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Memo

To:	Thomas Witt, Eileen Vaughan KYTC Division of Planning	From:	Mark Butler, AICP Stantec Consulting Services, Lexington, KY
File:	KYTC Travel Time Savings	Revised:	September 24, 2018

Reference: Recommendations Regarding the Estimation of Travel Time Savings

The Kentucky Transportation Cabinet (KYTC) asked Stantec to review the methods it has initially employed to measure the travel time savings (TTS) of proposed roadway projects under review in KYTC's Strategic Highway Investment Formula for Tomorrow (SHIFT) program. During the first iteration of the SHIFT process, KYTC used either the Kentucky Statewide Traffic Model (KYSTM) or a spreadsheet calculation tool to estimate TTS and factored the daily TTS to a 10-year aggregate TTS value. The ten-year TTS was then used as a metric in the SHIFT program's cost-benefit analysis. In reviewing a sample of TTS estimates for projects analyzed with both methods, KYTC staff noted significant disparities between the estimates of the two methods. KYTC asked Stantec to consider and provide comments on the two approaches, as well as on the overall measurement of TTS in general. This memorandum addresses four questions related to improving upon the current methods:

1. When is it appropriate to use the KYSTM to analyze travel time?
2. What are the best options to account for TTS for smaller projects and projects associated with intersections?
3. How to best convert daily travel time estimates and the associated benefits to a 10-year period?
4. Should the value of time differ within regions of Kentucky?

1. When is it appropriate to use the KYSTM to analyze travel time?

The first round of SHIFT used the Kentucky Statewide Traffic Model, Version 17 (KYSTM) to estimate aggregate travel times, represented as Vehicle Hours Traveled (VHT) for "build" and "no build" scenarios of individual projects, with the difference in VHT between scenarios representing the net TTS of each project. The projects initially selected for testing with the KYSTM were projects that included new alignments, major widenings that increased through-lane capacity, and minor widenings and reconstructions with no additional through-lanes constructed. In general, intersection improvement projects were not analyzed because the KYSTM does not calculate or consider intersection delay during its trip distribution or assignment steps.

Before assessing the suitability of particular project types to be tested with the KYSTM, a brief consideration of the model's functionality and capability is warranted. First and foremost, the KYSTM is the most high-level planning forecasting tool available in Kentucky. While it is under continuous revision and refinement (Version 18 of the KYSTM is currently underway), and it is intended to be compatible with the network and zonal attributes of the various county and regional models in Kentucky, it is by design intended to provide a "big picture" perspective on travel demand, as opposed to providing details of specific traffic operation. From this perspective, it is similar in its purpose to all other demand models. It trades precision and specificity at individual locations and time periods for expansive statewide coverage of daily demand. While it is a consistent tool to use throughout the state for every project, it's primary value is as a general demand forecasting tool, and more accurately, as a generator of demand growth forecasts that must be further refined for use in specific project analysis.

The particular limitation the KYSTM has in assessing TTS is its daily analysis period. While the model follows the standard practice of first calculating network link capacities on an hourly basis, these link capacities are factored to the daily level to be compatible with the trips that are being generated, distributed, and assigned at the daily level. Therefore, for most of the network links in the state, cumulative traffic volumes over the course of a full day are well below their cumulative capacity of a full day. For most links in the network, increased traffic volumes would not substantially affect travel speeds because they do not trigger the model's volume delay function. Therefore, the KYSTM will distribute and assign trips using essentially free flow speeds on most links in the network, regardless of the actual presence of peak hour congestion that most capacity enhancing projects are intended to alleviate. As a result, most capacity enhancement projects do not generate significant VHT reductions in the KYSTM's output or any significant redistribution or reassignment of trips.

