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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

MOSAIC
MODEL OF SUSTAINABILITY AND INTEGRATED CORRIDORS
PHASE 3: COMPREHENSIVE MODEL CALIBRATION AND VALIDATION AND ADDITIONAL MODEL ENHANCEMENT

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16. Abstract

The Maryland State Highway Administration (SHA) has initiated major planning efforts to improve transportation efficiency, safety, and sustainability on critical highway corridors through its Comprehensive Highway Corridor (CHC) program. This project developed a Model Of Sustainability and Integrated Corridors (MOSAIC) to assist SHA in selecting the most sustainable corridor improvement option for its Highway Needs Inventory and long range planning processes. Products from this research project will also help SHA achieve its mobility, safety, socio-economic and environmental stewardship objectives.

Phase 1 of the project focused on defining a comprehensive set of sustainability indicators that could be quantitatively evaluated for major geometric improvement options, such as: adding general purpose lanes and converting at-grade intersections to grade-separated interchanges. Phase 2 of the project focused on extending this quantitative evaluation of sustainability indicators to additional multimodal corridor improvement options, including high occupancy vehicle (HOV) lane, high occupancy toll (HOT) lane, bus rapid transit/bus-only lane, light rail transit, truck-only lane, express toll lane, and road diet (i.e. lane removal). Phase 3 of the project further extends MOSAIC's ability to analyze multiple-improvement options. In addition, comprehensive calibration and validation is conducted using Maryland data to customize MOSAIC to local Maryland conditions.

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EXECUTIVE SUMMARY

The Maryland State Highway Administration (SHA) has initiated major planning efforts to improve transportation efficiency, safety and sustainability on critical highway corridors through its Comprehensive Highway Corridor (CHC) program. It is important for planners to be able to compare various types of highway improvement options during the need analysis and long-range planning processes to select the best program-level plans for the corridor. SHA funded a research project titled "Comprehensive Highway Corridor Planning with Sustainability Indicators" to support the CHC and Sustainability Initiatives and to develop a Model Of Sustainability and Integrated Corridors (MOSAIC), which will help SHA estimate the sustainability impact of multimodal highway improvement options early in the transportation planning and environmental screening processes. The results from this research project can also help SHA achieve its mobility, safety, socio-economic and environmental stewardship objectives.

This research project had three specific objectives:

1. Define sustainability indicators that are relevant to SHA's CHC program.
2. Develop a high-level planning model that helps SHA integrate the identified sustainability indicators into the CHC program at the project/corridor level.
3. Provide analysis tools for integrating safety, mobility, environmental stewardship, and socio-economic objectives into SHA's corridor planning process with consideration for multimodal corridor improvement options.

Based on these research objectives, a team of researchers at the University of Maryland, College Park, worked closely with SHA's technical liaisons and research staff to successfully develop the MOSAIC tool. Six categories of sustainability indicators (mobility, safety, socio-economic impact, natural resources, energy and emissions, and cost) and more than thirty sustainability performance measures were defined as evaluation criteria for the selection of highway corridor improvement options. MOSAIC considers three geometric improvement options (adding general purpose lanes, removing lanes through a road diet and upgrading at-grade intersections to grade-separated interchanges), six multimodal improvement options (adding high occupancy vehicle

and high occupancy toll lanes, adding express toll lanes, adding bus rapid transit/bus-only lanes, adding light rail transit, and adding truck-only lanes) in addition to the no-build improvement option. Other than analyzing a single improvement option, MOSAIC allows users to select a combination of one geometric improvement option and one multimodal improvement option, which is referred to as the multiple-improvement option. Various quantitative models were developed, calibrated and validated to analyze the impacts of these alternative corridor improvement options on the identified sustainability indicators. Such impacts were then evaluated based on policy considerations and SHA priorities.

The MOSAIC tool was developed through three research phases. In Phase 1, two highway capacity improvement types were considered: adding general-purpose lanes and converting at-grade intersections to grade-separated interchanges. In Phase 2, the research team improved MOSAIC by incorporating a third capacity adjustment option (removing lanes or road diet), and six multimodal highway corridor improvement options: adding high occupancy vehicle, high occupancy toll lanes, express toll lanes, bus rapid transit/bus-only lanes, light rail transit, and truck-only lanes. With Phase 3 research efforts, MOSAIC became capable of analyzing corridor improvement scenario that includes two types of improvements at the same time (e.g., one capacity improvement option plus one multimodal improvement option). In addition, MOSAIC was comprehensively calibrated and validated based on Maryland data.

This project report summarizes the cumulative findings and products from all three research phases of MOSAIC. Certain Chapters from the Phase 1 and Phase 2 projects reports (Chapter 2-7 from Phase 1 report, Chapter 2-9 from Phase 2 report) are also presented herein, so that a reader does not have to refer to previous reports when learning or applying the MOSAIC tool. Major findings from Phase 3 are summarized in several sections. For instance the method used for evaluating multiple-improvement options is introduced in Chapter 9 Section 9.2. Research efforts and methods for model calibration and validation are presented in Section 9.3. Research findings and results from model calibration and validation can be found in Chapter 3 and Chapter 4, where specific sustainability evaluation modules are also summarized.

MOSAIC is current implemented as a C# program, and has been integrated into the SHA Enterprise GIS (eGIS) environment through a desktop-accessible widget. This integrated MOSAIC-eGIS system leverages powerful GIS datasets in eGIS to drive high-level MOSAIC sustainability models, enabling streamlined statewide corridor planning and environmental screening applications. The MOSAIC-eGIS tool employs Phase 1 research products, and analyzes two capacity improvement options: adding general purpose lanes and upgrading at-grade intersections to grade-separated interchanges. In the future, SHA may invest in integrating Phases 2 and 3 MOSAIC research products into eGIS to enable multimodal corridor improvement scenarios throughout the State of Maryland.

The UMD research team and SHA technical liaisons share a common vision: MOSAIC will become a flagship application of the SHA CHC Program and a roadmap to sustainability initiative by assisting SHA in multimodal highway corridor improvement decision-making and demonstrating SHA's commitment to incorporating social, economic, environmental, and sustainability considerations in its transportation planning and investment processes.

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CHAPTER 1: INTRODUCTION

The Maryland State Highway Administration (SHA) is committed to integrating safety, mobility, environmental stewardship, and socio-economic objectives into its transportation planning process through its Comprehensive Highway Corridors (CHC) program. To support its sustainability initiatives, SHA funded the development of a Model Of Sustainability And Integrated Corridors (MOSAIC), which defines sustainability indicators, analyzes the sustainability impacts of corridor improvements, and identifies environmental mitigation needs early in the planning process. The sustainability indicators include mobility, safety, air quality, energy consumption, natural resource impact, pollution and greenhouse gas emissions, socio-economics and cost. When implemented during the highway needs assessment and long-range planning stages, MOSAIC can help SHA identify the corridor improvement option that best balances these sustainability indicators. Also, it avoids recommending options with major negative environmental impacts, as they often require costly and lengthy environmental screening and mitigation procedures. MOSAIC is different from microscopic traffic simulation (e.g. Synchro, Vissim) and EPA emission models (e.g. MOVES) that provide detailed pollution and greenhouse gas (GHG) emission estimates for a particular project with a predetermined improvement type; instead, MOSAIC integrates sustainability objectives before the selection of an improvement type. Furthermore, it incorporates a more comprehensive set of sustainability indicators and provides high-level impact analysis with minimum requirements on staff time and other resources.

A transportation corridor planning study usually consists of several sequential steps that include problem identification, determination of goals and evaluation criteria, development/evaluation of initial alternatives, development/evaluation of detailed alternatives, financial analysis, alternative selection, transportation plan updates, project development and project implementation. The affected communities and interested stakeholders may also be involved in each corridor-planning step. This is essential because the greatest benefits and the most streamlined process of transportation corridor improvements are obtained when relevant agencies and stakeholders are involved early in the planning process. Also, as environmental impact mitigation has to be provided in a proactive and systematic fashion, the multiple corridor projects need to be considered at the program level (instead of on a project-by-project basis). Decisions need to be driven by clear goals and objectives, high-quality data, and valid objective modeling tools. For instance, the concept of “environmental banking” allows highway agencies to provide mitigation in advance of the actual needs for replacement/restoration of wetlands and habitat. A negative impact in one corridor can be balanced cost-effectively by a benefit in another corridor. However, the successful application of such proactive measures would require prior knowledge of the likely sustainability impacts of multiple corridor improvement projects, so that the appropriate types and amount of mitigation can be planned ahead systematically.

MOSAIC has gone through 3 phases. In Phase 1, two geometric improvement types were considered: adding a general-purpose lane and converting at-grade intersections to grade-separated interchanges. In Phase 2, the research team improved MOSAIC by incorporating one additional geometric improvement option (removing lanes through a road diet), and six multimodal improvement options (adding high occupancy vehicle and high occupancy toll lanes, adding express toll lanes, adding bus rapid transit/bus-only lanes, adding light rail transit, and adding truck-only lanes). In Phase 3, MOSAIC was given the ability to analyze multiple-improvement options, which were the combinations of one geometric improvement option and one multimodal improvement option. In addition, MOSAIC was comprehensively calibrated and validated using Maryland data to localize models to the state of Maryland.

This project report summarizes the methods and main results from the three research phases of MOSAIC for estimating the sustainability of various corridor improvement options. The remainder of the project report is organized as follows:

- Chapter 2 introduces the general model framework of MOSAIC.
- Chapters 3 through 8 describe the six sustainability evaluation modules of MOSAIC in detail respectively: mobility, safety, socio-economic, natural resources, energy and emission, cost. In addition, Chapters 3 and 4 include the calibration and validation procedures used in the respective mobility and safety models.
- Chapter 9 explains additional program modules including the mode choice models and multi-improvement analysis framework. In addition, chapter 9 provides the general procedure for the calibration and validation processes.
- Chapter 10 describes the MOSAIC outputs.

CHAPTER 2: MOSAIC MODEL OVERVIEW

Users first select a corridor for analysis. This corridor is split into sections based on changes in roadway geometry, functional classification and AADT. Users then select either a single improvement option, or a combination of one geometric improvement option and one multimodal improvement option.

Table 1 MOSAIC Improvement Options

GEOMETRIC IMPROVEMENTS	MULTIMODAL IMPROVEMENTS
Add General Purpose Lanes	Add High Occupancy Vehicle (HOV) Lane
Remove Lanes (Road Diet)	Add High Occupancy Toll (HOT) Lane
Convert At-grade Intersection to Grade Separated Interchange	Add Express Toll Lane (ETL)
	Add Bus Only Lane / Bus Rapid Transit
	Add Truck Only Lane
	Add Light Rail Transit (LRT)

As shown above in Table 1, MOSAIC includes three geometric improvement options, and six multimodal improvement options. Through the multi-improvement analysis framework, MOSAIC also allows users to apply both a geometric improvement and multimodal improvement to a section at the same time (i.e. using both a lane removal on a section in combination with installing a light rail line).

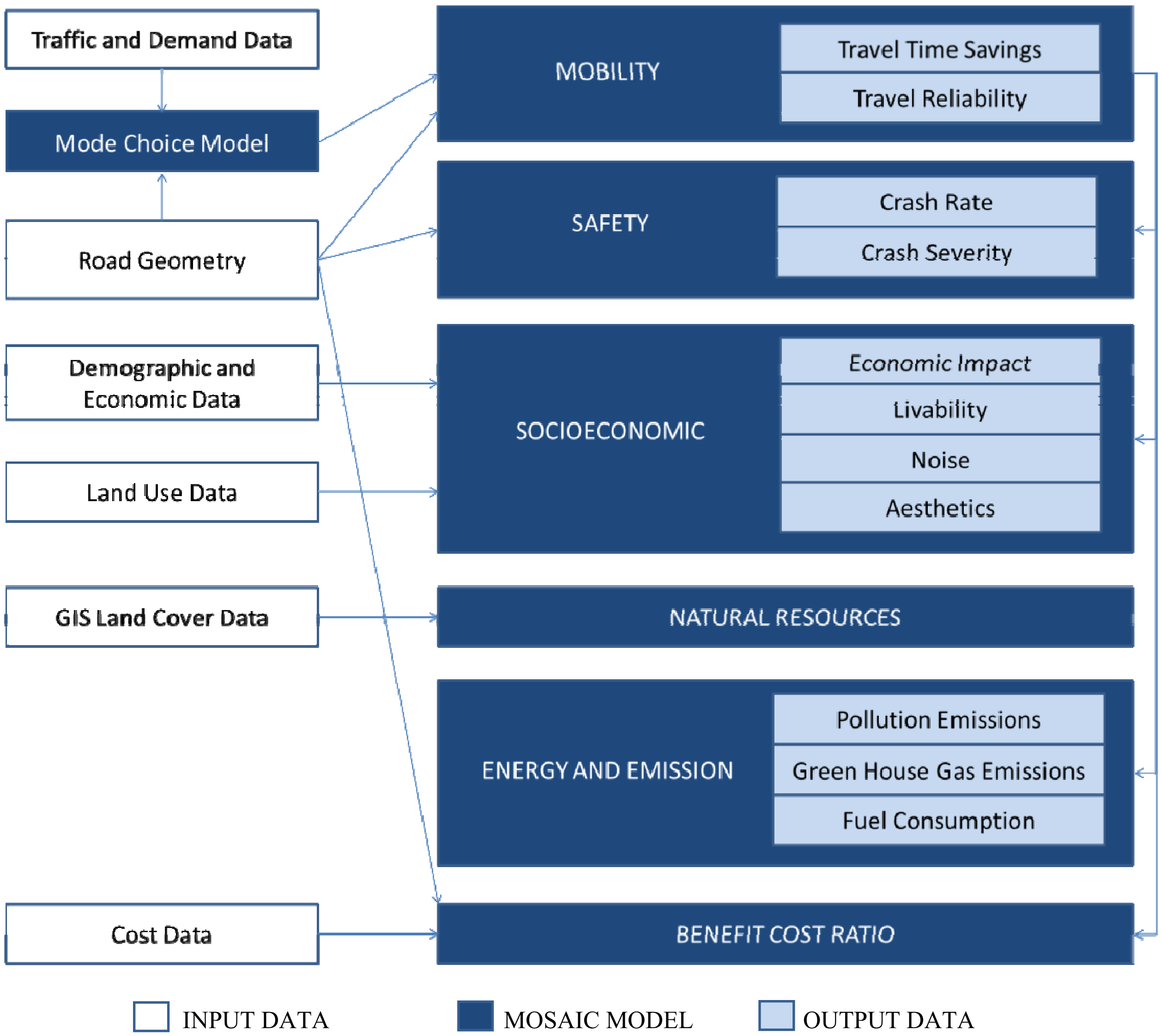


Figure 1 MOSAIC Model Framework

As shown in Figure 1, various data inputs are needed including traffic, road geometry, demographic, economic, land use and GIS data. After collecting the necessary inputs through a combination of user supplied values and automatic geo-spatial queries, MOSAIC applies the pivot-point and enhanced incremental mode choice models to generate new mode shares based on the selected improvement alternatives. The results of the mode choice model, together with other inputs, are used in the six calibrated and validated evaluation models, which include mobility, safety, socio-economic, natural resources, energy and emissions, and cost. The results of the six models are then combined to provide a comprehensive evaluation of the improvement option. Through the SHA eGIS environment, a final evaluation report is generated based on the results of the MOSAIC program, which includes: location maps, final sustainability indicator scores, section and corridor level performance scores and raw module output data (i.e. effective roadway speeds, travel time savings, annual crashes, vehicle emissions, etc.)

In order to have an objective and accurate evaluation for the highway improvement options, the research team incorporated various indicators in each of the six evaluation models. After an extensive review of the literature and best practices, along with several discussions with SHA project liaisons and other SHA staff members, the UMD research team defined a comprehensive set of sustainability indicators that were incorporated and quantitatively evaluated in MOSAIC (see Table 2). For comparison purposes, the sustainability indicators adopted by the Texas DOT for its Sustainability Enhancement Tool (SET) are also listed in Table 2.

Table 2 Sustainability Indicators in MOSAIC Compared with SET

MOSAIC		SET (TxDOT)	
Sustainability Categories	**Sustainability Indicators**	**TxDOT Goals**	**Performance Measures**
Mobility	Travel Time Savings	**Reduce Congestion**	Travel Time Index
	Delay		Buffer Index
	Speed		
	Level of Service (LOS)		
	Travel Reliability		
Safety	Crash Counts and Rate	**Enhance Safety**	Annual Severe Crashes per Mile
	Crash Severity		Percentage Lane-miles under Traffic Monitoring/ Surveillance
Socio-Economic Impact	Economic Impact	**Expand Economic Opportunity**	Land-use Balance
	Compatibility with Existing Land Use		Truck Throughput Efficiency
	Within Smart Growth –PFA Boundaries	**Increase the Value of Transportation Assets**	Average Pavement Condition Score
	Livability		Capacity Addition within Available Right of Way
	Noise		Proportion of Non-single-occupant Travel
	Esthetics		
	Compatibility with Sustainable Transportation Modes (Transit/Bike/Walk)		
Cost	Costs		Cost Recovery from Alternative Sources
Energy and Emission	Green House Gas	**Improve Air Quality**	Daily NOx, CO, and VOC Emission per Mile of Roadway
	Pollution emissions		Daily CO2 Emission per Mile of Roadway
			Attainment of Ambient Air Quality Standards
	Fuel Consumption		
Natural Resources	Quantity of and degree of disturbance on Impacted Cultural/Historical Sites, Steep Slopes, Highly Erodible Soils, Wetlands, Waterways, Floodplains Forests, Critical Areas, Springs/Seeps, Bedrock/Geology Areas, Natural Species, Storm Water Facilities, etc		

CHAPTER 3: MOBILITY

3.1. TRAVEL TIME SAVINGS

Travel time savings are computed for each improvement scenario by comparing them with the base-case scenario for peak periods. The general steps for the estimation of travel time savings are: (1) dividing the corridor into several sections, (2) calculating the peak-hour travel time for each section, (3) summarizing the total travel time for the whole corridor, and (4) comparing the total travel time for base and improved cases.

