to determine the alternative with the lowest total user delays.

Work Zone modeling with a modified regional travel demand model
The evaluation of construction alternatives using a regional travel demand model in this paper extends the work of Sinha et al. in two key aspects. The first is that the regional model is applied in hybrid form that considers the types of trips that may be sensitive to construction. Second, cost parameters consistent with the regional model are used to develop user costs by construction alternative scenario.

The example application of this approach was done under significant time constraints so a microsimulation model could not be developed. Fortunately, the static assignment model results were substantially different so definite recommendations could be made about the construction alternatives.

The next section walks through each aspect of a regional travel demand model and discusses potential modifications to support work zone modeling.

APPROACH
This section presents a proposed approach to adapt a regional travel demand model to evaluate construction alternatives. Note that this approach would be useful even if a DTA model were being implemented – the static assignment process that is used to generate trip tables should be constructed in the same manner.

First, the definition and representation of discrete construction alternative stages in the regional travel demand model are discussed. Next, each aspect of the demand model is reviewed and modifications are proposed for construction modeling. Finally, the results of the demand model are considered at different geographic levels, from the entire region to the study area of interest and down to the project corridor level.

Construction alternative definition
Depending on the length and complexity of the project, construction alternatives may be divided into multiple stages with a specified time period and unique road impact.

The selection of a construction staging alternative within a project plan occurs prior to developing a detailed mitigation strategy. A typical regional travel demand model is only able to identify construction impacts at the level of road closures, number of lanes, and lane capacities. The actual roadway conditions may vary at the daily level during construction. In these cases, the network would need to be configured to represent average conditions throughout the construction stage. It is advantageous to develop as few stages as possible to minimize the number of model runs.
Model Inputs
Once the road impacts for each stage have been established they are implemented in the regional travel demand model. Changes to the model network and demand inputs are described in this section.

Network  The network changes include creation of new links, modification of the link attributes and changes to transit services over the network links.

Number of Lanes  The number of lanes during construction may change during construction.

Road Closures / New Roads  The planned projects may temporarily or permanently close roads and new roads may be available prior to the end of construction.

Lane Capacity  The per lane capacity should be reduced if the lanes are narrower or a shoulder is eliminated through the construction zone. The construction capacity is determined either through consultation with the local agency and use of local data for work zone capacity and/or application of Exhibit 10-14 in the Highway Capacity Manual 2010 (6), which gives a summary of construction zone capabilities and includes an adjustment factor that can be applied for lane width reductions.

Transit-Specific Impacts  Transit service may be impacted by construction. If transit operates in the study area, it is likely to be impacted by the construction either through road closures causing detours or increased congestion on the route corridor. Transit detours may require an updated transit network or assumptions about the extent of level of service impacts.

Demand  Distinct demand inputs for each stage, e.g. socioeconomic and land-use data, are only developed if significant changes are expected during the construction project. Modelers should exercise caution when changing demand inputs as they may confuse interpretation of the results when comparing construction alternatives.

Changes in demand due to construction impacts are represented within the model. For example, trips may choose a different destination or time of day to avoid traveling through the impacted area. These types of impacts are discussed in the following section.

Model Operation
This section reviews the aspects of a typical regional demand model and discusses which ones are most appropriate to implement in the construction screening process. The four steps to a traditional regional demand model are Generation, Distribution, Mode Choice, and Assignment. The assignment step is the one most commonly applied to study construction effects, but the other three steps have the potential to reveal insights into network conditions and user impacts during construction.

Generation  If the generation step implemented in the regional demand model is sensitive to network accessibilities then it may offer some insight into the construction stage impacts. Otherwise, the trips generated in the base model can be used across all construction screening alternatives.

Distribution  More often than generation, the distribution step of a regional demand model is sensitive to network accessibilities. It may not be reasonable, however, to assume that all trip purposes are equally sensitive to the temporary construction project. While one may assume that shopping trips may change their destination to avoid a construction area, it is less expected that work trips would change their destination in response to a construction project. To model this behavior, the distribution step can predict work and school related trip distributions using the base network as shown in Figure 1.
Figure 1: Hybrid Distribution Model Implementation

Mode Choice
Mode split changes depend on the availability of other modes and distinctions between the modes. Shared ride, transit and non-motorized modes all require certain conditions for there to be an expected mode shift from drive-alone.

It’s possible that travelers will carpool more in response to increasing construction related congestion. As trips become longer due to delays, the real cost difference between drive-alone and shared-ride becomes greater. However, unless there are HOV lanes, much of the reduced congestion benefit of shared ride activity is distributed across all users through externalities and little of the resulting travel time savings is realized by the decision maker. Therefore, unless HOV lanes or other network features exist to encourage carpooling, a substantial mode shift from drive-alone to shared ride is not expected.

If the study area is served by transit, then there may be greater transit demand due to the lower LOS of auto. This may be offset, however, by a lower LOS of the transit if it is not in separated right of way. Construction corridors where a dedicated right of way is available, such as rail, should see larger mode shifts.