With that "daily" limitation in mind, the initial setting of the model's free flow travel speeds became the mechanism of how roadway improvements were analyzed and how TTS between build and no-build scenarios were ultimately calculated. While the KYSTM has link level speed and capacity calculators from the Highway Capacity Manual (HCM) that convert roadway improvements like widened shoulders or a divided median into improved free flow speeds, these speed adjustments are relatively insignificant compared to the base free flow speed, which for most roadways is derived from the posted speed limit. While more details of a network link's physical attributes, including the road class and terrain, will result in more precise HCM speed estimates, the calculators in the model can never be as accurate as observed free flow speeds, especially on low volume rural roads or in areas with rugged terrain. While KYTC staff has been diligent in using the KYSTM's speed override function to input observed free flow speeds, the result has been that the actual free flow speeds of most links in the model are manually set by the speed override and not the model's HCM calculation of speed. Therefore any adjustments to free flow speed estimates as a result of a roadway reconstruction or minor widening require removing the speed override so that the HCM speed estimates are calculated and used instead of observed speeds.

In the context of the first SHIFT TTS analysis, the speed override issue was resolved by presuming that existing observed speeds are the result of substandard road conditions, and that the correction of those substandard conditions would result in the use of the HCM estimate of free flow speed. Therefore, the TTS established in such instances was mostly due to the difference between observed speeds and the new HCM estimated speed, which likely changed slightly from the original HCM estimated speed.

It is important to note that Version 18 of the KYSTM, which is currently under development, includes new speed adjustment factors to ensure that base free flow speeds more accurately reflect observed speeds before HCM adjustments. Further, Version 18 will have greater directional speed sensitivities due to the presence of passing lanes or other directional attributes. Therefore, the next version of the KYSTM will be capable of effectively analyzing more projects. However, the principle that TTS measured by the model is the product of speed adjustments between build and no build scenarios is still relevant. While Version 18 will estimate speed more accurately, the actual difference in free flow speed due to the project improvements may still be relatively small depending on the size and scope of the project.

Recommend Guidelines for Modeled Projects

Given these limitations, the KYSTM is best suited for major projects which derive their travel time savings from new alignments or major facility upgrades rather than smaller scale projects whose TTS can only be reflected in the model by relatively small adjustments to free flow speeds associated with changes in secondary roadway attributes. Stantec recommends the following guidelines for identifying which projects should be analyzed using the KYSTM.

1. <u>New alignments:</u> Projects running on a new alignment offer new connectivity and potentially shorten the paths between numerous points in the model network. The KYSTM is designed to analyze these projects.

2. Major widenings and facility upgrades: A major upgrade in facility type, whether from a two-lane highway (HMPS classes 4-7) to a multi-lane highway (HPMS 3); or the upgrade of a multi-lane highway to a freeway (HPMS 1 or 2), should significantly affect base free flow speeds and capacity, which will be reflected in the model output of VHT. For the current Version 17 of the KYSTM, a major upgrade should represent an increase in the number bi-directional through lanes, or the upgrade to a freeway facility. Given its directional sensitivity, Version 18 of the KYSTM can be used to analyze "2+1" passing facility upgrades.

3. Minimum distance and ADT: For roadway improvements that do not increase bi-directional through lane capacity or upgrade facility type, the combination of the project distance and average ADT on the corridor should be set at a minimum threshold to ensure the TTS resulting from the project is sufficiently great enough to exceed the relative noise of the model. Further, the longer the project, the larger the area of influence the project has on affecting path choices between trip ends. Stantec recommends the "rule of 10,000" as a minimum product of ADT multiplied by project mileage. By this standard, a 1-mile long project would require at least 10,000 ADT while a 2-mile project would require at 5,000 ADT, etc. This is not a firm rule, and professional judgement should be used when selecting projects for model analysis.

Limiting the number of projects modeled by the KYSTM means more time can be spent on the individual projects that are modeled. More tests can be performed to make sure network attributes and inputs are correct, analysis areas are appropriate and create stable outcomes, and model outputs are reasonable. Also, KYTC modeling staff can spend less coordination time with model analysts compiling and organizing data and more time discussing individual project attributes and their results. Establishing a minimum threshold of project size in terms of distance and ADT should result in fewer instances of unexpected TTS results. In such cases, additional scrutiny of project analysis area boundaries roadway attributes should be performed, and the project should also be analyzed via KYTC's spreadsheet analysis tools discussed below.

