Addendum to Traffic Analysis Toolbox Volume XIV: Guidebook on the Utilization of Dynamic Traffic Assignment in Modeling

Reliability Analysis Guidance Addendum

October 2023

U.S. Department of Transportation
Federal Highway Administration

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16. Abstract
This document reflects up-to-date guidance, as of the date of this report, on incorporating travel time reliability (TTR) in the Traffic Analysis Toolbox. Specifically, it provides guidance to practitioners, managers, and software developers on methods for applying dynamic traffic assignment (DTA) in transportation modeling. This guidance will inform metropolitan planning organizations and State departments of transportation (DOTs) of the potential benefits and applications that are possible from utilization of DTA modeling tools. This document suggests processes and implementations for using DTA tools in transportation analyses. This document also provides transportation practitioners with guidance on the appropriate application of DTA tools for transportation decisionmaking.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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CHAPTER 1. PURPOSE

This document is an addendum to FHWA-HOP-13-015.[1] It reflects up-to-date guidance, as of the date of this report, on incorporating travel time reliability (TTR) in the Traffic Analysis Toolbox. This addendum consists of additional content to be appended to the Toolbox volume.

[1]Sloboden, J., J. Lewis, V. Alexiadis, Y.-C. Chiu, and E. Nava. 2012. *Traffic Analysis Toolbox Volume XIV: Guidebook on the Utilization of Dynamic Traffic Assignment in Modeling*. Report No. FHWA-HOP-13-015. Washington, DC: Federal Highway Administration. https://ops.fhwa.dot.gov/publications/fhwahop13015/index.htm.

CHAPTER 2. ADDITIONAL CONTENT TO BE APPENDED TO THE TOOLBOX VOLUME

OVERVIEW OF RELIABILITY IMPLEMENTATION IN DYNAMIC TRAFFIC ASSIGNMENT

The purpose of this addendum is to expand on the guidance provided in the *Traffic Analysis Toolbox Volume XIV: Guidebook on the Utilization of Dynamic Traffic Assignment in Modeling* by providing best practices for incorporating TTR into dynamic traffic assignment (DTA) analysis.

The major benefit of using DTA is the capability of the modeling method to consider the spatial and temporal effects of congestion in determining route choice, time of departure choice, and mode choice. DTA is suitable for analyses involving incidents; construction zones; and active transportation and demand management, integrated corridor management, intelligent transportation systems (ITS), and other operational and capacity-increasing strategies. DTA is an optimal tool for TTR evaluations because reliability analyses require a robust set of operating conditions to gain a comprehensive assessment of network travel performance. The intent of this guidance is to supply the necessary steps and tools for expanding upon analyses that are performed in isolation (e.g., in time, space, etc.) by producing meaningful performance measures that are reflective of operations over an extended period (e.g., 1 year).

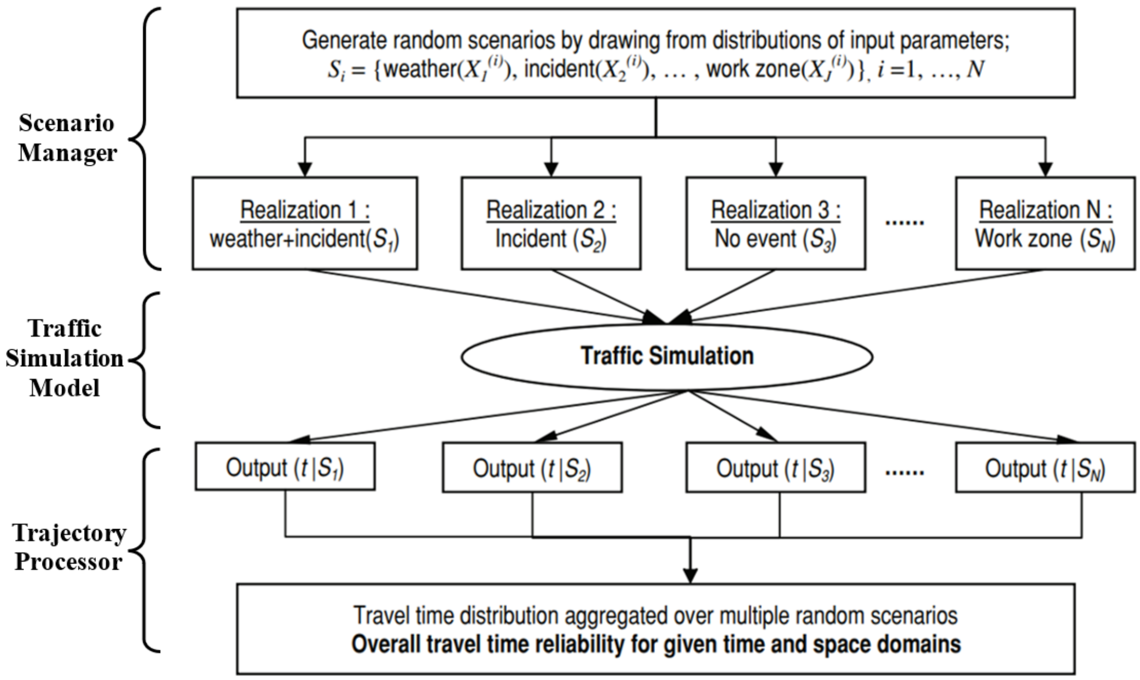
SCENARIO DEVELOPMENT METHODS

Approaches to Assessing Reliability

TTR is a relative concept in that it depends on the temporal and spatial boundaries for which travel times are observed. For example, the TTR for weekdays is different from that for weekends on the same road network. Therefore, defining time and space domains needs to precede assessing reliability. In general, the time domain is specified by a date range of the overall period (e.g., June 1, 2012, through August 31, 2012), day of the week (e.g., Monday through Friday), and time of day (e.g., 6 through 10 a.m.). The time domain also could be a specific season or day of each year (e.g., Thanksgiving Day). The space domain defines at which level travel times are collected and the reliability measures are calculated (e.g., network-, origin-destination (O-D)-, path-, and link-levels). Two different approaches are available to assess the TTR for given time and space domains: (1) Monte Carlo, and (2) mix-and-match (Mahmassani et al. 2014). The former tries to generate all possible scenarios that could occur during the given temporal and spatial boundaries to introduce realistic variations in the resulting travel time distribution; the latter constructs scenarios by manually choosing various combinations of scenario components. These approaches are discussed in more detail below.

Monte Carlo Approach

Many of the travel time unreliability factors fall into the area in which the randomness can be parameterized, and probabilities can be assigned based on the known parameters of the demand, supply, or both (Mahmassani et al. 2014). This approach uses Monte Carlo simulation to prepare input scenarios aimed at propagating uncertainties in selected scenario components X into uncertainties in the generated scenarios *Si (i = 1, . . . , N)*, which can be, in turn, translated into the resulting travel time distribution. As depicted in figure 1, the scenario manager performs Monte Carlo simulation to generate hundreds or thousands of input scenarios by sampling from the joint probability distribution of scenario components. Each scenario from the sampling process is equally likely, thus allowing the trajectory processor to simply aggregate travel time distributions from many simulation runs to obtain the most likely (probable) outcome of a set of reliability performance indicators for the given time and space domains.