Non-motorized modes are a good alternative to congested streets, but only for short distance trips. If the construction occurs in a dense area where many short trips are taking place then non-motorized modes could replace auto trips through the construction area.

Assignment and Time of Day
The most typical traveler response to construction within an urban system is to use an alternate route. This is modeled in the assignment process. As long as the construction impacts are assumed to be consistent for a period long enough that network equilibrium can be reached, static assignment can be used.

Travelers are also likely to change their time of travel in response to increased congestion. The capability to model shifts in time of travel requires a time-of-day model that is sensitive to network accessibility. If the regional model does not include a time-of-day model, the application of a hybrid model for construction analyses is still worthwhile because all the construction alternatives are being
compared with the same constraints. A model that does not support temporal trip changes in response to congestion will present a more conservative situation on the roads.

**Model Output Analysis**

Once the regional model has been modified and executed, results can be analyzed for the entire region as well as by study area and key corridors to validate the model effects, gain insight into the volume dispersion, and set up a more detailed traffic mitigation process once the construction alternative is selected.

User impacts are monetized from travel delay and vehicle miles traveled. The user cost calculation has different coefficients depending on the type of vehicle (auto vs. truck) and the number of people in the vehicle. It is also important to weight any potential user benefit of the completed project in the calculation of aggregate user costs. For example, an alternative with slightly higher user costs during construction, but a shorter construction period may have the lowest net user costs if the completed project provides a large benefit. The relative user costs between alternatives are compared to determine the recommend alternative.

Besides the assignment results, it may be useful to analyze the change in trip destinations and compare them to the base network and the density of trips by attraction. Construction activity can be much more efficient under a Full Closure type alternative; however there may be negative impacts on the community other than increases in travel time and delay. For example, changes in trip destinations away from the construction area could lead to a reduction in economic activity for that area. This analysis requires the distribution model to not be constrained to fit the number of attractions, i.e. not doubly-constrained.

**IMPLEMENTATION FOR SAINT PAUL CAYUGA BRIDGE AND MNPASS CONSTRUCTION ALTERNATIVES**

The Minnesota Department of Transportation (MnDOT) is reconstructing I-35E from north of Downtown St Paul to Little Canada Road. The reconstruction is comprised of two separate projects, the replacement of the Cayuga Bridge with a new interchange at Cayuga Street and the construction of managed lanes within the corridor. Figure 2 illustrates the two construction project limits.
The department considered a number of construction staging alternatives. The proposed alternatives included tradeoffs between a reduction in project duration and mitigating the user impacts. The proposed construction alternatives were: Full Closure; Four Lane Alternative; and Six Lane Alternative.

Alternative Definition
The three construction alternatives were segmented into stages that could be coded into the regional travel demand model network. The construction stages for these projects are expected to be reasonably stable throughout an eight-month construction season and that traffic conditions would return to near normal through the winter. A brief summary of the construction alternatives and stages is shown in Table 1.

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<td>Full Closure</td>
<td>Close I-35E</td>
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<td>Four Lane</td>
<td>Traffic routed to</td>
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<td>NB side (4 lanes)</td>
<td>SB side (4 lanes)</td>
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<td>8 months</td>
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<tr>
<td>Six Lane</td>
<td>Traffic on NB side (6 lanes)</td>
<td>Traffic on SB side (6 lanes)</td>
<td>Cayuga Finishing</td>
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<td>8 months</td>
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Model Configuration
The base condition mode network is modified to reflect the ramp closures, number of lane changes, and new ramp openings for each alternative and construction stage. In addition, the available lanes through the construction zone will be narrower than standard lanes. The recommended lane-width adjustment factor in the 2010 Highway Capacity Manual for lanes between 10.0 and 11.9 ft is 0.91 (6). This factor is applied to the I-35E lanes throughout the construction area.

The Metropolitan Council maintains a Regional Travel Demand Forecasting Model (RTDFM) for this area. It is a standard 4-Step travel demand model encompassing 9 counties across the Minneapolis - St. Paul region. The model is run using a batch file that calls various TP+ and FORTRAN routines. The RTDFM has an initial loop where, after trip generation, it goes through an iterative process of:

- Skimming the networks (transit and highway),
- Distributing the generated trips,
- Mode choice (performed in FORTRAN), and
- Trip Assignment (AM and Mid-Day time periods only)

After the RTDFM has gone through this loop, it then splits the final daily trip table into 24 time period specific segments. Each of these segments is then assigned to the highway network for the corresponding time period. A full run of the model takes on the order of 1-2 days to complete on a reasonably fast desktop computer.

In the RTDFM, the trip production step is not sensitive to the network conditions. Therefore, there will be the same number of trips made under any construction scenario. The model was pre-calibrated to counts from 2009. Construction is expected to take place in 2014 and 2015, but the 2009 demand was used for all testing because the model error is likely greater than the expected change in demand form 2009 to 2015.
As described in the previous section, it is not reasonable to expect the destination to change for school or work trips. Non-mandatory trips, such as home-based shopping, may change the destination in response to the construction. Model runs with a constrained distribution step that fixed work and school based trip destinations from the base network were combined with non-mandatory trips from the construction network.