The corridor under consideration should first be divided into several sections based on Average Annual Daily Traffic (AADT). Ideally, each section should have uniform traffic flow characteristics such as traffic volume, number of lanes, etc. Each section may include more than one intersection or interchange. Based on intersection/interchange locations, a section is further divided into multiple links (see Figure 2). With sections and links defined, the methodology for estimating peak hours' travel time savings can be applied to individual sections in various scenarios. Link-level travel time savings are then aggregated to corridor-level estimates.

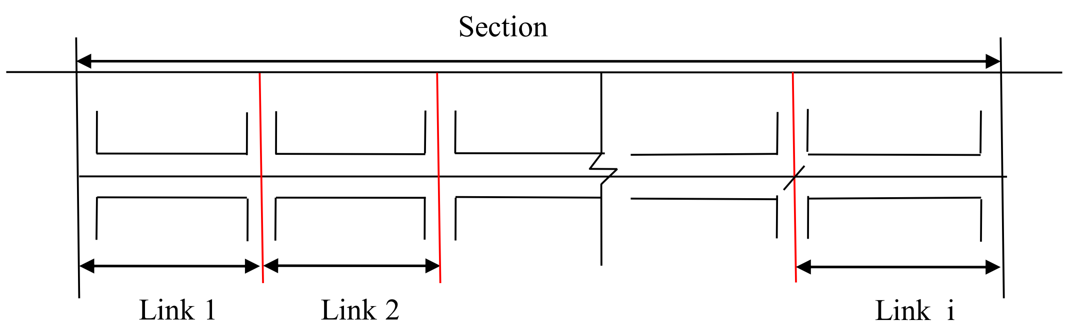


Figure 2 Section and Link Definitions in MOSAIC

3.1.1. TRAVEL TIME FOR GENERAL PURPOSE LANES

To estimate general purpose lanes' speeds during peak periods for both freeway and arterial streets, MOSAIC would follow the flow chart presented in Figure 2 below.

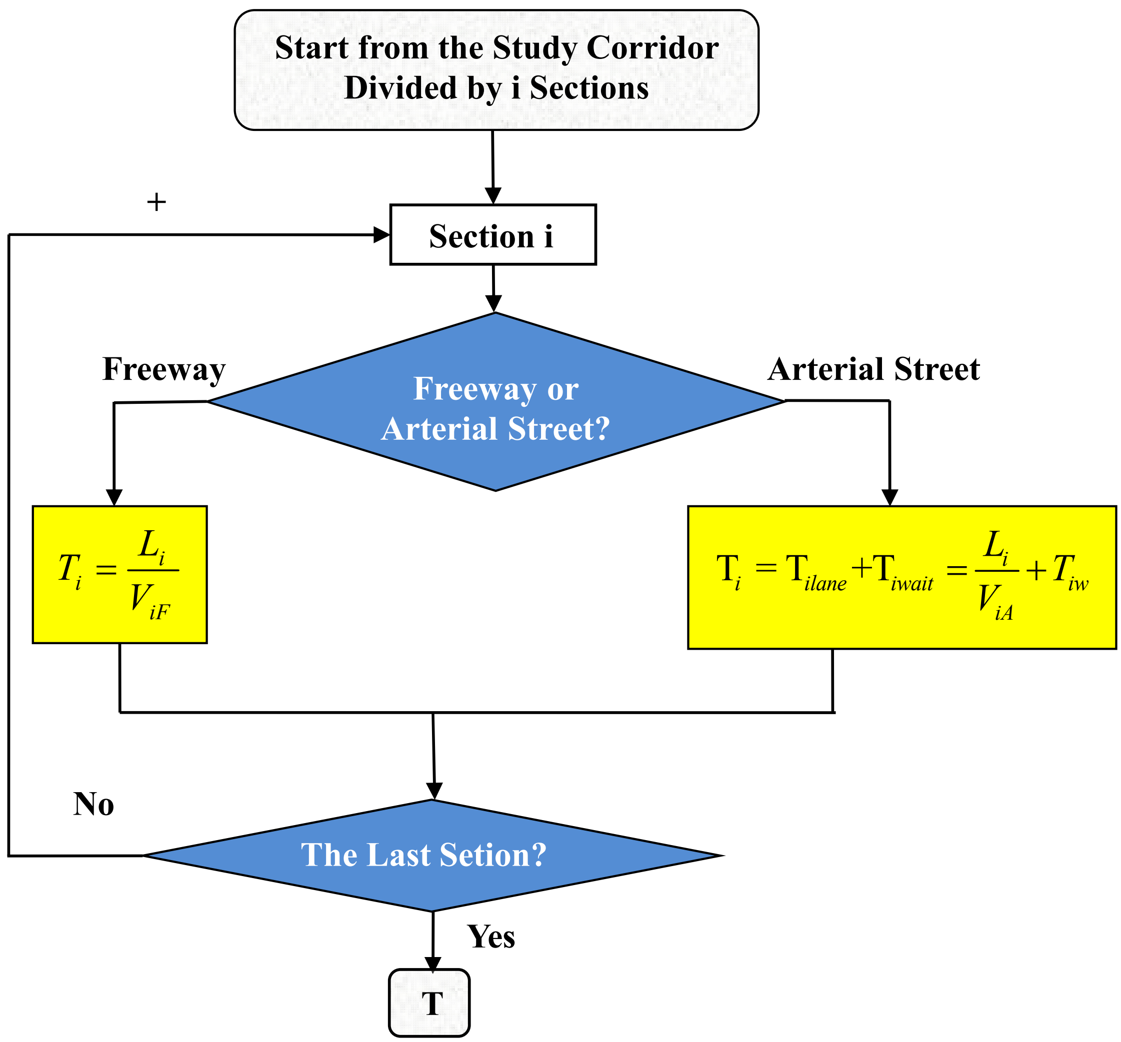


Figure 2 General Purpose Lane Travel Time Estimation

Notation:

T_{ilane} : Average travel time along the roadway (excluding time for crossing intersections) in section i;

T_{iwait} / T_{iw} : Average time spent on stop control at intersections in section i;

V_{iF} : The travel speed for freeways in section i;

V_{iA} : The travel speed for arterial streets with at-grade intersections in section i;

L_i : The length of section i;

n_i : Number of links along section i.

The procedure for estimating freeway and arterial street speeds (V_{iF} and V_{iA}) outlined in the Texas Transportation Institute's Urban Mobility Report (David, 2007) was employed (See Table 3).

Table 3 Speed Estimation Based on Daily Traffic Volume per Lane

Facility and Congestion Level	Daily Traffic Volume per Lane	Speed Estimate Equation Peak Speed (mph)
Freeway		
Uncongested	< 15,000	60
Medium	15,001 – 17,500	70-(0.9*ADT/LANE)
Heavy	17,501-20,000	78-(1.4*ADT/LANE)
Severe	20,001-25,000	96-(2.3*ADT/LANE)
Extreme	>25,000	76-(1.46*ADT/LANE)
		Lowest speed is 35 mph
At-grade Arterial Street		
Uncongested	< 5,500	35
Medium	5,501 – 7,000	33.58-(0.74*ADT/LANE)
Heavy	7,001-8,500	33.80-(0.77*ADT/LANE)
Severe	8,501-10,000	31.65-(0.51*ADT/LANE)
Extreme	>10,000	32.57-(0.62*ADT/LANE)
		Lowest speed is 20 mph
Source: David Schrank, Tim Lomax, The 2007 Urban Mobility Report, Texas Transportation Institute, The Texas A&M University System, September 2007, http://mobility.tamu.edu)		

(**Here ADT/Lane is in thousands; example: 15,000 ADT per lane has a value of 15 in the equation.*)

The travel delay due to traffic signal or stop sign control is based on the Level of Service (LOS) at un-signalized and signalized intersections. The traffic control delay at the intersections was determined (in Table 4) by employing the LOS method from the Highway Capacity Manual (see Table 5).

Table 4 Traffic Control Delay at Intersections

Facility and Congestion Level	Daily Traffic Volume per Lane		Average Delay at Intersections (Seconds per vehicle)	
	Freeway	Arterial	Signalized Intersections	Unsignalized Intersections
Uncongested	< 15,000	< 5,500	10	10
Medium	15,000-17,500	5,500-7,000	20	15
Heavy	17,501-20,000	7,001-8,500	35	25
Severe	20,001-25,000	8,501-10,000	55	35
Extreme	>25,000	>10,000	80	50

(Source: Highway Capacity Manual (HCM), 2000)

Table 5 Level of Services at Intersection

Signalized Intersections		Unsignalized Intersections	
Level of Service	Average Delay Time (seconds)	Level of Service	Average Delay Time (seconds)
A	≦10	A	≦10
B	>10 - ≦20	B	>10 - ≦15
C	>20 - ≦35	C	>15 - ≦25
D	>35 - ≦55	D	>25 - ≦35
E	>55 - ≦80	E	>35 - ≦50
F	>80	F	>50

(Source: Highway Capacity Manual (HCM), 2000)

3.1.2. TRAVEL TIME FOR MANAGED LANES

For the travel time saving analysis, three improvement alternatives - High Occupancy Vehicle (HOV) Lanes, High Occupancy Toll (HOT) Lanes and Express Toll Lanes can be categorized as the managed lane improvement types.

The estimation process of the travel time along HOV is similar to that of the general-purpose lanes as illustrated in Figure 3; however, the AADT per lane must first be computed for the proposed alternative scenarios based on the vehicle counts produced by the mode share modules. The following functions were used to determine both the AADT on existing general purpose lanes and managed lanes:

$$AADT / lane_{(HOV/HOT)} = \frac{VC_{HOV} / N_{HOV/HOT}}{VC_B / N_B} \times AADT / lane_{(Base)}$$

$$AADT / lane_{(GP)} = \frac{VC_{GP} / N_{GP}}{VC_B / N_B} \times AADT / lane_{(Base)}$$

Notation:

$AADT / lane_{(HOV/HOT)}$: Annual Average Daily Traffic Volume per lane (veh/d/lane) along proposed HOV or HOT lanes;

$AADT / lane_{(GP)}$: Annual Average Daily Traffic Volume per lane (veh/d/lane) along General Purpose (GP) lanes after the proposed improvement;

$AADT / lane_{(Base)}$: Annual Average Daily Traffic Volume per lane (veh/d/lane) in the base case;

$VC_{HOV/HOT}$: Peak-hour vehicle counts along HOV or HOT lanes;

VC_{GP} : Peak-hour vehicle counts along general purpose lanes;

VC_B : Total peak-hour vehicle counts in the base case;

$N_{HOV/HOT}$: Number of proposed HOV or HOT lanes;

N_{GP} : Number of GP lanes after the proposed improvement;

N_B : Total number of lanes in the base case.

The peak-hour vehicle counts can be counted by considering:

$$VC_{HOT} = VC_{NSOV} + VC_{SOV(HOT)}$$

$$VC_{GP} = VC_{SOV(HOV)} + VC_{Truck}$$

Notation:

VC_{NSOV} : Number of carpool vehicles along the section during the peak hours;

$VC_{SOV(HOT)}$: Number of single-occupied vehicles using proposed HOT lane during the peak hours;

$VC_{SOV(HOV)}$: Number of single-occupied vehicles using proposed HOT lane in the corresponding HOV scenario during the peak hours;

VC_{Truck} : Number of trucks along the section during peak hours.

In terms of the number of single-occupancy vehicles using the proposed HOT lane, the research team assumed that it is the difference between the number of vehicles using a proposed HOT lane and the number of vehicles using a proposed HOV lane in the corresponding HOV scenario during the peak hours. It is presented as:

$$VC_{SOV(HOT)} = VC_{(HOT)} - VC_{(HOV)}$$

All vehicle counts in the proposed scenarios were obtained from the pivot-point mode choice model as described in chapter 9.

3.1.3. TRAVEL TIME FOR BUS/TRUCK ONLY LANES

When building additional bus-only or truck-only lanes, it was assumed that all buses or trucks use the new lanes, while other vehicles use the existing, general-purpose lanes along the roadway.

The corresponding AADT/lane levels were calculated using the following functions:

$$AADT / lane_{(Bus/Truck)} = \frac{VC_{Bus/Truck} / N_{Bus/Truck}}{VC_B / N_B} \times AADT / lane_{(Base)}$$

$$AADT / lane_{(GP)} = \frac{VC_{GP} / N_{GP}}{VC_B / N_B} \times AADT / lane_{(Base)}$$

Notations:

$AADT / lane_{(Bus/Truck)}$: Annual Average Daily Traffic Volume per lane (veh/d/lane) along proposed bus-only or truck-only lanes;

$VC_{Bus/Truck}$: Peak-hour vehicle counts along bus-only or truck-only lanes;

$N_{Bus/Truck}$: Number of bus-only or truck-only lanes.

3.1.4. TRAVEL TIME FOR LRT

In the Light Rail Transit (LRT) scenario, a certain amount of person trips will be attracted to LRT. The LRT person trips and the remaining vehicle counts on the existing roadway were estimated by applying the extended version of the incremental logit model, see chapter 9.

The travel time on the roadway was computed using the travel time equations for general purpose lanes and the remaining AADT per lane. The travel time for the LRT mode is equal to the roadway length divided by the LRT speed. The assumed average LRT speed is 24 miles/hour, in accordance with the Baltimore LRT system.

The final outputs of travel time savings module are the travel time differences between each improvement case and its base case for peak and off-peak trips respectively:

$$T_{peak} = T_{pimproved} - T_{pbase}$$
$$T_{offpeak} = T_{oimproved} - T_{obase}$$

3.2. TRAVEL RELIABILITY

Reliability is measured as the additional travel time (in minutes, percent extra time, etc.) that travelers endure under worse-than-normal traffic conditions (PMF, 2009).

The research team evaluated travel reliability by incorporating the Reliability Index and Travel Time Index concepts. These indices represent the extent to which the longest travel times (including peak and off-peak) exceed the average travel time, based on the distribution of travel times for a given section of roadway over a period of time (day-to-day or month-to-month).

$$\text{Reliability Index} = \frac{\text{95th Percentile Travel Time - Average Travel Time}}{\text{Average Travel Time}}$$

The Texas Transportation Institute has developed an empirical relationship between the Reliability Index and the Travel Time Index using available real-time data (Tara et al, 2008):

$$\text{Reliability Index} = 2.189 \times (\text{Travel Time Index-1}) - 1.799 \times (\text{Travel Time Index-1})^2$$

Where :

$$\text{Travel Time Index} = \frac{\text{Peak Hour Travel Time}}{\text{Travel Time at Posted Speed Limit}}$$ for the peak-hour direction and,

$$\text{Travel Time Index} = \frac{\text{Off-peak Hour Travel Time}}{\text{Travel Time at Posted Speed Limit}}$$ for the off-peak one.

Peak or off-peak hour travel time can be obtained from Table 2 for travel time estimation. The speeds corresponding to the AADT per lane less than 15,000 for the freeways, and 5,500 for the arterial streets, are estimated as the posted speed limit.

As with the Travel Time Index, the Reliability Index (RI) was estimated for each individual section and then calculated for the entire corridor as the average across all sections, weighted by vehicle miles traveled (VMT) on each section:

$$\mathrm{RI} = \frac{\sum_i (RI_i \times VMT_i)}{\sum_i VMT_i} = \frac{\sum_i (RI_i \times AADT_i \times L_i)}{\sum_i (AADT_i \times L_i)}$$

Where:

RI_i : Reliability Index along section i;

VMT_i : The average vehicle miles traveled along section i;

$AADT_i$: Annual average daily traffic volume along section i, (vehicles/day);

L_i : The length of section i (miles);

A higher Reliability Index indicates less reliable travel conditions. For example, an RI value of 40% means a traveler should budget an additional 8 minutes for a 20-minute trip under average traffic conditions to ensure on-time arrival 95% of the time. The Reliability Index is also positively correlated with level of congestion and the Travel Time Index.

In terms of reliability in the LRT scenario, the research team assumed the LRT system has constant speed, and thus should achieve a reliability index of zero in this regard.

3.3. MOBILITY MODEL VALIDATION

In the mobility module, equations from the Texas Transportation Institute's Urban Mobility Report (David, 2007) and Highway Capacity Manual were used to estimate travel time; however, these equations were developed using national data. To determine if these equations were suitable for Maryland, the research team validated the travel time models using observed travel time data from Maryland. This process would then determine if further model calibration was needed.

In order to conduct reliable model validation and calibration, high quality and detailed travel time information was needed for Maryland corridors in peak and non-peak periods. In this project, INRIX data was used to provide objective travel time information.

INRIX provides real-time and historical travel time data to users. INRIX collects traffic data from more than 100 million vehicles in more than 32 countries and has very good coverage in Maryland. This data is obtained from different sources such as sensors on the network, local transport authorities, delivery vans, trucks, taxis and also users of the INRIX traffic application. INRIX gathers these raw sets of data and converts them to easy-to-understand real-time and historical data. The data can provide travel time and speed information every minute for selected road segments all day long.