2. What are the best options to measure for TTS for smaller projects and projects associated with intersections?

Despite its limitations, the KYSTM nonetheless provides a ready, statewide tool for producing travel time comparisons between build and no-build conditions for many of the larger-scale projects the SHIFT program is attempting to analyze. However, there are many roadway improvement projects that the KSYTM - and most demand models - cannot model simply due to the fact that the model does not recognize the roadway attributes being improved. Intersection improvements are the most prominent example since the KYSTM only includes intersections as the nodes between links and assigns no capacity constraint or delay directly to the node. All speeds and travel times are accounted for exclusively at the link level. This limitation extends to the presence of turn lanes, as the KYSTM only considers through travel lanes when estimating capacity. While the KYSTM makes minor speed adjustments based on improved roadway attributes, as previously stated, those specific adjustments may have a miniscule effect on a daily assignment, particularly if the distance of the improvement is short.

The limitations of macro-level models for quantifying the benefits of these projects illustrate the essential role of traffic operational analysis software like Highway Capacity Software (HCS) and microsimulation models like VISSIM and TransModeler. However, developing project level analyses with these tools is relatively time-consuming and requires extensive input data, and therefore not practical for a high-level analysis of hundreds of projects. Developing simpler spreadsheet-based tools, such as KYTC's current methodology for measuring TTS for widening projects (attached), is an example of an alternative that streamlines inputs and computational time. For this tool, the primary inputs for the computation, such as Average Daily Traffic (ADT), K and D factors, and Volume to Service Flow (VSF), are readily available in KYTC's Highway Information System (HIS). However, the methodology is limited to major widening projects that increase the number of through lanes only, and ideally should be limited to projects involving uninterrupted flow on unsignalized corridors. Regardless, this approach illustrates the streamlined approach that KYTC would like to take to measure TTS for interchange, intersection, and other roadway improvements.

Major Widenings

KYTC requested that Stantec review its methodology (attached) for estimating TTS for major widenings to assess its appropriateness and to examine opportunities for improvement. In terms of the specific equations, the initial equation for the relationship of the hourly Travel Time Index (TTI) to the hourly VSF was derived by KYTC from Table 3-5 of the research report from the Kentucky Transportation Center (KTC), *Methodology Update for Estimating Volume to Service Flow Ratio*, December 2015. The hourly TTI equation is presented below. The TTI values calculated from the equation, along with the TTI values for freeway/multilane and rural 2-lane roads published in Table 3-5 of the KTC report, are presented in **Figure 1.**

$$\mathbf{TTI = 2*VSF^2\text{-}1.1VSF+1,\ min\ 1.0}$$

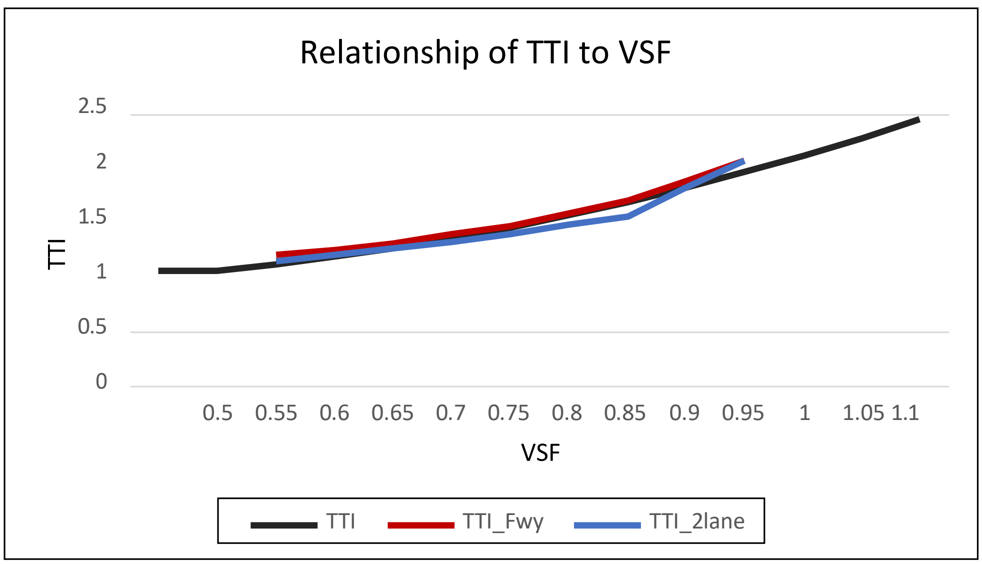

Figure 1. Calculated Travel Time Index (TTI)