A significant shift in mode was not expected in response to the construction of these projects. There are no HOV lanes through the study area so the shared-ride modes will not be much more attractive. Furthermore, the construction area extends for several miles so it is unlikely that non-motorized modes will be an available alternative for the impacted trips. Finally, transit in the study area is all shared right of way bus service so the travel times will increase along with the auto travel time and may also have less reliable service and longer headways unless the transit operator provides more vehicles on the route. Initial testing with the full model on preliminary construction stage networks confirmed that there is little change in mode split therefore the base network mode splits are used.

In the RTDFM, the time-of-day distribution is fixed so trips are not allowed to shift their time period in response to congestion. It is not advisable to change the factors for allocating the trips from AM and Midday to the 24 time periods because not all trips will be affected by the construction. Enhancing the model to allow trips to shift in time was not feasible in the project schedule.

**Volume Diversion Analysis**

Although the entire regional model was run each time, a study area was defined on which to focus attention and the presentation of the initial results. The study area was defined by examining the diverting volume from initial model runs. The study area was defined to be from I-35W to I-694 from east to west and between County Road 96 on the north and just south of downtown Saint Paul.

Study area maps were reviewed to validate the diversion patterns in the model and to compare the degree of traffic displacement and congestion across construction alternatives. Traffic diversions were identified by comparing the traffic volume in the construction network to the volume in the base network. Changes in the volume to capacity ratio were used to identify congestion during construction. Due to variation in traffic volumes, however, it made sense to use either the peak period or the maximum daily volume to capacity ratio to identify congestion. The maps in Figure 3 and Figure 4 show the directional link volume difference from the base network by the link width. Links that decreased in volume, e.g. I-35E corridor, have hairline widths. The maximum volume to capacity ratio during the day is shown to identify the worst congestion at any time.

The re-assignment patterns are as expected. Most of the traffic used the parallel routes near I-35E as well as the highways at the edge of the study area. The study area maps show an obvious difference in displaced volume and congestion between the two construction stages. Figure 4 shows less displaced volume and congestion and represents only one stage of a two year construction project, so the aggregate user impacts over the entire project need to be calculated in order to compare construction alternatives.
Intersection volume changes were also examined to identify potential “hot-spots” within the study area. The intersection volume changes supported a further windowing in on the project area around I-35E. The figure below also displays volume diversions during the AM peak period (6-9AM).
The user cost parameters shown in Table 2 are used to calculate aggregate user costs per construction stage in TABLE 3. The total cost per stage is calculated for the average weekday and summed by alternative to get the total alternative user costs.
In addition to reducing the user costs, another advantage of a shorter construction project is that the new facility is available sooner and users can start realizing the benefits of the construction improvement. The estimated near-term benefit of the MnPASS lanes and reconstructed Cayuga bridge is estimated to be $13.26 million per year. A two year benefit of $26.53 and one year benefit of $13.26 million are applied to the Full Closure and Four Lane alternatives because they complete in 1 and 2 construction seasons respectively, compared to the Six Lane alternatives three year construction period.

The Full Closure alternative user costs are significantly higher than the other two alternative user costs and thus there was little concern about eliminating this alternative. The Six Lane alternative did not show a great reduction in user costs over the Four-Lane alternative, which completes a full construction season faster. After factoring in the user benefits of completing the project earlier, the Four Lane alternative had the smallest net user costs.

**CONCLUSION**

The goal of construction alternative screening is to identify the construction alternative that will best balance project duration with user impacts. There are often alternative approaches to a construction
project that trade off immediate user impacts with construction efficiency and duration. Some example construction alternative approaches could be:

- **Full Closure**: the construction area is closed down completely or to a large degree to optimize construction activities.
- **Restricted access**: the construction area is not fully closed, however access is limited to deter demand to alternative routes.
- **Full access with limited demand**: Access to the construction area is not restricted although capacity is less due to construction activities.

Depending on the base level of traffic demand in the construction area, available detours, and difference in construction impact durations any of the above options may produce the lowest total user impacts. The project schedule may not allow for sufficient time to develop an operational simulation model. Moreover, the aspects of each construction alternative may not be known in sufficient detail to implement a microsimulation model. In these cases, a regional travel demand model is a good alternative as most regions have existing calibrated regional models. But, the regional model should not be implemented in the same manner as when evaluating a future year project, nor should all long-term behavior be assumed to be insensitive to the construction project.

This paper discussed each aspect of a travel demand model and proposed a hybrid application that reflects expected traveler responses to construction. The extent of the potential modifications are, of course, limited by the functionality of the available model, e.g. an activity-based model supports a much more nuanced approach than a trip-based four step model. The hybrid regional travel demand model application proposed in this paper would be appropriate even if an operational model were being implemented.

In the case of the Cayuga Bridge and MnPASS reconstruction, the static assignment model was sufficient to demonstrate that the user costs under a Full Closure alternative would be substantially higher than the Partial Closure alternative.

REFERENCES