US 15 and US 29 were selected as two representative corridors in Maryland for use in model validation. As shown in Figure 3, US 15 and US 29 were divided into 5 sections and 4 sections respectively.

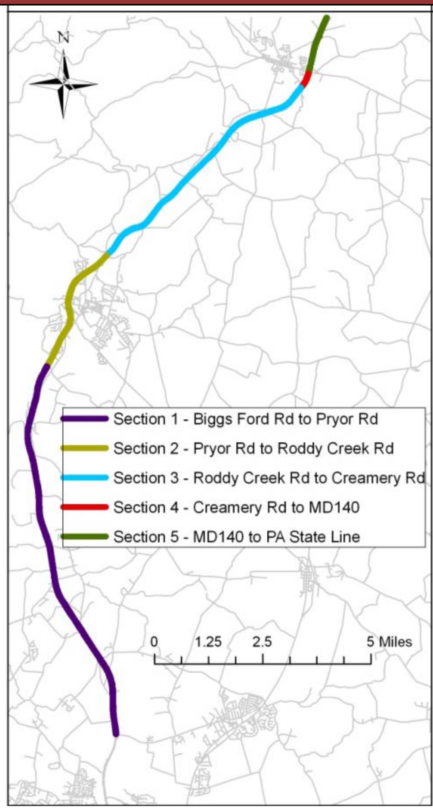
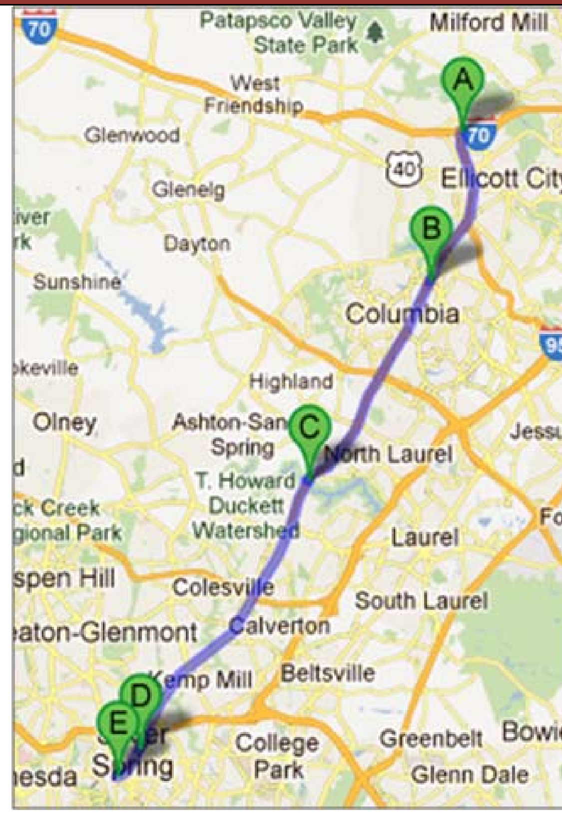
US 15	US 29
	
Section 1: Biggs Ford Rd to Pryor Rd. Section 2: Pryor Rd to Roddy Creek Rd. Section 3: Roddy Creek Rd to Creamery Rd. Section 4: Creamery Rd to MD 140 Section 5: MD 140 to PA State Line	Section 1: IS 70 to MD 175 Section 2: MD 175 to Montgomery Co. Line Section 3: Montgomery Co. Line to the Dale Dr. Section 4: Dale DR to D.C. Line

Figure 3 Study Areas of US 15 and US 29

One year of INRIX data (1/1/2010 - 12/31/2010) for the two corridors was collected and used to estimate average travel time for the selected sections for peak and off-peak periods. The corresponding MOSAIC travel time was calculated and compared with the INRIX travel time, as shown in Table 6 and Figure 5. For US 15, INRIX didn't break the road segment at Creamery Rd and data couldn't be got for section 3 and 4 separately. So section 3 and 4 are presented together in the results.

Table 6 MOSAIC Travel Time VS INRIX Travel Time for US15 and US29

ROUTE/ PERIOD	SECTION	MOSAIC TRAVEL TIME (min)	INRIX TRAVEL TIME (min)	RELATIVE ERROR
US15 Peak	1	8.90	8.66	3%
	2	3.10	3.06	1%
	3 and 4	6.50	6.40	2%
	5	1.30	1.28	1%
	Total	19.80	19.40	2%
US15 Off-Peak	1	8.90	8.63	3%
	2	3.10	3.04	2%
	3 and 4	6.50	6.38	2%
	5	1.30	1.28	2%
	Total	19.80	19.33	2%
US29 Peak	1	6.82	5.74	19%
	2	9.27	9.82	-6%
	3	13.57	17.21	-21%
	4	7.11	4.53	57%
	Total	36.77	37.31	-1%
US29 Off-Peak	1	6.22	5.42	15%
	2	9.27	9.23	0%
	3	13.57	14.66	-7%
	4	6.99	3.95	77%
	Total	36.06	33.26	8%

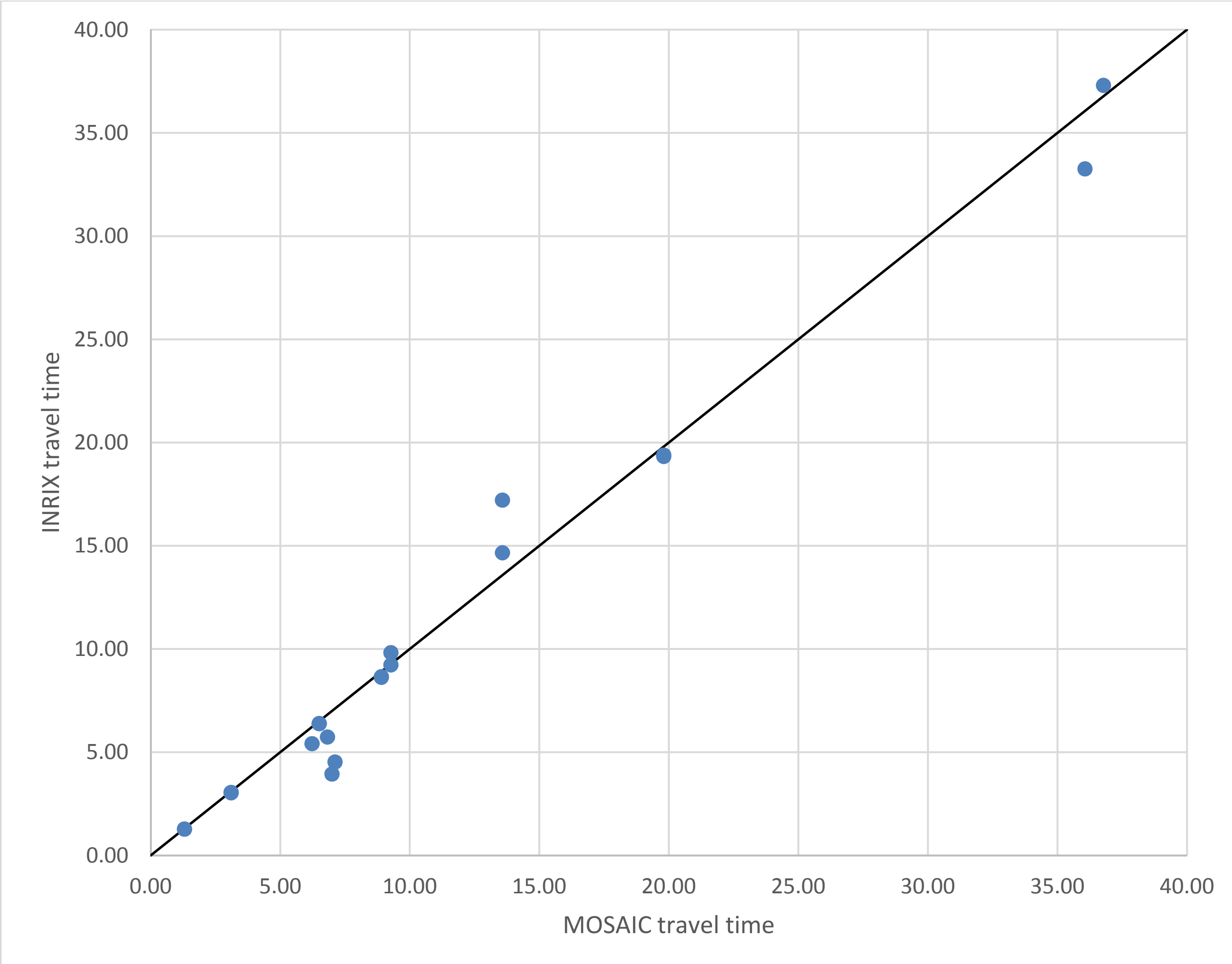


Figure 4 MOSAIC Travel Time V.S. INRIX Travel Time

Based on a comparison using US 15 and US 29 data, the MOSAIC results are generally consistent with INRIX observations (relative error < 10% for total travel time and most of the sections). Some significant errors may occur when travel time is less than 10 min (as seen in US 29 section 1 peak and non-peak, US 29 section 3 peak, and US 29 section 4 peak and non-peak). With a focus on total travel time, the differences are very small, 2%, 2%, -1%, 8% for US 15 peak, US 15 off-peak, US 29 peak, and US 29 off-peak respectively. Thus, the research team concluded that the MOSAIC travel time estimation model works well in Maryland and does not require further parameter calibration.

CHAPTER 4: SAFETY

4.1. CRASH RATES

Crash Rate is measured as the expected number of crashes per year for a corridor. The research team applied the Safety Performance Function (SPF) method from the 2010 FHWA Highway Safety Manual (HSM) to estimate total crash rates for both roadways and intersections. The expected number of crashes at the corridor level can be computed using the below formula:

$$N = \sum_i \left(N_{Ri} \times \prod CMF_{Ri} \times LCF_{Ri} + N_{Ii} \times \prod CMF_{Ii} \times LCF_{Ii} \right)$$

where:

N : Expected number of crashes along corridor (crashes/yr);

N_{Ri} : Expected number of crashes under roadway base conditions on section i (crash/yr);

N_{Ii} : Expected number of crashes under intersection base conditions on section i (crash/yr);

CMF_{Ri} : Combination of Crash Modification Factors (CMF) that adjust crash rate estimates based on real-world conditions on section i roadways;

CMF_{Ii} : Combination of CMFs that adjust crash rate estimates based on real-world conditions on section i intersections.

LCF_{Ri} : Local calibration factor for roadway crashes on section i.

LCF_{Ii} : Local calibration factor for intersection crashes on section i.

4.1.1. EXPECTED NUMBER OF CRASHES UNDER BASE CONDITIONS

4.1.1.1. Roadways

The expected vehicle-on-vehicle and non-driveway related crash rates for roadways can be computed using the following formula:

$$N_{bri} = \exp[a + b \times \ln(AADT_i) + \ln(L_i)]$$

N_{bri} : Expected number of crashes for base conditions (crashes/yr);

$AADT_i$: Annual Average Daily Traffic Volume (veh/d) along section i;

L_i : Length of the section i (mile);

a, b : Regression coefficients. (Refer to Table 7)

Table 7 Coefficients for Total Crash Rates on Various Types of Roadways

Roadway Types		# Lanes	a	b
Highway	Undivided	2	-8.228	1.000
		4	-9.653	1.176
	Divided	4	-9.025	1.049
Arterial Street	Undivided	2	-5.47 / -15.22	0.560 / 1.68
		4	-7.99 / -11.63	0.81 / 1.33
	Divided	3	-5.74 / -12.40	0.54 / 1.41
		4	-5.05 / -12.34	0.47 / 1.36
		5	-4.82 / -9.70	0.54 / 1.17

Note: On arterial streets the HSM provides estimation coefficients for single / multiple vehicle crashes separately as noted in the above table.
(Source: Highway Safety Manual, AASHTO, 2010)

Since the 2010 HSM only provides crash rate estimation procedures for a selection of typical roadway geometries, shown in the table above, the research team derived expected roadway crashes for the remaining configuration using interpolation.

For undivided highway segments, expected roadway crash rates were obtained by direct linear interpolation of the rates computed from two lane and four lane configurations. Similarly, for divided highway segments the 2010 HSM only provides estimates for four lane configurations. To compute the expected crash rates for other divided highway segments, the research team used the HSM's arterial street functions for three lane and five lane configurations. First, expected roadway crashes were computed for the three lane and five lane scenarios. Second, as the four lane divided highway uses a physical barrier (concrete barrier, wide grass median, etc.) to separate opposing traffic rather than the typical division in three and five lane arterial streets (center turn lane), the proportional differences in collision types (rear-end, head-on, side swipes) were adjusted to better match conditions found on divided highways. Initial proportions are obtained from Table 12-4 of the 2010 HSM. As the main difference in these road configurations is the inclusion of a physical barrier between opposing traffic, which greatly alters the proportion of head on collisions, the research team adjusted the expected crashes computed from the three and five lane scenarios by the proportion of head on collisions eliminated in creating a physically divided roadway. These adjusted crash estimates were then used to determine a slope (crashes/lane) for linear interpolation. Lastly, using the expected crashes computed from the four lane divided highway scenario, the research team established an intercept for the linear interpolation function for divided highway segments.

For undivided arterial street segments the direct linear interpolation of expected crash rates is separated into configurations that include a center turn lane (three and five lane scenarios) and configurations that do not (two and four lane scenarios).

For divided arterial street segments, the 2010 HSM only provides estimate coefficients for four lane divided arterial streets. Similar to the research team's process for interpolation on divided highway segments, the estimations for three and five lane arterial streets, which were adjusted to account for the physical division of opposing traffic by reducing the proportion of head-on collisions to match four lane divided arterials, were used to determine a slope (crashes/lane) for linear interpolation. The expected crashes computed from four lane divided arterial streets were then used to establish an intercept for the linear interpolation function.

4.1.1.2. Intersections

The expected crashes rates for intersections can be computed using the following formula:

$$N_{bii} = \exp(a + b \times \ln AADT_{major} + c \times \ln AADT_{\min or})$$

where:

N_{bii} : Expected number of crashes for base conditions at intersections (crashes/yr);

ADT_{major} : Average daily traffic volume (veh/day) on the major road along section i;

ADT_{minor} : Average daily traffic volume (veh/day) on the minor road along section i;

a,b,c : Regression coefficients. (Refer to Table 8)

Table 8 Coefficients for Total Crashes at Various Types of Intersections

	# Lanes	Intersection Type	a	b	c
Highway	2	Three-Leg STOP-Controlled	-9.86	0.79	0.49
		Four-Leg STOP-Controlled	-8.56	0.60	0.61
		Four-Leg Signalized	-5.13	0.60	0.20
	4	Three-Leg STOP-Controlled	-12.526	1.204	0.236
		Four-Leg STOP-Controlled	-10.008	0.848	0.448
		Four-Leg Signalized	-7.182	0.722	0.337
Arterial Street	-	Three-Leg STOP-Controlled	-6.81 /-13.36	0.16 / 1.11	0.51 / 0.41
		Three-Leg Signalized	-9.02 /-12.13	0.42 / 1.11	0.40 / 0.26
		Four-Leg STOP Controlled	-5.33 /-8.90	0.33 / 0.82	0.12 / 0.25
		Four-Leg Signalized	-10.21 /-10.99	0.68 / 1.07	0.27 / 0.23

Note: On arterial streets the HSM provides estimation coefficients for single / multiple vehicle crashes separately as noted in the above table.
(Source: Highway Safety Manual, AASHTO, 2010)

4.1.1.3. Corridor

The expected crash rates (crash rates per mile) for the entire corridor under base conditions can be estimated based on roadway and intersection crash rates:

$$N_{ub} = \sum_i N_{bi} / \sum_i L_i = \sum_i (N_{bri} + N_{bii}) / \sum_i L_i$$

where:

N_{ub} : Unit expected crash rate for base conditions (annual crash rates per mile) for the corridor;

N_{bi} : Total expected number of crashes for base conditions along section i (crashes/yr);

N_{bri}: Expected number of crashes for base conditions on the roadways along section i (crashes/yr);

N_{bii} : Expected number of crashes for base conditions at intersections along section i (crashes/yr);

L_i : Length of section i (mile);

4.1.2. Crash Modification Factors

The process of estimating roadway and intersection crashes assumes that segments meet the following base conditions: lane width of 12 feet, a paved 6 feet wide shoulder, no left or right turn lanes, and a 30-feet median on its multi-lane segments. The expected crash rates at this base section can be denoted as N_R for roadways, and N_I for intersections.

If roadway and intersection configurations on a highway section are not the same as those of the base condition, the actual crash rates should be adjusted with Crash Modification Factors (CMF). A CMF is an estimate of the change in the number of crashes expected after implementation of a countermeasure. The HSM provides multiple CMFs for various highway conditions.

4.1.2.1. Rural Roadways

- **Adjustment for Lane Width (CMF_{rl})**

The crash modification factors for lane width are distinctly different between two-lane and multi-lane divided or undivided sections. The CMFs for the crash types that are most likely to be affected by lane width CMF_{ra} (i.e., single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes) are listed below in Table 9.