(Source: Kentucky Transportation Center)

KYTC's equation is a reasonable representation of the relationship between TTI and VSF. Stantec recommends revising the ensuing methodology for estimating the overall daily travel time index (DTTI) from the hourly TTI to only encompass the average weekday TTI value, as opposed to the weighted weekday and weekend values, as the KYSTM is calibrated to replicate weekday values. Stantec assumes the equation of the relationship between DTTI and VSF is also reasonably representative. It is important to note that as with the KYSTM, KYTC's spreadsheet methodology is derived from a daily metric, ADT. On most roads (particularly rural corridors), where VSF is lower than 0.57 for almost every hour of the day, this methodology will not and should not result in significant TTS sensitivity to capacity improvements that would only be expected to affect short peak periods in the day. The methodology to expand the DTTI to a ten-year travel time and calculate the improved VSF, TTI, DTTI, and ten-year travel time for the build scenario will be discussed in the next section of this memo.

Stantec performed a general search of the transportation planning literature to determine if other computational formulas and methodologies were available as an alternative to the current KYTC methodology. Over the course of the search, the conclusion was drawn that while methodologies for determining speeds and capacities are presented in various contexts, they generally draw from the same recommended methodologies of the HCM, which require more extensive details of the build and no build conditions and are based on a one-hour time period. Ultimately, these various methods would also require similar levels of default assumptions to incorporate the effect of the peak period congested speed reductions into daily travel times based on a single ADT value. Further, all other methodologies warned of the the same basic drawbacks of estimating speed adjustments for corridors that include signalized intersections.

Given the alternatives, we do not recommend switching methodologies for measuring TTS for major widening projects. For the present time, the current methodology is acceptable primarily because it is practical, even if its sensitivity to peak period congestion is appropriately limited. The most important factor to emphasize is that this tool provides a consistent, transparent approach upon which to measure and compare projects. Ultimately, that is more important than the marginal expectation of improved precision or sensitivity that more complex, time intensive methods would require. Instead, KYTC should continue to test and refine the component parts of its current methodology. The current dataset of roadway segments used to estimate the formula for the relationship between DTTI and VSF could be expanded, perhaps with separate equations for area type, functional class, or volume. The factoring of weekday to weekend/holiday travel could be similarly refined for area type and functional class, using the count factors presented in the KYTC Forecast Report. (The development of an updated Forecast Report would be valuable for this purpose.) The expansion of the daily TTS to a 10 year TTS value will be discussed in the next section.

Intersections

Stantec also reviewed the methodology KYTC provided for measuring TTS for intersections. It is presented as follows:

<u>**Intersection Volume to Service Ratio**</u>

$$\text{IVSF} = \sum(0.1*\text{AADT}i)/(900*\text{N}i)$$

AADT Annualized Average Daily Traffic; default value 1000.

<u>**Design Hour Delay Reduction**</u>

if: $\text{IVSF} < 0.7$: $\text{DHDR} = 66.1*\text{IVSF}^\wedge 3.4$

if: $\text{IVSF} >= 0.7$: $\text{DHDR} = 100*\text{IVSF} - 50.41$

<u>**Travel Time Savings Intersection**</u>

$$\text{TTS}\mathit{Int}\ 0.1168*\text{DHDR}*\sum(\text{AADT}i/\text{D}i)$$

D*i*: 1 for Couplet or one way; 2 for two-way; default value 2;

AADT: Annualized Average Daily Traffic; default value 0;

N: Number of through lanes; default value 2.

This methodology appears to be at once too precise and too simplistic to be of much value. Stantec did not attempt to independently validate any of the parameters in the equations to a particular type or set of intersections, but their degree of precision (there is one parameter with four decimal points) implies a level of specificity that defies its practicality as a general tool for use with multiple intersection types. Further, given that the only improvement variable in the equation is of through lanes at the intersection, it is very limited in the type of improvements that it can consider. We recommend considering an alternative to this approach to measure intersection delay.

General Recommendations

Aside from KYTC's methodology for major widenings previously discussed, Stantec did not find in its general review a comparable methodology that uses regression equations or other formulas to measure TTS for intersections, interchanges, or other "spot" roadway projects. Further, as the intersection methodology above illustrates, attempting to establish highly-specified equations to apply to a large range of improvement projects based on limited input data can lead to a false sense of confidence in the validity of the analysis results.

Three alternative approaches warrant consideration. The first alternative, individual analysis in a traffic operations or microsimulation-based software format for each project, is simply too time-consuming and costly to be practical as a high-level screening process. The second alternative is the development of more complex spreadsheet applications, based on a "planning-level" application of the HCM methods. Two sources, ***NCHRP Report 618: Cost-Effective Performance Measures for Travel Time Delay***, and the more thorough ***NCHRP Report 825: Planning and Preliminary Engineering Applications Guide to the Highway Capacity Manual****,* offer methods of deriving capacity, speed, and delay metrics that could be developed within a spreadsheet application to produce a TTS measurement. These methods would be less extensive than the full HCM methodologies incorporated in HCS and imbedded in simulation software, but would adequately cover the majority of improvement types KYTC seeks to screen. The initial development of the spreadsheets and the protocols regarding data requirements will require a significant upfront effort. Given that they include more steps than a simpler formula, these analyses, while shorter than a fully independent HCS or microsimulation analysis, will take more time to analyze, but presumably less time than individual model runs using the KYSTM would take. Finally, these approaches will still require a method to correlate hourly measurements to daily totals when input data is limited to daily values. The hourly volume percentage by functional class tables in the KYTC Forecast Report could be used for this purpose.

The third alternative goes in a different direction than attempting to use specified formulas or formally tested procedures. Instead it acknowledges the high-level planning context under which the SHIFT screening process is taking place. This approach would develop a heuristic "rule of thumb" look up table that applies simple yet transparent TTS reduction factors to individual project improvements under the presumption that there simply is not enough details at the programming level concerning these projects to warrant more explicit estimations and measurements. For example, a common "rule of thumb" is that signal optimization typically reduces intersection delay by 10-15%. For any given intersection, this range may be incorrect, but given the lack of details necessary to accurately determine the delay reduction for a specific situation, applying this generally suitable range of reduction is likely to be as accurate as applying an analysis process that will ultimately rely on default data and parameters not specifically estimated for that situation.

The templates for this approach are the "TTS Assumptions by Scoring Improvement Type.xlsx" excel file that KYTC developed to depict the relative safety benefits of individual improvement types, and the Crash Modification Factors Clearinghouse (CMFC) (http://www.cmfclearinghouse.org) which provides analysts a single source for reviewing and comparing crash rate adjustment factors associated with various roadway improvements. While various "rule of thumb" statements regarding delay and TTS are scattered throughout the literature (for example, signal optimization typically reduces intersection delay 10-15%), there is no specific central source equivalent to the CMFC. We are not recommending developing such a web site (although it would be a great and appreciated contribution to the transportation planning community). Instead we suggest that KYTC develop a straightforward spreadsheet style database of heuristic tools like the CMFC, but for TTS. The basic principle of such a database would be to identify common (and ultimately less common) roadway improvements and provide a basic travel time reduction factor to associate with each improvement based on readily available data in the HIS, such as ADT, facility type, directional lanes, etc. The goals of the database would be the same as the computational methodology KYTC developed for major widenings: simplicity, consistency, and transparency.

Some of the factors that would populate the database could be sourced from prior studies and reports, similar to how the CMFC links to its factors and sources. This would clearly require a more detailed and methodical review of the literature than we have performed for this memorandum. A compilation and review of memos produced in response to KYTC's Policy for Traffic Engineering Analysis (KYTC Design Memo 3-11) could serve as a local data source, along with the solicitation of opinions and other data from the members of the ACEC-KY Planning Subcommittee and other KYTC consulting engineers. Where there were gaps or a need for a more consistent approach, baseline templates of common roadway improvements using conventional analysis tools (such as HCS and TransModeler) could be created or borrowed from previous work and run for multiple scenarios and simulations to develop these baseline reduction factors. For example, various interstate and freeway interchange design concepts could be run in TransModeler for a variety of input factors, such as volume, truck percentage, and K and D factors. The results of the analysis would be used to create look up reduction factors for various ranges of these inputs that are then applied to segment or system level travel times. The factors would not be as precise as an individual analysis of a specific project, but it would be consistently and transparently applied across all common projects. This seems appropriate given the sparse project details that would be available at the programming level.