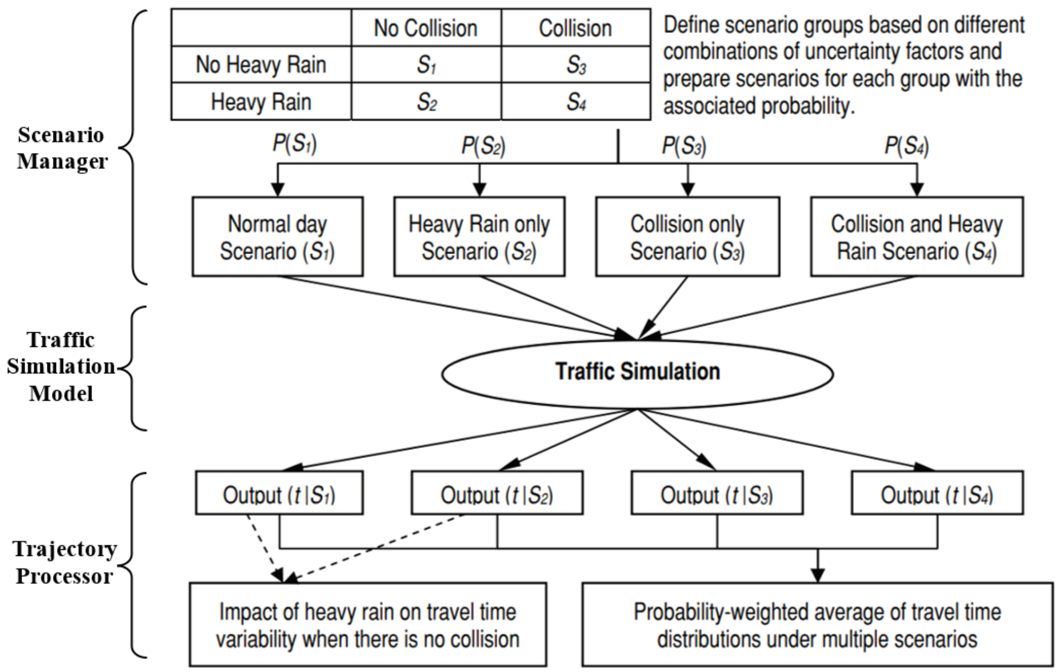


Source: Mahmassani et.al. 2014

Figure 1. Diagram. Monte Carlo approach to assessing travel time reliability.

Mix-and-Match Approach

Instead of randomly generating scenarios, given the underlying stochastic processes, one could explicitly specify scenarios with historical significance or policy interest (Mahmassani et al. 2014). The mix-and-match approach aims to construct input scenarios in a more directed manner, either by mixing and matching possible combinations of specific input factors, or by directly using known historical events or specific instances (e.g., holiday, ball game). Figure 2 shows a schematic diagram illustrating this approach with a simple example. Consider two scenario components—collision and heavy rain—where each component has two discrete states—occur and not occur. The Cartesian product of two components' states defines four possible scenario groups (as shown in figure 2). Suppose that a representative scenario for each group exists, and the scenario probability is assigned based on the joint probability of collision and heavy rain events. A probability-weighted average of travel time distributions under all four scenarios can be used as the expected travel time distribution to approximate the overall reliability measures. A more informative use of this approach is to understand the impact of a particular scenario component on travel time variability by investigating gaps between different combinations of output results.



Source: Mahmassani et.al. 2014

Figure 2. Diagram. Mix-and-match approach to assessing travel time reliability.

Combined Approach

Unlike the simple example in figure 2, it is often necessary to allow randomness in scenarios within each group, especially when there is no predefined representative scenario. It is also possible to have no probability value for each scenario group known to users. In both cases, the Monte Carlo approach can be used in conjunction with the mix-and-match approach—that is, sampling random scenarios from their conditional distributions given each group (for the former) and generating many scenarios for the entire scenario space and categorizing them into the associated groups to obtain the group probabilities (for the latter).

CLUSTER SELECTION

Phoenix Pilot Cluster Methodology

The following information summarizes a case study demonstrating how to effectively select sufficient types and number of clusters for reliability analysis. The second Strategic Highway Research Program 2 (SHRP 2) Project L04 Phoenix Pilot Team developed this documentation.

Introduction to Cluster Analysis

The full-year analysis process pilot tested in this project relied upon a large amount of observed baseline data and individual simulations. This reliance was necessitated by the need to systematically and accurately represent the wide range of traffic and environmental conditions that occurred over the course of the year for which actual conditions were observed and simulated. The study team used a mathematical procedure known as a hierarchical cluster analysis to minimize the number of simulation runs needed to develop a good representation of the full-year travel time distribution profile. The term “cluster analysis” encompasses many different algorithms that have been developed for grouping large numbers of objects with similar characteristics into much smaller discrete sets or taxonomies that can then be analyzed more efficiently.

The cluster analysis algorithm employed in this pilot test is embedded in an open-source statistical software package called R. The R software package was applied according to the following two-step procedure:

1. *Select an appropriate measure for quantifying the distance between clusters.* This project employed the commonly used Euclidean distance as the means for calculating the composite distance between observed data points and for calculating the distance between the centroids of the respective clusters. The equation in figure 3 presents the equation used for these purposes. All variables used in this project were normalized to values between zero and one, so the result of applying the equation is a relative distance measurement that has no dimensional units associated with it.

$$D_{ij} = \sqrt{\sum_{k=1}^{n} \left(x_{ki} - x_{kj}\right)^2}$$

Source: Federal Highway Administration,

Figure 3. Equation. Quantifying the distance between clusters.

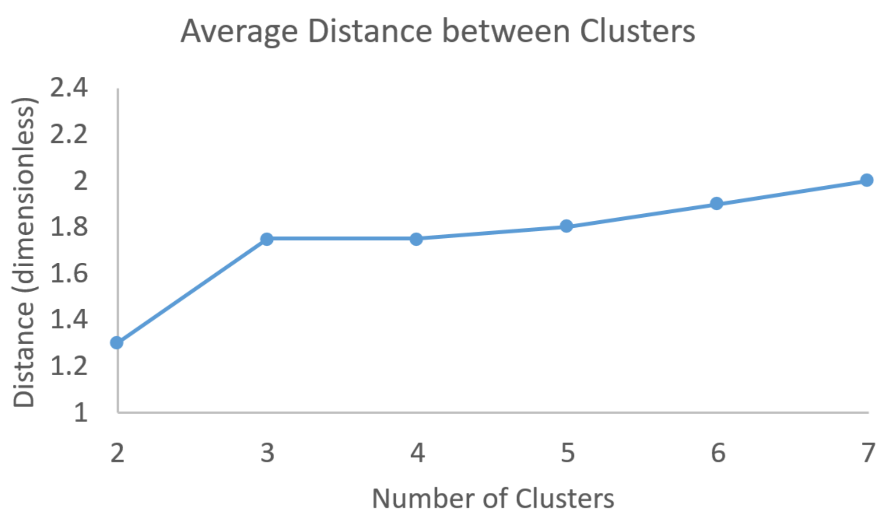
Where:
D_{ij} = distance between cases *i* and *j*.
x_{kj} = value of variable X_k for case *j*.

2. *Determine the appropriate number of clusters using the K-mean cluster analysis technique*. The K-mean cluster analysis technique is a well-documented method for partitioning a set of observed data points into clusters, wherein each observed data point is assigned to the particular cluster within a pre-established group of clusters that possesses the nearest mean. The user establishes the number of clusters that are to be created at the outset of the analysis, with two clusters being the minimum number. With this input, the K-mean cluster analysis technique then assigns each data point to one of the pre-established clusters in such a way as to maximize the Euclidean distance between each of the clusters. The mean for each cluster then becomes reflective of the total of all data points assigned to that cluster, and this mean will thereafter serve as the prototype for all the observed data points assigned to that particular cluster. Determining an appropriate number of clusters is an iterative process that usually begins with the minimum two clusters and then incrementally increases the number of clusters by one with each iteration until the point of diminishing returns is identified.

APPLICATION OF CLUSTER ANALYSIS IN THE PHOENIX PILOT TEST

The observed dataset for base year conditions on the Phoenix area freeway system consisted of observations across 253 separate weekdays (weekday holidays were excluded). The dataset covers 19 two-way corridors within the Phoenix area for a total of 38 one-way corridors. The temporal coverage of the data is from 3 to 7 p.m. in the year 2014. In this pilot test, the study team conducted two separate cluster analyses. The first focused upon identifying significant seasonal differences in the observed data. The second focused on identifying significantly different data clusters within each of the previously identified seasons.