Table 9 Crash Modification Factor for Lane Widths on Rural Roads CMF_{ra}

Land Width (ft)	# Lanes	Division	AADT < 400	401≤ AADT ≤ 2000	AADT > 2000
≤ 9	2	Undivided	1.05	1.05+0.000281 × (AADT-400)	1.50
	Multi-lane	Undivided	1.04	1.04+0.000213 × (AADT-400)	1.38
		Divided	1.03	1.03+0.000138 × (AADT-400)	1.25
10	2	Undivided	1.02	1.02+0.000175 × (AADT-400)	1.30
	Multi-lane	Undivided	1.02	1.02+0.000131 × (AADT-400)	1.23
		Divided	1.01	1.01+0.0000875 × (AADT-400)	1.15
11	2	Undivided	1.01	1.01+0.0000250 × (AADT-400)	1.05
	Multi-lane	Undivided	1.01	1.01+0.0000188 × (AADT-400)	1.04
		Divided	1.01	1.01+0.0000125 × (AADT-400)	1.03
≥12	2	Undivided	1.00	1.00	1.00
	Multi-lane	Undivided	1.00	1.00	1.00
		Divided	1.00	1.00	1.00

(Source: Highway Safety Manual, AASHTO, 2010)

Using this information, the crash modification factors for the effect of lane width on total crashes CMF_{rl} will be calculated by using the following formula:

$$CMF_{rl} = (CMF_{ra} - 1.0) \times p_{ra} + 1.0$$

CMF_{rl} : crash modification factors for the effect of lane width on total crashes;

CMF_{ra} : crash modification factors for the effect of lane width on related crashes (i.e., single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes), as shown in Table 9;

p_{ra} : Proportion of total crashes constituted by related crashes (default values are 0.574 for two-lanes and 0.27 for four-lanes) based on the related crash type distributions.

- **Adjustment for Shoulder Characteristics (CMF_{rs})**

The CMFs for shoulders consider both the width and the type of shoulder. The changes of CMFs with the Shoulder Effective Width (SEW) and AADT are presented below in Table 10 for both two-lane and four-lane sections. The CMFs for shoulder type are listed in Table 11.

Table 10 Crash Modification Factor for Shoulder Width on Rural Roads, CMF_{rsw}

Shoulder Effective Width (SEW) (ft)	AADT ≤ 400	401≤ AADT ≤ 2000	AADT >2000
0	1.10	1.10 + 0.000250 × (AADT - 400)	1.50
2	1.07	1.07 + 0.000143 × (AADT - 400)	1.30
4	1.02	1.02 + 0.0008125 × (AADT - 400)	1.15
6	1.00	1.00	1.00
≥ 8	0.98	0.98 + 0.0000688 × (AADT - 400)	0.87

(Source: Highway Safety Manual, AASHTO, 2010)

Table 11 Crash Modification Factor for Shoulder Type on Rural Roads, CMF_{rst}

Shoulder Type	0 (ft)	1 (ft)	2 (ft)	3 (ft)	4 (ft)	6 (ft)	8 (ft)
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

(Source: Highway Safety Manual, AASHTO, 2010)

The crash modification factors for the effect of shoulder width and type on total crashes will be CMF_{rs} and are calculated with the following equation:

$$CMF_{rs} = \left(CMF_{rsw} \times CMF_{rst} - 1\right) \times p_{ra} + 1.0$$

CMF_{rs} : Crash Modification Factor for the effect of shoulder width and type on total crashes;

CMF_{rsw} : Crash Modification Factor for related crashes (i.e., single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes), based on shoulder width (from Table 10);

CMF_{rst} : Crash Modification Factor for related crashes, based on shoulder type (from Table 11).

p_{ra} : Proportion of total crashes constituted by related crashes (default values are 0.574 for two-lanes and 0.27 for four-lanes) based on the related crash type distributions.

- **Median Width**

On divided rural highways, the most important benefit of medians is the separation of traffic. Additional benefits include: providing a recovery area for errant drivers, accommodating left-turn movements and allowing for emergency stopping (TRB, 2009), all of which can have a positive effect in reducing crash rates.

The CMFs for various median widths, given in 10 feet increments, are shown below in Table 22.

Table 22 Crash Modification Factor for Median Width for Rural Highway Sections

Median Width (ft)	**10**	**20**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
CMF	1.04	1.02	0.99	0.97	0.96	0.96	0.95	0.94	0.94

(Source: Highway Safety Manual, AASHTO, 2010)

A CMF of 1.00 is used for either divided sections that include median traffic barriers or undivided sections.

4.1.2.2. Urban Roadways

- **Median Width**

On urban roadway facilities the 2010 HSM includes crash modifiers for on-street parking and median widths. At this time, MOSAIC does not include an on-street parking modifier due to limited data availability.

The CMFs for urban roadways with various median widths are shown below in Table 33.

Table 33 Crash Modification Factor for Median Width for Urban Highway Sections

Median Width (ft)	10	15	20	30	40	50	60	70	80	90	100
CMF	1.01	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.93	0.92

(Source: Highway Safety Manual, AASHTO, 2010)

A CMF of 1.00 is used for either divided sections that include median traffic barriers or undivided sections.

4.1.2.3. Rural Intersections

- **Adjustment for Left-turn Lanes**

CMFs for rural intersections based on total left-turn approaches, organized by types of roadway and intersection configurations, are found in Table 44.

Table 44 Crash Modification Factors for Left-turn Lanes on Rural Road Approaches

Lanes	Intersection Type	Intersection Traffic Control	Number of Approaches with Left-Turn Lanes			
			One Approach	Two Approaches	Three Approaches	Four Approaches
2	Three-leg Intersection	Minor road stop control	0.56	0.31	--	--
	Four-leg Intersection	Minor road stop control	0.72	0.52	--	--
		Traffic Signal	0.82	0.67	0.55	0.45
Multi-Lane	Three-leg Intersection	Minor road stop control	0.56	--	--	--
	Four-leg Intersection	Minor road stop control	0.72	0.52	--	--

(Source: Highway Safety Manual, AASHTO, 2010)

- **Adjustment for Right-Turn Lanes**

CMFs for rural intersections based on total right-turn approaches, organized by types of roadway and intersection configurations, are found in Table 55.

Table 55 Crash Modification Factors for Right-turn Lanes on Rural Road Approaches

Roadway Type	Intersection Type	Intersection Traffic Control	Number of Approaches with Right-Turn Lanes			
			One Approach	Two Approaches	Three Approaches	Four Approaches
2	Three-leg Intersection	Minor road stop control	0.86	0.74	--	--
	Four-leg Intersection	Minor road stop control	0.86	0.74	--	--
		Traffic Signal	0.96	0.92	0.88	0.85
Multi-Lane	Three-leg Intersection	Minor road stop control	0.86	--	--	--
	Four-leg Intersection	Minor road stop control	0.86	0.74	--	--

(Source: Highway Safety Manual, AASHTO, 2010)

4.1.2.4. Urban Intersections

- **Adjustment for Left-turn Lanes**

CMFs for urban intersections based on total left-turn approaches, organized by types of roadway and intersection configurations, are found below in Table 66.

Table 66 Crash Modification Factors for Left-turn Lanes on Urban Road Approaches

Intersection Type	Intersection Traffic Control	Number of Approaches with Left-Turn Lanes			
		One Approach	Two Approaches	Three Approaches	Four Approaches
Three-leg Intersection	Minor road stop control	0.67	0.45	--	--
	Traffic Signal	0.93	0.86	0.80	--
Four-leg Intersection	Minor road stop control	0.73	0.53	--	--
	Traffic Signal	0.90	0.81	0.73	0.66

(Source: Highway Safety Manual, AASHTO, 2010)

- **Adjustment for Right-turn Lanes**

CMFs for urban intersections based on total right-turn approaches, organized by types of roadway and intersection configurations, are found below in Table 77.

Table 77 Crash Modification Factors for Right-turn Lanes on Urban Road Approaches

Intersection Type	Intersection Traffic Control	Number of Approaches with Left-Turn Lanes			
		One Approach	Two Approaches	Three Approaches	Four Approaches
Three-leg Intersection	Minor road stop control	0.86	0.74	--	--
	Traffic Signal	0.96	0.92	--	--
Four-leg Intersection	Minor road stop control	0.86	0.74	--	--
	Traffic Signal	0.96	0.92	0.88	0.85

(Source: Highway Safety Manual, AASHTO, 2010)

4.1.2.5. Corridor

The final corridor-level crash rate based on real-world corridor conditions was computed as the sum of crash rates by section.

$$N_{ub} = \sum_i N_i / \sum_i L_i = \sum_i (N_{ri} + N_{ii}) / \sum_i L_i$$

Where:

N_{ub} : Unit crash rate (annual crash rate per mile) for the corridor;

N_i : Total crash rate along section i (crashes/yr);

N_{ri} : Total roadway crash rate along section i (crashes/yr);

N_{ii} : Total intersections' crash rates along section i (crashes/yr);

L_i : Length of section i (mile);

4.2. CRASH SEVERITY

The research team considered severe crashes as crashes that involve fatalities and/or injuries. Similar to the estimation procedure for total crashes, empirically estimated coefficients were used to estimate the severe crash rates. To estimate severe crash rates, the total crash rate coefficients in the equations presented in Section 4.1.1 were replaced with these severe crash coefficients shown below in Table 18 and Table 19. In addition, CMFs for severe crash rate estimation were obtained using the same total crash estimation procedure.

Table 88 Coefficients for Severe Crash Rates on Various Types of Roadways

Roadway Types		# Lanes	a	b
Highway	Undivided	2	32.1% of Total Crashes	
		4	-8.577	0.938
	Divided	4	-8.505	0.874
Arterial Street	Undivided	2	-3.96 / -16.22	0.23 / 1.66
		4	-7.37 / -12.08	0.61 / 1.25
	Divided	3	-6.37 / -16.45	0.47 / 1.69
		4	-8.71 / -12.76	0.66 / 1.28
		5	-4.43 / -10.47	0.35 / 1.12

Note: On arterial streets the HSM provides estimation coefficients for single / multiple vehicle crashes separately as noted in the above table.
(Source: Highway Safety Manual, AASHTO, 2010)

Table 19 Coefficients for Severe Crashes at Intersections

	# Lanes	Intersection Type	a	b	c
Highway	2	Three-Leg STOP-Controlled	41.5% of Total Crashes are Severe		
		Four-Leg STOP-Controlled	43.1% of Total Crashes are Severe		
		Four-Leg Signalized	34% of Total Crashes are Severe		
	4	Three-Leg STOP-Controlled	-11.989	1.013	0.228
		Four-Leg STOP-Controlled	-10.008	0.848	0.448
		Four-Leg Signalized	*	*	*
Arterial Street	-	Three-Leg STOP-Controlled	** /-14.01	** / 1.16	** / 0.30
		Three-Leg Signalized	-9.75 /-11.58	0.27 / 1.02	0.51 / 0.17
		Four-Leg STOP Controlled	** /-11.13	** / 0.93	** / 0.28
		Four-Leg Signalized	-9.25 /-13.14	0.43 / 1.18	0.29 / 0.22

Note: On arterial streets the HSM provides estimation coefficients for single / multiple vehicle crashes separately as noted in the above table.
*Equation 11-12 from HSM with coefficients a = 12.011 and d = 1.279.
**Equation 12-27 from HSM with Portion of Combined Crashes = 0.31 (3ST) and 0.28 (4ST)
(Source: Highway Safety Manual, AASHTO, 2010)

Similar to the methodology used to interpolate expected total crash rates for highways and arterial streets, severe crash rates were obtained through interpolation for roadway configurations not included in the 2010 HSM.

4.3. LOCAL CALIBRATION FACTORS (LCF)

To apply the 2010 HSM's predictive method to Maryland, one final step needed to be taken: the development of local calibration factors (LCF). An LCF for a certain facility is the ratio of total predicted crashes to total observed crashes. It accounts for differences between local characteristics in Maryland data and the HSM's base model data from select jurisdictions in the United States. In a recent research conducted by Morgan State University titled "*The Development of Local Calibration Factors for Implementing the Highway Safety Manual in Maryland*", LCFs for 18 facility types were calibrated using Maryland data. Specific LCFs for severe crashes (fatal plus injury) were also calibrated. LCFs for total and severe crashes on roadway segments are shown in Table 20.

Table 20 Local Calibration Factors for Total and Severe Crashes-Roadway Segments

FACILITY	R2U	R4U*	R4D	U2U	U3T	U4U	U4D	U5T
LCF for Total Crash	0.6956	2.3408	0.5838	0.6814	1.0785	0.8788	0.8269	1.1891
LCF for Severe Crash	N.A.	1.9499	0.4193	0.6125	1.3053	0.7696	1.0665	1.1918

Note 1: The asterisk denotes that the facility did not meet HSM minimum sample size criteria of 30-50 sites or the minimum annual crash threshold of 100.
Note 2: N.A. means that no SPF is available in HSM.
(Source: the Development of Local Calibration Factors for Implementing the Highway Safety Manual in Maryland, Morgan State University, 2014)

Where:
- R2U – Undivided Two-Lane Highway
- R4U – Undivided Four-Lane Highway
- R4D – Divided Four-Lane Highway
- U2U – Undivided Two- Lane Arterial
- U3T – Undivided Three- Lane Arterial w/ Turn Lane
- U4U – Undivided Four-Lane Arterial
- U4D – Divided Four-Lane Arterial
- U5T – Undivided Five-Lane Arterial w/ Turn Lane

LCFs for total and severe crashes on intersections are shown in Table 21.

Table 21 Local Calibration Factors for Total and Severe Crashes-Intersections

FACILITY	R23ST*	R24ST*	R24SG*	RM3ST*	RM4ST*
LCF for Total Crash	0.1645	0.2011	0.2634	0.1788	0.3667
LCF for Severe Crash	N.A.	N.A.	N.A.	0.255	0.3923
FACILITY	RM4SG*	U3ST*	U4ST*	U3SG	U4SG
LCF for Total Crash	0.1086	0.1562	0.3824	0.3982	0.4782
LCF for Severe Crash	0.1327	0.2273	0.4964	0.5967	0.6285

(Source: the Development of Local Calibration Factors for Implementing the Highway Safety Manual in Maryland, Morgan State University, 2014)

Where:

- R23ST – Two-Lane Highway Three-Leg Stop Controlled
- R24ST – Two-Lane Highway Four-Leg Stop Controlled
- R24SG – Two-Lane Highway Four-Leg Signalized
- RM3ST – Multi-Lane Highway Three-Leg Stop Controlled
- RM4ST – Multi-Lane Highway Four-Leg Stop Controlled
- RM4SG – Multi-Lane Highway Four-Leg Stop Signalized
- U3ST – Arterial Three-Leg Stop Controlled
- U4ST – Arterial Four-Leg Stop Controlled
- U3SG – Arterial Three-Leg Signalized
- U4SG – Arterial Four-Leg Signalized

CHAPTER 5: SOCIO-ECONOMIC IMPACTS

5.1. ECONOMIC IMPACT

Labor productivity increases as firms in the same industry cluster near each other. A number of factors contribute to this increase, including a specialized labor force, technological spillover, and a greater number of suppliers. If a transportation improvement project reduces travel time, it effectively brings firms closer to each other and increases the effective density of firms. The research team applied the methodology developed by the U.K. Department of Transport in its 2005 "Wider Economic Benefits and Impacts on GDP" study (U.K. DOT 2005) to calculate the economic benefits due to economies of agglomeration induced by transportation investment. This is a more sophisticated method for economic impact analysis compared to the multiplier method that is typically employed (i.e. multiply the direct transportation benefits by a >1 factor to obtain total benefits, including transportation and broader economic benefits).

The first step in estimating agglomeration effects is to measure the effective density (ED) of the employment in a corridor in the base case and then in the improved case. In order to do this, the corridor must be divided into different sections. Ideally, these sections would be divided based on areas where a specific productivity elasticity for each industry is provided and areas where the transportation improvement would have a sizable impact. The study area should include areas from which employees commute to the affected employment area.

In order to streamline the analysis and simplify input requirements for MOSAIC, the research team decided to divide the corridor into different sections based on the previous methodologies (i.e. based on different AADT levels) as shown below by the formula:

$$\mathrm{ED_j} = \sum_{\mathrm{K}} \mathrm{E_K T_{jk}^{-1}}$$

$\mathrm{ED_j}$: Effective density in section j

$\mathrm{E_k}$: Employment in section k

$\mathrm{T_{jk}}$: Generalized cost of travel between sections j and k

The team calculated the base-case effective density (ED) from the number of employees within the buffer zone and the existing travel times between zone pairs. Then, the team proceeded to calculate the improvement-case ED from the travel time savings and the current employment within each zone. For T_{jk}, the team assumed a cost equivalent to \$4 (i.e. 8 miles) to travel within a zone, a \$15/hour value of time, and \$0.50/mile cost of travel. Next, the agglomeration benefits were estimated from the change in effective density.

$$\mathrm{WB} = \sum_{j} [(\frac{\Delta \mathrm{ED_j}}{\mathrm{ED_j}} \times \mathrm{ElP}) \times \mathrm{GDP_j} \times \mathrm{E_j}]$$

WB: Economic benefits from agglomeration effects

ElP: Productivity elasticity

$\mathrm{GDP_j}$: Output per worker in zone j

$\mathrm{E_j}$: Employment in zone j

In the absence of firm-level employment data broken down by industry, the team had to use a productivity elasticity (ElP) estimate for all firms in the economy. Ciccone and Hall's (1996) density elasticity of 0.06 was used, which signifies that if density is doubled in an area then output will increase by six percent due to agglomeration effects.

Economic benefits from agglomeration effects were calculated according to the previous equation. WB is the sum for all zones of the change in effective density in each zone multiplied by the productivity elasticity, output per worker, and employment in that zone.