Separate templates and factor tables would be developed for interchanges, intersections, signalized corridors, and rural highway segments. While there would be some initial development costs involved in building these templates, their development could be implemented incrementally according to KYTC's highest priorities. Once created, they would be available to KYTC to refine or expand inputs, giving KYTC a catalogue of common templates to use for future project analyses. In this respect, the variety of interchange designs Stantec and perhaps the larger consulting industry has previously developed for KYTC in TransModeler, such as conventional diamond interchanges and double crossover diamond (DCD) interchanges, could serve as initial templates. Similar templates of intersections and corridors also exist from previous projects performed for KYTC.

The look-up table approach would ultimately most accurately reflect the high-level planning the KYTC is doing for the SHIFT program. TTS could still be measure at the daily level and expanded to a ten-year value, but the TTS measurement itself would be easily traceable based on the improvement and basic conditions of volume, facility type, area type, etc. It would help demystify how TTS measurements are calculated.

3. How to best convert daily travel time estimates and the associated benefits to a 10-year period?

In KYTC's methodology for measuring TTS for major widenings, its final step is expanding a daily TTS value to a ten-year TTS value. Having annualized the average week day and weekend/holiday values into a common DTTI value, the method simply multiplies that daily value by 3,650, the number of days in ten years. While this method is straightforward, it is notably static in that it does not assume any change in DTTI over the ten-year period. If no future year ADT forecast is available and only the base year ADT is available for analysis, then this approach is reasonable if only because it is straightforward. However, if future "no build"" ADTs are available from the KYSTM or developed from default annual growth factors, they could be applied to create a future year DTTI. In this scenario, the daily TTS of both the base year and the future year could be included in a linear estimation of annual TTS between the base and future TTS.

The North Carolina Department of Transportation (NCDOT) has used the following formula to produce a linear interpolation of TTS:

(min(b,f)*p)+(abs(f-b)*p/2)*(1+1/p)*d

b = base year daily TTS (hours)
f = future year daily TTS (hours)
p = time interval (years, future year – base year)
d = days per year (in the case of KYTC's annualized common day, 365)

4. Should the value of time be estimated differently at a regional level?

Based upon a review of the SHIFT "Criteria Equations.xlsx" excel file provided by KYTC, the "Travel Time Benefit $" incorporates the delay cost by vehicle type associated with each project's TTS. In this regard it introduces the value of time as an essential factor of monetizing travel time. Typically, for personal vehicles, the value of time is established as a percentage of the average wage rate of the commuter. Given that congestion affects regions of the state differently, it may make sense to incorporate specific average wage rates for individual regions in a similar manner to how poverty rates and household income are used to score the economic effects of projects regionally. In urban areas where congestion is the greatest, wage rates tend to be higher than in rural areas where congestion is less prevalent over the course of the day. In rural areas, commute times are understood to be more likely a result of distance, not congestion. As the SHIFT criteria already reflect, the economic benefits of improved accessibility and connectivity as measured by regional indicators of economic conditions help emphasize the economic benefits for rural projects. By valuing the cost of delay more accurately, the price of congestion and the economic benefit of urban projects would be more accurately measured against the most relevant criteria.

Regardless of the potential benefits of distinguishing the value of time by region, the pragmatic reality of implementing such an approach is limited by the perceptual challenge that such differences may appear subjective and prejudicial. As such, the introduction of differing value of time estimates could undermine the overall methodology's credibility.

Stantec appreciates the opportunity to share our thoughts and findings relative to the Division of Planning's goal of developing more robust and appropriate tools for estimating travel time savings for potential future projects. We always look forward to working with you to help refine and improve the analytical tools KYTC can use to execute the next round of the SHIFT program.

Attachment: **Segment Method Summary.docx**

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