The seasonal analysis was conducted by including date information as one of the variables in the cluster analysis process. It was expected and found that including a "date" variable at this analysis stage resulted in a high likelihood of data observed during the same week or month being assigned to the same seasonal cluster. The results of the iterative cluster analysis procedure conducted at the seasonal analysis stage are presented in figure 4. Based on these results, the study team concluded that "three" is the appropriate number of seasons to use for the 2014 observed data in the Phoenix pilot test site.

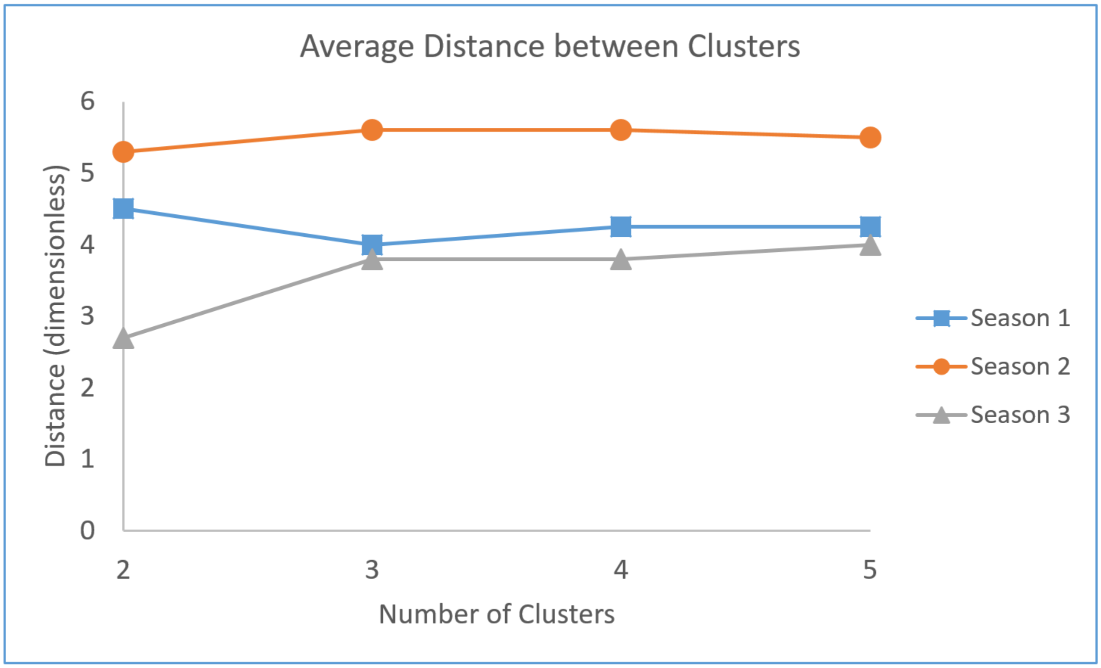


Source: Federal Highway Administration, Maricopa Association of Governments (Phoenix L04 Pilot)

Note: the distance is a dimensionless Euclidean distance.

Figure 4. Graph. Seasonal cluster analysis results for Phoenix pilot test site.

For each of the three seasonal data clusters that resulted from the previous analysis, an additional cluster analysis was conducted to evaluate the need for separate data clusters within each season. The only difference between the seasonal cluster analysis conducted earlier and these cluster analyses is the exclusion of the "date" variable for each within-season cluster analysis. The results of the iterative process of cluster investigations within seasons 1, 2, and 3 are shown in figure 5.



Source: Federal Highway Administration,

Note: the distance is a dimensionless Euclidean distance.

Figure 5. Graph. Within-season cluster analysis for seasons 1, 2, and 3.

The analysis results presented in these figures indicate that no significant benefit will be gained from analyzing more than two clusters in any of the three seasons. This finding also highlights a key characteristic of the cluster analysis methodology that can have an important effect on the analyst's ultimate workload: To calculate the maximum distance between clusters, one must begin the analysis with at least two clusters. Thus, the remaining unanswered question is whether even two clusters are necessary.

To answer this question, the project team determined the centroid of the single cluster for each season and then applied the cluster analysis methodology manually to calculate the Euclidean distance between the single-cluster centroid for each season and the centroids of the two initial clusters developed for each season. The results of this analysis are presented in table 1 for Season 1 and show that, in this case, two clusters were found to be better than one.

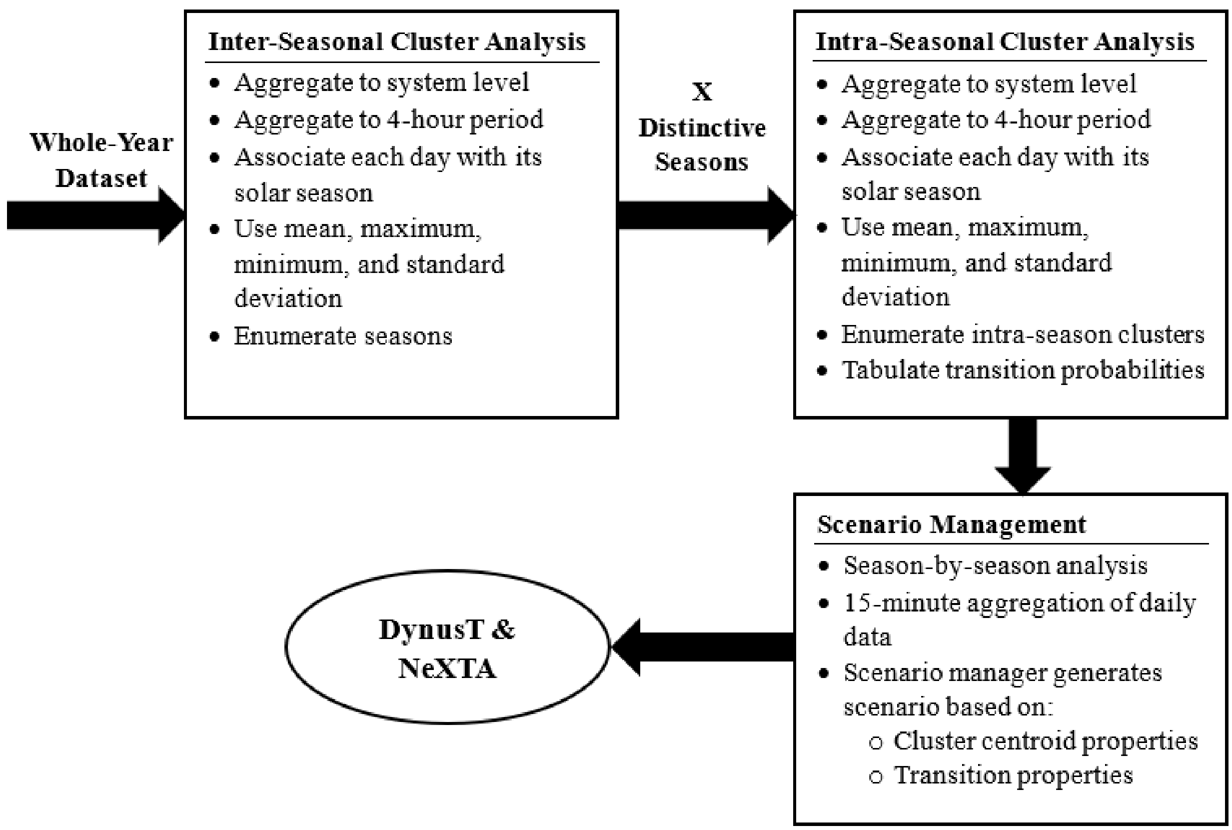
Table 1. Comparison of single-cluster versus two-cluster analysis results.

Scenario	Scaled Distance
Comparison of single-cluster centroid with centroid of Cluster 1	3.184
Comparison of single-cluster centroid with centroid of Cluster 2	1.045
Comparison of Cluster 1 centroid with Cluster 2 centroid	4.434

Source: Federal Highway Administration

For this project, two within-season clusters were found to be the most appropriate number of clusters for each of the three seasons. Figure 6 summarizes the process used for the cluster analysis and its role in relation to the scenario development stage of the reliability analysis. Cluster analysis variables include:

- Demand: total vehicle miles traveled (VMT) during a 4-hour period per lane-mile.
- Speed: average space-mean speed during a 4-hour period in miles per hour.
- Crash Duration: number of hours crash presence per 4-hour period per lane-mile.
- Crash Severity: number of lanes blocked during a 4-hour period per lane-mile.
- Weather: duration in minutes in each weather type (clear, light rain, medium rain, heavy rain) during a 4-hour period.



Source: Federal Highway Administration,

Figure 6. Chart. Process used for cluster analysis.

MANUALLY GENERATED SCENARIO APPROACH

In the absence of special pre- and postprocessor tools to support TTR analysis, a DTA model user may consider developing a relatively small number (e.g., a dozen or so) of "core scenario" datasets manually. The first consideration is defining the reliability reporting period (RRP). Note that terms such as RRP, spatiotemporal matrix, analysis box, and analysis cube are sometimes used interchangeably, but they all involve the prerequisite choice of temporal and spatial analysis boundaries.

Once the RRP is defined, traffic volume demands associated with that particular physical network and time horizon could be grouped into a small number of scenarios (e.g., low, medium, high). Similarly, there could be additional scenarios to reflect the impacts of nonrecurring events (i.e., weather, incidents, work zones, and special events). There are many options for modeling nonrecurring events in DTA simulation. These include adjustments to free-flow speed, facility capacity, route choice, and traffic demand. In the manually generated scenario approach described here, the DTA model user would apply engineering judgment to implement proper adjustments within the scenario datasets.

The number of scenarios used in a manually generated approach would presumably be smaller than the number used with a tool like the scenario generator. Table 2 illustrates what would happen if the demand, weather, and incident variations throughout the RRP were grouped into a very small number of scenarios (i.e., 3×2×2=12). In this manner, expanding from two weather groupings (ideal and poor) into three (ideal, light precipitation, and heavy precipitation) could inflate the overall number of scenarios from 12 to 18; adding a fourth grouping with two options (e.g., work zone inactive, work zone active) would multiply the number from 18 to 36, and so on.

Table 2. Obtaining a travel time distribution via manually generated scenarios.

Core Scenario	1	2	3	4	5	6	7	8	9	10	11	12
Demand	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Demand Frequency	20%	40%	40%	20%	40%	40%	20%	40%	40%	20%	40%	40%
Weather	Ideal	Ideal	Ideal	Poor	Poor	Poor	Ideal	Ideal	Ideal	Poor	Poor	Poor
Weather Frequency	70%	70%	70%	30%	30%	30%	70%	70%	70%	30%	30%	30%
Incidents	None	None	None	None	None	None	Yes	Yes	Yes	Yes	Yes	Yes
Incidents Frequency	70%	70%	70%	70%	70%	70%	30%	30%	30%	30%	30%	30%
Relative Frequency	9.8%	19.6%	19.6%	4.2%	8.4%	8.4%	4.2%	8.4%	8.4%	1.8%	3.6%	3.6%
Random # Seed Realizations	98	196	196	42	84	84	42	84	84	18	36	36

Source: Federal Highway Administration

Table 2 further illustrates what would happen if the analyst applied frequency weighting factors to each scenario. In this example, high demand occurs 40 percent of the time, clear weather occurs 70 percent of the time, and so on. Relative frequency (second-to-last row) is the product of demand, weather, and incident frequencies for each core scenario. Combined with a number of random seed realizations weighted by frequency of occurrence, the table 2 exercise would initially produce 1,000 travel time outcomes. Typical reliability performance measures (e.g., travel time index, 85th percentile day, and buffer index) and accompanying visualizations (e.g., scatterplots, histograms, probability density functions, and cumulative density functions) could be obtained from this set of 1,000 outcomes. If the analyst did not have time to process 1,000 runs, the number of runs could be reduced proportionally (e.g., divided by 10).

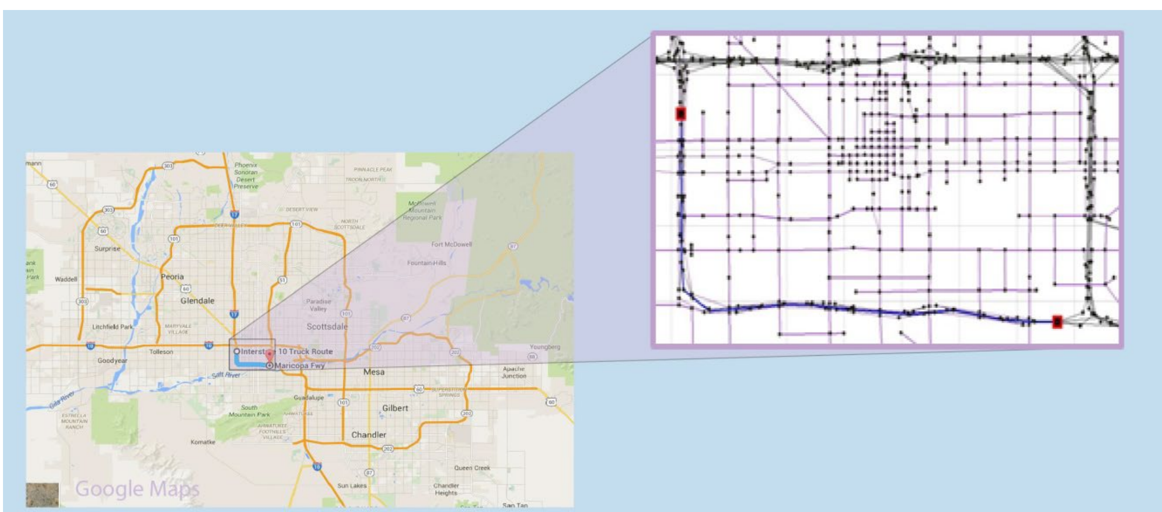
CASE STUDY: STRATEGIC HIGHWAY RESEARCH PROGRAM 2 L04 PHOENIX PILOT TEST SITE

The following pilot test case study, which coincides with the cluster selection example described earlier in this document, was produced by the Phoenix pilot test site team through SHRP 2 Project L04: Incorporating Reliability Performance Measures in Operations and Planning Modeling Tools. The study team used the DTA model DynusT in conjunction with scenario manager and trajectory processor developed in accordance with SHRP 2 to conduct the corridor TTR evaluations. Information detailing the analysis process and study results follows.

Investigated Corridors

Four separate corridors were evaluated in the Phoenix pilot test site, ranging in length from 6 to 15 miles:

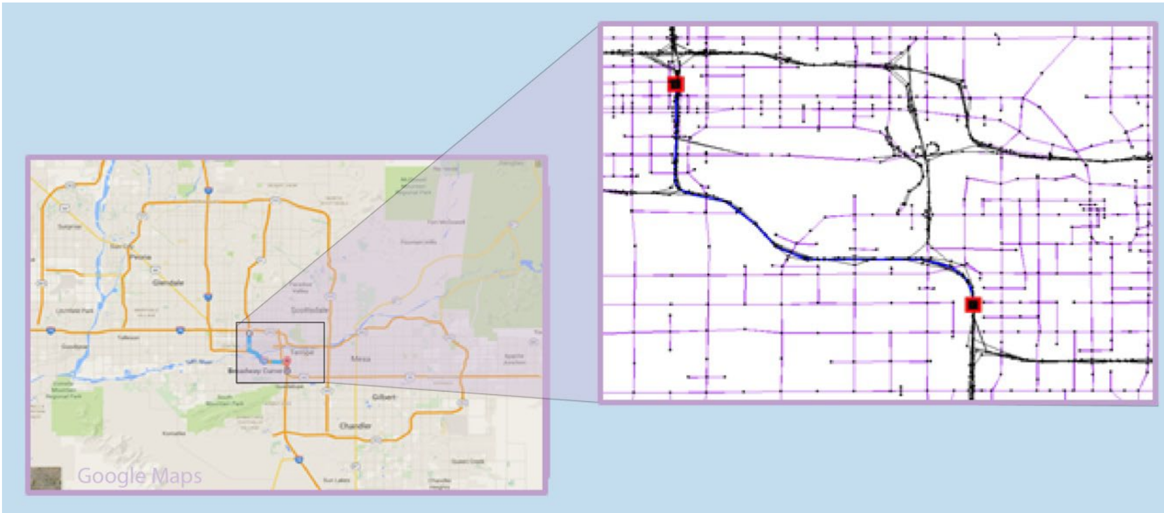
1. *Corridor 1: southbound I–17 from Van Buren Street to the I–10 freeway* interchange. The location of this 6.3-mile section within the Phoenix area is shown in figure 7. This freeway section consists of three basic lanes and is often congested during the evening peak period.



Source: Federal Highway Administration,

Figure 7. Screenshot. Corridor 1: southbound Interstate 17 (Van Buren to Interstate 10).

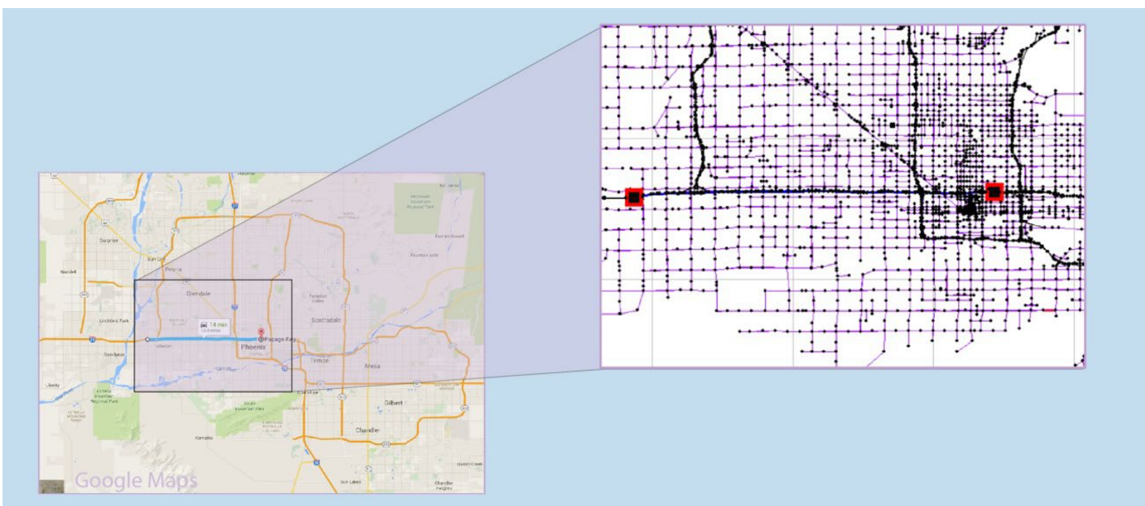
2. *Corridor 2: eastbound I–10 from Roosevelt Street to Southern Avenue*. The location of this 6.5-mile section within the Phoenix area is shown in figure 8. This freeway section consists of four basic lanes and is sometimes congested during the evening peak period.



Source: Federal Highway Administration,

Figure 8. Screenshot. Corridor 2: eastbound Interstate 10 (Roosevelt to Southern).

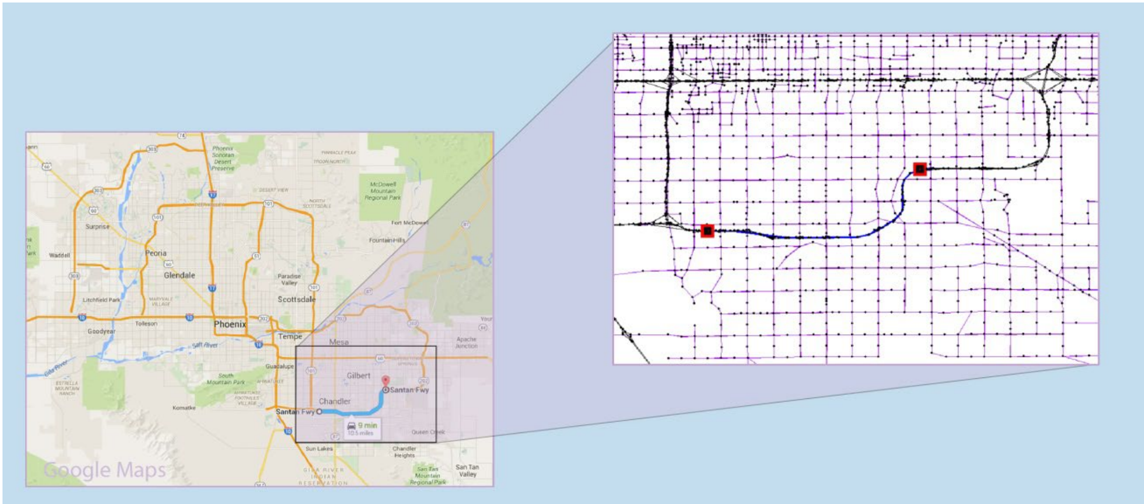
3. *Corridor 3: eastbound I–10 from 107th Avenue to 11th Street.* The location of this 15.08-mile section within the Phoenix area is shown in figure 9. This freeway section consists of four basic lanes and is sometimes congested during the evening peak period.



Source: Federal Highway Administration,

Figure 9. Screenshot. Corridor 3: eastbound Interstate 10 (107th to 11th).

4. *Corridor 4: westbound US 60 from Higley Road to Dobson Road*. The location of this 10.3-mile section within the Phoenix area is shown in figure 10. This freeway section consists of three basic lanes and is often uncongested during the evening peak period.



Source: Federal Highway Administration,

Figure 10. Screenshot. Corridor 4: westbound US 60 (Higley to Dobson).

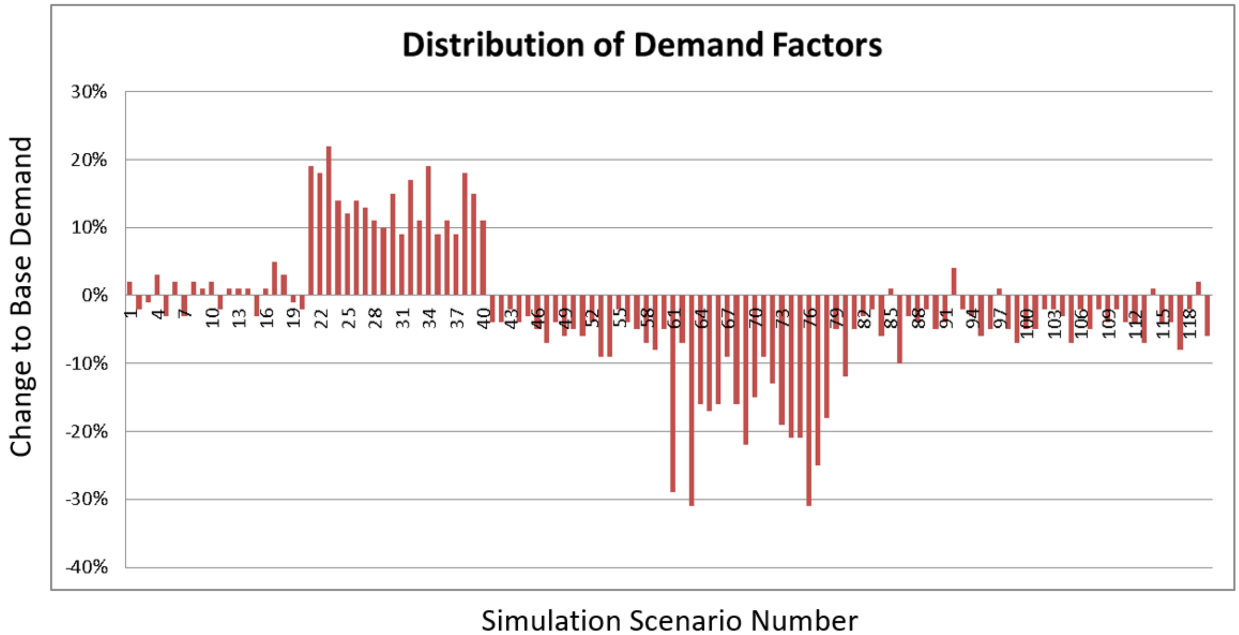
Simulation Procedure and Implementation of Dynamic Traffic Assignment Runs

The 120 scenarios the scenario manager generated for the Phoenix pilot test collectively represent the range of PM peak period conditions the Maricopa Association of Governments/Phoenix region experienced during 2014. More specifically, a set of 20 scenarios was created for each of 2 clusters within each of 3 seasons (as described in the Cluster Selection section in this document). Individual scenarios differed from one another according to the combination of three nonrecurring event factors (demand, weather, and incident variations) that were incorporated into each. These factors were then translated into demand and network changes that were then applied to the base model for each DTA simulation run. The details of that translation are discussed below.

Scenario Inputs

Demand

The demand factor used in the simulation runs is in the form of a multiplier applied to the base demand. The demand factors used in the Phoenix area pilot test, and reflective of the actual observed demand variation, ranged between 0.69 and 1.22. The distribution of demand factors used in the 120 simulated scenarios is illustrated in figure 11.



Source: Federal Highway Administration

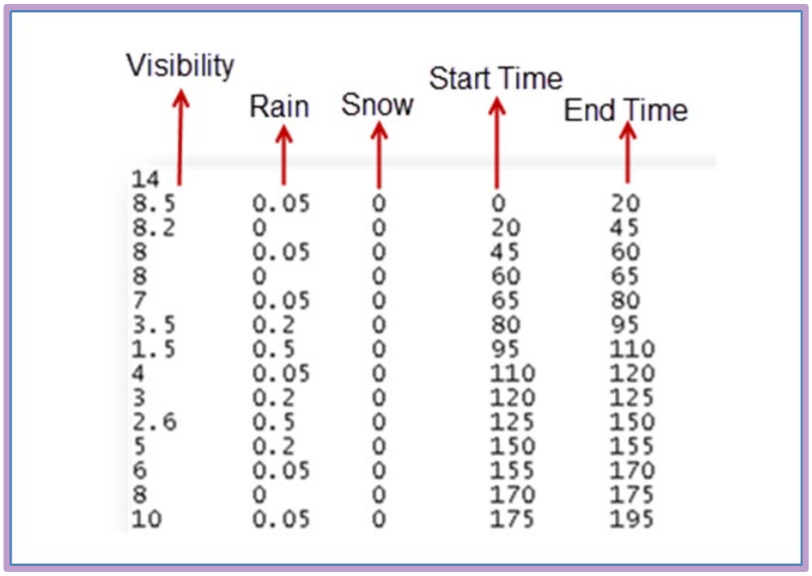
Figure 11. Graph. Distribution of demand factors across simulated scenarios.

With respect to the application of DynusT and to maintain temporal and O-D consistency among all scenario runs, a master vehicle roster was created at the outset, representing the base demand multiplied by a factor of 1.25. Then, for each simulated scenario, a random selection process was used to select the number of vehicles from the master roster that exactly matched the targeted scenario total. The details of the master roster are discussed in the following section.

Weather

The weather factor implemented in DynusT is composed of five variables that collectively define the important characteristics of each weather event (figure 12):

- Visibility
- Rain precipitation (inches)
- Snow precipitation (inches)
- Start time (nearest 5-min period)
- End time (nearest 5-min period)



Visibility	Rain	Snow	Start Time	End Time
14				
8.5	0.05	0	0	20
8.2	0	0	20	45
8	0.05	0	45	60
8	0	0	60	65
7	0.05	0	65	80
3.5	0.2	0	80	95
1.5	0.5	0	95	110
4	0.05	0	110	120
3	0.2	0	120	125
2.6	0.5	0	125	150
5	0.2	0	150	155
6	0.05	0	155	170
8	0	0	170	175
10	0.05	0	175	195

Source: Federal Highway Administration,

Figure 12. Graph. Example weather data input record format for DynusT.

Where multiple weather events occurred during a single simulation time interval, the most severe weather event was assumed to be in place for the entire time interval; this was done to simplify and expedite the simulation runs. It is recognized that the assumption also introduced some inaccuracy into the analysis process, but any such inaccuracies will have an insignificant to minor overall effect on the final results.

The effects of each weather event on capacity and speed were simulated in DynusT using the capacity and free-flow speed adjustment factors presented in table 3. These adjustment factors were developed in SHRP 2 Project L08[2] and are incorporated as default values into the most recent edition of the *Highway Capacity Manual* (Kittelson and Vandehey 2013).

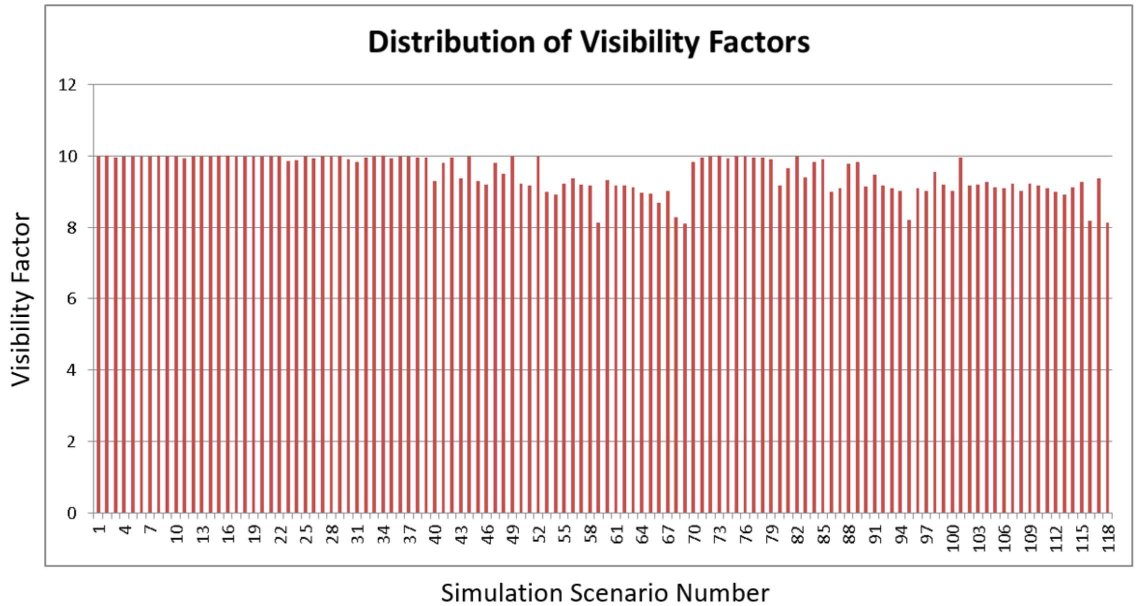
[2]National Academies of Sciences, Engineering, and Medicine. 2022. "SHRP 2 L08 [Completed]" (web page). https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2197, last accessed January 13, 2023.

Table 3. Capacity and speed reduction effects of weather events.

Weather Type		Capacity Adjustment Factors (CAF)					Free-Flow Speed Adjustment Factors (SAS)				
Free-Flow Speed (mph)		55 mph	60 mph	65 mph	70 mph	75 mph	55 mph	60 mph	65 mph	70 mph	75 mph
Clear	Dry Pavement	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Wet Pavement	0.99	0.98	0.98	0.97	0.97	0.97	0.96	0.96	0.95	0.94
Rain	<= 0.10 in/h	0.99	0.98	0.98	0.97	0.97	0.97	0.96	0.96	0.95	0.94
	<= 0.25 in/h	0.94	0.93	0.92	0.91	0.90	0.96	0.95	0.94	0.93	0.93
	> 0.25 in/h	0.89	0.88	0.86	0.84	0.82	0.94	0.93	0.93	0.92	0.91
Snow	<= 0.05 in/h	0.97	0.96	0.96	0.95	0.94	0.94	0.92	0.89	0.87	0.84
	<= 0.10 in/h	0.95	0.94	0.92	0.90	0.88	0.92	0.90	0.88	0.86	0.83
	<= 0.50 in/h	0.93	0.91	0.90	0.88	0.87	0.90	0.88	0.86	0.84	0.82
	> 0.50 in/h	0.80	0.78	0.76	0.74	0.72	0.88	0.86	0.85	0.83	0.81
Temp	< 50 deg F	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98
	< 34 deg F	0.99	0.99	0.99	0.98	0.98	0.99	0.98	0.98	0.98	0.97
	< -4 deg F	0.93	0.92	0.92	0.91	0.90	0.95	0.95	0.94	0.93	0.92
Wind	< 10 mph	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	<= 20 mph	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.97	0.96
	> 20 mph	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.97	0.97	0.96
Visibility	< 1 mi	0.90	0.90	0.90	0.90	0.90	0.96	0.95	0.94	0.94	0.93
	<= 0.50 mi	0.88	0.88	0.88	0.88	0.88	0.95	0.94	0.93	0.92	0.91
	<= 0.25 mi	0.90	0.90	0.90	0.90	0.90	0.95	0.94	0.93	0.92	0.91

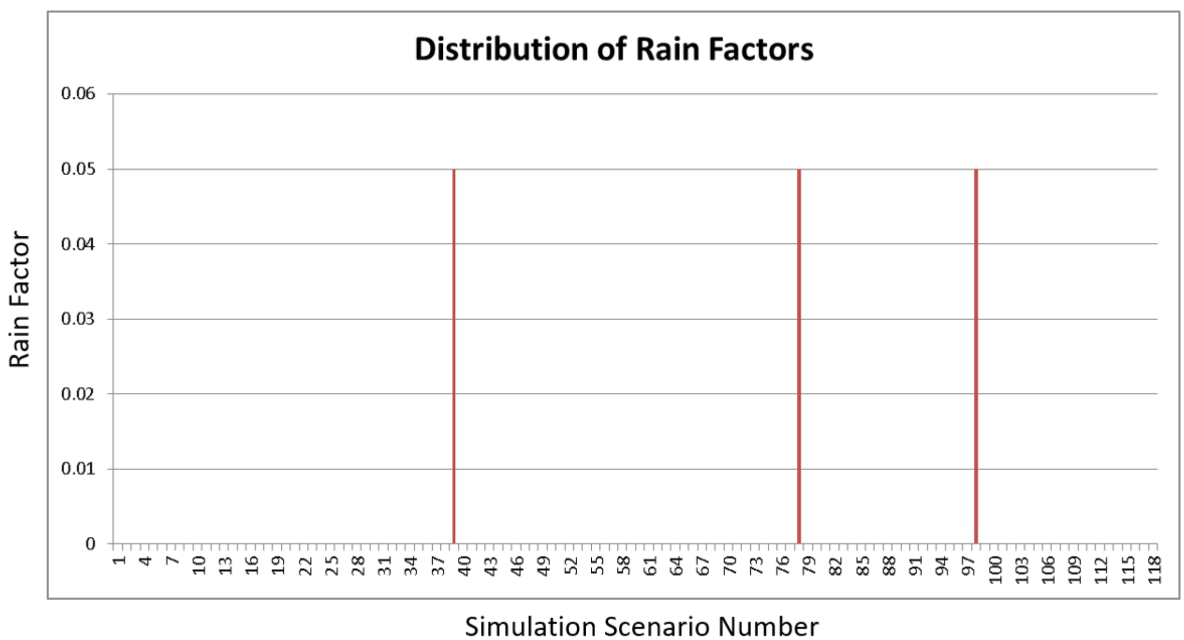
Source: Federal Highway Administration,

Figure 13 and figure 14 show the distribution of visibility and rain events, respectively, across the 120 simulated scenarios. The reported weather events likely were not uniform in how they affected the entire region, but, for the purposes of this pilot test, they were assumed to be so, and it was assumed that any resulting capacity and speed adjustments are applicable to the entire network.



Source: Federal Highway Administration,

Figure 13. Graph. Distribution of visibility factors across simulated scenarios.



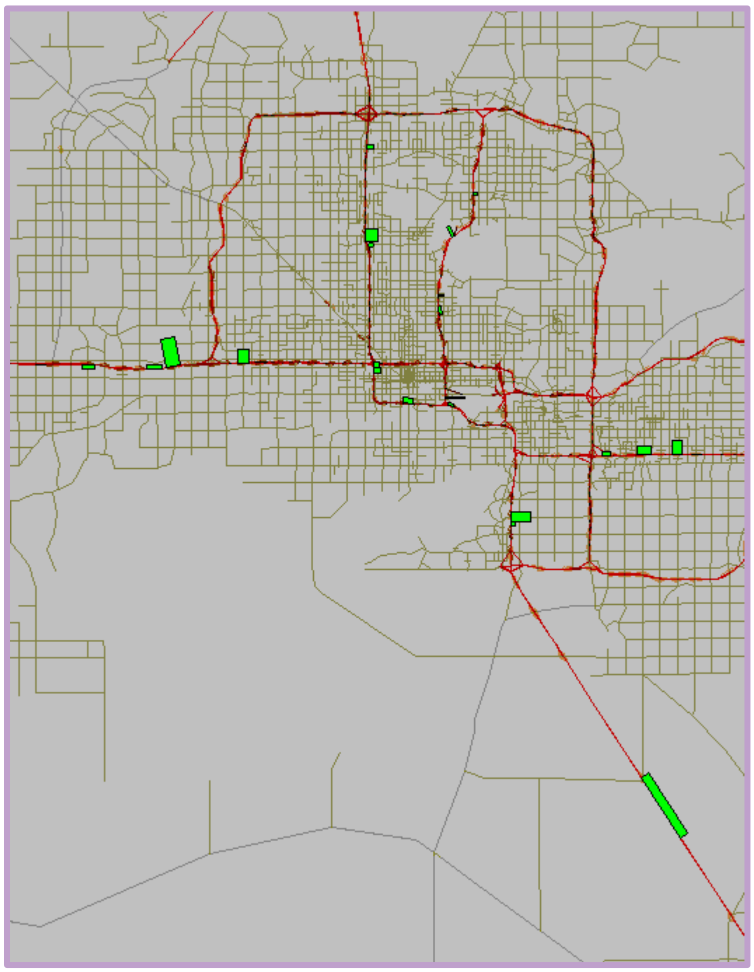
Source: Federal Highway Administration,

Figure 14. Graph. Distribution of rain precipitation levels across simulated scenarios.

Incidents

Scenario manager generates an "incident.dat" file that includes the link identification number for the location where the incident occurred, the incident duration (in min), and an incident severity factor. The incident severity factor is expressed in terms of the fraction of lane capacity that is estimated to have been lost due to the incident.

Figure 15 identifies the location of all incidents incorporated into the 120 scenarios simulated by DynusT. In figure 15, the incidents are identified in the form of a link bandwidth plot. The size of the bandwidth represents the total duration of all incidents that occurred on a particular link over the course of all 120 simulation scenarios. Therefore, a tall bar can indicate a high frequency of short-duration incidents or a relatively long duration of fewer incidents.



Source: Federal Highway Administration,

Figure 15. Map. Distribution of simulated incident locations on the Phoenix pilot test site freeway.

Master Vehicle Roster

As noted earlier, a master vehicle roster was created at the outset of the simulation effort to maintain temporal and O-D consistency throughout the DTA runs. The master vehicle roster was designed to include enough vehicles to accommodate every demand level present in the 120 simulated scenarios. The process by which the master roster was created is as follows:

- The weekday p.m. peak period O-D demand tables from the calibrated base year DTA model for single-occupant vehicles, high-occupancy vehicles, and trucks were increased by a factor of 1.25, resulting in a total of 5.6 million trips.
- DynusT was run to the point of user equilibrium with the updated demand tables.
- Individual vehicle trajectories generated during the simulation were saved into an HDF5® database, which could subsequently be easily queried to generate the demand levels needed to exactly match the individual scenario demand levels (The HDF Group 2006).

Batch Run Process

To efficiently execute the large number of DTA runs required in this project, a Python® script was written within the DynuStudio platform to allow for batch runs to be conducted (Python Software Foundation 2001–2023). The script can be easily modified and rerun for different numbers of scenarios. The essential functional steps the script performed include the following:

1. The demand factor associated with each scenario is read to determine the total number of vehicles to be simulated.
2. A subset of vehicles is randomly drawn from the master vehicle roster database that equals the targeted total number of vehicles to be simulated. From this new dataset, a pair of vehicle.dat and path.dat files is created and then used as the demand for the next DTA run.
3. Weather characteristics associated with the scenario are read to determine adjustments for the base capacity and speeds. A new network.dat file is created to reflect these adjustments.
4. Incident characteristics associated with the scenario are read and used to produce a new incident.dat file that will be used in the next DTA run.
5. DynusT was launched under the one-shot assignment method and with 540 minutes of simulated time using the given vehicle/path data. More importantly, all vehicles were assigned with the driving behavior assumption using the historical information to eliminate any possible route changes. Each run took about 1 hour to finish, with variations in actual simulation time being the result of variations in the number of vehicles simulated in each scenario.
6. The vehicle trajectory data resulting from each simulation were saved into a renamed file that the Vehicle Trajectory Processor (Network EXplorer for Traffic Analysis (NeXTA)) could subsequently use for comparative analyses.
7. Steps 1 through 6 were repeated for each scenario that was simulated.

METHODOLOGY FOR CONSTRUCTING A WHOLE-YEAR TRAVEL TIME PROFILE

Twenty simulated "days" for each of the 6 distinct clusters resulted in 120 simulations of the Phoenix network.

The travel time distribution patterns that resulted from each of the 6 sets of 20 simulations were combined by weighting each set in proportion to the number of days represented by each of the 6 clusters.

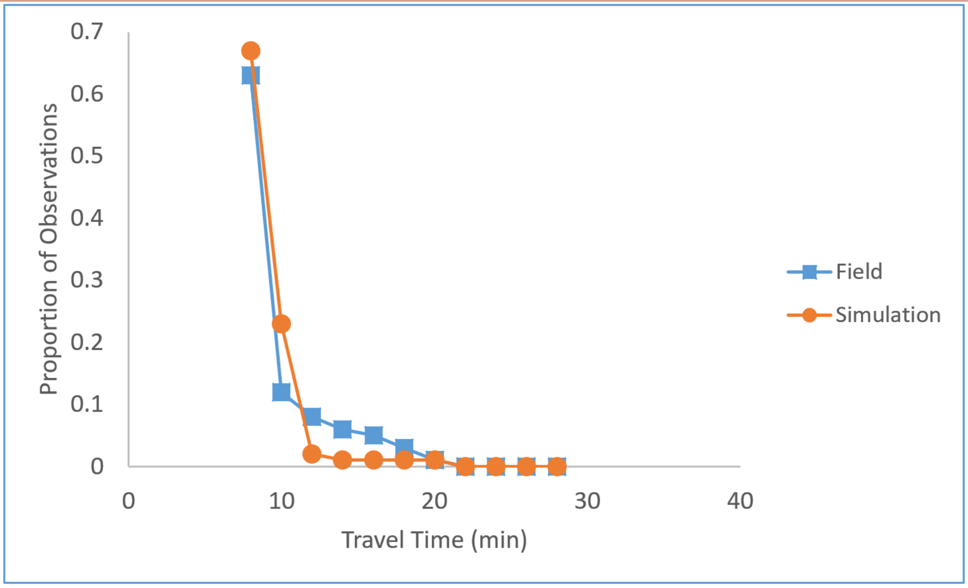
DETERMINATION OF AN APPROPRIATE VEHICLE TRAJECTORY SAMPLING RATE

It was evident that the computer resources typically available to most metropolitan planning organizations would be unable to load the entire set of vehicle trajectories produced in a whole-year analysis simultaneously. This is because for the Phoenix pilot test site approximately 4 million vehicle trajectories were produced in each simulated scenario, and 20 scenarios were necessary to complete the analysis for a single data cluster. The project team had sufficient computer resources at its disposal to accomplish this feat but recognized that many other organizations without such resources would probably be unable to do so. Therefore, the project team sought to identify an acceptable alternative approach. One alternative that has also been successfully used in other studies is to select and load only a sample of the generated trajectories. Under this alternative, the selected trajectories are distributed uniformly across the full duration of the simulation and are chosen in a repeatable, ordered manner (e.g., by selecting every third, fourth, or fifth vehicle trajectory that is produced, depending on the sampling rate that is ultimately chosen).

As the project team was able to load the complete set of vehicle trajectories produced in each data cluster analysis, it was possible to test the loss of accuracy associated with different sampling rates to select one that would minimize the total work effort without unduly compromising the final results' accuracy. More specifically, the project team tested the effects of multiple sampling rates (5, 10, and 20 percent) on the resulting travel time distribution profile across each of the four corridors being investigated within the Phoenix pilot test site. The results indicated that a 20-percent sampling rate can be used to reasonably reflect the travel time distribution of all vehicle trajectories produced in a single data cluster analysis; therefore, this was used for the purposes of the analysis and conclusions that follow.

WHOLE-YEAR ANALYSIS RESULTS

It was noted earlier that DynusT simulated 4 hours of weekday time (3 through 7 p.m.) across 20 scenarios, which the scenario manager generated for each of 2 data clusters contained in each of 3 separately defined seasons. A different number of days was assigned to each season; therefore, it was necessary to weight the results of each simulated scenario so that each represented its appropriate proportion of the year. The travel time results for each corridor were combined in this fashion to create whole-year travel time distribution profiles that could then be fairly compared with the corresponding base year (2014) travel time profiles generated from observed and recorded field data. The results of this comparative effort are presented in figure 16 for Corridor 1.



Source: Federal Highway Administration,

Figure 16. Graph. Corridor 1 whole-year analysis travel time results.

The simulation versus observed travel time results for each of the four corridors provided a strong basis for concluding that the software tools and the analysis methodology combine to produce a good approximation of the operational conditions being simulated. Some differences can be seen between the simulated and observed travel time results for every corridor, but the study team concluded that a good match was achieved with the following observations and caveats:

- The best fit between observed and simulated results occurred on the corridor with the lowest level of observed congestion (Corridor 4).
- The variation between observed and simulated results shown for Corridor 3 was judged to be due primarily to the miscalibration of one or more key car-following parameters rather than a failure of the scenario manager, vehicle trajectory processor, or the analysis methodology. In this regard, note that the links included within this corridor were not explicitly modeled or adjusted during an earlier model calibration exercise. Also, the results shown in figure 16 suggest that DynusT is estimating a lower capacity for at least one of the links within this corridor than is actually the case.

The team judged that the displacement between observed and simulated results for Corridor 2 was because this corridor is immediately downstream from Corridor 3; therefore, the mismatch between simulated and actual capacity in Corridor 3 has the effect of underestimating simulated travel times in Corridor 2.

FINDINGS AND CONCLUSIONS

The scenario manager and vehicle trajectory processor (and its enhanced successor, NeXTA) can have the effect of dramatically improving an agency's ability to estimate the likely net effects of one or more operational improvement strategies when used in conjunction with an open-source

DTA simulation model such as DynusT. This improvement is achieved because the tools allow an evaluation of the strategy's effects as they accumulate over an extended period in conjunction with varying combinations of weather; demand; and crash location, duration, and intensity conditions.

The analysis procedure described in this pilot test case study produces a travel time distribution profile that is far more informative than the single design-hour travel time estimate that traditional analytic tools provide. Supplementary information on the analysis process and methodologies used in the study can be found in the complete SHRP 2 L04 report, *Incorporating Reliability Performance Measures in Operations and Planning Modeling Tools: Guide for Use of Scenario Manager and NeXTA in Modeling Travel* (Kittelson et al. 2016).

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