5.2. LIVABILITY

Livability is a socioeconomic indicator that includes a variety of factors that should be considered in analyzing the effectiveness of highway corridor improvements. The research team combined qualitative and quantitative methods to measure livability from two aspects: land use compatibility and transportation accessibility. The land-use types considered are: industrial, commercial, recreational, agricultural, low and high density residential, high and medium density mixed-use and transit-oriented development. Transportation accessibility along the corridor includes local traffic accessibility and transit implementation proportion. Based on the team's definition, livability is enhanced if highway corridor improvements are compatible with existing or planned future land use and if they improve accessibility to activity locations.

5.2.1. LAND-USE SCORES

"Land Use Mix" refers to locating different types of land uses close together. Increasing land use mix tends to reduce the distance that residents must travel for errands and allows more use of walking and cycling for such trips. Certain combinations of land uses are particularly effective at reducing travel, such as incorporating schools, stores, parks and other commonly-used services within residential neighborhoods and employment centers.

The team's land-use scores measure the extent to which highway corridor improvements are compatible with different land-use types within a 1/4-mile buffer on either side of the highway corridors. This buffer distance was selected based on an extensive literature review on the social and environmental impact of highways. Land-use types considered in this project include: industrial, commercial, recreational, agricultural, as well as low and high density residential areas.

The land-use mix score on the base-case (no-build) condition was derived from the average land-use score for all of the traffic analysis zones (TAZs) within 1/4-mile buffer along the corridor, where 0 represents the worst land-use mix situation and 1 represents the best case. The research team then developed an online survey (shown in Appendix I) to obtain land-use scores representing individuals' opinions on how different highway improvement options affect various land-use types along a particular corridor (e.g. US 29) based on the score in the base case. The average scores from the survey were used as default impact scores in the current version of MOSAIC and are presented in Table 92.

Table 92 Impact of Highway Improvements on Land Use

Improvement Types	Land-use Mix Scores
No-build Condition	0.66
Adding one HOV lane or Converting one GP lane into HOV lane	0.65
Adding one HOT lane or Converting one GP lane into HOT lane	0.64
Adding one bus only lane	0.66
Adding one truck only lane	0.61
Building LRT	0.72
Removing one lane	0.70

5.2.2. TRANSPORTATION ACCESSIBILITY

The accessibility measure is the average of the travel time scores and transit implementation scores. Corridor travel times computed in the Mobility model provide a measurement of local traffic accessibility. The lower the travel time, the better the local traffic accessibility is. The transit implementation score represents the percentage of people using public transit, which includes bus transit and LRT. The higher the score, the better the transit implementation condition is.

5.3. NOISE

The impact due to traffic noise depends on both local land-use patterns and corridor traffic conditions. The buffer distance is set as 1/4-mile between noise receptors (i.e. residential and business developments) and the highway corridor centerline. Figure 5 illustrates the steps for evaluating noise impact.

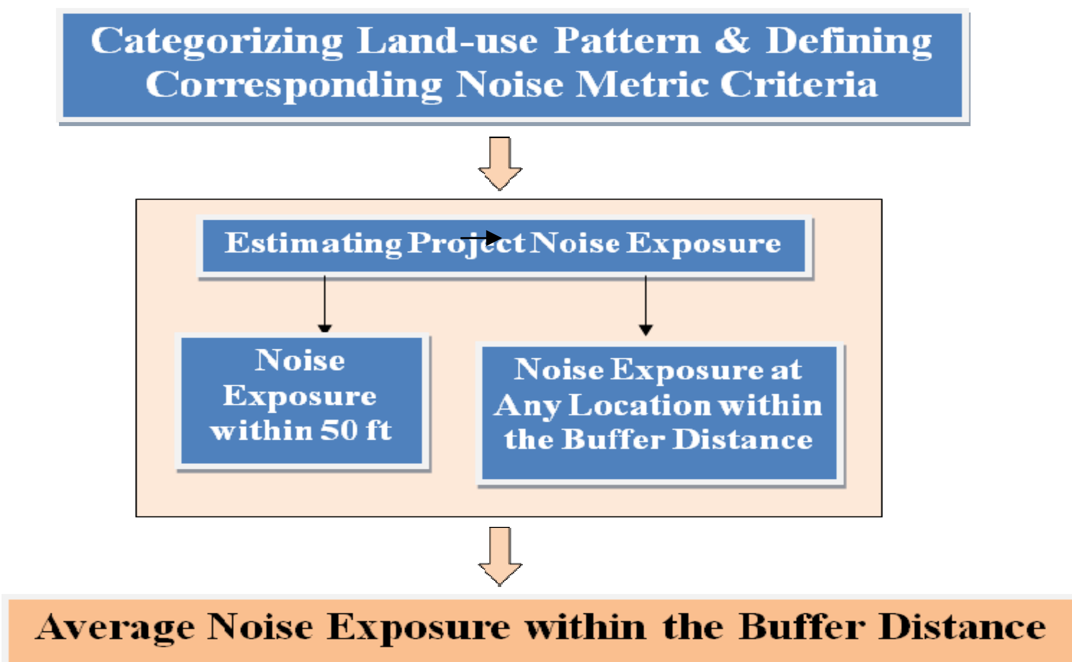


Figure 5 Measuring Noise Impact

5.3.1. LAND USE TYPES AND METRICS FOR TRAFFIC NOISE IMPACT ANALYSIS

The noise metrics used vary by different types of land-use. The research team categorized land-use into three major types, which are described in Table 23, along with the corresponding metrics used for noise impact analysis.

Table 23 Land Use Categories and Noise Metrics

Land Use Category	Noise Metric (dBA)	Description of Land Use Category
1	Outdoor L_{eq}(h)	Tracts of land where quiet is an essential element in their intended purposes. This category includes lands set aside for serenity and quiet, and land uses such as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls.
2	Outdoor L_{dn}	Residences and buildings where people normally sleep. This category includes homes, hospitals and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.
3	Outdoor L_{eq}(h)	Institutional land uses with primarily daytime and evening uses. This category includes schools, libraries, theaters, and churches where it is important to avoid interference with such activities as speech, meditation and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds and recreational facilities can also be considered to be in this category. Certain historical sites and parks are also included.

(Source: Transit Noise and Vibration Impact Assessment, Office of Planning and Environment Federal Transit Administration, Fta-Va-90-1003-06, May 2006)

where：

L_{eq}(h) (Hourly Equivalent Sound Level): Describes a receiver's cumulative noise exposure from all events over a one-hour period. It is adopted to assess traffic noise for non-residential land uses. For assessment, L_{eq} is computed for the loudest traffic facility hour during the hours of noise-sensitive activity;

L_{dn} (Day-Night Sound Level): Describes a receiver's cumulative noise exposure from all events over a full 24 hours. L_{dn} is adopted to assess traffic noise for residential land uses.

5.3.2. PROJECT NOISE ESTIMATION

5.3.2.1. Project Noise Impact at 50ft

The research team adopted the noise methodology and functions from the Federal Transit Administration's (FTA) Transit Noise and Vibration Impact Assessment, which uses Manhattan's existing Light Rail system as a case study (FTA, 2006). This methodology provides roadway noise impact on different land-use types at the distance of 50 feet from the highway centerline as:

Hourly L_{eq} at 50ft:

$$L_{eq} = SEL_{ref} + 10\log(V) + C_{emission} - 10\log(\frac{S}{50}) - 35.6$$

Daytime L_{eq} at 50ft:

$$L_{eq}(day) = L_{eq}(h)|_{V=V_d}$$

Nighttime L_{eq} at 50ft:

$$L_{eq}(night) = L_{eq}(h)|_{V=V_n}$$

L_{dn} at 50ft:

$$L_{dn} = 10\log\left[(15)\times 10^{(\frac{L_{eq(day)}}{10})} + (9)\times 10^{(\frac{L_{eq(night)}+10}{10})}\right] - 13.8$$

Other adjustment: -3 -> automobiles, open-graded asphalt

+3 -> automobiles, grooved pavement

Where:

SEL: Represents the Sound Exposure Level to predict the noise exposure at 50 feet with the definition as: $SEL = 10log_{10}$ [Total sound energy during the event]. The Federal Highway Administration (FHWA) categorized the default value for SEL, as shown in Table 104.

Table 104 Source Reference Levels at 50 feet from Roadway, 50mph

Source[↑]	Reference SEL (dBA)
Automobiles and Vans	74
Buses (diesel-powered)	82
Buses (electric)	80
Buses (hybrid)	83**

Note 1: [↑] assumes normal roadway surface conditions.
Note 2: ** for hybrid buses, reference SEL should be determined on a case-by-case basis.

V : Hourly volume of vehicles of certain type, (vehicles per hour);

V_d : Average hourly daytime volume of vehicles of a certain type, (vehicles per hour)

$$= \frac{\text{Total vehicle volume (7am to 10pm)}}{15};$$

V_n : Average hourly nighttime volume of vehicles of a certain type, (vehicles per hour)

$$= \frac{\text{Total vehicle volume (10pm to 7am)}}{9};$$

$C_{emission}$: Noise emission.

For buses: $C_{emission} = 25 \times \log(\frac{S}{50})$

For accelerating 3-axle commuter buses: $C_{emission} = 1.6$

For automobiles: $C_{emission} = 40 \times \log(\frac{S}{50})$;

S: Average vehicle speed, (mph) (using the method in travel time part).

The FTA General Noise Assessment procedure was used for calculating noise from transit sources associated with the proposed improvement, as shown in the FTA's report Example 5-4. General Noise Assessment for a Transit Center, based on the existing Noise Exposure Levels at 50 feet, can be estimated by applying the equations as follows:

Hourly L_{eq} at 50ft: $L_{eq} = SEL_{ref} + 10\log(V) + 10\log(N_{cars}) + 20\log(\frac{S}{50}) - 35.6$

Daytime L_{eq} at 50ft: $L_{eq}(day) = L_{eq}(h)|_{V=V_d}$

Nighttime L_{eq} at 50ft: $L_{eq}(night) = L_{eq}(h)\,|_{V=V_n}$

L_{dn} at 50ft: $L_{dn} = 10\log\left[(15)\times10^{(\frac{L_{eq(day)}}{10})} + (9)\times10^{(\frac{L_{eq(night)}+10}{10})}\right] - 13.8$

The reference-sound exposure level (SELref) for LRT at 50 feet from track equals 82 dBA, according to FTA's report (FTA, 2006).

By referring to the Manhattan EIS report, MOSAIC set V_d, which is the average hourly volume of traffic during daytime (7 am to 10 pm), as 4.3 trains/hour; V_n, which is the average hourly volume of traffic during nighttime (10 pm to 7 am) was set as 3.9 trains/hour. S was set as 15 miles per hour across the project corridor. The average number of cars per train, N_{cars}, is assumed to be three for this analysis (based on two cars during off-peak periods, three cars during peak periods, and four cars during special events).

5.3.2.2. Project Noise Impact at a Certain Arbitrary Receiver

For the distance between the arbitrary receiver and the noise location within the buffer distance, the research team considered that each L_{dn} and L_{eq} can be obtained from L_{dn} and L_{eq} at 50 feet developed above by using the following equation:

$$\mathrm{L}_{dn} \text{ or } \mathrm{L}_{eq} = (\mathrm{L}_{dn} \text{ or } \mathrm{L}_{eq})|_{at\,50\text{ ft}} - 10\log(\frac{D}{50}) - 10G\log(\frac{D}{29})$$

Where:

D : Represents the shortest distance between the geometric center of the receiver's area to the major noise location;

G : Large Ground Factors: large amounts of ground attenuation with increasing distance from the source. This coefficient is computed based on the FTA's report (FTA, 2006) Figure 6-5. Computation of Ground Factor G for Ground Attenuation. If no sources of ground attenuation are present, the coefficient G is set to zero.

5.3.3. EVALUATION OF THE NOISE IMPACT

Finally, since the receivers in the analysis are defined in GIS in terms of different land-use types and their areas, the Noise Impact Level and Average Noise Exposure within the Buffer Distance are obtained by considering the average existing noise exposures, which are:

$$L'_{eq} = 10 \times \log(\sum 10^{L_{eqi}/10})$$
$$L'_{dn} = 10 \times \log(\sum 10^{L_{dni}/10})$$

5.4. AESTHETICS

For highway aesthetics, four primary elements are considered: facility compatibility with the surrounding natural environment, land use attractiveness in the vicinity of the highway corridor, visual appeal, and historical roads and historical site protection.

As a part of this project, an online survey was developed and distributed (shown in Appendix I). The survey results assisted the research team in understanding the perceived impact of highway improvement on various aesthetic indicators. The following table shows the survey results for the US 29 corridor, which can be generalized to other corridors in Maryland. In general, the survey shows that respondents believe six highway improvement types have minimum impact on aesthetics (scores close to 0). However, visual appeal and historical site protection outrank facility compatibility and land use attractiveness in determining aesthetics along the corridor.

Table 115 Impact of Highway Improvements on Aesthetics along the US 29 Corridor

Elements	Average Rating Scores for the Aesthetics of Base and Improved Cases along US 15 (-3 ~ +3)							Average Weighting Scores (1 ~ 7)
	Base Case	HOV	HOT	Bus only	Truck only	LRT	Road Diet	
Facilities' Compatibility	0.00	1.00	0.67	0.57	1.00	0.71	-0.67	3.83
Land Use Attractiveness	0.14	0.75	0.75	0.43	0.50	1.38	-0.50	3.67
Visual Appeal	0.43	0.57	0.25	0.50	0.00	0.88	0.50	5.33
Historical Road and Sites Protection	0.43	0.00	0.00	0.25	-0.38	-0.63	0.75	5.00

Notes:

1) Facilities' Compatibility: Including traffic control devices, lighting, channelizing islands and roundabout design, markings, etc.;
2) Land Use Attractiveness: Including transportation network land use, landscaping, median, shoulder and other roadside design features, etc.;

3) Visual Appeal: Including visual friction (various interesting views as opposed to uninteresting ones), view conservation (without visual intrusions), sight distance and clear areas (decided by whether objects are blocking the drivers' view).
4) Historical Road and Site Protection: Indicating whether the base or improved cases did well in protecting the historical roads and sites.

The final column shows how survey respondents ranked the relative importance of the four aesthetics elements. The final score for aesthetics was computed as the weighted sum across all four aesthetics elements:

$$\text{Final Scores}_i = \frac{\sum(\text{Rank Score}_{ij} \times \text{Weight Score}_j)}{\sum \text{Weight Score}_j}$$

Where:

Final Scores$_i$: Case i's impact on aesthetics along the corridor (the higher the score is, the better effect on the aesthetics' condition);

Rank Score$_{ij}$: The impact level of case i on the corresponding element j;

Weight Score$_j$: The importance of element j in determining the aesthetics condition along the corridor.

CHAPTER 6: NATURAL RESOURCES

In this version of MOSAIC, areas of affected natural resources along a highway corridor were used to measure natural resource impacts. After a comprehensive literature review, a set of buffer distances were selected as listed in Table 126. The US 29 natural resource map is shown in Figure 7.

Table 126 Buffer Distances for Each Improvement Alternative

Improvement Types	Buffer Distance (mile)
Add General Purpose Lanes	1/4
Remove Lanes (Road Diet)	0
Convert At-grade Intersection to Grade Separated Interchange	1/2 miles at intersections
Add High Occupancy Vehicle (HOV) Lane	1/4
Add High Occupancy Toll (HOT) Lane	1/4
Add Express Toll Lane (ETL)	1/4
Add Bus Only Lane / Bus Rapid Transit	1/4
Add Truck Only Lane	1/4
Add Light Rail Transit (LRT)	1/8

Corridor roadway, intersection geometry and natural resource GIS shapefiles contained in the eGIS database are utilized to determine affected natural resources. Each individual section of the US 29 corridor designated by the user is buffered using a GIS proximity tool with the given improvement type's impact distance. The area of each natural resource type within the buffer is then computed with query tools and supplied to the MOSAIC program.

Once the necessary natural resource information within the buffer zones is obtained in GIS and subsequently imported into MOSAIC, the percentage of affected land within the buffer area is computed for each type of natural resource. Higher percentages indicate more severe impact to surrounding natural resources. Impacts on different types of natural resources (e.g. parks, streams, wetlands, historical places, easements) are weighted equally in this version of MOSAIC. This can be adjusted in future versions based on input from SHA.

For the nine improvement options currently available for analysis in MOSAIC, the natural resource impact is either negative or neutral at best.

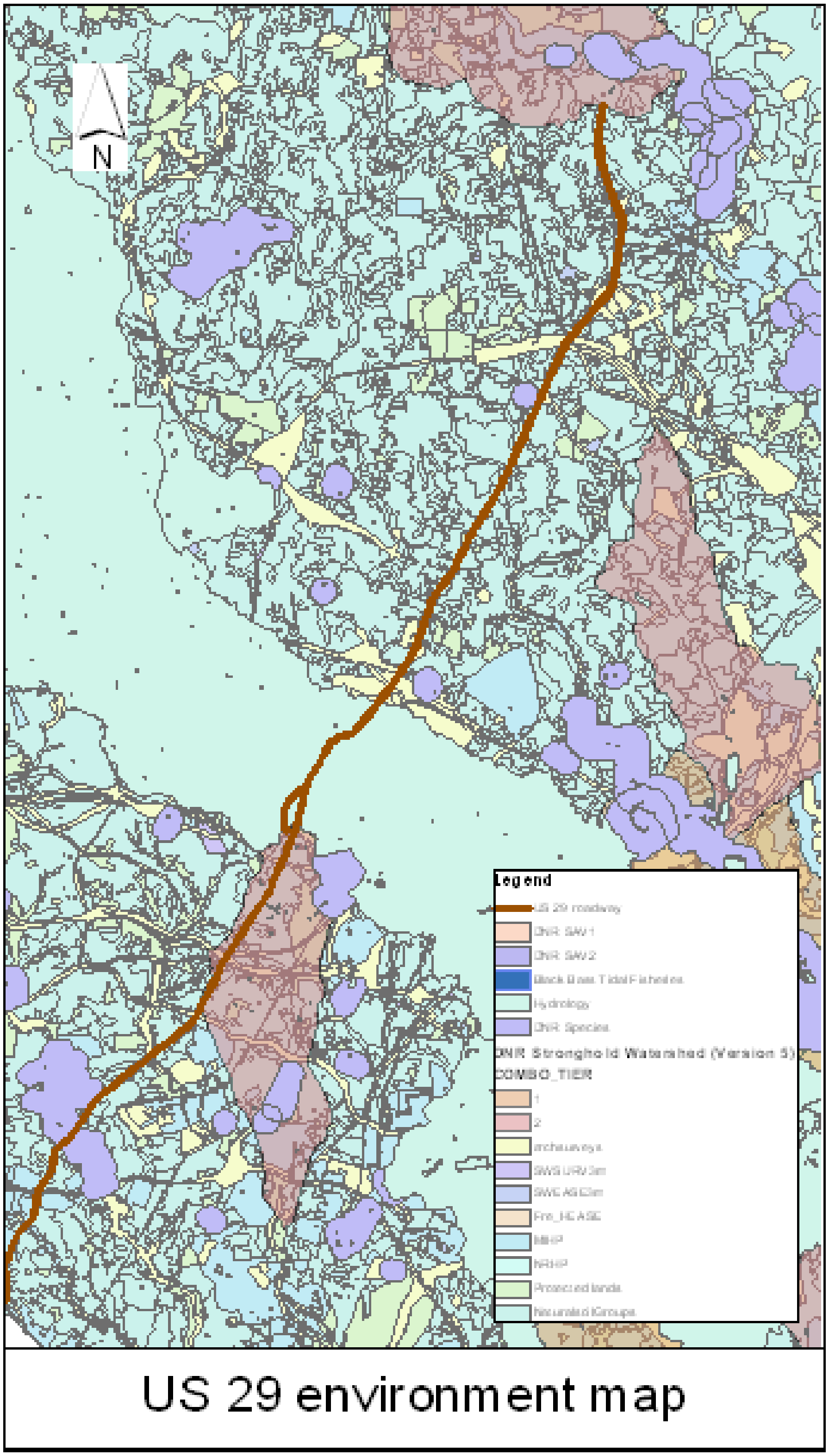


Figure 6 Impact Area of US 29 Corridor

CHAPTER 7: ENERGY AND EMISSIONS

7.1. POLLUTION EMISSIONS

Pollution emissions for different types of pollutants are computed based on vehicle miles traveled and per-mile emission rates that vary by travel speeds. Inputs for pollution emission estimation include daily traffic volume in peak and off-peak periods, section lengths, and section-by-section travel speeds in peak and off-peak periods. The roadway per-mile emission rates for Maryland, e, at different speeds are obtained by running MOVES2010a, the Motor Vehicle Emission Simulator developed by the U.S. Environmental Protection Agency (EPA) (See Table 137). In addition, MOSAIC obtains LRT emission rates from EPA's National Emission Trends (NET) database (See Table 8).

The roadway daily total pollution emission for each emission type can be expressed as:

$$E_j = \sum_i E_{ij} \text{ and } E_{ij} = e_{ijp} \times ADT_{ip} \times L_i + e_{ijo} \times ADT_{io} \times L_i$$

Where:

E_j : Daily total pollution emission for gas type j along the corridor (grams);

E_{ij}: Daily total pollution emission in section i for gas type j (grams);

ADT_{ip}: Average daily peak hour traffic volume in section i, (vehicles/day);

ADT_{io} : Average daily off-peak hour traffic volume in section i, (vehicles/day);

L_i : Length of the section i (miles).

e_{ijp} : Peak-hour emission rate in section i for gas type j (grams/vehicle/mile); (refer to Table 27)

e_{ijo} : Off-peak emission rate in section i for gas type j (grams/vehicle/mile); (refer to Table 27)

Since some managed lane improvement alternatives such as HOV, HOT, and the express toll lanes mostly operate during peak-hours and act as general purpose lanes during off-peak hours, the research team only analyzed pollution emissions for peak hour traffic volumes. In addition, different types of lanes may have different ADT as obtained from the mobility analysis.

Table 137 Roadway Emissions Rates from MOVES (Year 2011)

Speed (mph)	Total Emissions per vehicle (grams/mile)											
	Rural						Urban					
	Restricted Access			Unrestricted Access			Restricted Access			Unrestricted Access		
	CO	NOx	PM10	CO	NOx	PM10	CO	NOx	PM10	CO	NOx	PM10
2.5	16.55	12.30	0.54	16.30	5.79	0.24	15.39	5.26	0.22	15.39	3.61	0.14
5	9.32	6.49	0.28	9.74	3.21	0.13	8.87	2.94	0.12	9.32	2.12	0.08
10	5.82	4.04	0.17	6.57	2.13	0.08	5.61	1.91	0.07	6.34	1.47	0.05
15	4.67	3.46	0.16	5.55	1.85	0.07	4.50	1.63	0.06	5.37	1.30	0.04
20	3.98	3.08	0.15	4.89	1.68	0.07	3.83	1.44	0.06	4.73	1.19	0.04
25	3.67	2.86	0.14	4.18	1.56	0.06	3.54	1.35	0.05	4.02	1.11	0.03
30	3.59	2.81	0.14	3.89	1.47	0.06	3.49	1.33	0.05	3.74	1.03	0.03
35	3.70	2.54	0.11	3.58	1.35	0.04	3.70	1.27	0.05	3.41	0.96	0.03
40	3.83	2.51	0.11	3.36	1.32	0.04	3.88	1.27	0.05	3.16	0.94	0.02
45	3.90	2.49	0.10	3.19	1.30	0.04	3.99	1.27	0.05	3.00	0.93	0.02
50	3.83	2.43	0.09	3.08	1.28	0.04	3.93	1.25	0.04	2.94	0.93	0.02
55	3.68	2.37	0.08	3.10	1.27	0.03	3.79	1.22	0.04	2.94	0.92	0.02
60	3.57	2.35	0.08	3.10	1.26	0.03	3.68	1.22	0.04	2.99	0.93	0.02
65	3.57	2.46	0.08	3.21	1.31	0.03	3.70	1.26	0.04	3.13	0.97	0.02
70	3.82	2.57	0.08	3.50	1.38	0.03	3.99	1.33	0.04	3.43	1.03	0.02
75	4.41	2.55	0.08	4.34	1.42	0.03	4.69	1.36	0.04	4.30	1.08	0.02
Average Temperature	57.96	57.96	57.96	59.20	59.20	59.20	59.04	59.04	59.04	59.55	59.55	59.55
Average Humidity	61.19	61.19	61.19	61.33	61.33	61.33	61.36	61.36	61.36	61.28	61.28	61.28

Table 28 Emission Rates for LRT

CO (g/p-m)	NOx (g/p-m)	PM10 (g/p-m)
0.0355	0.6123	0.0232

7.2. GREENHOUSE GAS EMISSIONS

The total greenhouse gas (GHG) emission was estimated with a process similar to that of the pollution emission introduced above. Similarly, the roadway GHG emission rates for Maryland at different speeds are obtained by running MOVES2010a, the Motor Vehicle Emission Simulator developed by the EPA (See Table 149). The rate for LRT was also obtained from the EPA's National Emission Trends (NET) database, which is 284.66 grams per person mile.

Table 149 Roadway GHG Emissions Rates from MOVES (Year 2011)

Speed (mph)	Total Emissions per Vehicle (grams/mile)			
	Rural Restricted Access	Rural Unrestricted Access	Urban Restricted Access	Urban Unrestricted Access
2.5	3458.24	2674.44	2629.56	2404.15
5	1846.82	1471.58	1436.65	1340.43
10	1132.40	909.39	869.80	827.15
15	953.55	739.38	706.00	664.14
20	830.49	644.94	600.82	576.62
25	761.74	581.49	543.99	517.59
30	731.71	531.69	514.76	468.12
35	667.43	488.94	488.62	435.33
40	656.98	473.25	480.89	419.80
45	647.91	461.00	473.78	408.23
50	627.04	448.86	460.38	398.50
55	604.02	440.00	446.70	392.26
60	594.56	434.67	439.07	390.63
65	613.94	442.37	448.06	396.86
70	637.72	459.51	463.88	411.65
75	643.59	475.90	477.58	430.31
Average Temperature	57.96	59.20	59.04	59.55
Average Humidity	61.19	61.33	61.36	61.28

7.3. FUEL CONSUMPTION

The research team evaluated fuel consumption using British Thermal Units (BTUs) based on vehicle activities along a highway corridor. The total roadway fuel consumption is estimated with a process similar to that of the pollution emission discussed above, except for the e (million BTUs/mile/ADT). Here it represents the energy consumption rates for Maryland at different speed levels obtained by running MOVES2010a (see Table 30) at the appropriate point. The LRT's fuel consumption rate is set as 2,516 BTU/ (p-m), by referring to the Transportation Energy Data Book: Edition 30. Other inputs for fuel consumption estimation are ADT, section lengths and lane widths.

Table 30 Roadway Fuel Consumption Rates from MOVES (Year 2011)

Speed (mph)	Energy Consumption per Vehicle (million BTU/mile)			
	Rural Restricted Access	Rural Unrestricted Access	Urban Restricted Access	Urban Unrestricted Access
2.5	16.55	16.30	15.39	15.39
5	9.32	9.74	8.87	9.32
10	5.82	6.57	5.61	6.34
15	4.67	5.55	4.50	5.37
20	3.98	4.89	3.83	4.73
25	3.67	4.18	3.54	4.02
30	3.59	3.89	3.49	3.74
35	3.70	3.58	3.70	3.41
40	3.83	3.36	3.88	3.16
45	3.90	3.19	3.99	3.00
50	3.83	3.08	3.93	2.94
55	3.68	3.10	3.79	2.94
60	3.57	3.10	3.68	2.99
65	3.57	3.21	3.70	3.13
70	3.82	3.50	3.99	3.43
75	4.41	4.34	4.69	4.30
Average Temperature	57.96	59.20	59.04	59.55
Average Humidity	61.19	61.33	61.36	61.28

CHAPTER 8: HIGHWAY IMPROVEMENT COST

8.1. COSTS FOR GENERAL PURPOSE LANES

To estimate roadway project cost (PC) for general purpose lanes, two Maryland-specific data sources were used: an SHA-maintained website, which includes all in-progress and recently completed major State Highway construction projects in Maryland (SHA, 2010) and SHA's cost estimation guidelines for contractors.

Cost data was compiled for all projects that include costs for four major categories of the project: planning, engineering, right-of-way acquisition and construction. Based on project descriptions, all relevant projects were divided into three different categories: adding a lane by widening an existing roadway, adding a lane by reconstructing a roadway, and constructing a new interchange on an existing road. The projects were also separated into urban and rural categories. From this dataset, the average costs for projects that were completed in the last three years were estimated.

The SHA also provides a cost-estimation guide for contractors (SHA, 2009), which provides construction cost estimates of $6 million/lane-mile to add a 12-foot lane, $5.5 million to construct one lane-mile of roadway on a new location and $40 million to construct a full diamond interchange.

In the end, the cost estimates based on the SHA project database were combined with the cost estimates in the guidelines for contractors to produce cost estimates in MOSAIC (see Table 31).

Table 31 Highway Improvement Costs in Rural and Urban Areas in Maryland

Costs per lane mile or per interchange	Rural	Urban
Widening - Add a lane	$4,500,000	$5,500,000
Reconstruction - Add a lane	$5,500,000	$15,000,000
New Interchange	$35,000,000	$40,000,000

8.2. COSTS FOR OTHER ALTERNATIVES

In order to estimate the costs for the HOV or HOT scenario, the research team did a comprehensive literature review and determined that the I-395/I-95's construction report from the Financially Constrained Long-Range Transportation Plan for 2040, which was published by the National Capital Region Transportation Planning Board, fits the costs analysis the best. In the I-95 project, fourteen miles of HOV lanes were widened from two lanes to three lanes and two more nine-mile long HOV lanes were built along each direction. The total cost of this project was $1.01 billion. Thus, the research team set the construction costs of adding two-way HOV or HOT lanes as $31.56 million per mile. Since the construction of the two-way general-purpose (GP) lane costs $30 million per mile, the research team set the costs of converting two-way GP lane to a two-way HOV or HOT lane as $1.56 million per lane.

The research team set the cost rate for truck-only lane construction by referring to the I-70 Dedicated Truck Lanes Feasibility Study. This study included analysis on the Washington Commerce Corridor (WCC) a proposed North-South (N-S) alternative to Interstate-5 beginning in Lewis County, Washington, and extending north to the Canadian border that facilitates the movement of freight, goods, people and utilities. The WCC was estimated to cost between $42 billion and $50 billion if built for the full complement of passenger cars, rail transport, energy infrastructure and recreational trails. The associated cost for constructing dedicated truck-only lanes for the full 270-mile route was approximately $14.7 billion, or $18 million/lane-mile. Based on this study, the research team set the construction costs of the two-way truck-only lane as $36 million per mile. Meanwhile, since there are no major changes between GP lanes and bus-only lanes, the research team assumed the construction cost of two-way, bus-only lanes to be the same as general-purpose lanes at $30 million per mile and a conversion cost of $0 (in the real world, there will be conversion cost associated with labeling the bus only lanes, which is much lower than the construction cost. This parameter can be easily adjusted to a small positive cost).

Construction costs for LRT were established based on Maryland's Purple Line project. By referring to MTA's South Maryland Transit Corridor Preservation Study, the two-way LRT's construction cost was set to $120.6 million per mile. In addition, the LRT vehicle cost was set to $131 million per train.

CHAPTER 9: GENERAL MODEL COMPONENTS

9.1. MODE CHOICE MODELS

As introduced in Chapter 2, MOSAIC first applies the pivot-point and the extended incremental logit mode choice models in order to analyze the planning-level sustainability impacts (i.e. mobility, safety, natural resources, socio-economic factors, cost, and energy and environment) of multimodal improvements on highway corridors, relevant to the SHA's Comprehensive Highway Corridors program. MOSAIC uses these models to generate an updated mode share and ridership to help evaluate improvement options that would produce changes in mode choice. For instance, the model would assist in deciding whether to build light rail transit (LRT) or convert an existing general purpose lane to a high occupancy vehicle (HOV) lane, high occupancy toll (HOT) lane, or bus only lane.

The pivot-point or extended incremental logit mode choice models are able to generate new mode shares for future years under multiple improvement alternatives. This is done by modifying the existing mode shares based on changes in the characteristics of the transportation networks. While the extended incremental logit mode-choice model requires complete characteristics of the specific transportation system, the pivot-point model only needs the current mode share and the proposed changes of the Level of Service (LOS) variables for each alternative.

9.1.1. INITIAL PIVOT-POINT MODEL

The initial version of the pivot-point mode choice model is often used for the evaluation of Travel Demand Management (TDM) strategies aimed at reducing vehicle travel during peak periods without introducing any new modes. Early applications include the Spreadsheet Model for Induced Travel Estimation - Managed Lanes (SMITE-ML 2.2) (FHWA 2000), and the Sketch Planning for Road Use Charge Evaluation (SPRUCE) (Patrick 2003). MOSAIC applies the logit pivot-point mode choice model in its mode share analysis of the managed lanes, including the High Occupancy Vehicle (HOV) Lanes and High Occupancy Toll (HOT) Lanes.

Derived from the standard multinomial logit model, the formulation of the pivot-point model is presented as:

$$P_i^{'} = \frac{P_i \times e^{\Delta U_i}}{\sum_{i=1}^{k}(P_i \times e^{\Delta U_i})}$$

Where:

P_i : The baseline probability (share) of using mode i;

P_i': The revised probability of using mode i, and

ΔU_i : The changes in utility for mode i.

As mentioned above, the pivot-point model formulation is easier to implement, as it only needs to account for changes in the generalized utility functions, not their complete values. Therefore, if there is no new mode introduced, the mode-specific constants can be ignored, as they are canceled out in the changes of utility. The changes in utility for mode i can be expressed as:

$$\Delta u_i = b_i \times \Delta IVTT_i + c_i \times \Delta OVTT_i + d_i \times \Delta COST_i$$

Where:

$\Delta IVTT_i$, $\Delta OVTT_i$, $\Delta COST_i$: The changes in LOS variables for mode *i* (*IVTT*: In-Vehicle-Travel-Time; *OVTT*: Out-Of-Vehicle-Travel-Time; *COST*: Total Cost); and

b_i, c_i, d_i: The coefficients for each corresponding LOS variables for mode *i*.

IVTT is computed for base case and improvement cases by first obtaining the predicted mean speed for the section (s_i) using the standard BPR equation:

If v_i/c_i <= 1.85 $\qquad s_i = \frac{s_{fi}}{1+0.15\,(\frac{v_i}{c_i})^4}$

Else $\qquad s_i = \frac{s_{fi}}{2.857}$

Where:

v_i/c_i : The volume to capacity ratio for the roadway section i.

s_{fi} : The free flow speed for roadway section i.

The capacities (c_i) used for freeway and arterial sections are 1800 and 800 vehicles per lane per hour respectively. The free flow speed (s_{fi}) is assumed to be the posted speed limit for the roadway section.

The coefficients for LOS variables that MOSAIC uses were obtained from the Home-Based-Work (HBW) mode-choice model specific for Washington, D.C., area provided by the NCHRP report 365, which are -0.017 for $\Delta IVTT_i$, -0.058 for $\Delta OVTT_i$, and -0.004 for $\Delta COST_i$.

9.1.2. EXTENDED INCREMENTAL LOGIT MODEL

The extended version of the incremental logit model, unlike the previous version of the pivot-point model, can be used when introducing a new transit service. The extended incremental logit model provides the capability to predict the ridership impact of transit introduction or service changes using only information on existing mode shares and changes in transit service.

New transit service is expected to attract some riders from existing transit services and some from other modes. The combined transit services are expected to carry more riders than the existing service. The additional riders that the combined transit services carry than either service alone depends, in part, on the utility between the new and existing services.

The incremental logit equations to predict the proportion of riders using new transit and existing transit, for the case where there are no changes in any of the non-transit modes, are:

$$P'_{NT} = \frac{P_{XT} \times e^{(U'_{NT} - U_{XT})}}{P_{XT} \times [e^{(U'_{NT} - U_{XT})} + e^{(U'_{XT} - U_{XT})}] + [1 - P_{XT}]}$$

$$P'_{XT} = \frac{P_{XT} \times e^{(U'_{XT} - U_{XT})}}{P_{XT} \times [e^{(U'_{NT} - U_{XT})} + e^{(U'_{XT} - U_{XT})}] + [1 - P_{XT}]}$$

Where:

P'_{NT} (P'_{XT}): The expected probability of riders using new and existing transit services, respectively;

P_{XT} : The baseline probability of riders using existing transit services;

U'_{NT} (U'_{XT}): The expected utility measure of new and existing transit services, respectively;

U_{XT} : The baseline utility measure of existing transit services

The following equations can be applied to predict future ridership on each transit mode. This is based on knowledge of the existing transit share, the difference in service provided by the new transit service compared to the existing transit service, and changes in the existing transit service.

The share for other modes is given by:

$$P'_i = \frac{P_i}{P_{XT} \times [e^{(U'_{NT} - U_{XT})} + e^{(U'_{XT} - U_{XT})}] + [1 - P_{XT}]}$$
$$= P_i \times \frac{1 - P'_T}{1 - P_T}$$

Where:

P'_i (P_i) = The probability of riders using other mode *i* after (before) the transit improvement, respectively;

P'_T (P_T) = The probability of riders using transit after (before) the transit improvement, respectively.

For the specification of the parameters in the transit service function, the incremental prediction models described above can apply the parameter values listed in the following table. Such parameter estimates are generally based on the estimation of disaggregate models.

Table 32 Estimated Level of Service Coefficients for Work Trips

Study area	Parameter Estimates		
	Out-of-vehicle time (minute)	In-vehicle time (minute)	Out-of-pocket costs (cent)
San Francisco Bay Area	-0.0343[a]	-0.0224	-0.413/wage[b]
Washington, D.C.	-0.160/DIST[c]	-0.0154	-28.8/income[d]
New Bedford, Mass.	-0.101/DIST[c]	-0.0199	-87.3/income[d]
Los Angeles, Calif.	-1.186/DIST[c]	-0.0146	-24.4/income[d]
Chicago, Ill.[e]	-0.0201	-0.0082	-0.011
Chicago, Ill.	-0.040[f]	-0.040 [f]	-0.010
San Diego, Calif.	-0.0916	-0.0563	-0.0106
Minneapolis-St. Paul, Minn.	-0.044	-0.031	-0.014

Note 1: [a] For walk time, a much higher estimate (-0.194) for first wait is attributed to bias from other sources.

Note 2: [b] Wage rate for worker in cents per minute.

Note 3: [c] One way travel distance in miles (multiply parameter by 2.2 for use with kilometers).

Note 4: [d] Annual household income in dollars.

Note 5: [e] This estimation is based on CBD work trips only.

Note 6: [f] In-vehicle and out-of vehicle travel time constrained to be equal.

(Source: Predicting transit ridership in response to transit service changes. Koppelman, Frank S. Journal of Transportation Engineering 109.4 (1983): 548-564.)

9.2. MULTI-IMPROVEMENT OPTIONS

As previously mentioned, MOSAIC allows users to select a combination of one geometric improvement option and one multimodal improvement option per corridor section (see Table 1 for the nine improvement options currently considered). The combined analysis process initially relies on the mode choice utility function for In-Vehicle- Travel-Time as discussed previously in section 9.1. This function considers the final roadway configuration selected by the user versus the base case configuration to iteratively determine the shift in person trips between modes.

The two geometric improvements that deal with changes in general purpose lanes (adding general purpose lanes or removing lanes through road diet) directly alter the volume to capacity ratio of the roadway, which in turn alters the effective travel speed and thus travel time. Similarly, by adding managed lanes or alternative transit modes to a section, a mode shift in person trips results in a change in the volume to capacity ratio for both the remaining general purpose lanes and special managed lanes or transit. Lastly, the final geometric improvement option that upgrades at-grade intersections to grade-separated interchanges reduces the delay caused by intersection controls, which in turn reduces the travel time on the section.

The results of both the pivot point and incremental logit mode share models provide final vehicle counts that are then converted to AADT for general purpose lanes, managed lanes and transit. Subsequent sustainability modules operate on these three travel way types within each section to produce separate model outputs in addition to final section performance measures.

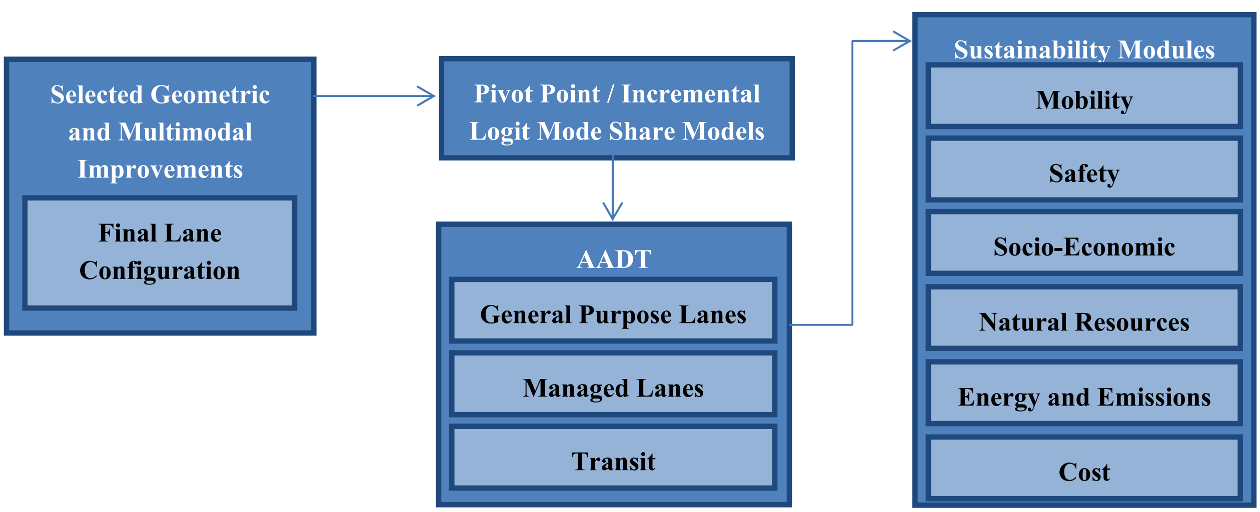


Figure 8 Multi-Improvement Framework

9.3. MODEL CALIBRATION AND VALIDATION

In order to implement MOSAIC in SHA's current planning practices, it is important that MOSAIC is comprehensively calibrated, validated, and tested using Maryland data. The model calibration and validation work flow is shown below in Figure 9. First, the research team identified which of the six evaluation modules in MOSAIC contained parameters that needed to be calibrated and validated. A literature review was then conducted to locate other studies that included calibration and validation of models similar to MOSAIC. The results of these studies were then used to facilitate the model calibration and validation process. In the event similar studies were not found, the research team collected local Maryland data and conducted additional calibration and validation.

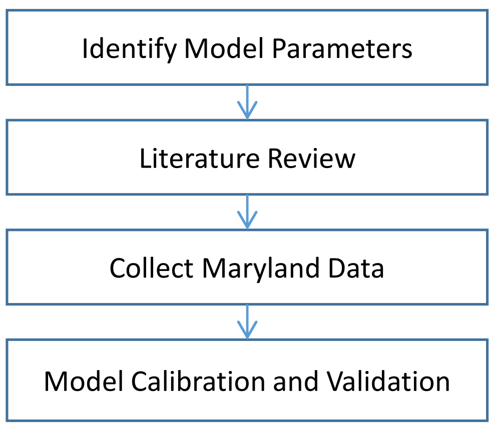


Figure 9 Model Calibration and Validation Work Flow

9.3.1. Identification of Model Parameters

Models and parameters that were identified for calibration and validation are shown below in Table 153.

Table 153 Model and Parameter Selection for Calibration and Validation

Model	Needs Calibration and Validation?	Parameters
Mobility	Yes	Speed estimation, intersection delay
Safety	Yes	Expected total crashes, expected severe crashes
Socio-economic	No	-
Natural resources	No	-
Energy and Emissions	No	-
Cost	No	-

A literature review showed that a study conducted by Morgan State University had already calibrated and validated the Highway Safety Manual (HSM) methods. The mobility module of MOSAIC still needs further calibration and validation.

9.3.2. Collect Maryland Data

As the literature review was unable to located any prior research on the calibration and validation of mobility models based on Texas Transportation Institute's Urban Mobility Report, the research team needed to collect two Maryland specific data sets: one data set which included the required variables needed to successfully run the MOSAIC mobility module and another data set that provided objective travel time information. In order to run the MOSAIC mobility module, traffic data and roadway geometry information needed to be collected for several case study corridors within Maryland. The research team relied on INRIX data to provide objective travel time information.

9.3.3. Model Calibration and Validation

First the research team validated the current mobility model with the selected Maryland corridors: US 15 and US 29. The results showed that the current MOSAIC travel time estimation model works well in Maryland. More details about the calibration and validation results for the mobility model can be found in Chapter 3.

CHAPTER 10: MOSAIC OUTPUT

10.1. NUMERICAL OUTPUT DATABASES

The C# MOSAIC program compiles an output database for each corridor analysis encoded as an XML report. This database contains raw numerical output data organized by corridor section for each of the six MOSAIC modules (Mobility, Safety, Socio-Economics, Natural Resources, Energy and Emissions, and Cost). Table 164 offers a sample from the output database that displays the effect a particular improvement case has on speed and travel in each of the five corridor sections. The effect of each improvement case in the six impact categories is then weighted and scaled based on either default or user-defined weights to produce a final weighted impact measure. This output database is used internally by MOSAIC to run interrelated impact modules (e.g. energy and environmental impact can only be assessed after mobility impact is estimated) and to provide a basis for a variety of graphical and summary outputs, which can be easily incorporated into reports and presentations by MOSAIC users.

Table 164 MOSAIC Output Database

Section #	Base Speed		Improved Speed	
	Peak Speed (mph)	Off-Peak Speed (mph)	Peak Speed (mph)	Off-Peak Speed (mph)
1	27.00	28.73	28.18	29.59
2	28.45	29.73	29.48	30.55
3	60.00	60.00	60.00	60.00
4	60.00	60.00	60.00	60.00
5	35.00	35.00	35.00	35.00
Section #	Base Travel Time		Improved Travel Time	
	BASE Peak (min)	BASE Off-Peak (min)	Improved Peak (min)	Improved Off-Peak (min)
1	17.29	16.32	16.62	15.88
2	13.72	13.18	13.28	12.85
3	8.00	8.00	8.00	8.00
4	18.00	18.00	18.00	18.00
5	14.97	14.97	14.97	14.97

10.2. MOSAIC-EGIS REPORTS AND GIS MAP FILES

In addition to the raw model output database, the MOSAIC program, through the eGIS environment, automatically generates customized reports and GIS mapping files. The final report includes corridor location maps (see Figure 10 below), a summary of analysis section information, existing traffic conditions, socio-economic conditions and nearby natural resources (parklands, waterways, wetlands, historic properties etc.).

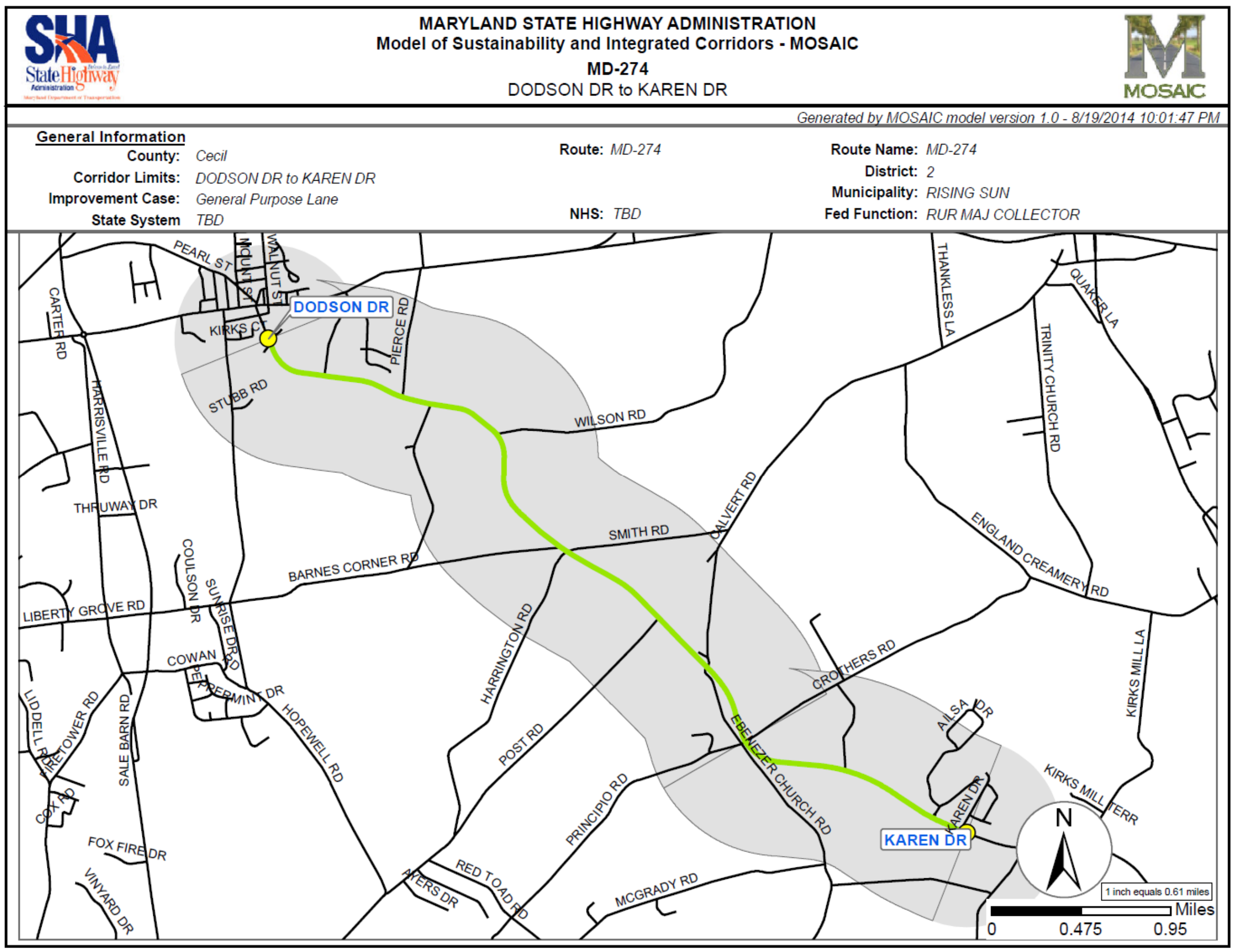


Figure 10 MOSAIC Report Corridor Location Map

In addition to automatically generated maps, eGIS-MOSAIC also performs geo-spatial clipping operations on the GIS layers using the improvement impact buffers (see Table 26 for respective buffers), which provides the user with a fully linked ArcMap MXD file allowing them to create custom map displays and conduct further geo-spatial analysis on their chosen corridor.

10.2.1. Section Level Output Summary

MOSAIC also provides a final summary, which includes graphical visualizations of the impact of each improvement case at both the section and corridor levels. As previously stated in Section 3.1-Travel Time Savings, each section represents a portion of the corridor where there are uniform traffic-flow characteristics such as traffic volume, number of lanes, etc. A final corridor score is also calculated based on weighted averages of corridor-level indicator scores using either default or user-defined weights. The user-defined weights represent how users value the relative importance of the six impact categories. For instance, certain users may highly value mobility and safety, while other users may prioritize natural resources, energy, and environmental impact mitigation.

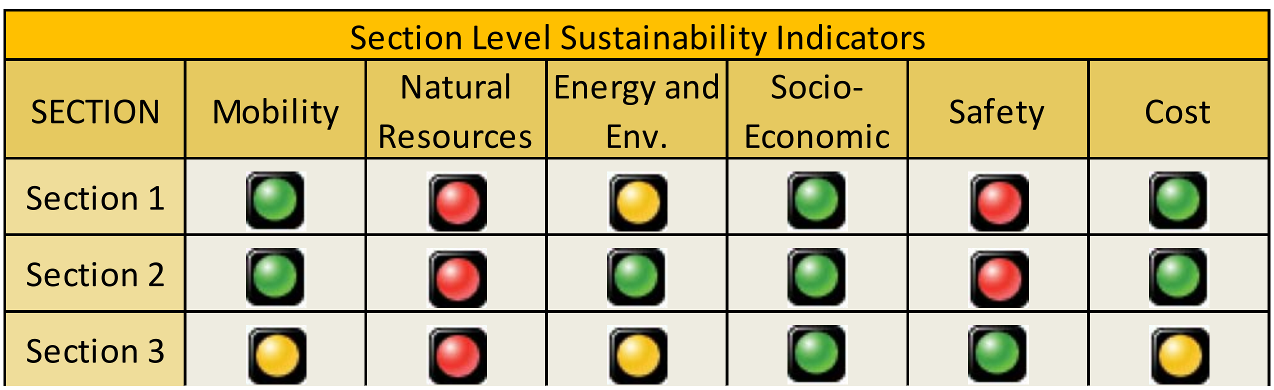


Figure 71 MOSAIC Section-Level Summary Output

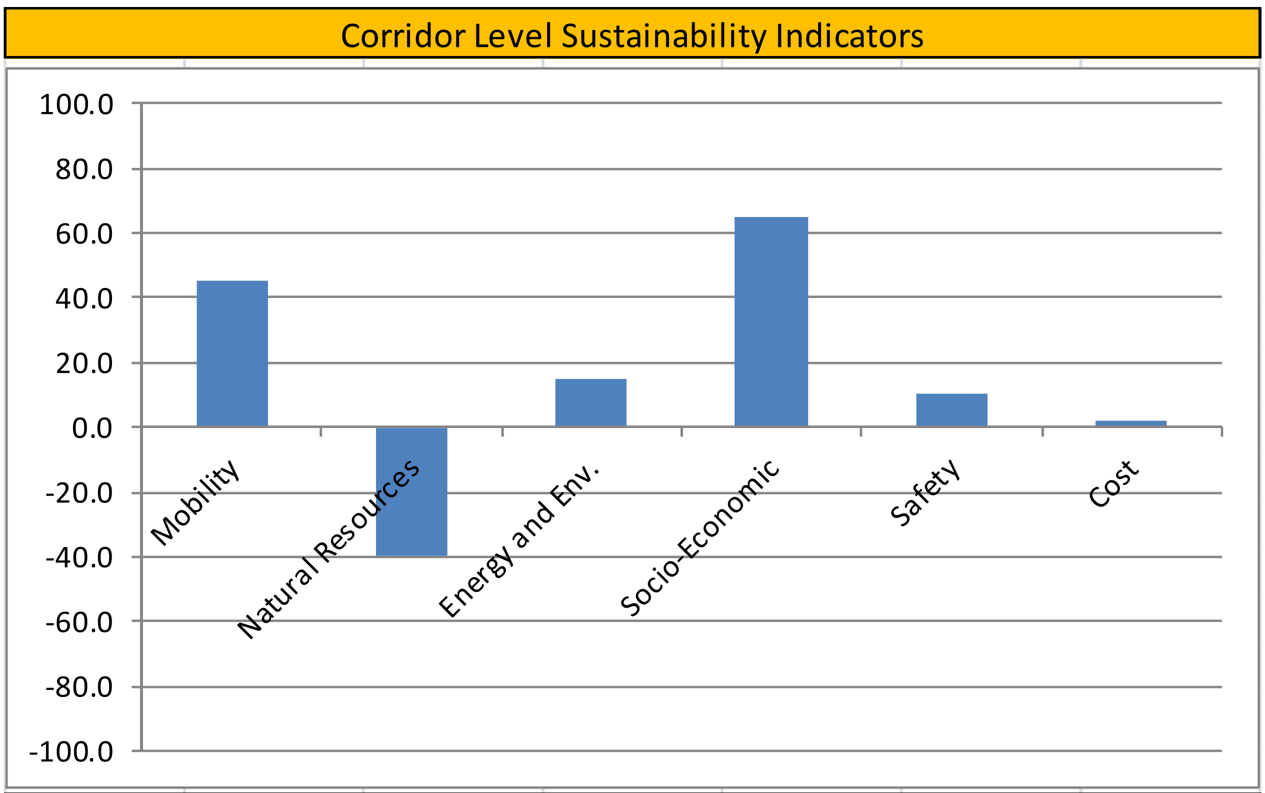
Figure 11 above shows the section-level analysis summary for one improvement case. In general, "green" implies positive effects and benefits from a corridor improvement scenario, "yellow" indicates neutral effects and "red" implies negative effects. Table 35 shows how the impact score for each of the six categories is computed based on the large number of performance measures introduced in previous chapters. Note that all impact scores are normalized to the same -100 to +100 percentage scale for comparison purposes.

Table 175 Computation and Normalization of Impact Scores

Mobility	Based on Travel Time Savings and Travel Reliability Scores	Average of the % Improvement Scaled from -100 to +100
Natural Resources	Based on Environmental Land Impacts score	Sum of Environmental Area Within Impact Area/Total Improvement Impact Area Scaled from -100 to +100
Energy and Emissions	Based on Fuel Consumption and Pollutant Discharge Scores	Total of the % Improvement Scaled from -100 to +100
Socio-Economic	Based on Aesthetics, Economic Agglomeration, Noise, and Livability Scores	Total of the % Improvement Scaled from -100 to +100
Safety	Based on Severe and Normal Crash Scores	Average of the % Improvement of Normal Crash rates and Severe Crash Rates Scaled from -100 to +100
Cost	Based on benefit cost analysis of Travel Time Savings and estimated Project Cost	Total Yearly Travel Time Savings/Improvement Cost Scaled from -100 to +100 based on the maximum ratio

10.2.2. CORRIDOR-LEVEL SUMMARY OUTPUT

The corridor-level impact scores are weighted averages of section-level impact scores. The weights for each section are based on vehicle miles traveled on that section. A custom graph is provided to visualize the corridor level impact (see Figure 12 for an example). These weighted average scores are scaled similarly to the section-level summary output, with 100 indicating a 100% improvement to the base case conditions, 0 indicating no effect, and -100 indicating a 100% decline in conditions.



MOE	Mobility	Natural Resources	Energy and Env.	Socio-Economic	Safety	Benefit Cost
Score	45.0	-40.0	15.0	65.0	10.0	2.0

Figure 82 MOSAIC Corridor-Level Summary Output

10.2.3. FINAL CORRIDOR SCORES AND WEIGHTING SYSTEM

MOSAIC provides a final score for each corridor analysis, which is determined as the weighted average of the six impact scores, as shown in Figure 13.

Improvement Case 1	
Final Score	4.58

Improvement Case 2	
Final Score	2.31

Figure 93 MOSAIC Final Improvement Case Scores

By default, the weights for each impact category are equal. However, MOSAIC provides an option for users to define the weights of these indicators. Shown below in Figure 104, the weighting system allows users to easily scale final scores to help identify the best improvement case according to users' goals (different SHA divisions may have different goals). Individual weights are numerically shown to the left, while relative weights are shown to the right.

Weighting System			
MOBILITY	8		2.96
NATURAL RESOURCES	3		1.11
ENERGY AND ENVIROMENT	5		1.85
SOCIO-ECONOMIC	2		0.74
SAFETY	7		2.59
COST	2		0.74

RESTORE DEFAULT WEIGHTS

Figure 104 MOSAIC Impact Score Weighting System

REFERENCES

AASHTO, Highway Safety Manual, 2010;

Alaska Department Of Natural Resources, Division Of Oil And Gas [Online], Nenana Basin exploration license, Department of Natural Resources, 2002; www.dog.dnr.state.ak.us/oil/products/publications/nenana/nenana_TOC.html,

Bellomo-McGee Inc., Midwest Research Institute, Highway Safety Manual, Two-Lane Highways, NCHRP Project 17-18(4), February 2003;

Ciccone, A. and Hall, R.E.. Productivity and the Density of Economic Activity, The American Economic Rveiw, Vol. 86, No. 1, pp 54-70, Mar., 1996;

Dane Westerdahl, Lead Investigator of California Air Resources Board, and Costantinos Sioutas, Lead investigator of Los Angeles PM Center/Supersite, Take a Supersite on the Road: monitoring particulate matter in community air, 2010;

David G. Penney, Ph.D., Professor of Physiology, Wayne State University School of Medicine, Detroit, MI, and Director of Surgical Research, Providence Hospital, Southfield, MI, Co Exposures And Scale Of Effects From Zero To One Million Parts Per Million, Carbon Monoxide (Co) Headquarters, 2002;

David Schrank, Tim Lomax, The 2007 Urban Mobility Report, Texas Transportation Institute, The Texas A&M University System, September 2007; http://mobility.tamu.edu;

Department of Transport. Transport, Wider Economic Benefits, and Impact on GDP. Discussion Paper. July, 2005;

Federal Highway Administration, GIS- based crash referencing & analysis system, Highway Safety Information System, North Carolina Center for Geographic Information, North Carolina DOT, University of North Carolina Highway Safety Research Center (UNC-HSRC), No. FHWA-RD-99-081, February 1999;

Federal Transit Administration (FTA), Office of Planning and Environment, Transit Noise and Vibration Impact Assessment, Fta-Va-90-1003-06, May 2006;

Girouard, P., M.E. Walsh, and D.A. Becker, BIOCOST-Canada: a new tool to evaluate the economic, energy, and carbon budgets of perennial energy crops. In Proceedings of the Fourth Biomass Conference of the Americas, Pp. 85-90., Elsevier Science, Ltd., Oxford, UK, 1999;

Guang qing Chi and Brian Stone Jr., Sustainable Transport Planning: Estimating the Ecological Footprint of Vehicle Travel in Future Years, Journal of Urban Planning and Development, Vol. 131, No.3, ©ASCE, ISSN 0733-9488/2005/3-170–180, 2005;

Highway Research Program, Performance Measurement Framework for Highway Capacity Decision Making Strategic, SHRP 2 Report S2-C02-RR, 2009;

IHSDM, Crash Prediction Module Engineer's Manual, USA, 2004;

James M. Witkowski, Benefit Analysis for Urban Grade Separated Interchanges, ASCE, Journal of Transportation Engineering, Vol. 114, No.1, January, 1988;

James R. Schutt, Kimberly L. Phillips and Harlow C. Landphair, Guidelines For Aesthetic Design In Highway Corridors: Tools And Treatments For Texas Highways, Texas Transportation Institute, The Texas A&M University System, 2001;

J. Bonneson and D. Lord, Role and Application of Accident Modification Factors in the Highway Design Process, Texas Transportation Institute, The Texas A&M University System, 2005;

J. Bonneson, K. Zimmerman, and K. Fitzpatrick, Interim Roadway Safety Design Workbook, May 2005; http://tti.tamu.edu/documents/0-4703-P4.pdf

J. Bonneson and K. Zimmerman, Procedure For Using Accident Modification Factors In The Highway Design Process, Texas Transportation Institute , 2007;

Joshua h. Schmidt1, Mark s. Lindberg, devin s. Johnson, and joel A. Schmutz, Environmental And Human Influences On Trumpeter Swan Habitat Occupancy In Alaska, Department of Biology and Wildlife and Institute of Arctic Biology, University of Alaska, National Marine Mammal Laboratory, Alaska Fisheries Science Center, NOAA, Seattle, U.S. Geological Survey, Alaska Science Center, AK, 2009;

K. Max Zhang, Oliver Gao, Cornell University, Development of Advanced Modeling Tools for Hotpot Analysis of Transportation Emissions, UTC Center Report, 2009;

Koppelman, Frank S. "Predicting transit ridership in response to transit service changes." Journal of Transportation Engineering 109.4 (1983): 548-564.

Lardner/Klein Landscape Architects, P.C. in Association with Oldham Historic Properties, Inc, Context Sensitive Solutions for the Maryland Historic National Road Scenic Byway, The Maryland State Highway Administration, Feb 2006;

Lena, T. S., V. Ochieng, M. Carter, J. Holguín-Veras, and P. L. Kinney. Elemental Carbon and $PM_{2.5}$ Levels in an Urban Community Heavily Impacted by Truck Traffic. *Environmental Health Perspectives*, Vol. 110, pp. 1009-1015, 2002;

Maged Hamed, Waleed Effat, A GIS-based approach for the screening assessment of noise and vibration impacts from transit projects, Journal of Environmental Management 84, 305–313, 2007;

Mark A. Marek, P.E., Landscape and Aesthetics Design Manual, TxDOT online Manual System, 2009;

Maryland Department of Transportation, Maryland Transit Administration, Purple Line alternatives analysis, September 2008;

McCarthy Hyder Consultants N22 Baile Bhuirne - Macroom (Baile Bhuirne to Coolcour) Environmental Impact Statement , financed by the Irish Government under the National Development Plan (NDP) 2007 - 2013 and part financed by the European Union, Oco 2009;

M. Dietz, D. Ebersbach, Ch. Lippold (TUD), K. Mallschutzke (INECO), G. Gatti (POLOBA), A. Wieczynski (PIAP), Road Safety Performance Function, 2005;

Morgan State University, the Development of Local Calibration Factors for Implementing the Highway Safety Manual in Maryland, MD-14-SP209B4J, March 2014;

Richard T. T. Forman and Lauren E. Alexander, Roads And Their Major Ecological Effects, Harvard University Graduate School of Design, Cambridge, Massachusetts 02138, Annu. Rev. Ecol. Syst. 29:207–31, 1998;

Ron Pfefer, Chair, TRB Task Force for the Development of a Highway Safety Manual, Road Safet Analysis Methods and Procedures, 2004;

Skatteudvalg, T., Modtaget via elektronisk Post. Der Tages forbehold for evt. fejl , July 11, 2002;

State Highway Administration (SHA), Highway Development Project Information, 2010; http://apps.roads.maryland.gov/WebProjectLifeCycle/ProjectHome.asp

State Highway Administration, Maryland Department of Transportation, Highway Construction Cost Estimating Manual, 2009;

Statistics Canada., Energy supply and demand, July 11, 2002;

Tara Ramani, Josias Zietsman, William Eisele, Duane Rosa, Debbie Spillane and Brian Bochner, Developing Sustainable Transportation Performance Measures For TxDOT's Strategic Plan: Technical Report, Texas Transportation Institute The Texas A&M University System, October 2008;

Transportation Research Board, Impact of Shoulder Width and Median Width on Safety, National Cooperative Highway Research Program, Report 633, 2009;

Trinh Pham, David Ragland, Summary of Crash Prediction Models Also known as Safety Performance Functions (SPFs), December 2005;

Wada, Y., Biophysical productivity data for ecological footprint analysis, UBC Task Force on Healthy and Sustainable Communities, 1994.

APPENDIX I: AESTHETICS AND LAND USE SURVEY

Model Of Sustainability and Integrated Corridors (MOSAIC) Survey

Introduction

The Maryland State Highway Administration (SHA) has initiated major planning efforts to improve transportation efficiency, safety, and sustainability on critical highway corridors through its Comprehensive Highway Corridor (CHC) program. Our Comprehensive Highway Corridor Planning with Sustainability Indicators project as well as the Model Of Sustainability and Integrated Corridors (MOSAIC) will assist SHA in selecting the most sustainable corridor improvement option for its Highway Needs Inventory to balance its mobility, safety and environmental stewardship objectives based on pre-defined policy goals.

In phase two, MOSAIC takes into account the no-build case and six highway improvement options, including adding one HOV or HOT lane, converting one general purpose lane to HOV or HOT lane, adding one bus or truck-only lane, adding new LRT, and applying the road diet.

Aesthetics

Aesthetics is a branch of philosophy dealing with the nature of beauty, art, and taste, and with the creation and appreciation of beauty, and it is sometimes called judgments of sentiment and taste. More broadly, scholars in the field define aesthetics as "critical reflection on art, culture and nature." MOSAIC incorporates four aesthetic factors into its socioeconomic models: facility compatibility, land use attraction, visual appeal, and historical roads' and sites' protection. Please rate and weight the factors below which would potentially affect the roadway aesthetics in the base case and six improvement options:

1. Facilities' Compatibility

How would you rate the facilities compatibility condition along US-29 in base case and six improvement alternatives? The facilities include traffic control devices, lighting, Splitter Island, roundabouts' design, etc.

2. Land Use Attraction

How would you rate the land use attraction condition along US-29 in base case and six improvement alternatives? The Land Use Attraction includes the transportation network's land use issue and landscape.

3. Visual Appeal

How would you rate the visual appeal condition along US-29 in base case and six improvement alternatives? Visual Appeal includes visual friction (various interesting views or boring too smooth views along the corridor), views conservation (with or without visual intrusive), sight distance and clear areas.

4. Historical Roads' and Sites' Protection

How would you rate the historical roads' and sites' protection condition along US-29 in base case and six improvement alternatives?

5. Please also weight each factor reflecting their importance in determining the performance of aesthetics. (1=not important at all; 7= most important)

6. Comments

If there are other factors that you think are important in affecting the performance of aesthetics, please list them below and give your weight with the scores from 1 to 7.

Land-use Mix Scores

Land use mix refers to locating different types of land uses close together. Increased land use mix tends to reduce the distances that residents must travel for errands and allows more use of walking and cycling for such trips.

MOSAIC regards the land-use mix condition as one of the main factors that affect the livability within a quarter mile buffer on either side of the highway corridors. Land-use types considered in MOSAIC include industrial, commercial, recreational, agricultural, and low and high-density residential areas. The land-use mix score along US-29 is 0.66 in base case, where 0 represents the worst land-use mix condition, while 1 represents the best condition. Please give your land-use scores below for six improvement alternatives along US-29: