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Estimation and Prediction of Statewide Vehicle Miles Traveled (VMT) by Highway Category and Vehicle Classification

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16. Abstract

Vehicle Miles Traveled (VMT) is a critical performance measure that is used extensively in highway transportation management for financial analysis, resource allocation, impact assessments, and reporting to oversight agencies. As highway revenue from fuel taxes continues to plummet and user-based taxes such as VMT fees become increasingly attractive, consistent and reliable VMT estimates have become critical for highway funding evaluation and administration. At the present time, there are several methods for VMT estimation that typically yield estimates that are inconsistent or inaccurate. This study was commissioned by the Indiana Department of Transportation (INDOT) to develop a benchmark method for VMT estimation and provide calibration factors for the VMT estimation methods.

The study's core outcome is a segment-level framework for VMT estimation For the state roads, a comprehensive database was developed which facilitates extensive aggregations of VMT by geographical scope, route, functional class, and vehicle class. For the local roads, a sample of counties of different spatial locations and degrees of urbanization were used, and cluster analysis, geographic information systems (GIS), and spatial interpolation techniques were used to expand the VMT estimates from the local road sample to the population of all counties in the state.

The results of this study indicate that there is significant variation in the results from the various VMT estimation methods. The technique developed in this study for reconciling these different VMT estimates was validated using the estimate from the benchmark method (segment-level) as a basis. The implementation platform developed in this study was designed to produce outcomes that address the VMT data needs of the intended end users and stakeholders and could be enhanced in the future as and when data become available.

17. Key Words

vehicle miles of travel, VMT estimation, travel

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EXECUTIVE SUMMARY

ESTIMATION AND PREDICTION OF STATEWIDE VEHICLE MILES TRAVELED (VMT) BY HIGHWAY CATEGORY AND VEHICLE CLASSIFICATION

Vehicle miles traveled (VMT) is a critical performance measure that is used extensively in highway transportation management for financial analysis, resource allocation, impact assessments, and reporting to oversight agencies. As highway revenue from the fuel tax continues to fall and user-based taxes such as VMT fees become increasingly attractive, highway agencies seek consistent and reliable VMT estimates for the purpose of evaluating the efficiency and equity of possible VMT fee structures. This report presents the methodology and results of a study that was commissioned by the Indiana Department of Transportation (INDOT) in 2013 to develop alternative approaches for VMT estimation at various levels of aggregation, including spatial (corridor, county, district, state) and user group (vehicle classes 1 to 13), at any future year. The study was also needed to identify one of these approaches to serve as a benchmark for VMT estimation and to provide calibration factors between the other approaches and the benchmark approach. It included a literature review of existing VMT approaches and a questionnaire survey of stakeholders of VMT data. This information search helped researchers to streamline the study effort, categorize the different techniques for VMT estimation, identify their limitations, and design an appropriate spreadsheet-based output for reporting the VMT estimates.

The core outcome of this study is a comprehensive framework that estimates the VMT contributed by each vehicle class at each link in the state's road network, including local roads. Local road VMT estimation involved considerable effort due to the historical underrepresentation of local roads in past VMT studies, the low accuracy of past estimating methods, and the dominant share of local roads of the total road inventory in the state. For the local road VMT estimation, a sample of counties of different spatial location and degree of urbanization was used. Analytical techniques and tools, including cluster analysis, geographic information systems (GIS), and spatial interpolation techniques, were used to expand the VMT estimates from the local road sample to the population of all counties in the state. This was done for different rates of travel growth. For the state road VMT estimation, a comprehensive database was developed to facilitate extensive aggregations of VMT by geographic scope, road functional class, and vehicle class. Table E.1 presents a summary of the predicted aggregate statewide VMT using the link-specific approach for VMT estimation for different scenarios of travel growth rate (illustrated in Figure E.1). Table E.2 presents the predicted statewide VMT for all FHWA vehicle classes, using a medium growth factor. It was determined that the current statewide VMT (2013) is approximately **77 billion vehicle-miles**, and is expected to grow to **95.2 billion vehicle miles** in 2035.

For each VMT estimation approach, the description and results are presented in Table E.3. The results of this study indicate that there is significant variation in the results from the various VMT estimation methods compared with the benchmark VMT (Figure E.2). For each approach, calibration factors were established to reconcile the differences in VMT estimates relative to the benchmark VMT. The implementation platform (spreadsheet) was designed to produce outcomes that address the specific VMT data needs of the intended end users. As additional data become available in future, the spreadsheet can be modified easily to yield the updated estimates of VMT. The deliverables from this study are expected to have far-reaching impacts on the various functional areas of highway management and administration, the evaluation of VMT fee as an alternative or complement to the fuel tax for highway revenue, and the generation of required reports to the federal oversight agencies.

TABLE E.1
Summary of predicted aggregate statewide VMT.

	State Routes Annual VMT (billions)			Local Routes Annual VMT (billions)			Statewide Annual VMT (billions)		
Year	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
2009	39.240	39.921	40.602	34.840	35.154	35.468	74.080	75.075	76.069
2010	39.098	39.779	40.460	35.102	35.416	35.730	74.201	75.195	76.190
2011	39.911	40.592	41.273	35.367	35.680	35.994	75.277	76.272	77.266
2012	39.665	40.346	41.027	35.633	35.946	36.260	75.298	76.292	77.287
2013	40.588	40.702	40.817	36.214	36.214	36.214	76.802	76.917	77.031
2014	40.942	41.174	41.407	36.415	36.482	36.549	77.357	77.656	77.956
2015	41.300	41.652	42.007	36.617	36.752	36.887	77.917	78.404	78.894
2016	41.662	42.137	42.616	36.820	37.024	37.228	78.482	79.161	79.844
2017	42.027	42.627	43.234	37.025	37.298	37.573	79.052	79.925	80.807
2018	42.396	43.124	43.863	37.230	37.574	37.920	79.626	80.698	81.783
2019	42.769	43.627	44.501	37.437	37.852	38.271	80.205	81.479	82.772
2020	43.145	44.136	45.149	37.645	38.132	38.625	80.790	82.269	83.775
2021	43.525	44.653	45.808	37.854	38.414	38.982	81.379	83.067	84.791
2022	43.909	45.176	46.478	38.064	38.699	39.343	81.973	83.874	85.821
2023	44.297	45.705	47.158	38.275	38.985	39.707	82.572	84.690	86.865
2024	44.689	46.242	47.849	38.487	39.273	40.074	83.176	85.516	87.923
2025	45.085	46.786	48.551	38.701	39.564	40.445	83.786	86.350	88.996
2026	45.485	47.337	49.264	38.916	39.857	40.819	84.401	87.194	90.083
2027	45.889	47.895	49.989	39.132	40.152	41.197	85.021	88.047	91.186
2028	46.297	48.460	50.725	39.349	40.449	41.578	85.646	88.909	92.303

(Continued)

TABLE E.1
(Continued)

Year	State Routes Annual VMT (billions)			Local Routes Annual VMT (billions)			Statewide Annual VMT (billions)		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
2029	46.710	49.033	51.474	39.567	40.748	41.962	86.277	89.781	93.436
2030	47.126	49.613	52.234	39.787	41.050	42.350	86.913	90.663	94.585
2031	47.548	50.201	53.007	40.008	41.354	42.742	87.555	91.555	95.749
2032	47.973	50.797	53.792	40.230	41.660	43.137	88.203	92.457	96.930
2033	48.403	51.401	54.590	40.453	41.968	43.536	88.856	93.369	98.127
2034	48.838	52.013	55.401	40.678	42.278	43.939	89.515	94.291	99.340
2035	49.277	52.633	56.225	40.903	42.591	44.346	90.180	95.224	100.571

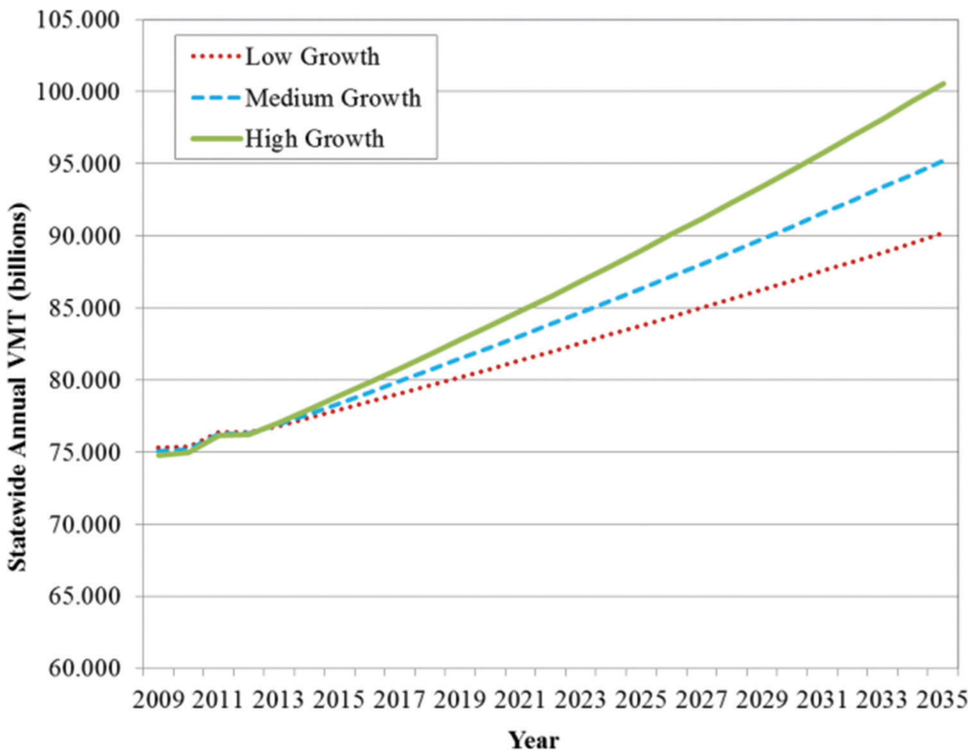

Figure E.1 Predicted statewide VMT for varying growth rate scenarios.

TABLE E.2
Predicted statewide VMT (billions) by FHWA vehicle class, using medium growth factor.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
CLASS 1: MOTORCYCLES												
	0.407	0.408	0.422	0.417	0.420	0.424	0.428	0.432	0.436	0.441	0.445	0.449
CLASS 2: PASSENGER CARS												
	46.483	46.523	48.596	47.818	48.111	48.570	49.033	49.502	49.976	50.455	50.939	51.428
CLASS 3: PICKUPS, PANELS, VANS												
	18.575	18.611	19.554	19.065	19.257	19.438	19.621	19.806	19.993	20.182	20.374	20.567
CLASS 4: BUSES												
	0.141	0.142	0.129	0.168	0.147	0.149	0.150	0.152	0.153	0.155	0.157	0.158
CLASS 5: SINGLE UNIT 2 AXLE TRUCKS												
	1.785	1.791	1.774	2.303	1.941	1.961	1.981	2.002	2.022	2.043	2.064	2.086
CLASS 6: SINGLE UNIT 3 AXLE TRUCKS												
	0.567	0.573	0.786	0.976	0.736	0.743	0.750	0.757	0.764	0.772	0.779	0.786
CLASS 7: SINGLE UNIT 4 AXLE+ TRUCKS												
	0.169	0.172	0.251	0.315	0.230	0.233	0.235	0.237	0.239	0.241	0.244	0.246
CLASS 8: SINGLE TRAILER 3–4 AXLE TRUCKS												
	0.599	0.601	0.388	0.458	0.520	0.525	0.531	0.537	0.542	0.548	0.554	0.560
CLASS 9: SINGLE TRAILER 5 AXLE TRUCKS												
	6.040	6.074	4.120	4.535	5.276	5.333	5.390	5.448	5.507	5.567	5.627	5.688
CLASS 10: SINGLE TRAILER 6 AXLE TRUCKS												
	0.089	0.089	0.058	0.068	0.078	0.078	0.079	0.080	0.081	0.082	0.083	0.084
CLASS 11: MULTI TRAILER 5 AXLE TRUCKS												
	0.141	0.136	0.085	0.108	0.120	0.121	0.122	0.124	0.125	0.126	0.128	0.129
CLASS 12: MULTI TRAILER 6 AXLE TRUCKS												
	0.049	0.047	0.029	0.038	0.042	0.042	0.043	0.043	0.044	0.044	0.045	0.045
CLASS 13: MULTI TRAILER 7 AXLE TRUCKS												
	0.028	0.028	0.078	0.021	0.039	0.040	0.040	0.041	0.041	0.042	0.042	0.043
State Routes & Local Routes Total	**75.075**	**75.195**	**76.272**	**76.292**	**76.917**	**77.656**	**78.404**	**79.161**	**79.925**	**80.698**	**81.479**	**82.269**

TABLE E.3
Summary of VMT estimation approaches/methods.

Method	Code	Specific Approach and Assumptions	Coverage
Fuel-Revenue	F-1	Fuel distributed with *disaggregate* approach; gallonage from *EIA estimates*	Statewide
Fuel-Revenue	F-2	Fuel distributed with *disaggregate* approach; gallonage from *tax revenues*	Statewide
Fuel-Revenue	F-3	Fuel distributed with *aggregate* approach; galloange from *EIA estimates*	Statewide
Fuel-Revenue	F-4	Fuel distributed with *aggregate* approach; gallonage from *tax revenues*	Statewide
Fuel-Revenue	F-5	Fuel distributed with *aggregate* approach; gallonage from *EIA estimates* (FHWA distribution)	Statewide
Fuel-Revenue	F-6	Fuel distributed with *aggregate* approach; gallonage from *tax revenues* (FHWA distribution)	Statewide
Socioeconomic Regression	SE-1	Actual economic conditions as model inputs	Statewide
Socioeconomic Regression	SE-2	Predicted economic conditions as model inputs	Statewide
Vehicle Registrations	VR-1	Higher estimate of annual passenger automobile mileage	Statewide
Vehicle Registrations	VR-2	Lowest estimate of annual passenger automobile mileage	Statewide
Socioeconomic Travel Surveys	STS-1	Sample of households in Indiana	Statewide (Non-Commercial)
Socioeconomic Travel Surveys	STS-2	Sample of households in neighboring states (IN, KY, OH, WI, IA)	Statewide (Non-Commercial)
Licensed Drivers Surveys	LDD-1	Sample of households in Indiana	Statewide
Licensed Drivers Surveys	LDD-2	Sample of households in neighboring states (IN, KY, OH, WI, IA)	Statewide
HPMS	HPMS-1	Reported from the HPMS for all functional classes (AADT sampling)	Statewide
Trend Analysis	TA-1	Linear trend functional form	Statewide
Trend Analysis	TA-2	Polynomial trend functional form	Statewide
Trend Analysis	TA-3	Growth curve model functional form	Statewide
Trend Analysis	TA-4	S-curve trend functional form	Statewide
Trend Analysis	TA-5	Growth factors approach (without regression or curve fitting)	Statewide
Link-Specific	LS-1	Link-specific method for state and local routes	Statewide
Link-Specific	LS-2	Link-specific method for state and local routes	Statewide (Non-Commercial)

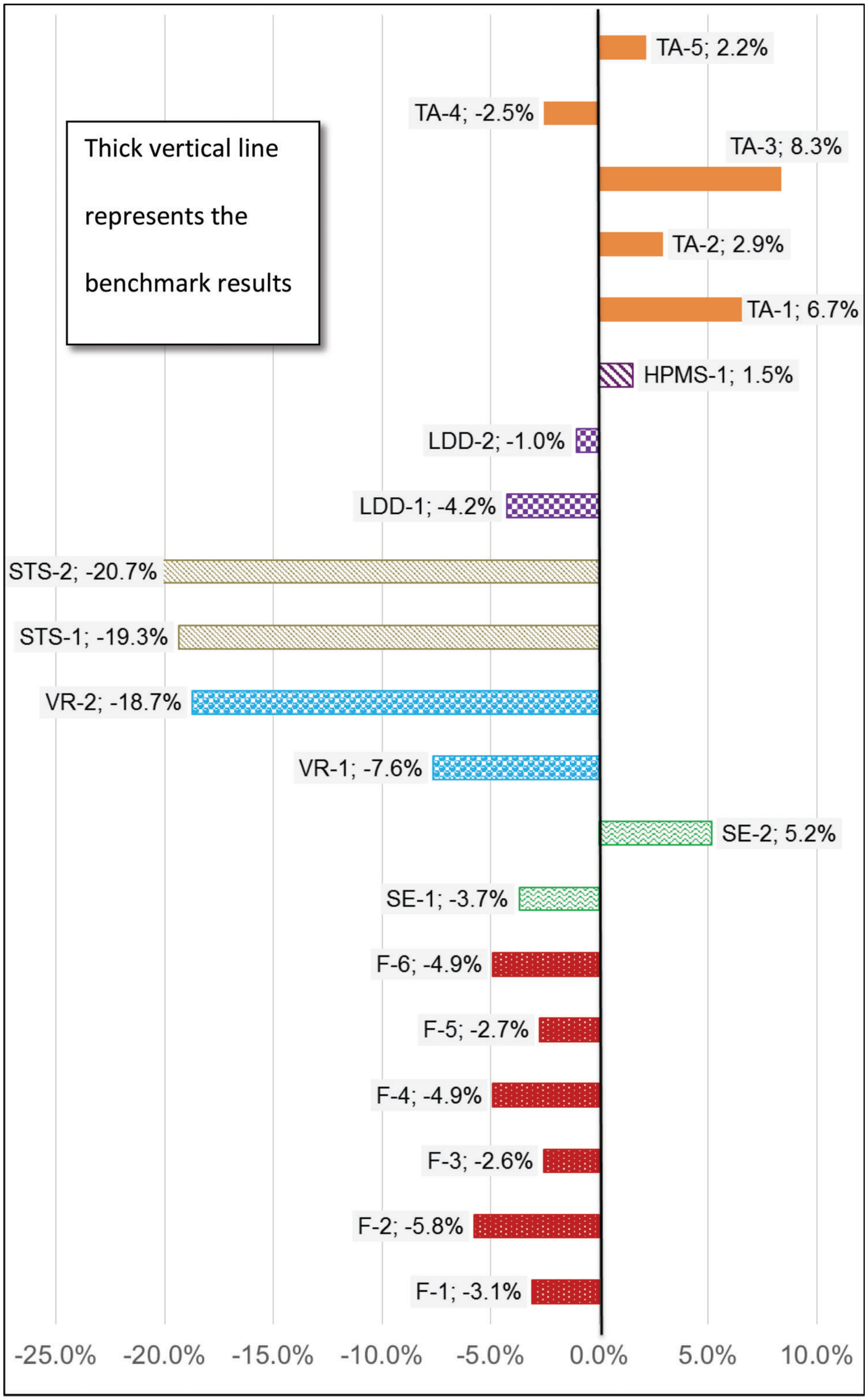

Figure E.2 Deviations of VMT estimated from benchmark VMT, by estimation approach.

PART I CONTENTS

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1. INTRODUCTION

1.1 Background

Estimates of vehicle miles of travel (VMT) are used extensively for a variety of highway transportation management functions, including asset management, financial analysis, resource allocation planning, estimation of emissions and energy consumption, and traffic impact assessments (Figure 1.1) for a number of reasons. First, reliable estimates or predictions of VMT are critical for estimating or predicting highway revenue levels. Second, VMT data are integral to the reporting of highway asset performance in terms of system preservation, congestion mitigation, safety, and mobility. For example, network-wide safety performance is often measured in terms of the number of fatalities per million VMT. Third, VMT data are useful for high-level oversight of the transportation system, as well as for investigating the impacts of changes in policy. State legislatures often request aggregate travel information on the state highway network, particularly in the current era when states have begun to consider legislation related to new or existing revenue sources. Fourth, due to the current and projected sharp reductions in fuel tax revenue, state and the federal governments are considering the feasibility of switching from the current fuel tax to a mileage-based user tax such as a VMT fee. State highway agencies (SHA) need the capability to generate reliable and consistent VMT estimates and VMT forecasts in order to predict the expected revenue from any mileage-based user fees in the future. Fifth, as evidenced by past trends, there appears to be strong and positive correlation between VMT and the economic output of a region; VMT values can potentially serve as a gauge of the economic output in a state.

Sixth, VMT data is a key item in the preparation of annual asset operations reports for submission to FHWA. VMT information is also useful in transportation planning and highway cost allocation where the common costs of highway infrastructure repair or reconstruction are attributed to highway users on the basis of their VMT contributions. Other uses of VMT information includes network-level highway performance reporting, environmental and energy impact assessments, and evaluation of the operational impacts (safety and mobility) of highway interventions and policies. Thus, VMT data are used by state transportation agencies, metropolitan planning organizations (MPOs), regional planning organizations (RPOs), local municipalities, federal agencies, and legislatures for a variety of specific business processes and functions.

Furthermore, the VMT has critical implications for highway funding administration because VMT levels influence each state's "share" of federal highway funding. The Interstate Maintenance Program (IMP), National Highway System (NHS), Surface Transportation Program (STP), and Highway Safety Improvement Programs (HSIP) funds are allocated, in part, using a formula relating the extent of the VMT on the appropriate highway system. For example, apportionment formulas for federal-aid eligible highway programs including the IMP, NHS, STP, and HSIP, have weights of 33.33%, 35.00%, 40.00%, and 33.33%, respectively, based on the VMT. Within state transportation planning and the decision-making processes, VMT information assists with compliance with federal regulations and legislation. The Clean Air Act Amendments of 1990 (CAAA), the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA-91), the Transportation Equity Act for the 21st Century (TEA-21), SAFETEA-LU of 2005, and most recently, MAP-21 require VMT information to varying extents. As these distributions are based highway class and vehicle class, VMTs information broken down by these criteria is important for compliance and funding.

1.2 Problem Statement

VMT estimates can be determined using any of the several estimation approaches, and there exists significant variation among these approaches. Some of these approaches are aggregate in nature, other are disaggregate. In theory, the total VMT estimate from disaggregate approach should add up to yield a total value from the aggregate approach; however, in practice, this is not always the case. Such inconsistency across VMT estimates from different approaches is a particularly worrisome situation because of the critical role that VMT plays in INDOT's tactical and strategic policy analysis and decision-making. Such inconsistency could be attributed to the different sample sizes, computational techniques, and resource levels associated with each approach. Also, different assumptions and techniques affect the VMTs obtained using each method.

Different stakeholders at INDOT require VMT estimates at different levels of aggregation. Currently, INDOT lacks the capability to readily provide VMT by vehicle class and highway functional class. As a result, the agency's applications such as revenue predictions and cost allocation attributions by vehicle class and highway class, asset deterioration, and operational performance associated with each vehicle class, and other applications, are handicapped by the lack of a consistent and reliable VMT estimates or estimation framework.

In view of the importance of VMT at INDOT, an objective analysis of statewide VMT at state and local levels and using different approaches is needed.

1.3 Study Objectives and Scope

This study seeks to identify the various approaches for VMT estimation that have been used in the literature, outline the limitations and advantages of each approach, choose one of these as the benchmark approach, and assess quantitatively the extent of deviation of the VMT estimate of other approaches compared to the benchmark VMT. The study also seeks to evaluate the alternative VMT estimation approaches in terms of accuracy and ease-of-computation. The benchmark approach is intended to be used as a basis to develop a framework for reliable estimation and prediction of statewide VMT at the project and network levels that can be used by INDOT's business units. A final objective is to develop a

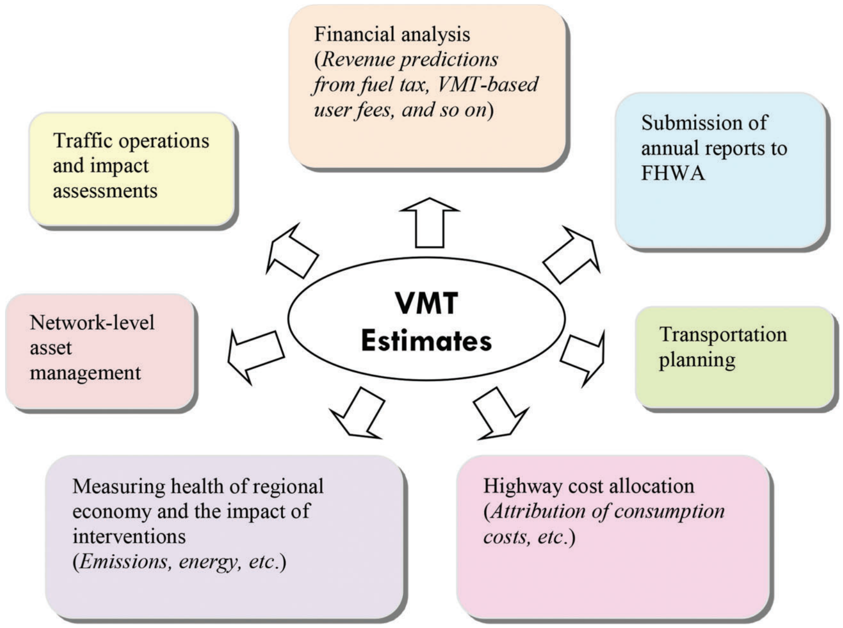

Figure 1.1 Applications of VMT estimates in highway agencies.

spreadsheet tool to implement the framework. This tool will serve as a central source for summary outputs and will provide tabular and graphical results that aim to quantify existing VMT and highlight changing trends with VMT throughout the state. The scope of this study is the state and local routes that comprise the Indiana public highway system, which covers 90,000 miles. State routes are defined for this study as interstates (I), US highways (US), and state roads (SR). The local routes, as defined for this study, are non-INDOT owned city streets (CS) and county roads (CR).

The entire report is presented in two parts. Part I (this part) is the main report, which summarizes the study and presents a brief synthesis of the reviewed literature, the study methodologies, and the results. Part II provides greater detail on the literature review, methodology, and results.

2. LITERATURE REVIEW

2.1 Prelude

Past literature that comprehensively reviewed VMT estimation approaches had identified two broad approaches that differ by input data type (Figure 2.1). The first broad approach, institutionalized in the FHWA's Highway Performance Monitoring System (HPMS), involves the use of traffic counts taken at different points along the road network and expanding them to produce an area-wide VMT estimate based on the roadway attributes associated with each sampling location. This is referred to as the VMT approach based on traffic counts.

The second broad approach, which is not based on traffic counts, estimates VMT mostly based on network-level transportation attributes that influence the extent of travel, such as fuel consumption and fuel efficiency, the number of households, household incomes, licensed drivers, and vehicle registrations. In some of the approaches in this broad approach, however, a small part of the data requirements relate to traffic information. Different types and levels of resources are required for each broad approach. The literature review helped highlight the qualitative and quantitative merits and limitations associated with each approach in order to identify the most desirable VMT estimation approach and method for implementation at INDOT.

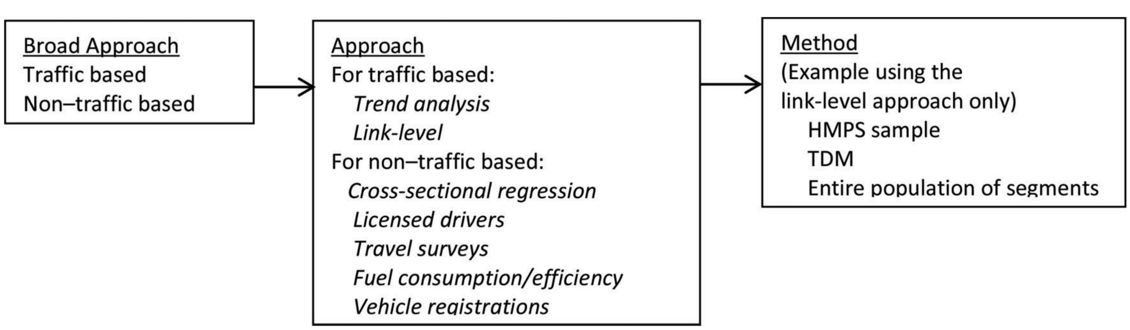

Figure 2.1 Hierarchy of estimation approaches.

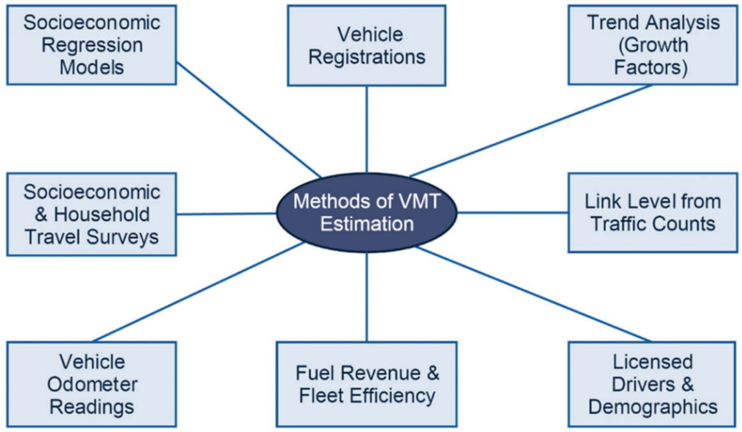

Figure 2.2 VMT estimation approaches for statewide coverage.

Estimation Characteristic / VMT Estimation Method	Traffic-Based	Non-Traffic Based	Directly Obtainable By Functional Class	Directly Obtainable By Vehicle Class	Demographics Data	Fuel Tax Reports	Socioeconomic Data	Uses Growth Rates or Expansion Factors	Travel-Survey Based	Time Series Data
Trend Analysis (Growth Factors)	X	X						X		X
Regression Analysis		X		X			X			
Socioeconomic (Household) Travel Surveys		X			X		X		X	
Licensed Drivers & Demographics		X			X				X	X
Link Level (Sample - HPMS)	X		X					X		
Link Level (Actual - Population)	X		X	X						
Odometer Readings		X							X	
Fuel Usage & Fleet Effiencies		X				X				
Link Level (Estimated - TDM)	X	X					X	X		
Vehicle Registrations		X		X						

Figure 2.3 Nature of input data for the various VMT estimation approaches.

2.2 Characteristics of VMT Estimation Approaches

In VMT estimation related to traffic counts, the traffic volume that is used as an input is determined using traffic counts collected for the population of highway segments or for a sample thereof. After the HPMS was developed in 1978, state highway agencies (SHAs) have used the HPMS sample as a basis for annual reporting to FHWA on their highway infrastructure operations, condition, and performance. The HPMS mandates that all federally-funded highway segments must be covered by count stations. Using the data from the permanent (continuous count) and temporary (coverage count) stations, appropriate seasonal and daily adjustment factors are used to convert the raw accounts into average annual daily traffic values.

The type of input data and procedures used for calculations serve as the basis for distinguishing between the different methods of VMT estimation. Figure 2.2 presents the VMT estimation methods that are capable of yielding a statewide VMT estimate. Some of these are also capable of reporting separate VMTs by vehicle class, road class, or jurisdiction. Furthermore, the VMT estimation process is enriched where there is a capability to estimate the in-state and out-of-state split of the statewide VMT by vehicle class or functional class (see Volovski et al., 2015).

Figure 2.3 summarizes the differences between the methods for VMT estimation based on the data type used. The different end users have different requirements of VMT report format and output. For example, certain end users will be more interested in VMT estimates generated from household surveys while others will be more interested in VMT estimates generated from fuel consumption. Also, some end users may require just a total statewide VMT while others may be more interested in VMT estimates for a specific vehicle class, road functional class, or administrative jurisdiction. For users interested in forecasting potential revenue from mileage-based user fees, the link-level method that yields VMT estimates by vehicle class, may be most appropriate.

3. RESEARCH METHODOLOGY

3.1 Introduction

The developed framework for statewide VMT estimation, based on the selected benchmark approach, involves the estimation of the VMT at every segment of the state's road network. This approach uses actual on-the-ground traffic counts. However, with Indiana's 90,000+ miles road network, this approach is limited by the costs and resources of installing and managing ATRs, WIM stations, and coverage counts, as well as the costs of processing and managing the collected data. It is impractical to have such coverage for local roads due to the relatively vast expanse of that network of roads.

This study established a database using traffic counts from INDOT, MPOs, RPOs, and other organizations. A robust, comprehensive, and adaptable database that covers all the mileage of public roadways was established. State routes are defined as interstates, US roads, and state roads and are under the jurisdiction of the state government. Local routes are defined as city streets and county roads and are under the jurisdiction of municipalities and counties. For state routes, the entire population is used for the VMT estimation; for local roads, a sample is used.

Also, this study reconciled the different approaches and methods of VMT estimation Different approaches based on fuel, vehicle registration, licensed drivers, and trend analysis were used to estimate VMT, and their outcomes were processed to yield the deviations from the benchmark method for VMT estimation. This analysis increased the reliability and consistency of different VMT estimates and provided a framework that includes suitable calibration factors.

3.2 Desired Qualities of Framework

With regard to the proposed VMT estimation framework, it was desired to have certain key characteristics. First, it should be such that it can provide VMT estimates that will serve as benchmarks for comparing the VMT estimates from other approaches and methods. Secondly, it should be capable of duly making use of the vast amounts of traffic count data made available from the state's short-term and long-term count program. Third, it should be able to generate VMT by different levels of spatial aggregation: corridor or road links, cities or MPO areas, counties, districts, and the entire state. Fourth, it should be able to generate VMT estimates by state and local road jurisdictions. Fifth, it should be capable of generating VMT by functional class. Sixth, it should be capable of generating VMT estimates by user group (FHWA vehicle classes 1 to 13). Such capability of disaggregation by attributes related to the vehicle, road class, jurisdiction, or spatial scope are essential for agency processes such as highway cost allocation, revenue forecasting, and other applications discussed in Chapter 1. Seventh, it should be easy to accommodate changes in the factors that influence VMT (for example, new road construction, realignment of existing roads, decommissioning or devolution of roads, and so on). Eighth, it should be able to implement the framework on a flexible and modular platform such as a spreadsheet.

3.3 Selection of Estimation Methodology

As evident from the literature review, the VMT estimation approaches that are not based on traffic counts tend to be prone to discrepancy, generally require excessive data compilation resources and effort, and often lack the capability for disaggregation as discussed in the previous section. So, while the traffic-based methods are preferable, at least for purposes of serving as a benchmark, it must be added that even those methods face significant obstacles when they are applied to local routes where there exists severe lack of traffic data.

From the literature review's synthesis of findings and desired framework qualities, a segment of the project level approach (which will be called the "link-level method" for the remainder of this report) was selected as the ground-truth or benchmark VMT estimation method.

This link-level method uses actual on-the-ground traffic counts obtained from both short-term coverage stations and long-term permanent stations to represent statewide travel on Indiana's roadways. The link-level method is capable of providing VMT estimates for a specific range of locations, such as a corridor, as well as aggregations of VMT of all routes to produce an area-wide VMT estimation. VMT estimation by vehicle class and road functional class is fully possible and robust using this method. Finally, the link-level method was implemented with Excel or GIS, providing powerful analytical capabilities and an updatable inventory. As more recent traffic data become available, the modular nature of this method becomes advantageous because it facilitates updating of the VMT estimates.

4. RESULTS AND CONCLUSIONS

This section provides the results from the statewide VMT estimations at the link level, aggregated over the different scopes (spatial, jurisdictional, functional class, and so on). Aggregations based on the available link level traffic data were provided by county, administrative district, road class, and HPMS. In addition, the predicted statewide VMT at the link level was provided for future years. Finally, the results from the VMT estimation methods other than the link-level method were presented and discussed.

4.1 Reconciliation of Estimation Methods

The findings indicate significant variations among the estimation methods and the approaches within those methods, based on a comparison of obtained estimates to the link-level benchmark adopted for this study (Figure 4.1). It is observed that the commercial VMT estimated using the non-traffic methods tends to be an underestimate of the actual VMT. For VMT estimates obtained using methods other than the benchmark method (the solid black line in Figure 4.1), the extent of deviation from the benchmark VMT are presented graphically in the figure. Table 4.1 presents the calibration factor table for the VMT estimation methods to reconcile VMT estimates obtained from different methods and techniques that may be used within the agency and other organizations. Calibration factors were developed based on the percent deviation for each VMT estimation method and technique. The technique codes refer to Table 5.30 in Part II of this report. To demonstrate the application of these calibration factors, numerical examples are provided. For example, if the VMT is obtained from linear trend analysis (TA-1), the calibration factor of 0.933 is used: the VMT estimate is multiplied by 0.933 to yield the true VMT. Similarly, if the fuel revenue method (F-2) is used for VMT estimation, then the estimate obtained should be multiplied by the calibration factor of 1.058 to yield the true VMT.

4.2 Summary of Developed Framework

The first task of the study was a comprehensive review of the literature and qualitative analysis of VMT estimation methods appropriate for different application contexts and levels. Also, a survey of VMT stakeholders helped to identify the challenges faced with VMT estimation and to identify the preferred outputs of any platform for VMT estimation. These initial steps were undertaken to streamline the study effort, categorize the different methods of VMT estimation, and identify their limitations.

The non-traffic methods were deemed inadequate for meeting the entirety of agency needs because they do not readily provide VMT by vehicle class, road functional class, jurisdiction (state vs. local), or administrative region (district, county). The segment or link-level method was thus selected as the best method to serve as the benchmark method for reconciling the inconsistencies in different VMT methods.

The proposed benchmark method uses traffic counts at the segment level to provide full coverage of the road inventory. This method was implemented in a series of Excel spreadsheets that collectively provide a platform for present and future VMT information and allow for easy updates of the data and also the resulting VMT estimate. Using Indiana traffic data, a database was developed with traffic counts covering the entire population of state routes (interstates and US and state roads) and a representative sample local routes (city streets and county roads). The developed comprehensive database facilitates extensive aggregations from the segment level by spatial scopes, highway category, route, vehicle class, and road functional class. These Excel spreadsheets are accompanied by a user's manual provided as part of the study's deliverables.

To facilitate VMT prediction for a future year, growth factors were developed based on the observed traffic data. These growth factors were developed by functional class and were applied at the segment level to represent any time-horizon selected in the spreadsheet system. To account better for the stochastic nature of long-term traffic forecasting, a low, medium, and high range of estimates were produced for several different VMT aggregations, thereby providing a scenario-based analysis of traffic growth to quickly assess possible future VMTs.

Spatial interpolation techniques were applied to impute the missing AADTs at local roads. Specifically, neighboring traffic counts were used to estimate traffic volumes at segments where such data were unavailable. Different spatial interpolation techniques with ArcGIS were investigated, including kriging, natural neighbor, inverse distance weighting, and trend. Each interpolation technique produced a raster surface of the continuous variation of AADT spatially. To assess the accuracy and appropriateness of each technique for local road VMT estimation, the techniques were validated by functional class for each of the representative counties analyzed. Also, a county-wide total VMT was developed, establishing benchmark values for future use. The capabilities of spatial interpolation were quantitatively demonstrated for estimating local VMT for Indiana.

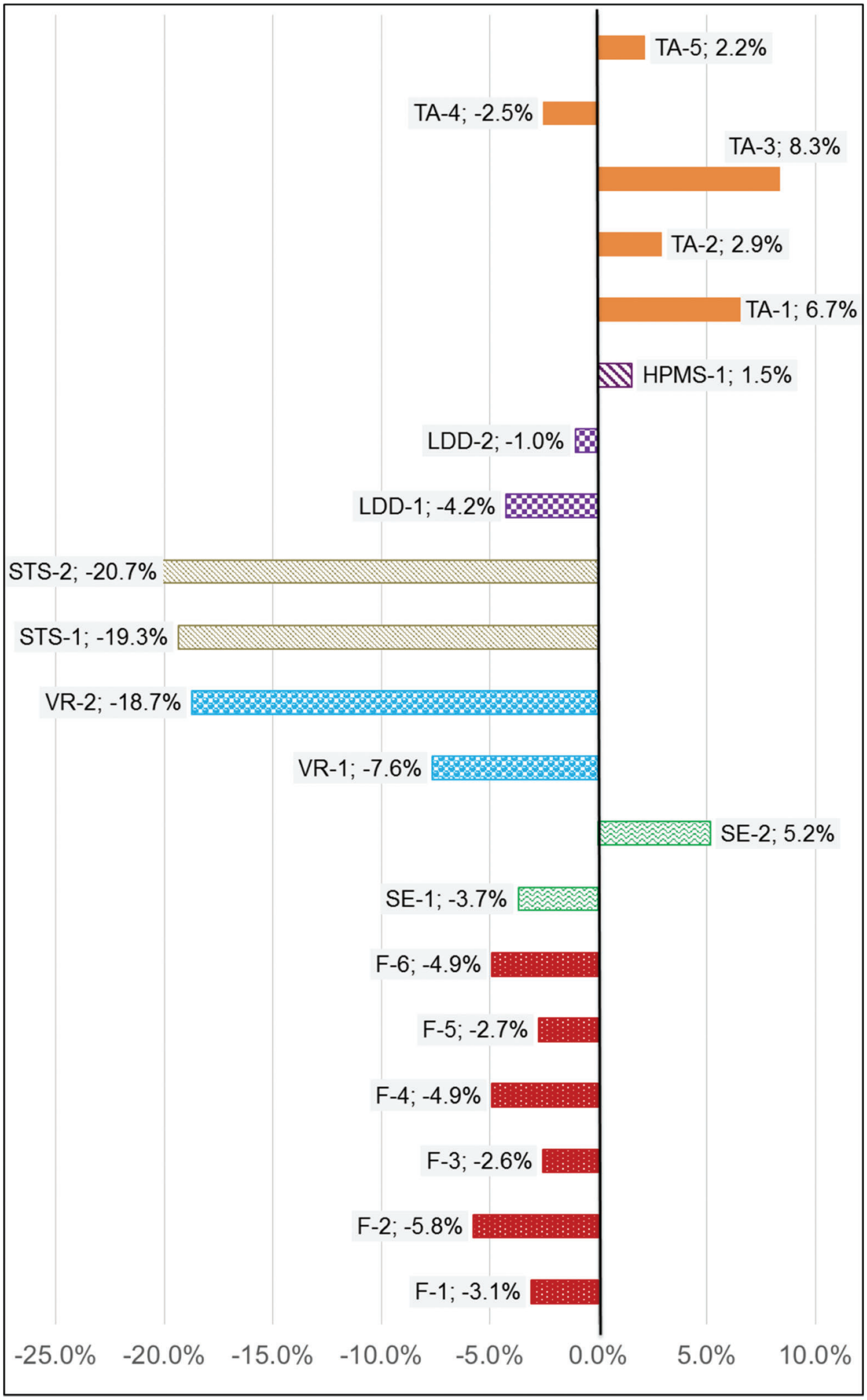

Figure 4.1 Deviations of VMT estimated from benchmark VMT by estimation approach.

TABLE 4.1
Calibration factor table for VMT estimation methods.

Method	Technique	Percent Deviation	Calibration Factor
Trend Analysis	TA-1	6.70	0.933
	TA-2	2.90	0.971
	TA-3	0.30	0.997
	TA-4	-2.50	1.025
	TA-5	-3.10	1.031
	TA-6	-2.90	1.029
	TA-7	2.20	0.978
HPMS	HPMS-1	1.50	0.985
Licensed Drivers and Demographics	LDD-1	-1.00	1.010
	LDD-2	-4.20	1.042
Socioeconomic Travel Surveys	STS-1	-20.70	1.207
	STS-2	-19.30	1.193
Vehicle Registrations	VR-1	-7.60	1.076
	VR-2	-18.70	1.187
Socioeconomic Regression	SR-1	-3.70	1.037
	SR-2	5.20	0.948
Fuel-Revenue	F-1	-3.10	1.031
	F-2	-5.80	1.058
	F-3	-2.60	1.026
	F-4	-4.90	1.049
	F-5	-2.70	1.027
	F-6	-4.90	1.049

TABLE 4.2
Summary of total VMT across different estimation methods.

Annual VMT Estimates (units in billions)		
Code	**Estimation Methodology**	**4–5 Year Average**
F-1	Fuel-Revenue	73.706
F-2	Fuel-Revenue	71.678
F-3	Fuel-Revenue	74.101
F-4	Fuel-Revenue	72.318
F-5	Fuel-Revenue	73.974
F-6	Fuel-Revenue	72.333
SR-1	Socioeconomic Regression	73.260
SR-2	Socioeconomic Regression	79.975
VR-1	Vehicle Registrations	70.239
VR-2	Vehicle Registrations	61.802
STS-1	Socioeconomic Travel Surveys	53.661
STS-2	Socioeconomic Travel Surveys	52.760
LDD-1	Licensed Drivers/ Demographics	72.828
LDD-2	Licensed Drivers/ Demographics	75.258
HPMS-1	HPMS	77.222
TA-1	Trend Analysis	81.140
TA-2	Trend Analysis	78.260
TA-3	Trend Analysis	82.392
TA-4	Trend Analysis	74.130
TA-5	Trend Analysis	77.692
LS-1	Link-Specific (Benchmark)	76.052
LS-2	Link-Specific (Benchmark)	65.689

4.3 Summary of Findings across Different Methods

The results from the different non-traffic VMT estimation methods varied greatly, not only across methods, but with respect to the assumptions and specific techniques within each method (see Table 4.2). This variation is illustrated using data spanning 2009–2013. For example, the fuel-revenue method, on average, yielded underestimates in the range of 71.678 to 74.101 billion but were close to the benchmark value. However, the fuel-revenue method was found to be less accurate in estimating individual vehicle class VMT and underrepresented commercial VMT. The results from the licensed drivers method indicate that its accuracy varied by year and technique, with a range of 72.828 to 75.258 billion. However, as the inputs are self-reported mileage from travel surveys, such wide variation probably suggests that this method may be vulnerable to misrepresentation and infrequent updating. With regard to the regression method of VMT estimation method using cross-sectional economic data, using the actual economic conditions as the input data yielded a value of 73.260 billion, while using the predicted economic conditions led to a higher value of 79.975 billion; this suggests that the VMT derived using cross-sectional regression techniques is susceptible to economic fluctuations and unforeseen demographic changes. Table 4.3 presents a summary of VMT estimates for key classifications (for the medium growth range), and Table 4.4 presents a summary of VMT by highway system and vehicle class (for the medium growth range).

TABLE 4.3
Summary of key VMT estimates (medium growth range).

			Annual VMT Estimates (units in billions)										
Aggregation	**Category**	**Average % of Total**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Jurisdiction	All	100.0%	78.404	79.161	79.925	80.698	81.479	82.269	83.067	83.874	84.690	85.516	86.350
	State Routes	53.7%	41.652	42.137	42.627	43.124	43.627	44.136	44.653	45.176	45.705	46.242	46.786
	Local Routes	46.3%	36.752	37.024	37.298	37.574	37.852	38.132	38.414	38.699	38.985	39.273	39.564
Highway Route Type	Interstates	23.3%	18.278	18.456	18.636	18.818	19.002	19.188	19.375	19.565	19.756	19.949	20.145
	US Highways	13.5%	10.398	10.529	10.662	10.797	10.934	11.073	11.214	11.357	11.502	11.649	11.798
	State Highways	16.9%	12.977	13.151	13.328	13.508	13.690	13.875	14.063	14.254	14.447	14.643	14.843
	Local Roads	46.3%	36.752	37.024	37.298	37.574	37.852	38.132	38.414	38.699	38.985	39.273	39.564
FHWA Functional Class	FC 1	23.3%	18.278	18.456	18.636	18.818	19.002	19.188	19.375	19.565	19.756	19.949	20.145
	FC 2	2.1%	1.629	1.648	1.668	1.688	1.709	1.729	1.750	1.771	1.792	1.814	1.836
	FC 3	26.2%	20.396	20.623	20.852	21.085	21.320	21.559	21.800	22.045	22.293	22.545	22.799
	FC 4	19.6%	15.380	15.519	15.660	15.803	15.946	16.092	16.239	16.387	16.537	16.688	16.841
	FC 5	24.9%	19.654	19.823	19.993	20.165	20.339	20.514	20.691	20.870	21.050	21.232	21.416
	FC 6	1.1%	0.844	0.851	0.858	0.865	0.873	0.880	0.888	0.895	0.903	0.910	0.918
	FC 7	2.8%	2.223	2.240	2.256	2.273	2.290	2.307	2.324	2.342	2.359	2.377	2.394
Administrative District (State Routes Only)	Crawfordsville	13.2%	5.508	5.572	5.637	5.703	5.770	5.837	5.905	5.974	6.044	6.115	6.187
	Fort Wayne	14.8%	6.174	6.246	6.318	6.392	6.467	6.542	6.619	6.696	6.775	6.854	6.935
	Greenfield	26.2%	10.909	11.036	11.164	11.294	11.426	11.560	11.695	11.832	11.970	12.111	12.253
	Laporte	20.0%	8.321	8.418	8.516	8.615	8.716	8.818	8.921	9.025	9.131	9.238	9.347
	Seymour	16.3%	6.804	6.883	6.963	7.044	7.126	7.210	7.294	7.379	7.466	7.554	7.642
	Vincennes	9.4%	3.936	3.982	4.028	4.075	4.122	4.171	4.219	4.269	4.319	4.370	4.421
Commercial	All	100.0%	9.322	9.420	9.519	9.620	9.722	9.825	9.929	10.035	10.142	10.250	10.359
	State Routes	74.9%	6.943	7.024	7.105	7.188	7.272	7.357	7.443	7.530	7.619	7.708	7.799
	Local Routes	25.1%	2.379	2.396	2.414	2.432	2.450	2.468	2.486	2.505	2.523	2.542	2.561

TABLE 4.4
Summary of VMT by highway system and vehicle class (medium growth range).

FHWA Vehicle Class	Primary Highway Systems	VMT Estimates by Year (units in billions) 2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
1	State Routes	0.209	0.211	0.214	0.216	0.219	0.221	0.224	0.226	0.229	0.232	0.234	0.237	0.240	0.243	0.246	0.249	0.252	0.255	0.258	0.261	0.264
	Local Routes	0.220	0.221	0.223	0.224	0.226	0.228	0.229	0.231	0.233	0.235	0.236	0.238	0.240	0.242	0.243	0.245	0.247	0.249	0.251	0.253	0.254
2	State Routes	25.046	25.337	25.632	25.930	26.233	26.539	26.850	27.164	27.483	27.805	28.132	28.464	28.799	29.139	29.483	29.832	30.186	30.544	30.907	31.275	31.648
	Local Routes	23.988	24.165	24.344	24.524	24.706	24.889	25.073	25.258	25.445	25.634	25.823	26.014	26.207	26.401	26.596	26.793	26.991	27.191	27.392	27.595	27.799
3	State Routes	9.455	9.565	9.676	9.789	9.903	10.019	10.136	10.255	10.375	10.497	10.620	10.745	10.872	11.001	11.131	11.262	11.396	11.531	11.668	11.807	11.948
	Local Routes	10.166	10.241	10.317	10.393	10.470	10.548	10.626	10.704	10.784	10.863	10.944	11.025	11.106	11.189	11.271	11.355	11.439	11.523	11.609	11.695	11.781
4	State Routes	0.111	0.112	0.113	0.115	0.116	0.117	0.119	0.120	0.122	0.123	0.125	0.126	0.127	0.129	0.130	0.132	0.134	0.135	0.137	0.138	0.140
	Local Routes	0.039	0.040	0.040	0.040	0.040	0.041	0.041	0.041	0.042	0.042	0.042	0.043	0.043	0.043	0.044	0.044	0.044	0.045	0.045	0.045	0.046
5	State Routes	1.355	1.370	1.386	1.402	1.419	1.435	1.452	1.469	1.486	1.504	1.521	1.539	1.558	1.576	1.595	1.613	1.633	1.652	1.672	1.691	1.712
	Local Routes	0.627	0.632	0.636	0.641	0.646	0.650	0.655	0.660	0.665	0.670	0.675	0.680	0.685	0.690	0.695	0.700	0.705	0.711	0.716	0.721	0.727
6	State Routes	0.371	0.376	0.380	0.384	0.389	0.394	0.398	0.403	0.408	0.412	0.417	0.422	0.427	0.432	0.437	0.442	0.448	0.453	0.458	0.464	0.469
	Local Routes	0.379	0.381	0.384	0.387	0.390	0.393	0.396	0.399	0.402	0.405	0.408	0.411	0.414	0.417	0.420	0.423	0.426	0.429	0.432	0.436	0.439
7	State Routes	0.105	0.106	0.108	0.109	0.110	0.112	0.113	0.114	0.116	0.117	0.118	0.120	0.121	0.122	0.124	0.125	0.127	0.128	0.130	0.131	0.133
	Local Routes	0.129	0.130	0.131	0.132	0.133	0.134	0.135	0.136	0.137	0.138	0.139	0.140	0.141	0.142	0.143	0.145	0.146	0.147	0.148	0.149	0.150
8	State Routes	0.410	0.415	0.420	0.425	0.430	0.435	0.440	0.445	0.450	0.456	0.461	0.466	0.472	0.478	0.483	0.489	0.495	0.501	0.507	0.513	0.519
	Local Routes	0.121	0.121	0.122	0.123	0.124	0.125	0.126	0.127	0.128	0.129	0.130	0.131	0.132	0.133	0.134	0.135	0.136	0.137	0.138	0.139	0.140
9	State Routes	4.338	4.389	4.440	4.492	4.544	4.597	4.651	4.705	4.761	4.817	4.873	4.931	4.989	5.048	5.107	5.168	5.229	5.291	5.354	5.418	5.482
	Local Routes	1.052	1.059	1.067	1.075	1.083	1.091	1.099	1.107	1.115	1.124	1.132	1.140	1.149	1.157	1.166	1.175	1.183	1.192	1.201	1.210	1.219
10	State Routes	0.062	0.063	0.063	0.064	0.065	0.066	0.066	0.067	0.068	0.069	0.070	0.070	0.071	0.072	0.073	0.074	0.075	0.076	0.076	0.077	0.078
	Local Routes	0.017	0.017	0.017	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.020	0.020	0.020	0.020
11	State Routes	0.115	0.116	0.118	0.119	0.120	0.122	0.123	0.125	0.126	0.128	0.129	0.131	0.132	0.134	0.135	0.137	0.138	0.140	0.142	0.143	0.145
	Local Routes	0.007	0.007	0.007	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.009
12	State Routes	0.040	0.041	0.041	0.042	0.042	0.043	0.043	0.044	0.044	0.045	0.045	0.046	0.047	0.047	0.048	0.048	0.049	0.049	0.050	0.051	0.051
	Local Routes	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
13	State Routes	0.035	0.035	0.035	0.036	0.036	0.037	0.037	0.038	0.038	0.038	0.039	0.039	0.040	0.040	0.041	0.041	0.042	0.042	0.043	0.043	0.044
	Local Routes	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006

PART II CONTENTS

LIST OF TABLES

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ACRONYMS AND ABBREVIATIONS

AADT	Average Annual Daily Traffic
ATR	Automatic Traffic Recorder
AVMT	Annual Vehicle Miles Traveled
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
BMV	Bureau of Motor Vehicles
CAAA-90	Clean Air Act Amendments
CRHV	County Roads High Volume
CRLV	County Roads Low Volume
CSHV	City Streets High Volume
CSLV	City Streets Low Volume
CT	Combination Trucks
EGR	Economic Growth Region
EIA	Energy Information Administration
FC	Functional Classification
FHWA	Federal Highway Administration
GF	Growth Factor
GIS	Geographic Information System
GVW	Gross Vehicle Weight
HPMS	Highway Performance Monitoring System
HS	Highway Statistics
HSIP	Highway Safety Improvement Program
HTF	Highway Trust Fund
INDOT	Indiana Department of Transportation
IMP	Interstate Maintenance Program
ISTEA-99	Intermodal Surface Transportation Efficiency Act
LRS	Location Referencing System
MAP-21	Moving Ahead for Progress in the 21st Century Act
MACOG	Michiana Area Council of Governments
MPO	Metropolitan Planning Organization
NHS	National Highway System
NHTS	National Household Travel Survey
NN	Natural Neighbor
OHPI	Office of Highway Policy Information
RPO	Regional Planning Organization
SHS	State Highway System
SHA	State Highway Agency
SUT	Single-Unit Trucks
STP	Surface Transportation Program
STT	Single-Trailer Trucks
TAPC	Tippecanoe Area Plan Commission
TCDS	Traffic Count Database System
TDM	Travel Demand Model
UAB	Urban Area Boundaries
USC	United States Census
USDOT	United States Department of Transportation
VC	Vehicle Classification
VMT	Vehicle Miles of Travel or Vehicle Miles Traveled
WIM	Weigh-in-Motion

1. INTRODUCTION

Vehicle miles of travel (VMT) estimates are used extensively for a variety of highway transportation management functions, including asset management, financial analysis, resource allocation planning, estimation of emissions and energy consumption, and traffic impact assessments, as shown in Figure 1.1. VMT serves as a critical input for this wide range of applications for a number of reasons.

First, reliable estimates or predictions of VMT are critical for use in highway revenue forecasting models that require, as input data, the future-year VMT by vehicle class. Second, the reporting of highway asset performance (system preservation, congestion mitigation, safety, and mobility) is often reported in terms of VMT. For example, network-wide safety performance is often measured in terms of the number of fatalities per million VMT. Third, VMT data is useful for high-level oversight of a transportation system and also for investigating the impacts of changes in policy. State legislatures often make requests for aggregate travel information (VMT by vehicle class and by highway class) on the state highway network, particularly in the current era when states have begun to consider legislation related to new or existing revenue sources. Due to current and projected sharp reductions in fuel tax revenue, state and federal governments are considering the feasibility of switching from the current fuel tax to a mileage-based user tax such as a VMT fee. State highway agencies (SHA) need the capability to generate reliable and consistent VMT estimates and VMT forecasts in order to estimate the expected revenue from any mileage-based user fees in the future. Fourth, as evidenced by past trends, there appears to be a strong and positive correlation between VMT and the economic vitality of a region, and VMT estimates can therefore potentially serve as a gauge of the economic output in a state. Fifth, VMT has critical implications for highway funding because VMT levels influence each state's "share" of federal highway funding. The funding provided by the Interstate Maintenance Program (IMP), the National Highway System (NHS), the Surface Transportation Program (STP), and the Highway Safety Improvement Program (HSIP) is allocated, in part, using a formula relating the extent of the VMT at each highway class. For example, apportionment formulas for federal-aid eligible highway programs including the IMP, NHS, STP, and HSIP, have weights of 33.33%, 35.00%, 40.00%, and 33.33%, respectively, based on the VMT contribution (FHWA, 2014). Finally, For transportation planning in general, VMT information assists in the compliance process for federal regulations and legislation such has the Clean Air Act Amendments of 1990 (CAAA), the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA-91), the Transportation Equity Act for the 21st Century (TEA-21), SAFETEA-LU of 2005, and most recently, MAP-21. As seen in Figure 1.2, each legislation has provisions that implicitly require VMT estimation (Fricker & Kumapley, 2002; OHPI, 2014a; Vadlamani, 2005). Appropriations of highway funding and IM and STP programs are affected by TEA-21. The IM program finances an essential range of projects, from routine upkeep of interstate HMA pavement overlays to inspections and geometric safety improvements to reduce crashes (OHPI, 2014a,b; Stanley, 2002). MAP-21 also affects highway trust funds and the state and metropolitan planning processes, which heavily rely on VMT estimates as critical inputs.

For the reasons stated above, reliable VMT data at a current year or for future years are sought by a variety of

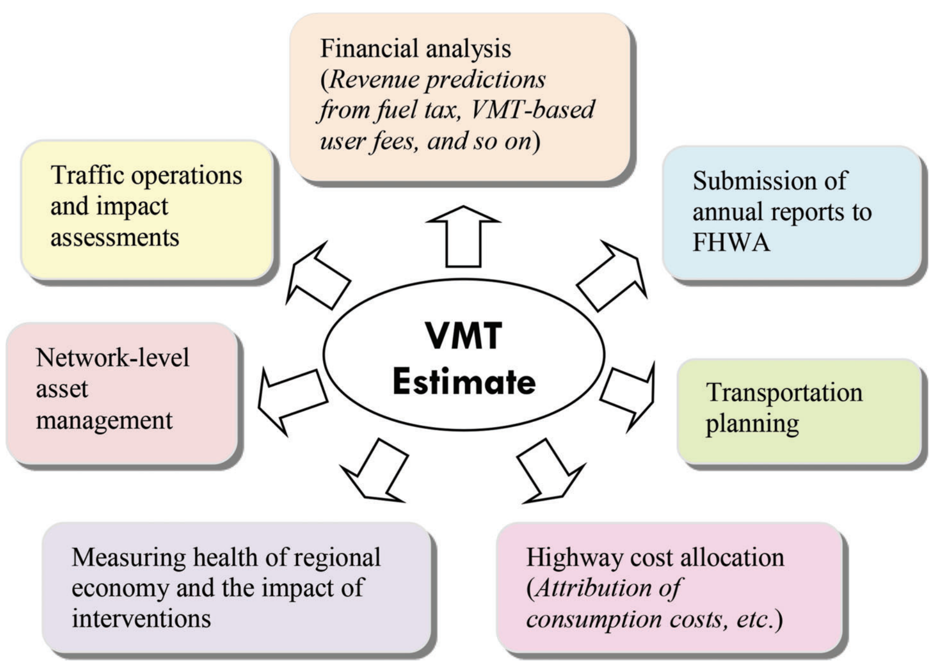


Figure 1.1 Applications of VMT estimates in highway agencies.

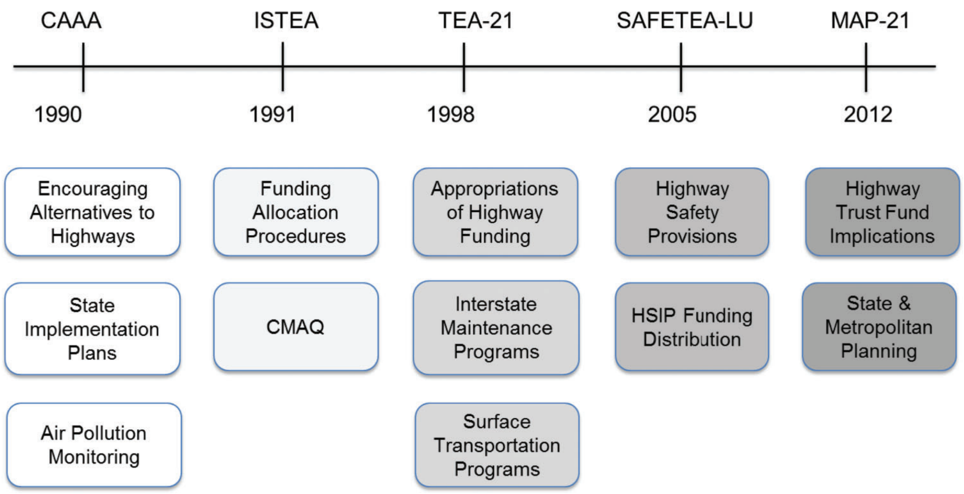


Figure 1.2 Timeline of federal legislation that implicitly require VMT estimates.

organizations and agencies of various levels of government, including state transportation agencies, metropolitan planning organizations (MPOs), regional planning organizations (RPOs), local municipalities, and federal agencies and legislators (EPA, 1999; Fricker & Kumapley, 2002; Gunawardena & Sinha, 1994; Kumapley & Fricker, 1994; Varma, Sinha, & Spalding, 1992).

1.1 Problem Statement

VMT estimates typically come from a wide variety of sources, and it has been observed that there exist wide variations among the VMT estimates developed from these sources. In theory, the VMT estimates from disaggregate methods should be consistent with those from reported aggregate methods. However, in practice, this is not often the case. Such inconsistency is a particularly worrisome situation given the critical role of VMT estimates in the tactical and strategic policy analysis, decision-making, and functions related to multiple applications as presented in Figure 1.

For the different methods of VMT estimation, different sample sizes, computational techniques, and resource levels are used to satisfy the intended end use. At the current time, INDOT does not have the capability to readily provide reliable VMT estimates by vehicle class and highway functional class. As a result, there exist obstacles to applications including revenue predictions and attributions by vehicle class and highway class, and the reporting of asset deterioration and operational performance associated with each vehicle class and highway class. Furthermore, reliable and consistent VMT estimates and forecasts broken down by vehicle class and highway functional class are needed to evaluate the efficiency and equity of a possible mileage-based user fee scheme.

1.2 Study Objectives and Scope

Considering the importance of VMT, an objective analysis of different approaches for VMT estimation is needed. This study seeks to outline the limitations and advantages of each approach, identify the best approach to serve as the benchmark approach and quantitatively assess the extent of deviation of their VMT estimates from the benchmark estimate. The study also seeks to develop a spreadsheet tool to implement the framework. This tool will serve as a central source for summary outputs and will provide tabular and graphical results that aim to quantify existing VMT and highlight changing trends with VMT for the entire public road network in the state. The study also intended to develop recommendations regarding an implementation and management strategy for storing and updating the VMT information intended to enhance the implementation of the study product throughout INDOT.

The scope of the study is state and local routes that comprise Indiana's 90,000-mile public highway system. State routes are defined for this study as interstates (I), US highways (US), and state roads (SR). All interstates, a majority of US highways, and a few state roads constitute the NHS. The local routes, as defined for this study, are non-INDOT owned city streets (CS) and county roads (CR). City streets include avenues, boulevards, downtown streets, lanes, and other neighborhood streets.

1.3 Report Organization

This document (Volume II) is an appendix to the main report (Volume I). It has six chapters that correspond to each major task of the study. Chapter 1, which contains the preface and background information, introduces the subject of VMT in highway management, and discusses the problem statement and objectives. Chapter 2 presents a literature review of past studies related to VMT estimation. In Chapter 3, the study methodology is presented. VMT estimation using the link-level (traffic related) and non-link-level (non-traffic) is discussed. Chapter 4 presents the analysis and modeling for state routes and local routes. Chapter 5 presents the results and discusses the statewide VMT aggregations for both estimation and prediction of state and local route VMT. Finally, Chapter 6 summarizes the study methodology and framework, and discusses the conclusions and recommendations, problems encountered, and directions for future studies on this subject.

2. LITERATURE REVIEW

2.1 Introduction

Past comprehensive reviews of VMT estimation approaches (Kumapley & Fricker, 1996; Fricker & Kumapley, 2002; Liu & Kaiser, 2006; Vadlamani, 2005) have identified two broad approaches that differ by input data type for statewide VMT estimation (Figure 2.1).

The first approach is based on the road network traffic counts. The use of this approach is evident in the FHWA's Highway Performance Monitoring System (HPMS) (OHPI, 2014a). The broad approach uses traffic counts at different points along the road network and the road mileage associated with each sample point to produce an area-wide VMT estimate. The second broad approach determines VMT based on non-traffic data sources and typically yield VMT estimates for entire geographic areas rather than for highway corridors. Certain approaches associated with this broad approach consider the location, sources, and purpose of the travel that influence statewide VMT. The broad approach typically uses data on variables that are indirect predictors of VMT such as the number of households, household incomes, licensed drivers, fuel revenues, and vehicle registrations. In a few approaches that use this broad approach, some traffic data are used. These broad approaches and approaches have their inherent merits, demerits, and different data requirements.

2.2 Characteristics of VMT Estimation Approaches

This section discusses the background and literature associated with the identified statewide VMT broad approaches that primarily use either traffic or non-traffic data. A summary of the key characteristics of each approach, by data type and application level, is provided in the sections that follow.

2.2.1 VMT Estimation Using Traffic-Based Approaches

In VMT estimation related to traffic counts, use is made of traffic volumes determined from continuously-collected traffic data. This data cover the population of highway segments or, more often, only for a sample thereof. The actual (on-the-ground) traffic counts are obtained at various times seasonally and daily, such as peak and off-peak hours. The HPMS mandates that all federal-aid eligible highway routes must have traffic volumes measured through count stations to assess current and predict future traffic conditions (OHPI, 2014a). Therefore, since 1978, highway agencies have used the HPMS sample as a basis for estimating VMT for their annual reports to federal oversight agencies including the FHWA regarding their highway infrastructure operations, condition, and performance (EPA, 1999; OHPI, 2014a). The annual average daily traffic (AADT), a common measure of traffic volume, is estimated using count data from both temporary and permanent traffic count stations. This is subsequently expanded to yield an area-wide or statewide VMT estimate by functional class (FHWA, 2013b).

Permanent count stations collect daily traffic data on a continuous basis (OHPI, 2014b). These stations are equipped with automatic traffic recorders (ATR). As of 2015, Indiana maintains 106 pieces of this equipment. These traffic counts must often be adjusted to more accurately represent traffic conditions depending on the time of year and day of the week. To do this, past researchers have used a variety of techniques, including neural networks and weighted-distance methods (Jin & Fricker, 2008; Sharma, Lingras, Xu, & Liu, 1999). The state of Indiana also has 35 weigh-in-motion (WIM) detectors that provide important data for developing ESAL values, temporal adjustments to short-term counts, identify long-term trends, and measure vehicle weights (INDOT, 2015a,b).

Count stations of the short-term (also referred to as coverage or temporary) collect count data on a rotational program, typically 2–3 year intervals. The Statewide Coverage Count Program implemented by INDOT collects traffic counts for state-owned routes and non-state owned Federal Aid Routes, with 10,000 and 6,000 counts required annually, for state owned

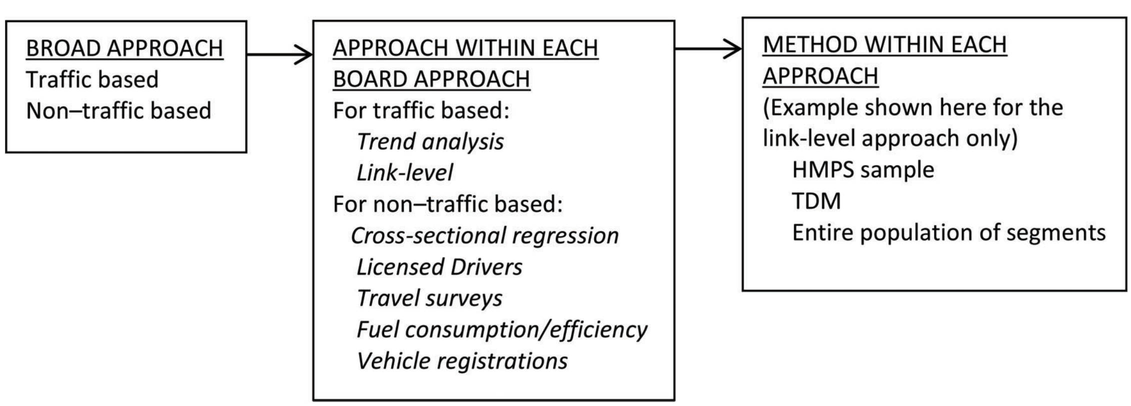


Figure 2.1 Broad approaches, approaches, and methods for statewide VMT estimation.

routes and non-state owned Federal Aid Routes, respectively (INDOT, 2015a). The temporary stations collect at least 48 hours of traffic counts, which are subsequently averaged to 24 hours to produce AADT estimates and are then commonly used as inputs for VMT estimation among other applications (OHPI, 2014b).

However, one of the recurring issues with traffic monitoring (and thus, VMT estimation) is the lack of count consistency and reliable coverage for local routes (Fricker, 1987; Mohamad, 1997; Mohamad, Sinha, Kuczek, & Scholer, 1998; Seaver, Chatterjee, & Seaver, 2000). Local routes, such as, city streets and county roads typically have far lower availability of traffic data compared to local routes, such as interstates and US highways. The extent of data collected depends on the road classification, "importance", and availability of traffic counting equipment. For example, interstates are extensively monitored, many with permanent ATRs capable of providing volume, classification, and weight data for each of the 13 FHWA vehicle classes.

Figure 2.2 presents the generic link-level method (or segment-level) of the traffic-based approaches for VMT estimation. This method can be based on actual or estimated counts, from either the population or a sample thereof as in the HPMS dataset. Travel demand models (TDMs) are an example of this approach, where the estimated counts are expanded to the road network to simulate traffic, often for project-level applications.

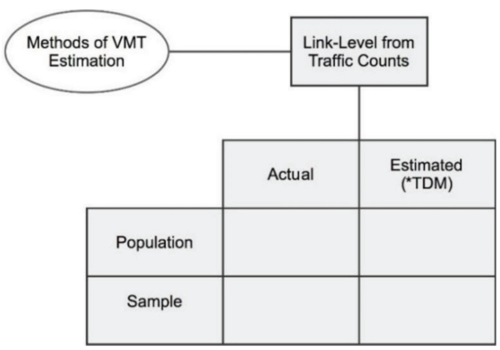


Figure 2.2 Hierarchy of link-level estimation from traffic counts.

2.2.2 VMT Estimation Using Methods Not Based on Traffic Counts

Over 25 years ago, it was realized that travel-related economic indicators, such as gasoline sales, income, employment, and vehicle registrations could be used as a basis for VMT estimation (Erlbaum, 1989). Since then, a number of past researchers have used methods that are based mostly on other attributes besides traffic counts. These include the driving-age cohort and demographic characteristics, odometer readings, fuel sales, socioeconomic regression models, and vehicle registrations (Agbelie, Bai, Labi, & Sinha, 2010; Kumapley & Fricker, 1994; Maring, 1974; Schipper & Moorhead, 2000; Vasudevan & Nambisan, 2013). It is worthy to note that data on demographics, household characteristics, economic activity, and fuel efficiencies must be updated because these attributes change with time. It is therefore fortunate that travel surveys, which are critical inputs for many non-traffic methods, such as the National Household Travel Survey (NHTS) (FHWA, 2009) and the U.S. Census (USC) (U.S. Census, 2010), are updated every 5–6 and 10 years, respectively. Unfortunately, the resulting VMT estimates are often limited and too aggregate to be of practical use to certain end users.

2.2.3 VMT Estimation Methods by Type of Data

The different approaches and methods for VMT estimation can be distinguished by the type of input data and procedures they use. Figure 2.3 presents the methods that are capable of providing statewide values of VMT. Certain methods, discussed this section provide VMT estimates for each of the vehicle classes or for certain classes only. A matrix was developed to summarize the differences in the methods for VMT estimation based on the data type (Figure 2.4). The type

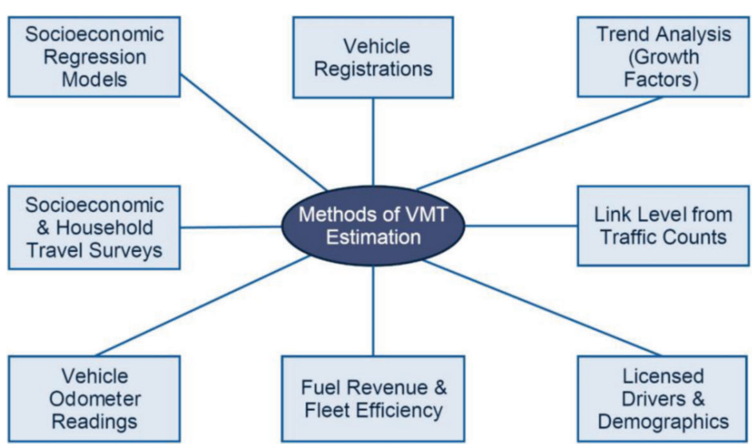


Figure 2.3 VMT estimation methods that provide statewide estimates of VMT.

VMT Estimation Method \ Estimation Characteristic	Traffic-Based	Non-Traffic Based	Directly Obtainable By Functional Class	Directly Obtainable By Vehicle Class	Demographics Data	Fuel Tax Reports	Socioeconomic Data	Uses Growth Rates or Expansion Factors	Travel-Survey Based	Time Series Data
Trend Analysis (Growth Factors)	X	X						X		X
Regression Analysis		X		X			X			
Socioeconomic (Household) Travel Surveys		X			X		X		X	
Licensed Drivers & Demographics		X			X				X	X
Link Level (Sample - HPMS)	X		X					X		
Link Level (Actual - Population)	X		X	X						
Odometer Readings		X							X	
Fuel Usage & Fleet Effiencies		X				X				
Link Level (Estimated - TDM)	X	X					X	X		
Vehicle Registrations		X		X						

Figure 2.4 VMT estimation approaches by data input.

of method, coverage level, and data requirements are indicated. For a given end user, the usefulness of a VMT estimation method depends on the desired coverage level and nature of the intended end application. For example, if the end use is related to revenue forecasting, then VMT is desired by vehicle class, then a link-level method that provides VMT by vehicle class, is most appropriate.

2.2.4 VMT Estimation Methods by Level of Coverage

The level of coverage required by the end user, and whether it is at the project, regional or metropolitan, or statewide level, greatly affects which VMT estimation approach is most appropriate. As seen in Figure 2.5, the link-level methods (which are based on traffic counts) provide the most coverage, from the project level to the network level. The provision of adequate coverage is desirable, considering the wide range of agency applications that use VMT estimates.

Details of attributes for a specific road may be vital at the project level (that is, at the segment or link level) where the VMT of a specific corridor is required for some application (for example, the VMT level or VMT trends for a specific route is important for safety or congestion performance measurement and monitoring). Similarly, the VMT estimate of an entire region or metropolitan area may be required in the evaluation of current or predicted patterns of truck travel across different economic zones. Also, if aggregation by highway functional class is what is needed, then VMT estimates from socioeconomic and licensed driver travel surveys do not fulfill this end use; in this case, the most appropriate method would be a link-level method. Trend analysis, another method of VMT estimation, uses historical data to predict future travel; therefore, sudden economic downtowns or upsurges may limit this approach and significantly increase the deviation of the estimated VMT from the actual VMT values.

2.3 Literature Specific to Statewide VMT Estimation

While there has been much study on AADT/VMT estimation, the focus of this literature review is the applications at the statewide level. The methods related

Level of Coverage / VMT Estimation Method	Link or Project Level	Regional or Metropolitan Level	Statewide Level
Trend Analysis (Growth Factors)			X
Regression Analysis	X	X	X
Socioeconomic (Household) Travel Surveys		X	X
Licensed Drivers & Demographics			X
Link Level (Sample - HPMS)	X		X
Link Level (Actual - Population)	X	X	X
Odometer Readings			X
Fuel Usage & Fleet Efficiencies			X
Link Level (Estimated - TDM)	X	X	X
Vehicle Registrations			X

Figure 2.5 Methods for VMT estimation by level of coverage.

to non-traffic and traffic inputs are examined in this section.

2.3.1 Methods of Non-Traffic-Based Estimation

Early studies that estimated VMT in the 1970s and 1980s (Greene, 1987; Maring, 1974) were mostly based on the use of data on the driving age population, licensed driver populations, and average annual mileage driven to forecast nationwide trends. For this, travel surveys, particularly the National Personal Transportation Survey (NPTS) (currently named the National Household Travel Survey (NHTS)) were available and demographic trends are key inputs. Using the average annual miles by licensed drivers and the distribution by gender and age groups, researchers generated a nationwide 2020 estimate. The results were not validated using VMT estimated from a traffic-based method possible because the latter data were not available. Building upon this work, a Purdue study (Kumapley & Fricker, 1994) developed two cross-classification models for Indiana to supplement INDOT's traffic-based VMT estimation. Their method addressed the sampling bias that typically accompanies traffic-based VMT estimation because functional classes are not used as inputs. An updated version (Fricker & Kumapley, 2002) concluded that with respect to the actual personal VMT, the actual estimate was 5% lower than that estimated by the highway agency. The travel surveys used for developing personal VMT estimates are often edited to remove errors; however, it can be expected that discrepancies still exist from travel surveys.

Demographic and licensed driver's data are compiled by the NHTS and FHWA's *Highway Statistics* series (OHPI, 2014d), as well as data from the *American Fact Finder* specific to Indiana (US Census, 2010) for the inputs required for VMT estimation from these methods. These inputs typically include state population, population eligible to be licensed drivers, and annual mileage per licensed driver by the different age groups and gender. The total annual statewide VMT is estimated by multiplying the total annual VMT by the number of licensed drivers per capita and the population (Kumapley & Fricker, 1996).

The commercial or trucking component of VMT cannot be determined using driving age and demographic information because travel survey inputs typically gauge personal (automobile) travel. Considering that Indiana has a significant amount of commercial traffic as many major interstates pass through the state, the use of these methods to represent statewide VMT can be problematic and should be avoided.

Regression models that use cross-sectional data have been applied to estimate VMT for a specific spatial area. The explanatory variables may include the per capita income, gross state income, gross domestic product, and vehicle registrations (Agbelie et al., 2010; Sinha, Labi, Hodge, Tine, & Shah, 2005; Varma et al., 1992).

Forecasting techniques can be implemented using growth factors or regressions using time-series data (INDOT, 2014; Liu & Kaiser, 2006). Growth factors, which are used to adjust one year's traffic volume on the basis of a past year's traffic volume, are popular with SHAs due to their simplicity and ease of application. A number of researchers have examined more advanced techniques for doing this, such as empirical Bayesian forecasting techniques (Masaeid & Al-Omoush, 2014; Davis & Guan, 1996; Zheng, Lee, & Shi, 2006). By relating existing known AADT data with updated data where available, Bayesian techniques may have the potential of more accurately estimating the future traffic volumes. This is helpful for transportation planning applications that use VMT estimation based on traffic estimates at a given jurisdiction.

Socioeconomic models based on national travel surveys, such as the NHTS, or other reliable traveler information include a variety of inputs such as explanatory variables of vehicle registrations, households, population density, and gasoline and diesel prices. California's state transportation agency, Caltrans, uses a "motor vehicle stock, travel, and fuel forecast" model with socioeconomic variables including vehicle registration, fuel consumption, population, and income to forecast VMT (Jones, 1998). Some researchers consider this macroeconomic method to be more robust (compared to the traditional statewide travel demand models) for estimating VMTs for purposes of environmental assessment and economic development planning.

A model developed in 2002 in Indiana (Fricker & Kumapley, 2002) to estimate that state's VMT was based on NHTS data including household size, household income, and number of vehicles to determine the personal component of VMT, applicable for personal vehicles (vehicle classes 1 to 3). For the commercial vehicle (Classes 4–13) contribution to the statewide VMT, the researchers used fuel sales records to generate a rough estimate of VMT. The personal and commercial components were summed to yield the overall statewide VMT.

Time-series techniques are similar in that quality input data are required. Regressing AADT to forecast future traffic volumes has been widely studied (Lowry & Dixon, 2012; Zhao & Chung, 2001). Spatial intepolation of AADT data has the potential to improve the accuracy of AADT predictions (Eom, Park, Heo, & Huntsinger, 2006). These methods may be more suitable for project-level or regional-level applications but not for statewide projections.

For FHWA reporting, relating fuel consumption to the amount of statewide travel is thought to be the earliest method of determining VMT dating back to the 1950s when the interstate highways were constructed. To estimate total VMT, the total fuel revenue for the study area, fleet fuel efficiency, and current fuel tax rates are used (Kumapley & Fricker, 1996). The fuel-revenue method facilitates the generation of an aggregate estimate of the statewide VMT but is limited by its inability to estimate VMT by road functional class. A New York DOT study (Erlbaum, 1989) proposed that VMT could be estimated using a county's average share of the state highways and a proportion of car registrations. Generally, the estimates produced from fuel-based methods are expected to underestimate the actual VMT because several types of vehicles, such as class 5 trucks and government vehicles, are often exempt from certain taxes; thus, this method yields an underestimation of fuel consumption, and hence incorrect VMT estimates. The reliability of fuel inputs including the traffic stream distribution and fuel efficiencies are also of concern (Vasudevan & Nambisan, 2013): biased estimates of VMT could arise from high but unmeasured higher levels of fleet fuel efficiency caused by government mandates and automotive improvements. Other factors such as weather conditions, road surface, and vehicle age, can affect the specified fuel efficiency of a vehicle. This may affect the reliability of VMT estimates developed using this method.

Odometer readings have been proposed as a means to estimate VMT; however, this is not considered a method that is reliable or supplementary to traffic-based VMT methods. Due to a long list of challenges including data acquisition difficulty and possible errors, including rollovers, tampering, faulty odometer calibration, and reporting errors, past research has shied away from the use of odometer records for VMT estimation (Kumapley & Fricker, 1994; Vadlamani, 2005). Several states do not require a self-reported odometer mileage on annual vehicle registration renewal forms sent to motor vehicles agencies. There are also discrepancies with self-reported mileage data: an Energy Information Administration (EIA) report found that self-reported mileage is often higher than the actual mileage traveled (Schipper & Moorhead, 2000).

2.3.2 Traffic-Based Methods for VMT Estimation

For link by link estimation of VMT for the state highway system, either the entire population or a sample thereof can be used. For the latter, a stratified random sample is deemed appropriate. A number of past studies have stratified the traffic count sample at the statewide level by per capita income, highway mileage, and population density (Fricker & Saha, 1986; Mohamad, 1997). Such a sample is the HPMS, a national repository of traffic, pavement, and performance data, deemed to be representative of each state's state highway system. A full documentation of the HPMS sampling procedures and traffic data processing is available in the *Traffic Monitoring Guide* (OHPI, 2014b).

To generate a universe-wide (statewide) daily VMT estimate, $DVMT_{total}$, Equation 2.1 is used, where i represents the volume group, j represents the functional class, and k represents the sample section. The HPMS submittal software provides expansion factors, to represent universe-wide VMT that are frequently evaluated by FHWA staff for accuracy and representation (OHPI, 2014c).

$$DVMT_{total} = \sum_i \sum_j \sum_k DVMT_{ijk} x EF_{ij} \quad (2.1)$$

In past work, researchers have modeled traffic data using GIS and software including TransCAD to connect roadside attributes such as speed limits, high occupancy vehicles (HOV) lanes, and land-area usage, to estimate the AADT distribution (and subsequently to establish VMT distribution). The regional VMT can be estimated using this approach and used for applications including air quality studies and transportation planning (Bhat & Nair, 2000; Vadlamani, 2005).

Agencies that use this method typically realize that the quality of the sampling design is crucial for the end quality of the resulting VMT estimate. Heterogeneous road attributes within a road class can lead to incorrect estimates for example, differences in the number of lanes or volume characteristics (Fricker & Kumapley, 2002; Vadlamani, 2005).

Travel demand models (TDM), a variation of the link level approach, that develops estimates for AADT and subsequently for VMT, can be used to estimate statewide VMT. However, the road network and traffic counts data would have to be extensive for all regions of the state and must fully cover all the local roads. Thus, TDM is often used at the project level to simulate travel behavior and also to carry out scenario-based analysis (Atkins Company, 2013; Cambridge Systematics et al., 2012). At the project level, traffic, socioeconomic, and land-use data can be used to forecast traffic volumes on the road network. A gravity model is a key component of the four-step TDM process: trip generation, trip distribution, mode choice, and trip assignment (Wang, 2012; Zhong & Hanson, 2009; see Figure 2.6). Mode choice commonly involves automobile, transit, and non-motorized vehicles. Traffic assignment uses origin-destination trip tables to "route" trips on the road network. Traffic flows by time-of-day and vehicle class (truck/auto), are then used to estimate the daily VMT for the study area.

For the local road system, the use of link-level approaches for local roads is more problematic compared to the state highway system. Indiana's local road network consists of approximately 84,000 miles of county roads and city and town streets, estimated based on annual operational reports and INDOT road inventory (Local Technical Assistance Program, 2009). With this extensive mileage of local roads in Indiana, it is not efficient or feasible to install traffic counting devices for all road segments of the network. Instead, sampling procedures are often used to represent local roads traffic volumes and thus VMT. For relatively homogenous road networks, such as paved county roads or gravel county roads, simple random sampling may be suitable for traffic volume estimation. However, several local road networks are heterogeneous, and an alternative sampling

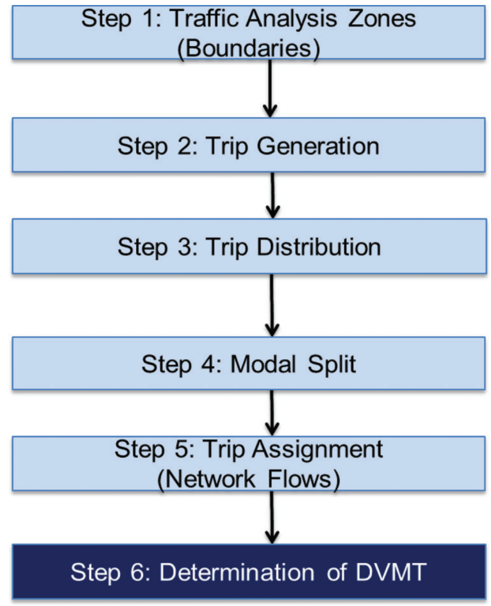


Figure 2.6 VMT estimation using the travel demand model.

TABLE 2.1
Merits and demerits of link-level methods based on sampling procedures.

Advantages	Disadvantages
Based on actual traffic counts	Time-consuming traffic data collection
Provides by functional classes	Minimal traffic data outside of the SHS
Not reliant on self-reported travel surveys	Higher costs from training and field staff
System familiarity	Expansion factors may be erroneous
Clearly defined processes	Accounting for changing travel patterns
Annual reporting to the federal government	Possible bias from random sampling
Recommended by the EPA for air pollution assessments	
Interstates and the SHS are well-represented	

approach is stratified random sampling, which uses a limited sample of highway sections within a specific functional class. This approach is more reliable if the average sample AADT represents the greater population of traffic counts (Mohamad, 1997; Mohamad et al., 1998).

Therefore, notwithstanding its many merits, the link-level approaches tend to underrepresent travel on local and county roads. Secondly, building a database covering the entire road networks is often impractical for local roads due to their sheer expanse. Traffic counting for local roads is typically the responsibilities of county engineers, MPOs or RPOs, or city planning authorities. It is challenging to obtain consistent data to represent local roads at different regions of the state. Table 2.1 compares the advantages and disadvantages of a link-level method from a sample, such as the well-known HPMS for estimating statewide VMT from a sample of representative highway segments and their respective traffic counts.

2.4 Highway Classification

The classification schemes used for the highway vehicles and roads is the same as the standard FHWA scheme, as described in the section that follows.

2.4.1 Vehicle Classification

Traffic data for this study were classified based on the FHWA 13 vehicle classes (Table 2.2), as described in FHWA's *2013 Traffic Monitoring Guide* (OHPI, 2014b). These vehicle classes (illustrated in Figure 2.7), are as specified in FHWA's publications (OHPI, 2011). The distinction between trucks is based on the weights and the number and configuration of axles. Classes 1–3 are personal vehicles, Class 4 is buses, Classes 5 to 7 are commercial single-unit trucks, and Classes 8 to 13 are commercial combination trucks. For purposes of this study, the commercial component of VMT is defined as classes 4–13.

TABLE 2.2
FHWA vehicle classification system (OHPI, 2014b).

Vehicle Class	Vehicle Description
Class 1	Motorcycles
Class 2	Passenger cars
Class 3	4 tire, single-unit vehicles (pickup trucks)
Class 4	Buses
Class 5	2 axle, 6 tire, single unit trucks
Class 6	3 axle, single-unit trucks
Class 7	4 axle or more, single-unit trucks
Class 8	4 axle or less, single trailer trucks
Class 9	5 axle, tractor semitrailer trucks
Class 10	6 axle or more, single trailer trucks
Class 11	5 axle or less, multi-trailer trucks
Class 12	6 axle, multi-trailer trucks
Class 13	7 axle or more, multi-trailer trucks

2.4.2 Functional Classification

Due to changes in the designation of urban area boundaries (UAB), and to better align with the priorities of the U.S. Census (USC), the highway functional classification system has changed after 2008. There is no longer a separate rural and urban category for each division of road, such as Urban Interstates and Rural Interstates. Migration from the previous twelve functional classes shown in Table 2.3 to the current seven functional classes was required (OHPI, 2014b). The current FHWA functional classes (Table 2.4) were used in this study.

2.5 Chapter Summary

This chapter presented a review of the past literature on the two main approaches for VMT estimation:

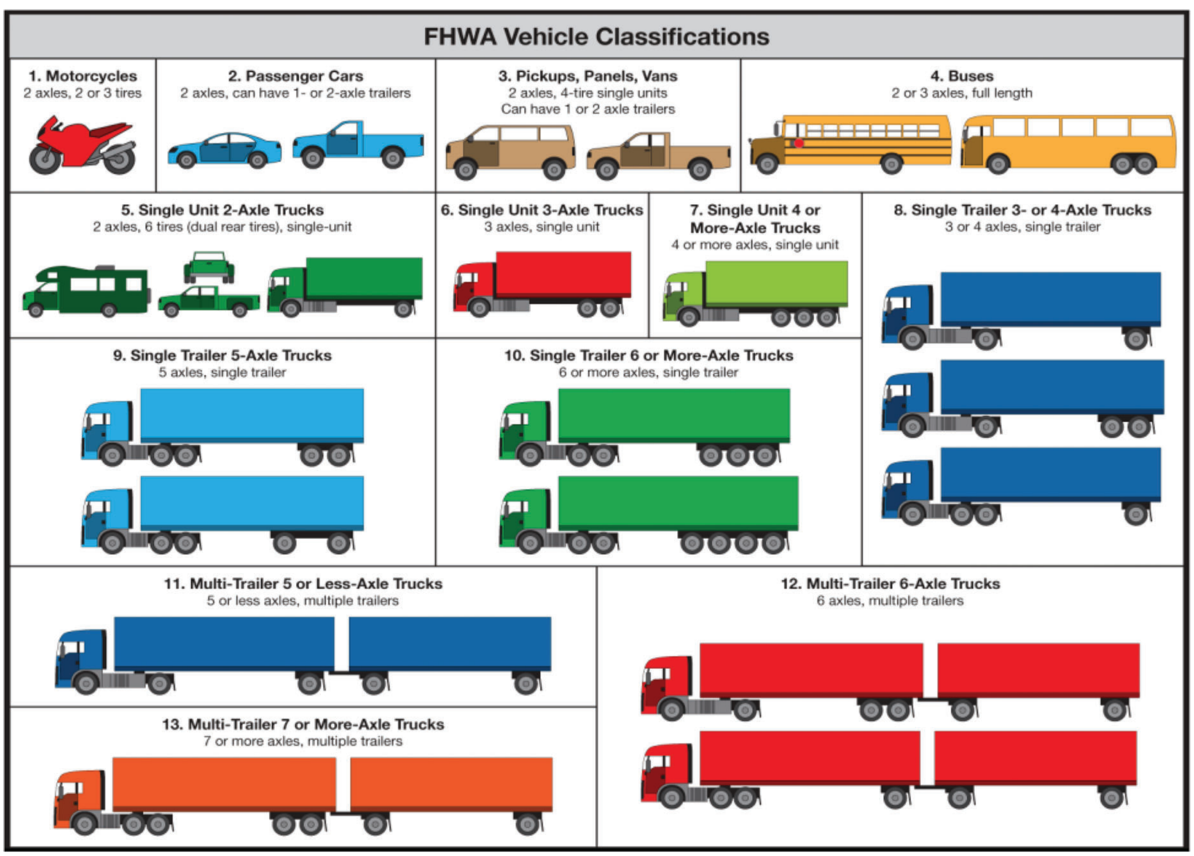


Figure 2.7 FHWA's vehicle classification (OHPI, 2011).

TABLE 2.3
Previous FHWA functional classification system (FHWA, 2013a).

Category	Division	Subcategory	Code
Rural	Principal Arterials	Interstate	1
Rural	Principal Arterials	Other Princpal Arterials	2
Rural	Minor Arterials	N/A	6
Rural	Collector	Major Collector	7
Rural	Collector	Minor Collector	8
Rural	Local	N/A	9
Urban	Principal Arterials	Interstate	11
Urban	Principal Arterials	Other Freeways & Expressways	12
Urban	Principal Arterials	Other Principal Arterials	14
Urban	Minor Arterials	N/A	16
Urban	Collector	N/A	17
Urban	Local	N/A	19

TABLE 2.4
Current FHWA functional classification system (FHWA, 2013a).

Category	Subcategory	Code
Principal Arterials	Interstate	1
Principal Arterials	Other Freeways & Expressways	2
Principal Arterials	Other	3
Arterials	Minor Arterial	4
Collector	Major Collector	5
Collector	Minor Collector	6
Local	N/A	7

traffic based and non–traffic based. The VMT estimation methods within each approach were discussed, and their associated merits and limitations were identified. The chapter discussed the characteristics of each method and the level of aggregation of the VMT estimate.

2.5.1 Limitations of Traffic-Based Methods

The high levels of staff training and expense for processing the raw traffic data is one of the problems with traffic-based methods. The external traffic-count contractors must be familiar with the agency's traffic count program, and the database must be updated with new links as roads are constructed or decommissioned. Also, sampling could be biased toward important sites, such as the locations in urban areas or those near commercial corridors. As discussed, local roads are often not adequately represented due to the lack of adequate traffic counts or incomplete definition of the inventory at such roads. Also, any changes in land-use and economic patterns may not be adequately accounted for. These factors impair the applicability of the expansion factors to develop a representative statewide VMT estimate. If travel demand models are used for VMT estimation, the local road network may have limited representation.

2.5.2 Limitations of Non-Traffic-Based Methods

Non-traffic methods use inputs that are dynamic and often require a wide-range of data from different agencies. Compiling this data is often cumbersome and may not be complete for each analysis year of VMT estimation in the fuel-based method of VMT estimation, for example, fuel efficiency, or the mileage per gallon that a vehicle uses, in particular, is a key input but is difficult to estimate. Also, the results of the national travel surveys are often not released annually, and thus may contain outdated data. Also, household surveys cannot typically account for commercial activity, and thus their applicability for statewide estimation is limited for states such as Indiana that have significant trucking activity. Fluctuations in economic conditions can also affect VMT estimates, leading to possible misrepresentation of actual VMT. This particularly impairs the efficacy of socioeconomic regression models where economic indicators are key inputs. Possible errors in the model specification could also impact the reliability of the results. Finally, with the exception of the fuel-based method, the non-traffic methods for VMT estimation often are unable to estimate VMT by vehicle class. The non-traffic methods typically yield aggregate VMT estimates (statewide totals) derived from non-traffic inputs such as fuel sales, regression models, socioeconomic, and demographic data. These methods are more suitable for a network level assessment of statewide VMT. As such, project-level applications are not possible when VMT is estimated suing these methods.

3. STUDY METHODOLOGY

3.1 Introduction

To develop a framework for estimating statewide VMT, the ideal approach would be to represent the VMT for every segment of the state's centerline road network. This approach uses actual on-the-ground traffic counts and thus is based on the vehicle movements that amount to vehicular travel. However, with Indiana's 90,000-mile road network, this approach is limited by the costs and resources required for installing and managing ATRs, WIM stations, and coverage counts, as well as the costs of processing and managing the collected data. For local roads, which are outside the state highway system and also dominate the state's road network, 100% coverage using this method is impractical.

This study developed a repository of traffic counts from INDOT, MPOs, RPOs, and other organizations. A robust, comprehensive, and adaptable database that covers all the mileage of public roadways was established. The state routes are defined as interstates, US roads, and state roads and are under the jurisdiction of the state government. Local routes are defined as city streets and county roads are under the jurisdiction of municipalities and counties. For state routes, all state-owned highway segments' traffic counts are used for the VMT estimation; for local routes, a sample of non-state owned road segments is used.

Also, this study provided a methodology to adjust the VMT estimates from the different methods using a calibration factor. This chapter discusses VMT estimation methods including those based on fuel, vehicle registration, licensed drivers, and trend analysis (discussed in Chapters 1 and 2) are analyzed to provide a range of percent deviations from the ground-truth control (the statewide VMT estimated by the selected (benchmark) method).

3.1.1 Desired Qualities of Framework

In developing the framework, certain important desired characteristics were considered. First, current traffic counts from both short-term and long-term count stations are required. Second, extensive coverage of all routes, both on and off the SHS, should be possible. Third, the end user should be provided with coverage for the project, regional, and statewide levels, as well as an easily updatable database to account for a dynamic road network inventory. Fourth, the framework should allow for aggregation by vehicle classification, functional classification or highway category, and geographic scope. These aggregations are essential for agency processes such as highway cost allocation, revenue forecasting, and other applications discussed in Chapter 1. Finally, the system must be easily accessible to INDOT personnel with readily-available software, such as a spreadsheet or GIS platform.

3.1.2 Survey of VMT-Data Stakeholders

To gauge the challenges faced and the level of aggregation required by the users and producers of VMT within INDOT's planning, economics, and traffic safety divisions, an electronic survey was conducted for those divisions. The survey was administered using Purdue Qualtrics, an online tool. The questions were designed to be addressed easily and were in both multiple-selection and open-ended formats. The responses yielded insight about the data needs for a proposed platform and identified the challenges that the VMT data stakeholders encounter with respect to the existing methodologies and procedures for VMT estimation.

3.1.3 Selection of Estimation Methodology

As evident from the literature review, the non-traffic-based approaches tend to be prone to discrepancies, require excessive resources for data compilation and estimation, and often lack full coverage regarding both personal and commercial travel. The existing traffic-based methods, as currently applied in practice, are woefully inadequate for applicability to local routes. It is important that city streets and county roads are better represented in the coverage count programs. From the literature review's synthesis of findings and desired framework qualities, a segment of the project level approach (which is herein termed the "link-level method" in the remaining sections of this report) was selected as the ground-truth VMT estimation method. This link-level method uses actual on-the-ground traffic counts obtained from both short-term coverage stations and long-term permanent stations to represent statewide travel on Indiana's highways. The link-level method is capable of providing VMT estimates for a specific range of locations, such as between a range of mileposts on a route, as well as aggregations of all routes to produce an area-wide VMT estimation. Using this method, VMT estimation by vehicle class and functional class is possible. Finally, the link-level method is implemented with Microsoft Excel or a GIS platform, providing powerful analytical capabilities and an updatable inventory. As and when more recent traffic data become available, this method allows the records to be updated. This method enhances consistency, reliability, and accuracy for both producers and users of VMT information.

3.2 Framework for Non-Traffic Methods of VMT Estimation

To investigate the discrepancies obtained using the different VMT estimation approaches, comprehensive data were collected from a variety of sources. These estimates were then compared to the benchmark, that is, the VMT estimated using the link-level method, in order to gauge the extent of under or over-estimation from each of these methods. The theoretical background behind the suitability of these methods for statewide estimation is provided in Chapter 2. Also, an overview of the required inputs and outputs, are provided not only to explain the estimation procedures, but also to provide insight into the suitability of each approach for any given end-application in question.

3.2.1 Based on Fuel Revenue and Fleet Efficiency

The fuel-based approach for estimating statewide VMT for revenue forecasting and long-term planning is one of the most common approaches for non-traffic-based VMT estimation. As shown in Figure 3.1, the three main inputs for the fuel-based method include fuel tax rates, fuel revenue, and fleet fuel efficiencies; and the fleet fuel efficiencies are affected by a variety of inputs. The fuel tax rates and fuel revenue are required for estimating the amount (gallons) of fuel used. Fuel tax rates are known and change infrequently. The past fuel revenues are reported in annual Department of Revenue (DOR) reports (IDOR, 2014). Other inputs affecting fleet fuel efficiencies (OHPI, 2014d) include the vehicle class distribution, the percent of vehicles running on gasoline and diesel, and the vehicle fleet age.

Typically, this method yields a statewide aggregate VMT because fuel revenue and fuel consumption amounts (gallons) are reported annually. The coverage

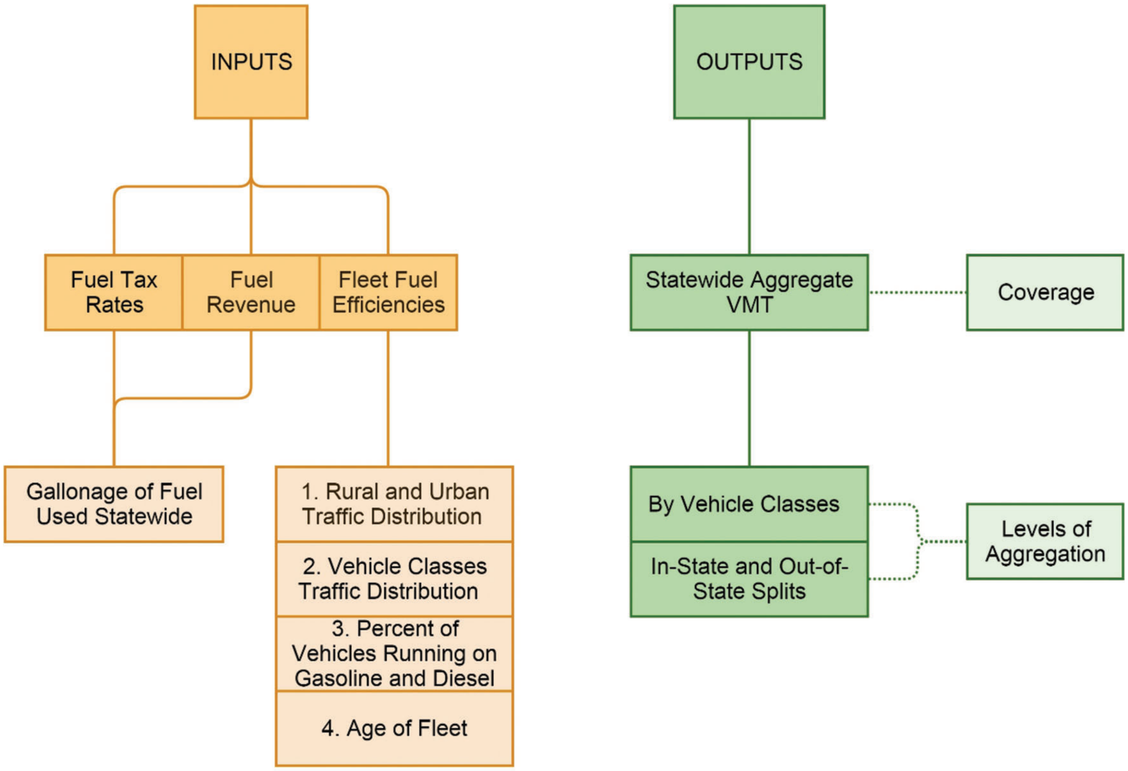


Figure 3.1 Flowchart for statewide VMT estimation involving fuel-related data.

provided is typically statewide aggregate VMT because fuel revenues and fuel consumption are typically reported on an annual basis. The basis of aggregation could include vehicle class and the split of travel between in-state vs. out-of-state vehicles, if known.

The calculation for statewide annual VMT is given as Equation 3.1; i is the fuel type (gasoline or diesel), and j is the individual vehicle class, with units of fleet fuel efficiency given in miles/gallon, fuel revenue in \$, and fuel tax rate in \$/gallon.

$$\text{Annual VMT} = \sum \left(\text{Fleet Fuel Efficiency}_{ij}\right) \left(\frac{\text{Annual Fuel Revenue}_{ij}}{\text{Fuel Tax Rate}_{ij}}\right) \quad (3.1)$$

Different assumptions affect the distribution of the estimated fuel consumption across the vehicle classes. For example, aggregate approaches often assume that personal or non-commercial vehicles (classes 1 to 3) are powered solely by gasoline. According to the Energy Information Administration (EIA, 2014a,b), approximately 98% of the existing vehicles in this group use gasoline. However, the same data show that (a) a significant number of vehicles in this group use diesel and (b) certain commercial vehicles, such as some Class 5 trucks, use gasoline.

In a disaggregate approach, for each vehicle class, estimates of the percentage of vehicles by fuel type are used to distribute the fuel consumption to each vehicle class, and then multiplied by FFE to estimate VMT. This, in theory, is expected to lead to greater accuracy of the result; however, the quality of the end product is only as good as the integrity of the input data.

3.2.2 VMT Estimation Based on Trend Analysis and Growth Factors

The analysis of historical data to predict future conditions has often been used as a benchmark for comparing VMT estimates. Estimation inputs include previously-reported historical VMT data for a continuous and consistent time span. FHWA has kept consistent records for over 20 years in the form of the HPMS statewide figures reported in *Highway Statistics*. Other sources include records (maintained by state transportation agencies such as INDOT) on VMT estimates by county and functional system. An aggregate statewide VMT for future years is predicted using time-series forecasting.

It is intuitively expected that as the analysis period increases from the last data point, the reliability reduces due to increased errors due to factors such as economic downtown, changing workforce, development of alternatives to personal travel, and so on). For example, prediction of VMT at year 2030 using 1990–2008 data may not be influenced by the major economic recession that occurred in 2009.

In this study, growth factors were developed by analyzing present and past time-series data. The developed factors can be applied to present-year AADT or VMT to obtain a future value. The equations used

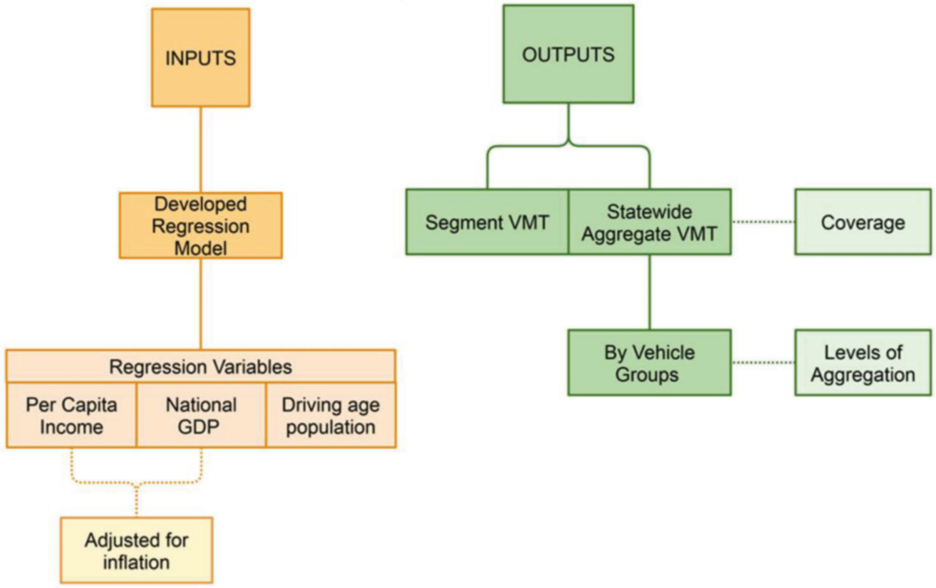


Figure 3.2 Flowchart for VMT estimation from socioeconomic regression model.

to calculate an annual growth factor and to predict a future value are presented as Equation 3.2 and Equation 3.3, respectively. N is the number of years of difference between the start and end of the time period, y is the future year for estimation, x = the most recent year, and i is the average annual growth rate.

$$\text{Annual Growth Rate, } i = \frac{\frac{AADT_{present} - AADT_{past}}{AADT_{past}}}{(N)} \quad (3.2)$$

$$\text{Future AADT, } AADT_y = AADT_x (1+i)^N \quad (3.3)$$

For the trend analysis in this study, a variety of functional forms can be investigated and the goodness of fit was gauged using the standard coefficient of error, R^2. In this study, the linear, exponential, polynomial, S-curve, and logarithmic functional forms were investigated for forecasting VMT. The results were validated using data points excluded from the modeling dataset.

3.2.3 VMT Estimation Based on Socioeconomic Regression

This method uses regression models and cross-sectional data on socio-economic characteristics. The regression models developed in a past Indiana study (Agbelie et al., 2010) were used in this study. As shown in Figure 3.2, the outputs of the regression models provide statewide coverage with aggregation by vehicle group. Inputs include the Indiana per capita income (PCI), U.S. gross domestic product (GDP), and the Indiana driving age population (DROP).

The regression models for the statewide VMT by vehicle class are presented by Equation 3.4 to Equation 3.9. Indiana's per capita income (PCI) is significant in the most models and greatly affects the VMT. US GDP is significant only in the VMT estimation model for large commercial trucks.

$$\text{Motorcycle VMT} = -1331.51 + 0.000368^{*}(\text{DROP}) \quad (3.4)$$

$$\text{Automobile VMT} = 35505 + 0.446^{*}(\text{PCI}) \quad (3.5)$$

$$\text{Light Duty Truck VMT} = -652652 + 64036^{*}\text{LN}(\text{PCI}) \quad (3.6)$$

$$\text{Bus VMT} = 9.27 - 0.000106^{*}(\text{PCI}) \quad (3.7)$$

$$\text{Single Unit Truck VMT} = 1866.02 + 0.0164^{*}(\text{PCI}) \quad (3.8)$$

$$\text{Class9} - 13\ \text{Truck VMT} = 4628 + 0.166^{*}(\text{USGDP}) \quad (3.9)$$

3.2.4 VMT Estimation Based on Vehicle Registrations

The number of vehicle registrations reported to the Bureau of Motor Vehicles (BMV) and estimates of the average annual travel per vehicle can be used to estimate aggregate statewide VMT. The FHWA *Highway Statistics* provides reports on the average travel per automobile. The effect of exempt vehicles or vehicles from out-of-state may cause this method to underrepresent VMT. It is assumed that the amount of travel by in-state vehicles on out-of-state roads is equal to that of out-of-state vehicles on in-state roads. Equation 3.10 presents the calculation of statewide VMT, where *i* and AAVMT represent the vehicle class and the average annual VMT.

$$\text{Statewide VMT} = \sum_{j} \sum_{i} (\text{AAVMT}_i) \text{x} \; (\text{Number of registration s}_i) \quad (3.10)$$

It has been determined in past research that different vehicle classes exhibit different levels of travel; for example, automobiles typically travels approximately 12,000 miles annually, and commercial vehicles typically travel approximately 30,000 miles annually. At a disaggregate level, vehicle registrations within each class are further decomposed by their gross vehicle weight (GVW).

3.2.5 Based on Licensed Drivers and Demographics

Travel surveys, such as the FHWA-sponsored National Household Travel Survey (NHTS) (FHWA, 2009) are conducted periodically to gauge travel behavior and identify trends. Using data related to demographic, licensed drivers, and travel, the statewide aggregate VMT was estimated. The framework is shown as Figure 3.3.

The average annual mileage driver by gender and FHWA age group was expanded to the population of drivers. For example, the population of licensed male drivers ages 16–19 and the average travel per driver yielded a statewide VMT estimate for this age group. The same process was repeated for all age groups, with different annual mileage per each age group. A sample of drivers from Indiana and surrounding states (Wisconsin, Iowa, Ohio, and Kentucky) was analyzed. These four states were selected based on the similarity in travel characteristics to Indiana, and were investigated in a similar past study (Kumapley & Fricker, 1994) for estimating statewide VMT from demographic, licensed driver, and travel variables. The samples had different average annual mileage for each driver group, and had data compiled from the 2009 edition of the NHTS.

3.2.6 VMT Estimation Based on Socioeconomic Travel Surveys

The online analysis tools of the most recent NHTS edition also allow for quick estimation of VMT using socioeconomic and household characteristics. As shown in Figure 3.4, an example flowchart for statewide VMT estimation from the 2009 NHTS that builds on the work of Fricker and Kumapley (2002). The online analysis tools allow for estimation of VMT using Indiana-specific socioeconomic and household characteristics. The number of vehicles by household income and land-type groups as well as an estimate of average annual VMT per vehicle, allow estimation of the statewide VMT to be estimate. The estimated VMT figure is for personal travel (classes 1 to 3) only.

The household VMT is calculated as the sum of the VMT of all households in Indiana, expanded from the sample to represent the population. The estimate of annualized mileage per vehicle was determined from the raw data after adjusting the latter to yield a more reliable representation of the actual amount of travel. The model requires the population within each land-area type cluster for statewide VMT estimation. For example, the estimated number of household within the three land types (rural, light-urban (suburban), and urban) is provided in the online analysis tools based on the household sizes in the 2000 US Census.

3.3 Data Collection for Non-Traffic Methods

To estimate Indiana's statewide VMT from the VMT estimation methods discussed, a variety of data sources is required. The acquisition, processing, and analysis of the data has degrees of ease and reliability that vary across the methods. The data collection considerations

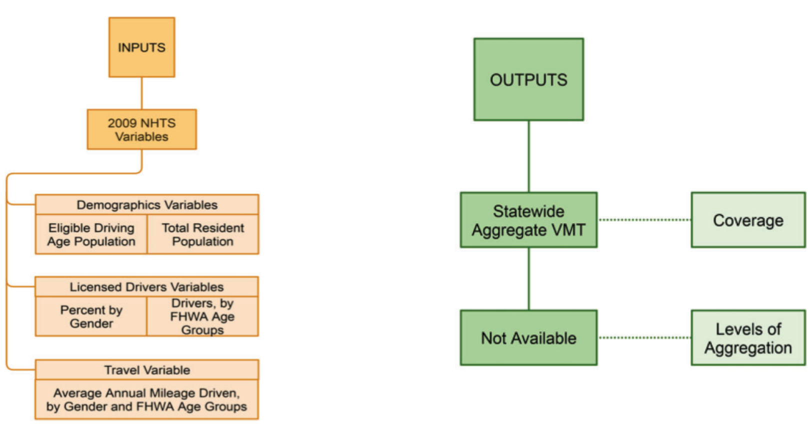


Figure 3.3 Flowchart for VMT estimation using licensed driver surveys.

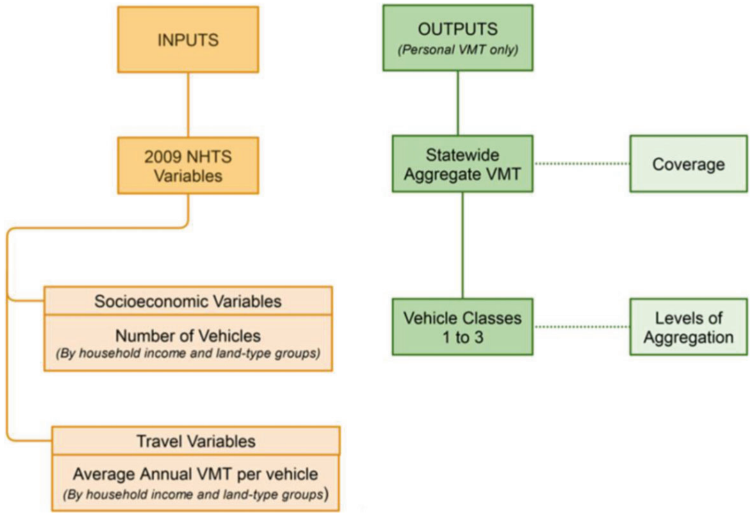


Figure 3.4 Flowchart for VMT estimation from socioeconomic travel surveys.

TABLE 3.1
Summary of data collected for non-traffic methods.

Method	Calculation Item	Source	Years Obtained	Ease/Level of Access	Level of Reliability
Fuel-Revenue	Gas and diesel tax revenues	IN DOR	2009–present	H	H
Fuel-Revenue	Fuel consumed for motor transportation	EIA	2009–2013	H	M
Fuel-Revenue	Gas and diesel tax rates	IN DOR	All	H	H
Fuel-Revenue	Fleet fuel efficiencies	Oak Ridge, FHWA Statistics	2009–2012	M	M
Fuel-Revenue	Vehicles powered by fuel type	EIA	2009–2012	M	M
Fuel-Revenue	Traffic stream distributions	SPR-3704, FHWA Statistics	2009–2013	M	H
Fuel-Revenue	In-state and out-of-state splits	SPR-3704	N/A	H	H
Fuel-Revenue	Age of vehicle fleet	Unavailable	N/A	L	L
Socioeconomic Reg.	Gross domestic product USA	BEA Regional Data	2009–2013	H	H
Socioeconomic Reg.	Driving age population of IN	FHWA Statistics	All	H	H
Socioeconomic Reg.	Per capita income of IN	BEA Regional Data	2009–2012	H	H
Socioeconomic Reg.	Inflation indices for USA, IN	Bureau of Labor, BEA	All	H	M
Socioeconomic Surveys	Average annual mileage per vehicle	NHTS	2009	M	L
Socioeconomic Surveys	Household vehicles by area type	NHTS	2009	M	L
Licensed Drivers	Number of male and female drivers	FHWA Statistics	All	M	M
Licensed Drivers	Total statewide resident population	U.S. Census, FHWA	All	H	H
Licensed Drivers	Average annual mileage per driver	NHTS	2009	L	M
Vehicle Registrations	Classes 1–3 vehicle registrations	Internal, FHWA Statistics	All	M	H
Vehicle Registrations	Classes 4–13 (trucks) registrations	Internal, FHWA Statistics	All	M	M
Vehicle Registrations	Average annual mileage	Dept. of Energy, FHWA	2015	H	M
Vehicle Registrations	Historical statewide VMT reports	INDOT, FHWA Statistics	All	H	H
Vehicle Registrations	Growth factors	Internal	2009–present	L	M
Link Level (HPMS)	Historical VMT by functional class	FHWA Statistics	All	H	H
Link Level (HPMS)	Data for HPMS road sections	INDOT TCDS, MPOs	2009–present	H	H

for the non-link-level methods by the required calculation item, accessibility, and reliability, are summarized in the following section.

3.3.1 Summary of Data Collected

Table 3.1 presents a summary of the attributes of the data collected for the non-traffic methods of VMT estimation. The table presents the types of non-traffic calculation items, data sources, years obtained, the ease of access, and the level of reliability (H represents high, M represents moderate, and L represents low). Low access and reliability, which are least desirable, exemplify the challenges faced in compiling and working with data for the non-traffic methods. The data is extensive and comes from a variety of sources different years;

inconsistencies were observed, and data needs updating for any future estimation of VMT.

In order to estimate VMT from non-traffic data, each method has degrees of data collection. For example, the fuel-revenue based method of VMT estimation requires the most extensive data collection, with fuel tax revenues, vehicle fleet fuel efficiencies, traffic stream distributions, and in-state vs. out-of-state split is required. The VMT estimation methods using vehicle registrations and travel surveys were observed to require the least extensive data collection. The data collection and compilation, specific to each VMT estimation method, are discussed in the following sections. Discussion of the inputs for each VMT estimation method and respective data sources, are provided.

3.3.2 Data for Fuel Revenue and Fleet Efficiency

With regard to the fuel-based method of VMT estimation, data on gasoline and diesel tax revenues, fuel consumed for motor transportation, gasoline and diesel tax rates, vehicle fleet fuel efficiencies, distribution of vehicles powered by fuel type, traffic stream distributions, and in-state vs. out-of-state split, were compiled. With the exception of the average vehicle fleet age, all these input data were available. Vehicle fleet fuel efficiencies by vehicle class were determined from the FHWA *Highway Statistics* VM-1 Tables (OHPI, 2014d) and the Oak Ridge Transportation *Energy Data Book* (Davis, Diegel, & Boundy, 2014; see Table 3.2).

Data on the share of vehicles that consume each fuel type were compiled from the Energy Information Administration (EIA) Annual Energy Outlook 2014 Tables (EIA, 2014a). These distributions are shown in Table 3.3, for diesel vehicles, and Table 3.4, for gasoline vehicles. Class 1 (motorcycles) are assumed to be 100% using gasoline.

The current fuel tax rates and historical data on gasoline and diesel fuel revenue were obtained from the Indiana Department of Revenue (DOR) 2012–2014 Annual Reports (IDOR, 2014). Surcharges for motor carriers and commercial shippers are additional revenue but do not affect fuel consumption. As shown in Table 3.5, based on the current gasoline tax rate of $0.18 per gallon and diesel tax rate of $0.16 per gallon, the gasoline and diesel consumption is estimated.

Fuel consumption (based on consumption estimates of fuel used for motor transportation) are provided by the EIA State Energy Data System (SEDS), transportation sector energy consumption estimates, for 2009–2013. As shown in Table 3.6, estimates of the total gallonage of gasoline and diesel consumed for statewide travel are provided. The original values were given in barrels and converted to gallons for consistency with Indiana DOR estimates. Data on the traffic distribution streams by vehicle class for the weighted fleet fuel efficiencies, were taken from Indiana's SPR 3704 report (Volovski et al., 2015) and the FHWA *Highway Statistics*. The rural and urban roads traffic distribution is from Table VM-4 of *Highway Statistics* (OHPI,

TABLE 3.2
Fleet fuel efficiencies (MPG) by FHWA vehicle classes (Davis et al., 2014; OHPI, 2014d).

Vehicle Class	2009	2010	2011	2012	2013
Class 1	43.20	43.40	43.20	43.50	43.50
Class 2	23.50	23.30	23.50	23.30	23.30
Class 3	17.30	17.20	17.30	17.10	17.10
Class 4	7.20	7.10	7.20	7.20	7.20
Class 5	7.40	7.10	7.40	7.30	7.30
Class 6	7.40	7.10	7.40	7.30	7.30
Class 7	7.40	7.30	7.40	7.30	7.30
Class 8	6.00	7.30	6.00	5.80	5.80
Class 9	6.00	5.90	6.00	5.80	5.80
Class 10	6.00	5.90	6.00	5.80	5.80
Class 11	6.00	5.90	6.00	5.80	5.80
Class 12	6.00	5.90	6.00	5.80	5.80
Class 13	6.00	5.90	6.00	5.80	5.80

TABLE 3.3
Estimation of percentage of vehicles powered by diesel (EIA, 2014a).

Vehicle Class	2009	2010	2011	2012	2013
Class 1	0.0%	0.0%	0.0%	0.0%	0.0%
Class 2	0.4%	0.4%	0.4%	0.5%	0.5%
Class 3	0.4%	0.4%	0.4%	0.5%	0.5%
Class 4	95.0%	95.0%	95.0%	95.0%	95.0%
Class 5	61.0%	61.0%	61.0%	61.0%	61.0%
Class 6	81.6%	81.6%	82.2%	81.0%	81.0%
Class 7	81.6%	81.6%	82.2%	81.0%	81.0%
Class 8	81.6%	81.6%	82.2%	81.0%	81.0%
Class 9	97.4%	97.4%	97.4%	97.4%	97.4%
Class 10	97.4%	97.4%	97.4%	97.4%	97.4%
Class 11	97.4%	97.4%	97.4%	97.4%	97.4%
Class 12	97.4%	97.4%	97.4%	97.4%	97.4%
Class 13	97.4%	97.4%	97.4%	97.4%	97.4%

TABLE 3.4
Estimation of percentage of vehicles powered by gasoline (EIA, 2014a).

Vehicle Class	2009	2010	2011	2012	2013
Class 1	100.0%	100.0%	100.0%	100.0%	100.0%
Class 2	99.6%	99.6%	99.6%	99.5%	99.5%
Class 3	99.6%	99.6%	99.6%	99.5%	99.5%
Class 4	5.0%	5.0%	5.0%	5.0%	5.0%
Class 5	39.0%	39.0%	39.0%	39.0%	39.0%
Class 6	18.4%	18.4%	17.8%	19.0%	19.0%
Class 7	18.4%	18.4%	17.8%	19.0%	19.0%
Class 8	18.4%	18.4%	17.8%	19.0%	19.0%
Class 9	2.6%	2.6%	2.6%	2.6%	2.6%
Class 10	2.6%	2.6%	2.6%	2.6%	2.6%
Class 11	2.6%	2.6%	2.6%	2.6%	2.6%
Class 12	2.6%	2.6%	2.6%	2.6%	2.6%
Class 13	2.6%	2.6%	2.6%	2.6%	2.6%

TABLE 3.5
Indiana DOR fuel-tax revenue by fuel type (IDOR, 2014).

Estimated Fuel Galloanges				
Year	**Gasoline Revenue**	**Diesel Revenue**	**Gasoline Gallonage**	**Diesel Gallonage**
2009	$535,851,300	$162,777,400	2.98E+09	1.02E+09
2010	$540,317,900	$167,332,100	3.00E+09	1.05E+09
2011	$543,037,900	$178,161,800	3.02E+09	1.11E+09
2012	$534,704,500	$183,742,000	2.97E+09	1.15E+09
2013	$529,619,800	$169,616,600	2.94E+09	1.06E+09

TABLE 3.6
EIA estimate of motor fuel consumed (EIA, 2014b).

Reported Fuel Gallonages		
Year	**Gasoline Gallonage (EIA)**	**Diesel Gallonage (EIA)**
2009	2.99E+09	1.20E+09
2010	3.07E+09	1.33E+09
2011	2.93E+09	1.37E+09
2012	2.89E+09	1.34E+09
2013	3.02E+09	1.49E+09

2014d) was used to adjust the original data provided by rural and urban designation.

3.3.3 Data for Trend Analysis and Growth Factors

Time-series data from 1992 to 2008 were modeled to predict annual VMT for 2009 to 2013. Historical VMT data by highway class and year were obtained for 1990 to 2008 (INDOT, 2013) and allowed for validation of the 2009 to 2013 VMTs. In Chapter 4, we discuss the performance of the different functional forms that were investigated for statewide VMT estimation. Growth factor data were derived on the basis of the trends observed in the traffic count database developed in this study. Data spanning four years of segment-level AADT data were used to develop traffic growth factors by functional class. For example, VMT estimates for present and past years, as well as those of intervening years, were used to calculate the growth factors. These growth factors were applied to the 2008 VMT to "forecast" VMT at each year from 2009 to 2013, for purposes of validation.

3.3.4 Data for Socioeconomic Regression Model

The regression model using cross sectional socioeconomic data was found to have good predictive capabilities. Actual economic data for 2009 to 2013 was compiled for comparison. All monetary values were adjusted for inflation and therefore were expressed in constant dollars of Year 2008. The sources for PCI and GDP data were the Bureau of Economic Analysis (BEA, 2015). The consumer price index (CPI) from the Bureau of Labor Statistics (BLS, 2015) was used to adjust PCI and BEA indices were used to adjust GDP. Table 3.7 presents the numerical model inputs. For 2009 to 2010, it was observed that the actual PCI is lower than that predicted by the model, obviously due to the 2008 national economic recession. A similar observation was made for GDP. The Indiana driving age population used in the socioeconomic regression model was compiled from the FHWA *Highway Statistics* Tables DL-1C (OHPI, 2014d).

3.3.5 Data for Vehicle Registrations

The vehicle registration method relies on two main inputs. The first is the amount of travel (annual VMT) per vehicle. To obtain this input, at least one estimate was obtained for each vehicle class. The second is the total number of registered vehicles in each vehicle class. VMT is estimated as the product of the average annual mileage per vehicle class and the total number of registered vehicles in that vehicle class. The statewide VMT was estimated for the low and high range of passenger car mileage. Table 3.8 shows a summary of the annual mileage per vehicle group. The sources of the mileage estimates are primarily from the FHWA *Highway Statistics VM-1 Series*, the American Public Transit Association (APTA, 2014) and the Alternative Fuels Data Center (AFDC, 2015).

3.3.6 Data for Licensed Drivers and Demographics

Demographic inputs required for calculations, including the number of male and female licensed drivers, total population, and ratios of male and female drivers relative to the total driving age population, were obtained from the FHWA *Highway Statistics* Tables DL-1C (OHPI, 2014d).

Indiana did not provide 2010 demographic data to the FHWA; therefore, trend analysis was used to impute the "missing" data for the year 2010. Also, data from 2011 and 2012 seemed to be grossly erroneous because the reported number of licensed drivers was approximately the same as the total statewide resident population. A similar discrepancy in the reported FHWA data for Indiana has been noted in a past report (Kumapley, 1994). For example, reported data shows 3.330 million male drivers and 3.240 million female drivers (totaling 6.570 million), whereas the statewide resident population is 6.516 million and 6.537 million, for 2011 and 2012, respectively. To improve the reliability of the VMT estimate obtained from this

TABLE 3.7
Summary of inputs for the socioeconomic regression model.

Year	Per Capita Income of Indiana		GDP of USA		Driving Age Population of Indiana	
	2008 Dollars		Billions of 2008 Dollars		Number of Drivers	
	Predicted	Actual	Predicted	Actual	Predicted	Actual
2009	$34,947	$30,393	$15,854	$13,143	4,844,014	5,015,383
2010	$35,245	$30,986	$16,091	$13,759	4,883,437	5,061,394
2011	$35,543	$32,811	$16,329	$14,242	4,922,860	5,102,910
2012	$35,841	$34,407	$16,566	$14,866	4,962,283	5,127,883
2013	$36,139	$35,616	$16,804	$14,851	5,001,706	5,164,988
2014	$36,437	$37,003	$17,041	$15,416	5,041,129	5,182,850

TABLE 3.8
Summary of annual mileage by vehicle group.

Vehicle Registrations: Annual Mileage Estimates					
Vehicle Group	Estimate (1)	Estimate (2)	Average Estimate	Source of Mileage Estimate(s)	
Motorcycles	2,423	2,529	2,476	(1) FHWA VM-1 (2013)	(2) FHWA VM-1 (2012)
Passenger Cars	11,262	13,476	13,476	(1) FHWA VM-1 (2012)	(2) FHWA NHTS (2009)
Light-Duty Trucks	11,346	11,712	11,529	(1) FHWA VM-1 (2013)	(2) AFDC, Department of Energy
Transit Buses	34,053		34,053	(1) APTA Tables 6, 7 (2014)	
School Buses	12,000		12,000	(1) National School Bus Fuel Data	
Long-Haul Trucks	66,260	68,155	67,208	(1) FHWA Table VM-1 (2012)	(2) FHWA VM-1 (2013)
Single-Unit Trucks	12,894	13,116	13,005	(1) FHWA Table VM-1 (2012)	(2) FHWA NHTS (2009)

TABLE 3.9
Average annual VMT per licensed driver for the Indiana sample.

Age Group	AVMT (Males)	AVMT (Females)	Sample Size (Males)	Sample Size (Females)	Average AVMT (All)
16–19	6,230	6,735	116	93	6,483
20–24	11,138	10,673	71	58	10,905
25–29	17,560	11,795	59	76	14,677
30–34	20,213	12,467	100	110	16,340
35–39	15,959	12,863	126	123	14,411
40–44	19,321	11,649	176	178	15,485
45–49	19,504	12,322	235	243	15,913
50–54	17,324	11,204	272	286	14,264
55–59	14,815	10,433	293	274	12,624
60–64	14,626	9,178	276	259	11,902
65–69	11,868	6,510	231	213	9,189
70–74	10,899	5,886	168	158	8,393
75 and over	8,558	3,820	238	235	6,189

method, trend analysis of historical data was used to substitute for the 2011 and 2012 with observed discrepancy.

Kumapley and Fricker (1994) compared samples of drivers from surrounding states of WI, OH, KY, and IA to develop a larger sample size that was statistically similar to IN. While the sample size of the 2009 NHTS has significantly increased, compared to the 1995 NHTS edition, with an IN sample of 2,361 male and 2,306 female drivers, this study compared the efficacy of both datasets. This comparison was facilitated using the built-in SAS script of the Table Designer that allows data to be quickly selected, exported, or processed.

As shown in Table 3.9 and Figure 3.5, the average annual travel is highest for ages 30 to 49; this is expected, due to the higher number of business and personal trips that are often undertaken by this age group. The lowest annual travel is for ages 75 and over, and 19 and under.

The result from the different sample sizes, for Indiana compared to surrounding states, is similar across all age groups (Figure 3.5). However, there is higher deviation between the two approaches for age groups 45 to 49, 60 to 64, and 65 to 69. This may be due to the nature of the sample of drivers that had participated in the NHTS survey.

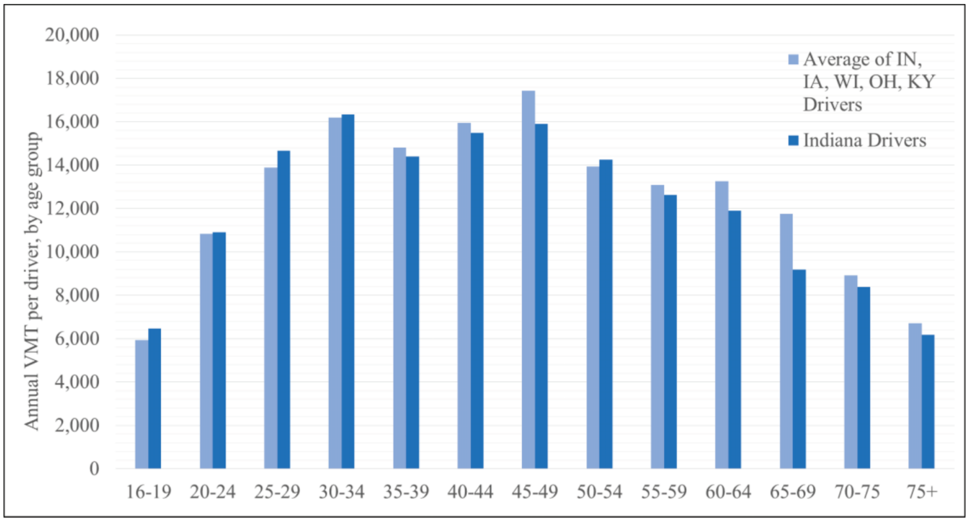


Figure 3.5 Annual VMT per licensed driver by age group.

3.3.7 Data for Socioeconomic Travel Surveys

Similar to licensed drivers, the data for VMT estimation based on socioeconomic travel surveys comes from the most current edition of the NHTS (FHWA, 2009). The input variables include the number of household vehicles, household family income, number of licensed drivers in household, and area type by block groups. For consistency with the 2010 U.S. Census (USC), the land-area type representing the degree of urbanization was defined by four groups: second city, suburban, town and country, and urban. Urban and second city are clustered as dense urban (DU), town and country as rural (RSW), and suburban (S) as Light Urban (LU). The NHTS reports the annualized mileage per respondent as the variable "bestmile", an adjusted derivation of the self-reported mileage. As well as providing an estimate of annual travel, the statistical analysis output provides an estimate of the number of vehicles in Indiana per household location groups. For example, dense urban, light urban, and rural location groups have an estimated number of vehicles per each of the $20K defined income groups. These aggregate estimates of vehicles per area-type are expanded by the average annual travel per vehicle to estimate the personal (classes 1 to 3) contribution to the statewide VMT.

3.4 Framework for Link-Level VMT Estimation

This section provides the development of the methodological framework and vehicle class distributions at the link level. This method is chosen to serve as the ground-truth control or benchmark for comparing statewide VMT because it yields the most comprehensive estimate that is based on extensive traffic counts across the state. For local routes, the VMT estimation is comprehensively analyzed and discussed due to the historical lack of attention, low accuracy, and inconsistencies associated with this critical component of VMT at this level of jurisdiction. A number of Microsoft Excel spreadsheets were developed to implement the framework and to serve as the platform for estimation of future VMT.

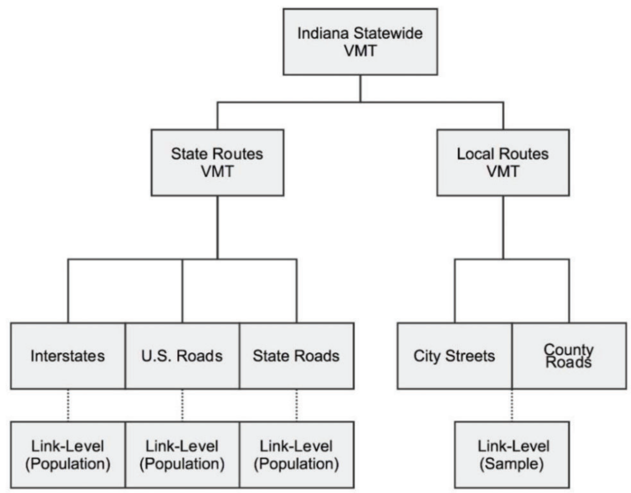


Figure 3.6 Flowchart for Statewide VMT estimation.

3.4.1 Development of Methodology Framework

As shown in Figure 3.6, state routes are defined for this study as INDOT-owned routes (Interstates, US Roads, and State Roads). This is the first part of the framework for statewide VMT estimation. At the end of the analysis, the estimated state route VMT is added to that of the local routes to yield the VMT for the entire Indiana highway system. Local routes are defined as city streets and county roads (these are roads not owned by the state government, but by counties, municipalities, and local governments). The population of traffic counts and continous segment-by-segment data are available for state routes, and a sample of counts is used as a basis for computing the local route VMT.

TABLE 3.10
Components of statewide VMT estimation and prediction.

Link Level Method (Statewide VMT Estimation)			**2009**	**2010**	**2011**	**2012**	**2013**	**………..**	**2035**
A	**State Routes (I, US, SR)**	Interstates (Ramps) Interstates (Mainline) US Highways (Mainline) US & State Highways (Ramps) State Highways (Mainline)	VMT is estimated using available 2009–2012 data				VMT is predicted using growth factors based on 2009–2012 data		
		Indiana Tollroad (I-90)	VMT is estimated using available 2011 data						
B	**Local Routes (City Streets & County Roads)**	Cluster 1 VMT Cluster 2 VMT Cluster 3 VMT Cluster 4 VMT Cluster 5 VMT Cluster 6 VMT Cluster 7 VMT Cluster 8 VMT	VMT is predicted (backward) using growth factors based on 2012–2014 data				VMT is estimated using available 2012–2014 data	VMT is predicted using growth factors based on 2012–2014 data	
C	**All Routes**	Statewide Annual VMT	C = A+B	C = A+B	C = A+B	C = A+B	C = A+B	C = A+B	C = A+B

Time-series traffic data were available for 2009 to 2012 (Volovski et al., 2015); this allowed for VMT estimation at the link level. These four years of traffic data were used to populate the comprehensive spreadsheet-based database developed in this study for estimating and predicting the future traffic volumes and consequently VMT. As shown in Table 3.10, an approximately 20-year horizon (2013 to 2035) was used to provide an estimate of future VMT assuming the continuation of observed trends.

Applying the observed growth factors by functional class allowed for AADT prediction (and subsequently, VMT prediction) at the segment or link level for the state routes. A sample of time-series traffic counts from MACOG was used to develop a growth factor specific to local routes. The VMT for local routes, discussed in Section 3.4.3, was estimated using cluster groups representing all 92 Indiana counties. The available data most closely represents 2013 data and is indicated as available in Table 3.10. The total statewide VMT “C” is the summation of components “A” and “B”, representing state and local routes, respectively, for the entire Indiana state highway system. The Indiana Tollroad (I-90) is not operated by INDOT; however, it has link-level traffic data available for 2011: the traffic data for 2011 was used as a placeholder for the remaining years (2009, 2010, and 2012) to ensure consistency when comparing aggregate VMT estimates at the statewide level.

3.4.2 State Routes Framework

Complete traffic data from 2009 to 2012 covers over 9,000 individual network links of the state routes (state highway system). Each link or highway segment has an associated length, AADT volume, functional class designation, indicator of NHS status, traffic growth factor, and vehicle class distribution. This link-level data are from INDOT’s milepost designations, with additional segments created for those with missing traffic data. This allows for a continuous AADT/VMT coverage for all state routes. To represent vehicle class distributions for all segments, sampling procedures from INDOT-sponsored research study SPR 3704 (Volovski et al., 2015) were used as a building block to develop a database representing vehicle class percentages for all state route segments. The data collection and compilation for state routes is discussed in Section 3.5.2. This VMT estimation framework provides significantly more detail than the non-traffic methods of VMT estimation, by allowing for the aggregation over the area of interest, such as district, county, route, statewide, and economic region.

3.4.3 Local Route VMT Estimation Framework

Local routes are county roads and city streets owned and operated by county and municipal governments. These are public roads not administered by the state government and therefore fall outside of the state highway system (interstate, US roads, and state roads), privately-owned roads, and national park roads. In Indiana, as with most states, local roads constitute a majority of the entire road network. The Indiana Local Technical Assistance Program (LTAP) estimated that 46% of the state’s total VMT was attributable to local roads (LTAP, 2009). However, there is a lack of a comprehensive program for traffic data collection on these roads. In this study, the three main problems with existing local road VMT estimation were observed as follows:

1. First, for many local roads, the availability of adjusted traffic counts is inconsistent. This study observed that some organizations collect extensive 48-hour adjusted AADT coverage counts on an annual or periodic basis; others have unadjusted 24-hour counts; some use HPMS

defaults for federal-aid eligible roadways; and the rest use none of these.
2. The second problem is that, for counties with available data, many segments of the road network often do not have counts that are required for VMT estimation at a regional level. An example of the gap in traffic counts coverage for the local road network (Tippecanoe County) and a city road network (Greater Lafayette-West Lafayette), is shown by Figure 3.7 and Figure 3.8, respectively, where light shading represent segments with unavailable data.
3. Third, close inspection of traffic counts data reveals that the selected sites are often in close proximity to urban areas, city boundaries, primary avenues or thruways, and other important sites. When expanded to a regional level, the use of these traffic counts may introduce bias and lead to inaccurate estimations of VMT.

To address these problems associated with local road VMT estimation, the framework shown in Figure 3.9 was developed for this study. Local roads are estimated with a sample of adjusted AADT traffic counts from counties at different geographic locations. Three alternative estimation approaches were identified for this study. All were expanded to represent statewide VMT using statistical cluster analysis. Cluster analysis, as applied for this study, allowed for counties with similar VMT-related characteristics to be grouped together.

1. The first, an average of all the sample of traffic counts was used to develop a VMT per mile (unit value), that was expanded to the population by using a known roadway inventory mileage. This approach may not account for the heterogeneous nature of the local roads network, as discussed subsequently in Section 4.3.3 of this report.
2. The second, an average of the sample of traffic counts within developed road classes, similarly produces a unit value of VMT per each road class. However, this unit value uses a form of stratified sampling to more accurately represent the average within each similar road class. This is expected to be more accurate than the average approach without segmentation.
3. The third, spatial interpolation uses weighted distance techniques to interpolate AADT values for all road segments. Implemented, with spatial analyst tools of a GIS platform, this uses algorithms such as Kriging, inverse distance weighting, natural neighbor, and trend. This approach is more appropriate for estimating traffic counts at locations without ground counts in a specific county. Spatial interpolation may be appropriate for MPOs and other organizations with incomplete traffic counts for its local routes.

For purposes of the "average by road class" and spatial interpolation approaches, road "classes" for the local road network were developed. These provide more detail and a basis for adjusting the estimates from the average approach. A crucial step is the inventory of the local road network and assignment by road classes. This required implementation with a GIS platform and analyzing AADT distributions to determine the selection criteria.

Five road classes were created for local routes at the county level. The definitions for these volume groups: county roads low volume has traffic of less than 1,000 AADT; county roads high volume has traffic of greater than 1,000 AADT; city streets low volume has traffic of less than 5,000 AADT; city streets high volume has a traffic volume of greater than 5,000 AADT; neighborhood roads have an AADT of 100–300. These four road classes containing

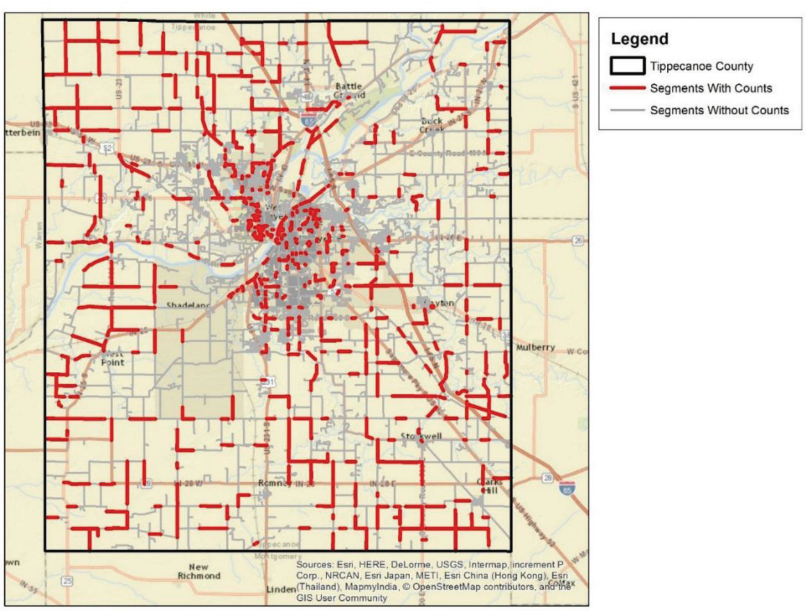


Figure 3.7 Traffic count coverage for an example local road network.

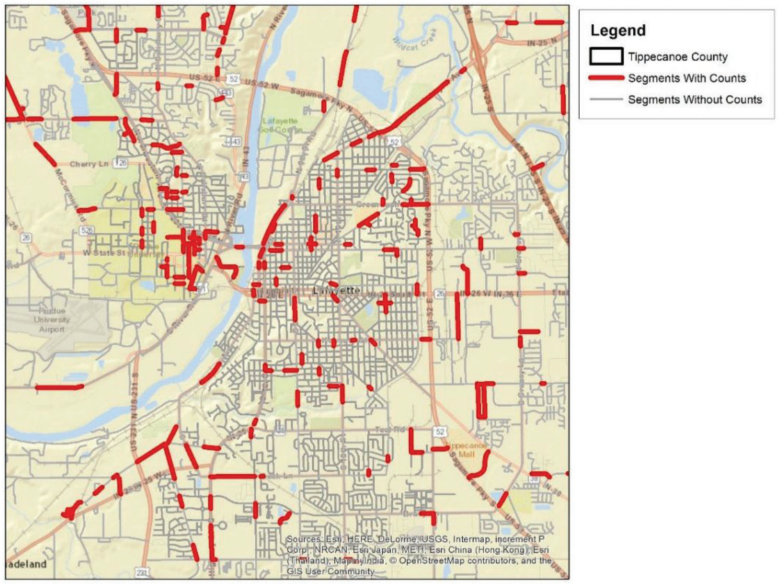


Figure 3.8 Gap in traffic counts coverage for an example city road network.

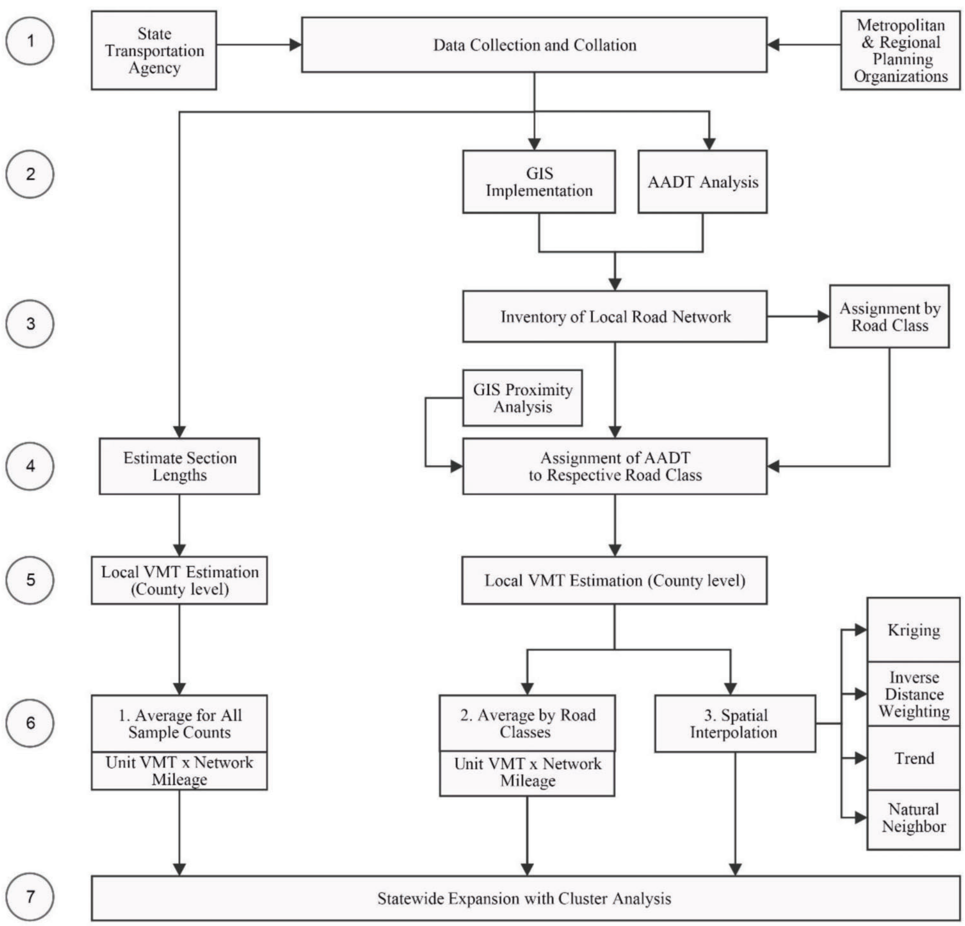
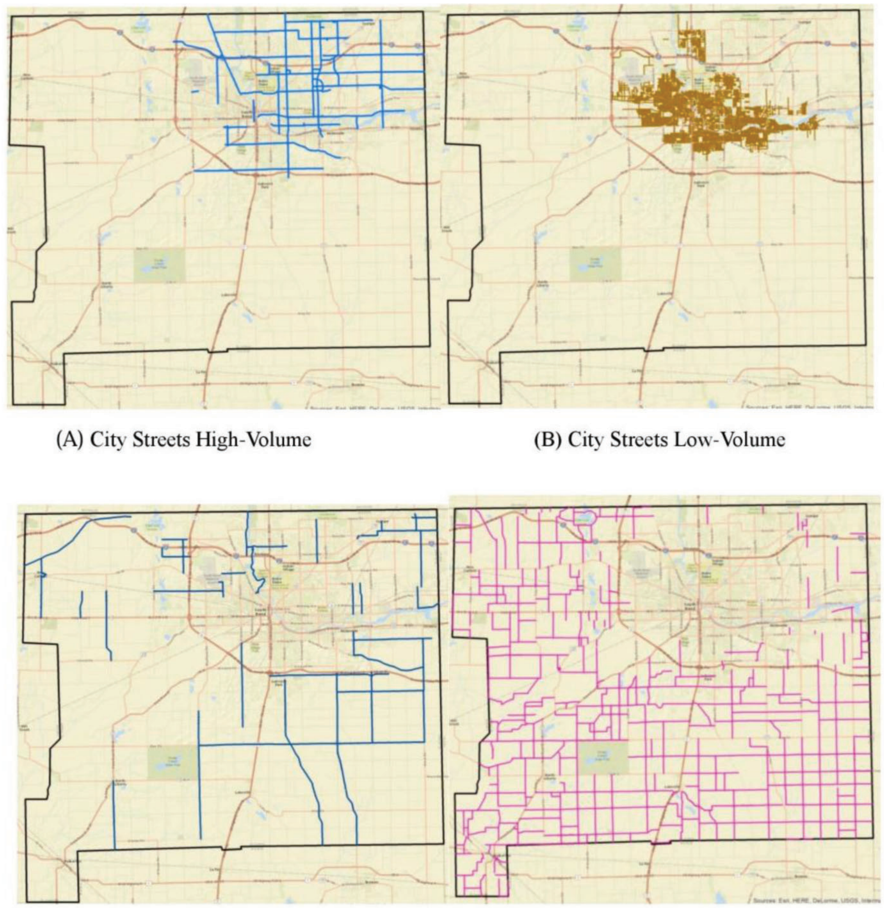


Figure 3.9 Flowchart for local route VMT estimation.



(A) City Streets High-Volume (B) City Streets Low-Volume

(C) County Roads High-Volume (D) County Roads Low-Volume

Figure 3.10 Road classes created for a sample county.

over 95% of the data are shown for St. Joseph County in Figure 3.10.

In the present study, a sample of 14 counties traffic counts was used, and the results were expanded to all 92 Indiana counties comprising of the population. Statistical cluster analysis (see Section 3.5.2) was used to group counties with similar VMT related attributes characteristics, instead of a grouping criterion based solely on population and land-area type. The cluster analysis helped establish a database involving several county-specific attributes (US Census, 2010): the mean household income, total state population, unemployment rate, per capita income, passenger car registrations, rural population, population density, housing density, percentage of single occupant drivers, percent of workers carpooling to work, percent of workers taking public transit, mean travel time to work, and number of vehicles available in household.

These clustering criteria variables were modeled using Minitab 17 software, a common statistical package. Options selected for clustering observations included Euclidean distance, complete linkage and average linkage (producing same clusters), and specifying a final partition of eight clusters. Clusters of size exceeding 8 were not selected because representative traffic data is required for each cluster, with predominantly rural counties lacking traffic counts.

3.4.4 Vehicle Class Distributions

Separate vehicle class distributions were developed for local routes and state routes. Data are available for 2009 to 2012; 2013 to 2035 were assumed to have the same vehicle class distribution as the 2009 to 2012 average. The observed 2009–2012 trends did not indicate significant variation in the relative distribution of vehicles at the statewide level. The vehicle classifications were determined using methods developed in the recently completed INDOT-sponsored SPR-3704 study (Volovski et al., 2015) which utilized weighted-distance methods with Kriging spatial interpolation to estimate vehicle class distributions across the state.

Segment-specific traffic data were unavailable for most local roads. Therefore, the vehicle distributions at the most closely related highway class (the non-NHS) was used to develop vehicle class distributions for the local routes. With regard to traffic volumes, data for local routes were unavailable for 2009 but assumed to have the same proportions as 2010, with 2010 to 2012 exhibiting minimal variation in the traffic stream. Class 2 (automobiles) was found to constitute an overwhelming majority of vehicles on local routes.

The state route vehicle class distributions are shown in Table 3.11 (Volovski et al., 2015). Personal VMT (classes 1 to 3) comprising 81.02% (2010) to 87.00% (2011) of the traffic stream, with commercial VMT comprising 13.00% (2011) to 18.98% (2010). The vehicle class distributions for local routes are shown in Table 3.12 (Volovski et al., 2015). The distribution of commercial vehicles on local roads changed from 5.94% (2010) to 7.23% (2012) over the analysis period. The overwhelming majority of local road travel is from non-commercial travel. Class 9 trucks constitute the majority of the commercial travel, with combination trucks comprising approximately 0.50% of commercial travel on local routes.

These variations between the vehicle class distributions for state and local routes emphasize the need for segregating the data. Vehicle class distributions are applied separately for state and local routes. The state route VMT is distributed using data presented in Table 3.11 and the local route VMT is distributing using data presented in Table 3.12.

3.5 Data Collection for Link-Level Estimation

Two different procedures for data collection are needed for link-level estimation of VMT. In the first procedure, a comprehensive database of continuous traffic counts, is developed for state routes. In the second procedure, a sample of local traffic counts from different counties of varying degrees of urbanization is expanded to represent the state. Data collection for these procedures is discussed in this section.

3.5.1 Data for State Routes

The database and procedures to develop this framework are a continuation of the VMT estimates developed as part of the Volovski et al. (2015) study. Traffic volumes and VMT were important inputs for cost allocations that the study team evaluated. This is the starting point for our study and uses similar years of available traffic counts, 2009–2012, for developing statewide VMT estimates and comparing alternative methods that VMT producers may utilize.

For the state routes, the data are robust and complete. This study uses an extensive traffic database for over 9,000 state route segments in Indiana. This database contains mileposts, traffic volumes, functional class, vehicle class, and locational identifiers. As shown in Figure 3.11 on the next page, GIS implementation layers were developed by highway category, with Interstates (upper left), US Roads (upper right), and State Roads (bottom).

The comprehensive database developed for this study was based predominantly on short-term coverage counts. Long-term counts are capable of providing traffic volumes by FHWA vehicle classes; however, this data was only available for 80–90 highway segments. To represent traffic volumes for the other 8,000 road segments of state routes in Indiana, short-term coverage counts were used. The developed database is structured by route, with each route section assigned a unique identified for road segments reported to the FHWA HPMS. This data was compiled from INDOT's traffic count map (INDOT, 2015b), with links created for missing route segments. Limited adjustments were made for centerline mileage because the developed database covers continuous start to end mileposts for each route, comprising of over 10,000 centerline pavement miles of state highways.

3.5.2 Data for Local Routes

Data were compiled from INDOT's traffic count database system (TCDS) and metropolitan and regional planning organizations. The Tippecanoe Area Planning Commission (TAPC) provided data for Tippecanoe County. Michiana Area Council of Governments (MACOG) provided data for northern Indiana counties of Elkhart, Kosciusko, Marshall and St. Joseph (MACOG, n.d.). Indy MPO provided data for Marion County. The TCDS was used for selecting non-state-owned AADT counts by county boundaries (INDOT, 2015a). This GIS-based system easily allowed non-state-owned (local) traffic counts to be exported in spreadsheet form. An example of the polygon buffer area to select all local routes traffic counts is shown in Figure 3.12. The exported data contained information on the geographic location, AADT volume, year collected, functional class, and location descriptions.

Data warehoused in the TCDS provided coverage for both rural and urban areas throughout Indiana. However, counts for non-state owned roads (local routes) were observed to contain many counts in urban areas. To better account for possible bias from many urban traffic counts, Tippecanoe County was selected as one of the case studies to develop road classes that serve as adjustment factors of the sample of traffic counts. Along with the TCDS data, compilation of MPO and RPO counts provided additional coverage throughout Indiana.

Data were available from 14 Indiana counties and used to estimate local route VMT. These counties were selected due to the availability of local traffic data and their representativeness of the different locations of the Indiana counties and of INDOT's six administrative districts. This representation is shown in Figure 3.13, with counties highlighted if they are part of the traffic count sample and the dark boundary lines representing the district boundaries. The counties contain major population centers, such as Indianapolis and Fort Wayne, as well as small-town and mixed-urban counties. The total number of traffic counts compiled per county

TABLE 3.11
State routes vehicle class distributions from segment level data.

FHWA Vehicle Class		2009	2010	2011	2012	2013	……….	2035
State Routes (I, US, SR)	Class 1: Motorcycles	0.49%	0.49%	0.52%	0.50%	0.50%	…	0.50%
	Class 2: Passenger Cars	58.56%	58.43%	62.80%	60.72%	60.13%	…	60.13%
	Class 3: Pickups, Panels, Vans	22.11%	22.10%	23.67%	22.92%	22.70%	…	22.70%
	Personal VMT: Classes 1–3	**81.16%**	**81.02%**	**87.00%**	**84.15%**	**83.33%**	**…**	**83.33%**
	Class 4: Buses	0.28%	0.28%	0.23%	0.27%	0.27%	…	0.27%
	Class 5: Single Unit 2 Axle Trucks	3.39%	3.41%	2.79%	3.40%	3.25%	…	3.25%
	Class 6: Single Unit 3 Axle Trucks	0.87%	0.88%	0.76%	1.07%	0.89%	…	0.89%
	Class 7: Single Unit 4+ Axle Trucks	0.24%	0.24%	0.21%	0.32%	0.25%	…	0.25%
	Class 8: Single Trailer 3–4 Axle Trucks	1.08%	1.09%	0.79%	0.98%	0.99%	…	0.99%
	Class 9: Single Trailer 5 Axle Trucks	12.32%	12.43%	7.65%	9.26%	10.42%	…	10.42%
	Class 10: Single Trailer 6+ Axle Trucks	0.16%	0.16%	0.12%	0.15%	0.15%	…	0.15%
	Class 11: Multi-Trailer 5 Axle Trucks	0.32%	0.31%	0.20%	0.26%	0.28%	…	0.28%
	Class 12: Multi-Trailer 6 Axle Trucks	0.12%	0.11%	0.07%	0.09%	0.10%	…	0.10%
	Class 13: Multi-Trailer 7+ Axle Trucks	0.05%	0.05%	0.19%	0.05%	0.08%	…	0.08%
	Commercial VMT: Classes 4–13	**18.84%**	**18.98%**	**13.00%**	**15.85%**	**16.67%**	**…**	**16.67%**

TABLE 3.12
Local routes vehicle class distributions from segment level data.

FHWA Vehicle Class		2009	2010	2011	2012	2013	……….	2035
Local Routes (City and County Roads)	Class 1: Motorcycles	0.60%	0.60%	0.59%	0.59%	0.60%	…	0.60%
	Class 2: Passenger Cars	65.73%	65.73%	64.75%	64.87%	65.27%	…	65.27%
	Class 3: Pickups, Panels, Vans	27.73%	27.73%	27.88%	27.31%	27.66%	…	27.66%
	Personal VMT: Classes 1–3	**94.06%**	**94.06%**	**93.22%**	**92.77%**	**93.53%**	**…**	**93.53%**
	Class 4: Buses	0.08%	0.08%	0.10%	0.16%	0.11%	…	0.11%
	Class 5: Single Unit 2 Axle Trucks	1.22%	1.22%	1.79%	2.59%	1.71%	…	1.71%
	Class 6: Single Unit 3 Axle Trucks	0.63%	0.63%	1.34%	1.52%	1.03%	…	1.03%
	Class 7: Single Unit 4+ Axle Trucks	0.21%	0.21%	0.46%	0.52%	0.35%	…	0.35%
	Class 8: Single Trailer 3–4 Axle Trucks	0.47%	0.47%	0.19%	0.17%	0.33%	…	0.33%
	Class 9: Single Trailer 5 Axle Trucks	3.19%	3.19%	2.85%	2.22%	2.86%	…	2.86%
	Class 10: Single Trailer 6+ Axle Trucks	0.07%	0.07%	0.03%	0.02%	0.05%	…	0.05%
	Class 11: Multi-Trailer 5 Axle Trucks	0.03%	0.03%	0.01%	0.01%	0.02%	…	0.02%
	Class 12: Multi-Trailer 6 Axle Trucks	0.01%	0.01%	0.00%	0.00%	0.01%	…	0.01%
	Class 13: Multi-Trailer 7+ Axle Trucks	0.02%	0.02%	0.01%	0.01%	0.02%	…	0.02%
	Commercial VMT: Classes 4–13	**5.94%**	**5.94%**	**6.78%**	**7.23%**	**6.47%**	**…**	**6.47%**

Figure 3.11 State routes data displayed in GIS platform by road designation.

is shown in Table 3.13, with Marion, Tippecanoe, and Lake comprising of the three largest samples.

It was observed that predominately rural counties, such as Dubois, Perry, Jennings, Lawrence, and Jefferson had fewer than 200 counts. One of the challenges with local VMT is the limited number of traffic counting programs and unavailability of data. Also, the use of these traffic counts without adjustment, may lead to misrepresentation of county-wide VMT.

3.6 Chapter Summary

This chapter discussed the methodology used for this study. The desired qualities for the estimation framework, the survey of users and producers of VMT information, and the selection of the best estimation methodology were discussed. Based on the study of this study, the link-level method was selected as the control or benchmark for comparing the VMT estimated using other methods and for future VMT estimation. The framework for VMT estimation at the link and non-link levels was explained in this chapter. Link-level VMT estimation consists of both the state and local route components that comprise the statewide VMT, and the vehicle class distributions were developed for link-level VMT estimation within these components. Also, the other VMT estimation methods were described; these include the methods that use fuel revenues, trend analysis, growth factors, socioeconomic regression models, vehicle registrations, licensed drivers, and travel surveys. Finally, the data needs and collection procedures were introduced in this chapter.

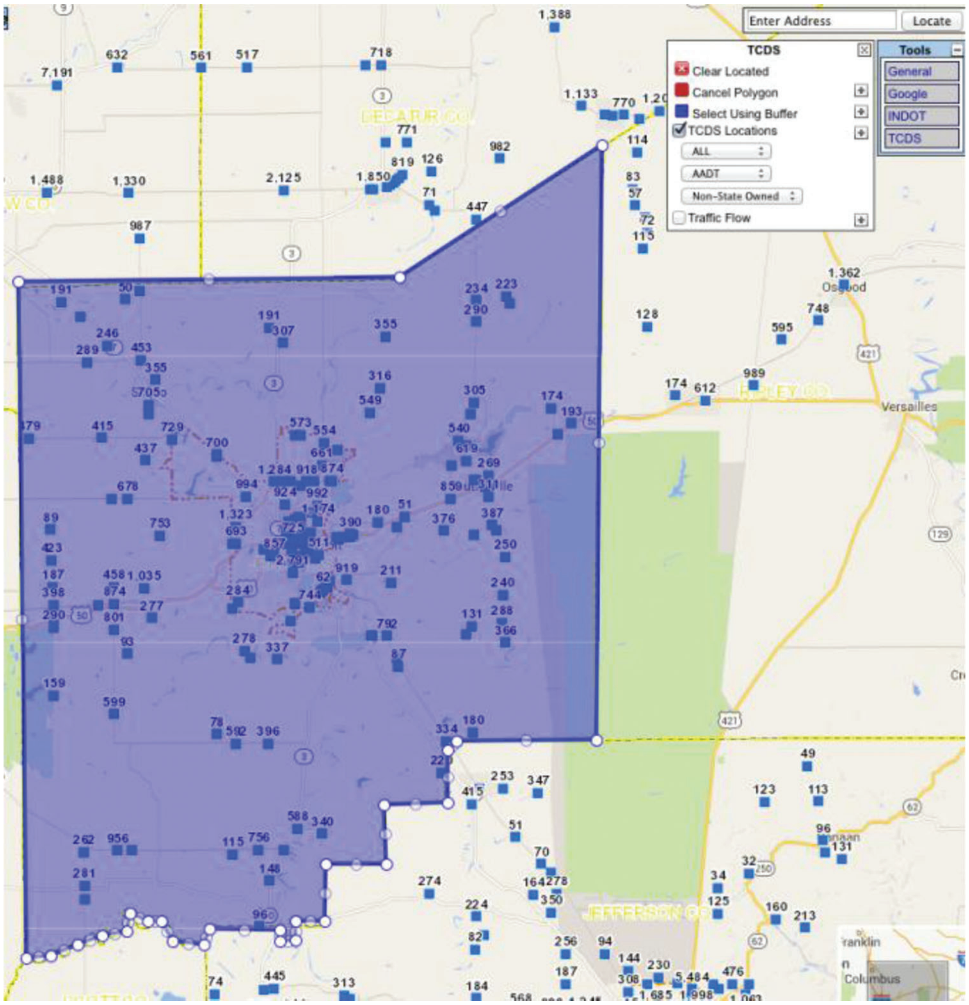


Figure 3.12 Selection of non-state owned traffic counts using the TCDS.

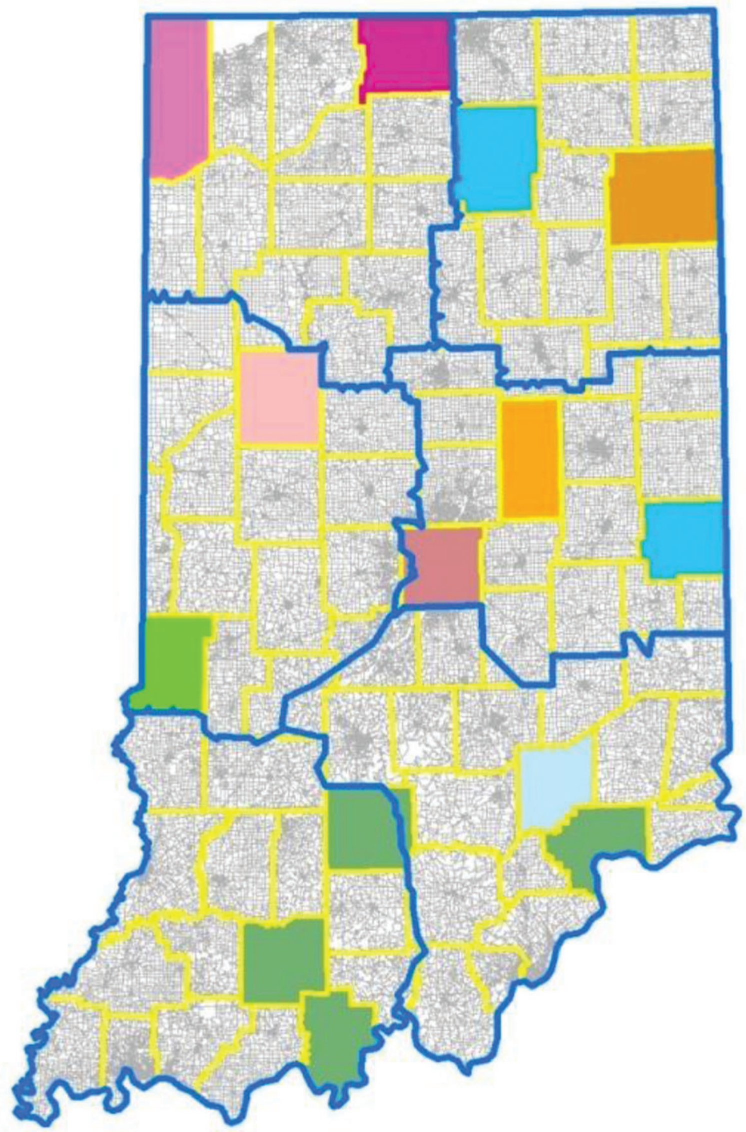


Figure 3.13 Sample of local routes traffic data by Indiana counties.

TABLE 3.13
Summary of traffic counts sample for local routes.

County in Sample	Number of Traffic Counts in Sample	Source(s)
Marion	677	INDOT TCDS
Lake	510	INDOT TCDS
St. Joseph	455	INDOT TCDS & MACOG
Allen	192	INDOT TCDS
Tippecanoe	611	INDOT TCDS & T. APC
Madison	202	INDOT TCDS
Vigo	126	INDOT TCDS
Wayne	156	INDOT TCDS
Kosciusko	236	INDOT TCDS
Jefferson	197	INDOT TCDS
Dubois	102	INDOT TCDS
Jennings	166	INDOT TCDS
Perry	63	INDOT TCDS
Lawrence	82	INDOT TCDS

4. ANALYSIS AND MODELING

4.1 Introduction

This chapter uses the study methodology discussed in Chapter 3 to carry out analysis and modeling for both state and local routes, but with emphasis on local routes. To accomplish this framework, the data collection and database development procedures used in this study are further described. Once the data were collected and processed appropriately for the study, alternative VMT estimation methods were applied.

The intermediate steps and analysis to estimate local VMT using the three outlined procedures in Chapter 3 are presented in this chapter. Within the proposed local route VMT estimation framework, a sample was used, which must be expanded to represent all of Indiana. To accomplish this expansion to the population, cluster analysis was applied and is discussed in this chapter. In order to assess the resulting local VMT estimates, this study's estimates and those reported in the literature are compared to gauge the extent of deviation. Spatial interpolation was investigated for use in this study. Spatial interpolation relates the interconnected nature and importance of proximity in transportation. Using weighted distance techniques implemented in a GIS platform, VMT estimates for local routes were produced.

The final part of this chapter discusses the modeling inputs and components for non-link-level VMT estimation using approaches other than the link level. These modeling inputs were provided by the different methods investigated in this study, such as those based on fuel, statistical regression of socio-economic data, licensed drivers, and vehicle registrations.

4.2 State Routes (Link-Level)

Traffic data for all mainline and ramps segments of interstates, and US and state roads are available in spreadsheet form (Microsoft Excel). This comprehensive traffic database required manual processing to provide complete and consistent data for the four-year analysis period (2009 to 2012). These years serve as the baseline inventory for future year predictions and to provide for existing conditions of statewide VMT in Indiana. The user's manual developed in this study explains the information contained in the spreadsheet, discusses its updatability, and provides instructions for VMT aggregations depending on the analysis desired.

4.2.1 Database Development

An overview of the database contents include link identification information, historical traffic data, estimated annual VMT at the link level, predicted annual VMT at the link-level, vehicle class distributions at the link level, and functional class identification. This level of detail serves as the inventory for future VMT estimation. Also, the inventory is dynamic, allowing for new roads to be incorporated into (or decommissioned roads eliminated from) the underlying database for the VMT estimation.

The data can also be filtered by route, designation, county, functional class, and economic region. For example, I-64 can be selected from routes that only aggregate the annual VMT for I-64. Aggregation is possible for the entire length or a subset of mileposts between !A cross-section of this link-level database for a section of I-64 is provided in Table 4.1. As can be seen, I-64 from milepost 0 (Indiana-Illinois border) to milepost 61.1 was selected for purposes for illustration. Examination of the AADT and VMT, the vehicle class, and the functional class can be determined for a given route and specific highway segment.

4.2.2 Forecasting VMT

To forecast VMT, AADT is predicted for each road segment of the state routes database, using common growth factors by functional class. Based on the four years of data, 2009 to 2012, growth factors were developed for all state route segments based on an average of 2009 to 2010, 2010 to 2011, and 2011 to 2012, for each functional class. A growth factor for city streets and county roads was developed based on observed county level data under MACOG jurisdiction. Random sampling was used to collect data from around 150 road segments with time-series data (MACOG, n.d.). Multiple year data allowed for an annual growth factor to be developed, specific to local routes. For example, as shown in Table 4.2, mainline Interstates (functional class 1) had 527 mainline segments for each year, with an observed mean of 1.58% for the 4-year period. Similarly, minor arterials, functional class 5, had an observed mean of 7.55%, one of the highest observed growth factors. Other descriptive statistics such as standard deviation, median, and quartiles were analyzed.

Functional classes 3, 5, 6, and 7, had the highest variance. Interstates, functional class 1, are often covered by permanent stations and part of more frequent counting programs, were observed to have the lowest variance and standard deviation. For the annual growth factor, arterials and collectors had the highest standard deviation, ranging from 28.09% to 56.07%, reflecting the limited coverage counts available for these functional classes.

To account for the stochastic nature of long-term traffic forecasting, a range of VMT predictions is presented. The range is indicated by the 25% lower than the median for the lower bound, median for the average, and 25% higher than the median for the upper bound. These ranges are incorporated into the statewide VMT aggregations shown in Chapter 5. The 1st and 3rd quartile are not used for predicting because these growth factors led to predictions in 2035 which varied from the current level of VMT.

Factors for AADT adjustment by functional class are provided in Addendum A of this report to facilitate the adjustment from current to future year

TABLE 4.1
Cross-section of link-level database for interstate section.

Link ID	Designation	Route	NHS-Int	Start MP	End MP	Link Length	Functional Class	County	Economic Region	AADT (2009)	AADT (2010)	Annual VMT (2009)	Annual VMT (2010)
1	Interstate	I-64	100.0%	0	4.33	4.33	FC 1	65	11	11,060	12,580	1.75E+07	1.99E+07
2	Interstate	I-64	100.0%	4.33	11.88	7.55	FC 1	65	11	10,620	12,170	2.93E+07	3.35E+07
3	Interstate	I-64	100.0%	11.88	17.44	5.56	FC 1	65	11	11,510	11,450	2.34E+07	2.32E+07
4	Interstate	I-64	100.0%	17.44	17.66	0.22	FC 1	82	11	12,220	12,150	9.81E+05	9.76E+05
5	Interstate	I-64	100.0%	17.66	23.5	5.84	FC 1	82	11	11,781	12,899	2.51E+07	2.75E+07
6	Interstate	I-64	100.0%	23.5	25.01	1.51	FC 1	26	11	12,760	12,750	7.03E+06	7.03E+06
7	Interstate	I-64	100.0%	25.01	26.3	1.29	FC 1	26	11	16,330	16,230	7.69E+06	7.64E+06
8	Interstate	I-64	100.0%	26.36	27.46	1.1	FC 1	82	11	16,330	16,230	6.56E+06	6.52E+06
9	Interstate	I-64	100.0%	27.46	29.34	1.88	FC 1	26	11	16,330	16,870	1.12E+07	1.16E+07
10	Interstate	I-64	100.0%	29.34	29.46	0.12	FC 1	26	11	17,080	17,030	7.48E+05	7.46E+05
11	Interstate	I-64	100.0%	29.46	39.18	9.72	FC 1	87	11	10,719	15,729	3.80E+07	5.58E+07
12	Interstate	I-64	100.0%	39.18	53.47	14.29	FC 1	87	11	10,200	15,157	5.32E+07	7.91E+07
13	Interstate	I-64	100.0%	53.47	54.46	0.99	FC 1	87	11	9,580	9,560	3.46E+06	3.46E+06
14	Interstate	I-64	100.0%	54.46	56.59	2.13	FC 1	74	11	13,000	12,950	1.01E+07	1.01E+07
15	Interstate	I-64	100.0%	56.59	61.1	4.51	FC 1	74	11	12,250	12,420	2.02E+07	2.05E+07

TABLE 4.2
Descriptive statistics for annual growth factors.

Functional Class	Annual Growth Factor for Study	Observed Mean	Total Traffic Counts	Standard Deviation	Variation	1st Quartile	Median	3rd Quartile
State Routes								
Interstates (FC 1)	1.02%	1.58%	527	9.86%	0.97%	-1.58%	1.02%	4.69%
Principal Arterials: Major Freeways and Expressways (FC 2)	0.03%	2.45%	172	24.49%	6.00%	-3.43%	0.03%	2.83%
Principal Arterials: Other (FC 3)	1.28%	6.10%	3020	56.07%	31.44%	-2.07%	1.28%	5.86%
Major Arterials (FC 4)	1.53%	6.10%	1579	28.09%	7.89%	-1.64%	1.53%	6.22%
Minor Arterials (FC 5)	1.35%	7.55%	2757	46.53%	21.65%	-2.13%	1.35%	6.49%
Major Collectors and Locals (FC 6–7)	3.20%	8.62%	134	34.63%	11.99%	-2.23%	3.20%	10.30%
Local Routes								
City Streets and County Roads (Locals)	0.74%	1.43%	111	4.63%	0.21%	-1.41%	0.74%	3.61%

AADT, and subsequently to develop VMT estimates. These calculations are completed automatically for the user in the spreadsheet. The "From AADT Year" represents the year from which an AADT is desired to be adjusted. The "To AADT Year" represents the year to which an AADT is desired to be adjusted. For example, if the user has an AADT count that was measured in 2011 for Interstates (FC 1) and desires to forecast for 2016, Table A.1 could be used to obtain the appropriate adjustment factor. This adjustment factor is multiplied by the present year AADT (in this example, 2011) to estimate the future year AADT at the given count station. The same procedure applies to any functional class. The annual growth factors used to develop Table A.1 to Table A.6 reflect a medium traffic growth prediction range (observing moderate VMT growth).

4.3 Local Routes (Link-Level)

A reliable benchmark for local route VMT was estimated using a sample of county-wide traffic counts. The distribution of the traffic sample was analyzed to help develop an estimation methodology. Based on initial estimates using an average approach without stratifying by road classes, a resulting overestimate warranted a need for developing adjustment factors. These adjustment factors were based on developing a comprehensive network inventory and estimation by local road classes that were developed in this study. A comparison of the estimates from the study and reported values is provided. By grouping counties based on VMT-related characteristics (using cluster analysis), the VMT estimation was carried out for all local roads in the state.

4.3.1 Displaying Traffic Data

The traffic data contained a minimum of the count's latitude, longitude, station name, location description, AADT volume, collection year, and functional class. The Excel point data was brought into ArcGIS and aligned with the platform's geographic coordinate system, using Earthpoint's spreadsheet, to KMZ, Google Earth File, (Clark, 2015) conversion tool which allows the data to be easily transferable to an ArcGIS shape file in the next workflow step. This step also allowed for visual inspection of the alignment of traffic counts to the correct segment. After saving the Google Earth KMZ as a KML file, this was exported to ArcGIS using the toolbox's conversion tools. The specific tool, "KML to Layer" took the input KMZ/KML file and produces a GIS-compatible layer required for spatial analysis. The next step of VMT estimation was to determine the respective segment lengths.

4.3.2 Estimating Segment Lengths

One of the problems encountered with determining local VMT from a traffic counts sample (point data) is estimating the applicable segment lengths required for VMT. Many full-coverage counts from ATRs for Interstates and other higher functional classes are linked to a specific and consistent road segment using location referencing system (LRS). This allows for VMT to be quickly estimated as the product of AADT and section length. However, when working with local routes traffic data, most counts are assumed to be from intersection to intersection. This may not always be the case for most local routes.

Three available options were observed for determining appropriate section lengths. First, if there are records of mileposts for the specific count, then the segment length is the difference in mileposts. This is not the case for many local routes and determining this for thousands of counts is not feasible. Second, judgment can be used to measure the length using mapping software. However, this is immensely time-consuming, particularly with a traffic sample of around 4,000 counts. Accuracy and reliably is also a concern. Third, spatial analyst tools within GIS can be used to determine and match the road segment to the AADT point layer. This is technically robust and time-effective for thousands of traffic counts. This option was selected for this study.

Proximity analysis using near and join commands was applied. The near tool (ESRI, 2013) searches the database of over 645,000 road segments in Indiana to identify the closest individual road segments for each count. New entries are created in the attribute table with the identified segment and its respective length; this was joined with the AADT points layer based on the common segment identifier. This process was completed on a per county basis, for each of the fourteen counties of the traffic sample. With the AADT and section length determined, VMT was estimated using the traffic count at each location.

4.3.3 Analysis of Traffic Sample

Using histograms, the distributions of AADT were analyzed to identify the type of distribution at the county level. It was observed that there is not a normal distribution, but skewed. A high number of observations had very low AADT, such as counts below 400, and a high AADT, such as counts greater than 8,000. The distributions for wide variety of Indiana counties, from predominantly urban, mixed urban, to predominantly rural, are shown in Figure 4.1 to Figure 4.3.

As observed from Figure 4.1, all counties in the sample had a high percentage of traffic counts with an AADT of less than 1,000. Similar observations can be drawn for predominately urban counties shown in Figure 4.2. Allen, Lake, and Marion County are skewed. These low traffic counts may be attributed to the rural county roads, with available traffic counts compiled for this study.

Finally, Figure 4.3 shows the AADT distribution for mixed urban counties such as Vigo, Madison, St. Joseph, Wayne, and Tippecanoe. Tippecanoe and St. Joseph County contained counts compiled from both INDOT and MPO data. Similar observations were made for mixed urban counties, with many low traffic counts of less than 1,000 AADT observed for St. Joseph and Tippecanoe County, in particular. The rural and urban counties presented can be drawn for mixed urban counties. These type of counties have many local routes which are outside of the city boundaries, such as low-volume county roads.

It is for these reasons that the simple average approach may produce a significant overestimate. A simple average of all data points may not represent the actual AADT distribution and over-represent cities and urban areas. County roads in the rural areas of the county are being assigned an overly high AADT when using an average AADT per mile approach with any further stratification. To avoid the introduction of bias toward "important" locations, traffic counts should be carefully selected to provide adequate county-wide coverage of all types of local roads.

4.3.4 Network Assignment by Created Road Class

Based on the analysis provided in Section 4.3.3, it is indicative that VMT estimation for all county-wide traffic counts may not be the most accurate approach. To remedy this problem, separate road and traffic networks were developed to estimate VMT more accurately. A master inventory of local roads was developed from the homogenous road network to allow for the average AADT within each road group to be expanded based on the centerline mileage within each

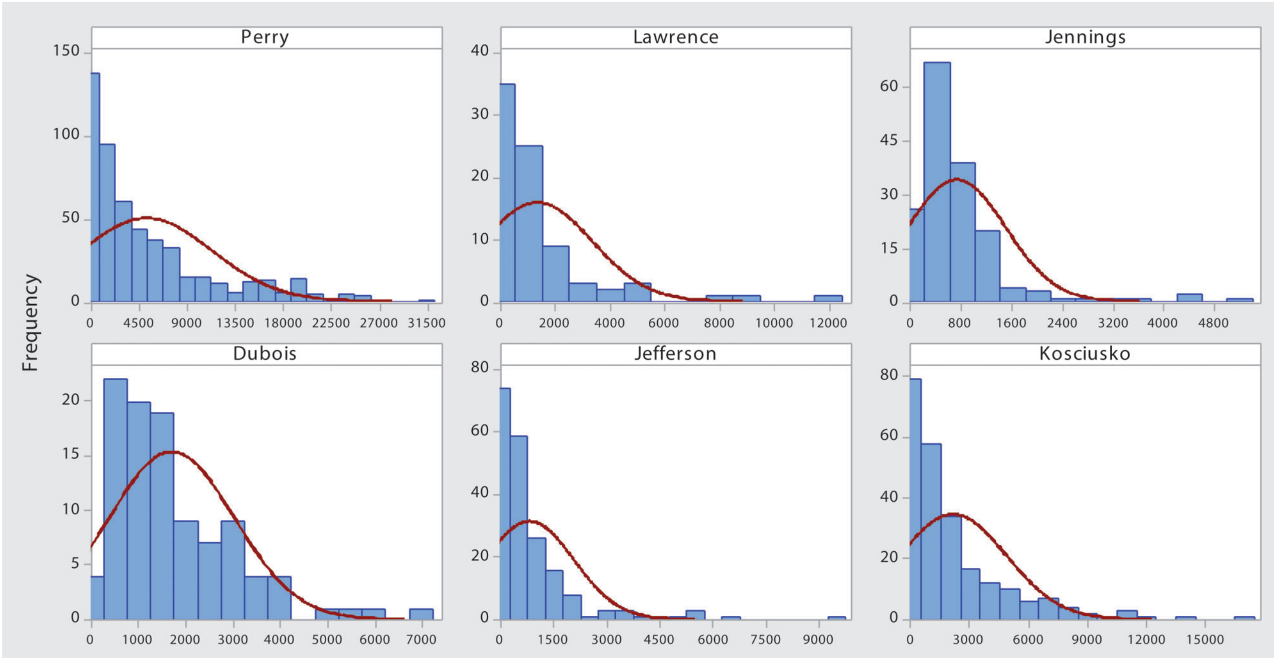


Figure 4.1 AADT distribution for local road segments in rural IN counties.

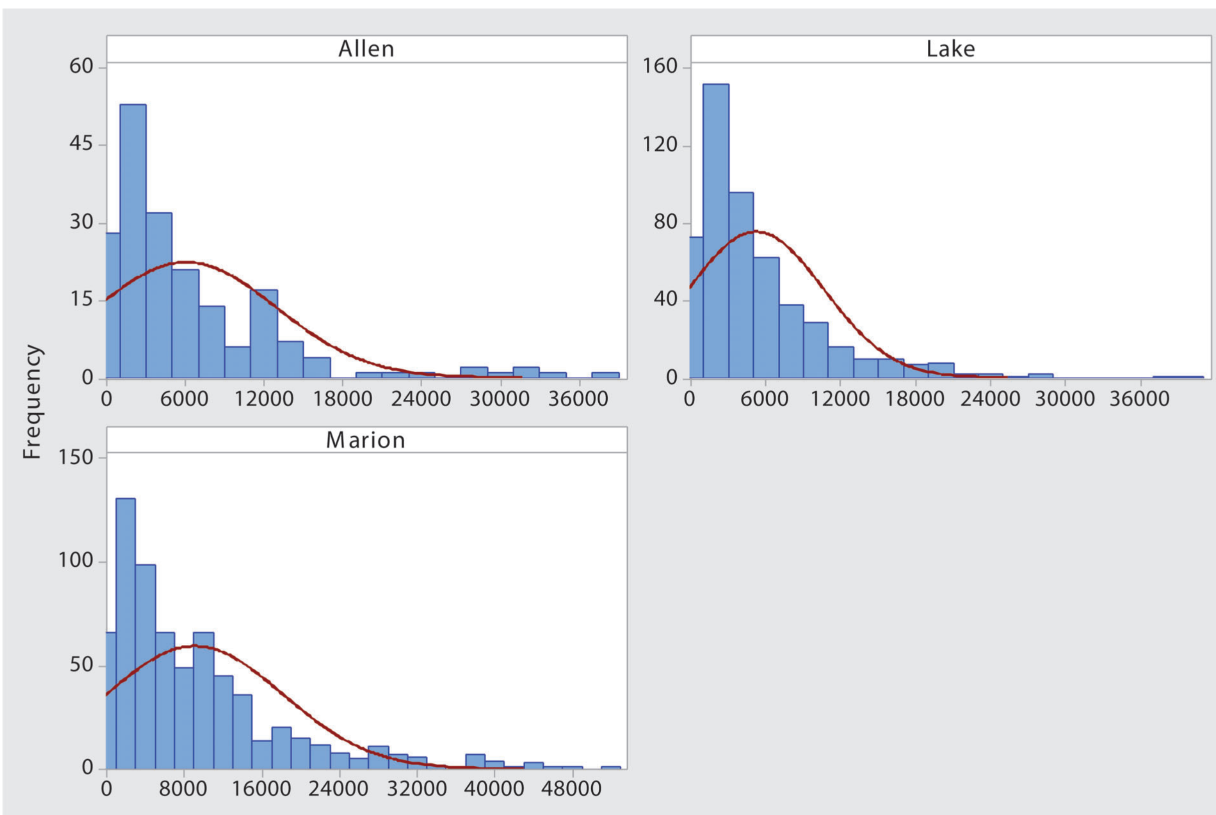


Figure 4.2 AADT distribution for local road segments in urban IN counties.

group. This allows for VMT to be more accurately estimated by road class and aggregated representing the total travel in a county.

The road network did not have complete attributes to allow for separation into unique networks. To remedy this, all road segments were assigned using

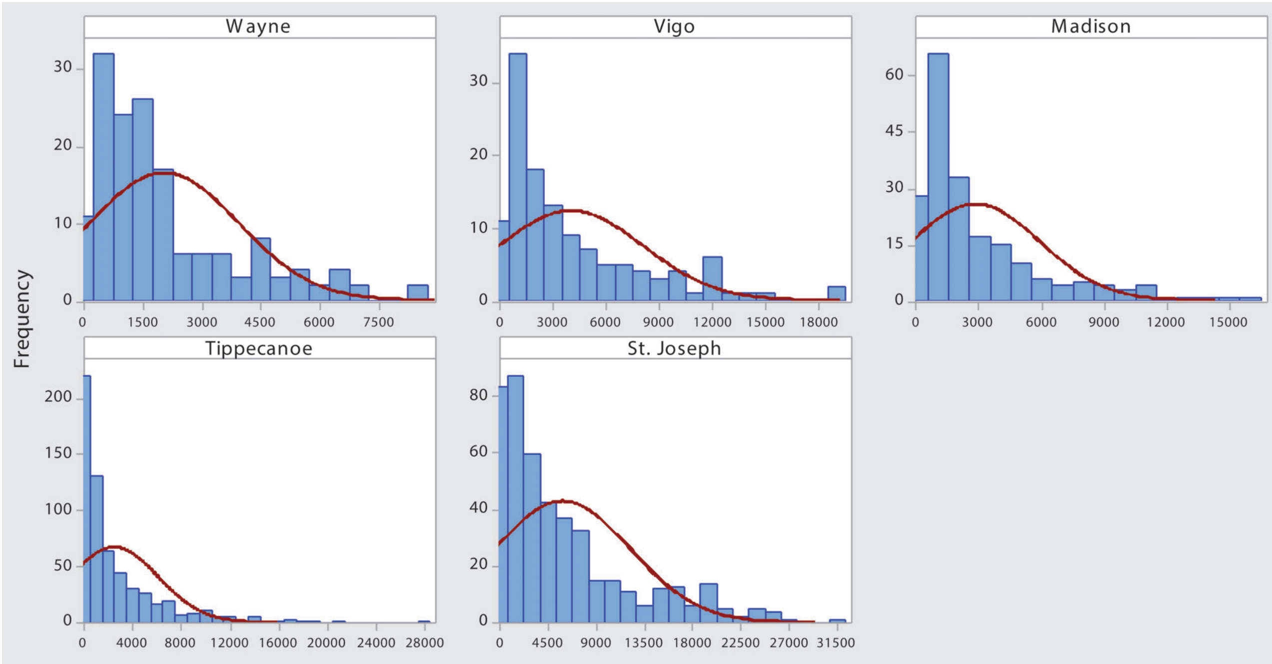


Figure 4.3 AADT distribution for local road segments in mixed urban IN counties.

TABLE 4.3
Local routes network inventory by road class.

Local Route Classes	Local Routes Traffic Sample Mileage (No. of Links) Jefferson County (Rural)	Tippecanoe County (Mixed)	St. Joseph County (Urban)
City Streets: Low Volume	40 (359)	183 (2484)	495 (6005)
City Streets: High Volume	N/A	90 (888)	128 (877)
County Roads: Low Volume	457 (1440)	498 (1227)	517 (933)
County Roads: High Volume	N/A	259 (1193)	138 (431)
Neighborhood Roads	271 (1742)	470 (4088)	511 (5319)
All Roads	768 (3541)	1500 (9880)	1789 (13565)

"select by attributes" and manual selection based on observed traffic counts at the locations of these different road classes. The AADT layer was displayed to aid with the assignment and show relative magnitudes of traffic counts. The volume definitions outlined in Section 3.4.2 were the basis for this assignment. Five unique road networks were created for St. Joseph and Tippecanoe County; and three road networks for Jefferson County. Low and high volume traffic groups were not distinguished for Jefferson County because of the limited traffic counts for this predominantly rural county. This framework for local road network assignment is presented in Table 4.3.

The local road network was decomposed into three to five unique GIS layers, each allowing for AADT assignment based on proximity analysis. The near analysis within ArcGIS identified the road type nearest to the traffic count, within a set search radius (10 meters used). For example, there are over 600 total counts for Tippecanoe County and to determine which counts are applicable for each road class, GIS proximity analysis was used. The subset of counts, specific to the road class of interest, was selected in the attribute table and exported as a new layer. This data subset retains the attributes of the original AADT counts and allows for spatial interpolation and other analysis within ArcGIS.

For example, Figure 4.4 shows the Tippecanoe County traffic counts assigned to the unique layers of CS high volume, CR high volume, CR low volume, CS low volume, and neighborhood. Similar procedures were applied to the other counties.

4.3.5 Representative Counties for VMT Adjustment

To adjust the overestimates from the average without stratification approach, representative Indiana counties including Tippecanoe, St. Joseph, and Jefferson, were used. To account better for the varying degrees of urbanization throughout Indiana, separate adjustment factors are developed based on VMT estimation by road class.

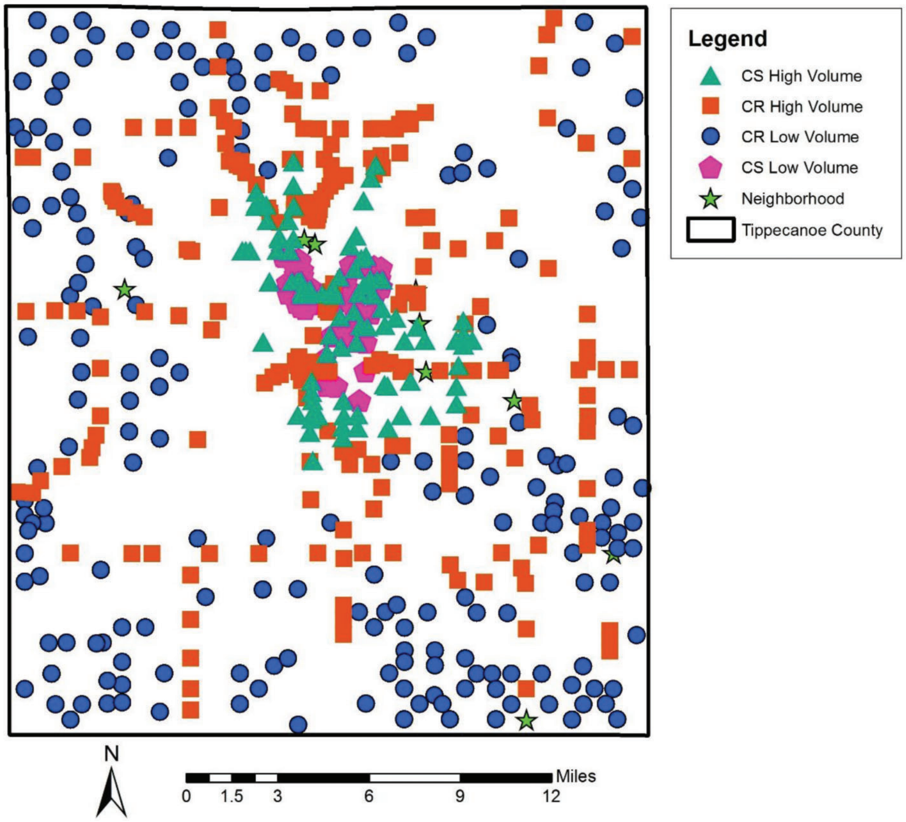


Figure 4.4 Assignment of AADT by road class for Tippecanoe County (illustration).

TABLE 4.4
Tippecanoe County estimation results by road class.

Road Classes	Network Links	Total Roadway Mileage	Average DVMT / Mile Per Group	Number of Traffic Counts	DVMT	AVMT
City Streets – High Volume	888	89.81	8,732	93	784,271	286,258,851
County Roads – Low Volume	1,227	497.50	154	203	76,482	27,915,979
County Roads – High Volume	1,193	258.73	2,067	223	534,792	195,199,199
Neighborhood Roads	4,088	469.62	200	9	93,924	34,282,421
City Streets – Low Volume	2,484	182.45	2,119	71	386,626	141,118,377
Totals	9,880	1498.11		599	1,876,095	684,774,828

Total VMT from Road Class Approach = 684,774,828
Total VMT from Average Approach = 1,186,018,256
Percent Difference = 73.198
Adjustment Factor = 1.732

A summary of the road and traffic networks definition and estimation results by functional class, for Tippecanoe County, is given in Table 4.4. The average daily VMT per mile, per group, ranges from 154 (CR low volume) to 8,732 (CS high volume). The total annual VMT is 684.78 million, compared to 1,186.02 million from the average approach described in Section 3.4.3. This is a 73.20 percent difference; thus, the adjustment factor is 1.732.

The distribution of the local routes county-wide VMT for Tippecanoe County is illustrated in Figure 4.5. The majority of the VMT is from CS high volume, at 42 percent, followed by CS low volume at 21 percent. Neighborhood roads and CR low volume comprise only 5 percent and 4 percent, respectively, of the total VMT of that county's local roads.

Similar methods were followed for the other two counties in the case study, St. Joseph and Jefferson. St. Joseph had higher traffic volumes, as may be intuitively expected for a more urban county than Tippecanoe. A summary of the networks definition and estimation results by road classes, for St. Joseph County, is given in Table 4.5.

The number of traffic counts available for the county is 514. The average daily VMT per mile, per group, ranges from 11,438 for CS high volume to 559 for CR low volume. Neighborhood roads did not have directly applicable traffic counts, a low AADT was estimated for this road class. Also, the neighborhood roads component had a very low contribution to the overall total VMT.

The total annual VMT for St. Joseph County is estimated as 1,394.27 million. This is significantly lower than the county total from an average approach, described in Section 3.4.3, of 4,039.91 million. The 189.75 percent difference warrants an adjustment factor of 2.898. The distribution of local VMT by road class (St. Joseph County) is provided in Figure 4.6.

Jefferson, the most rural, did not have noticeable difference between low and high-volume roads at which traffic counts were available. As shown in Table 4.6, county roads, city streets, and neighborhood roads are the three road classes analyzed. The daily VMT per mile, per group, ranged from 297 for county roads, 2,232 for city streets, to 200 for neighborhood roads. Again, an assumed value for neighborhood roads was applied. The VMT distribution (Figure 4.7) is primarily from county roads (all volume groups) at 49 percent, followed by city streets at 32 percent, and neighborhood roads comprising of 19 percent.

The total annual VMT was estimated as 102.23 million using a similar estimation procedure. Based on the average approach for VMT estimation, described in Section 3.4.3, a county-wide VMT of 188.59 million is estimated. An 84.48 percent difference between the two approaches yields an adjustment factor of 1.845.

These adjustment factors are used to more accurately represent the county's average VMT per mile, which is expanded from the unit quantity to the county level by

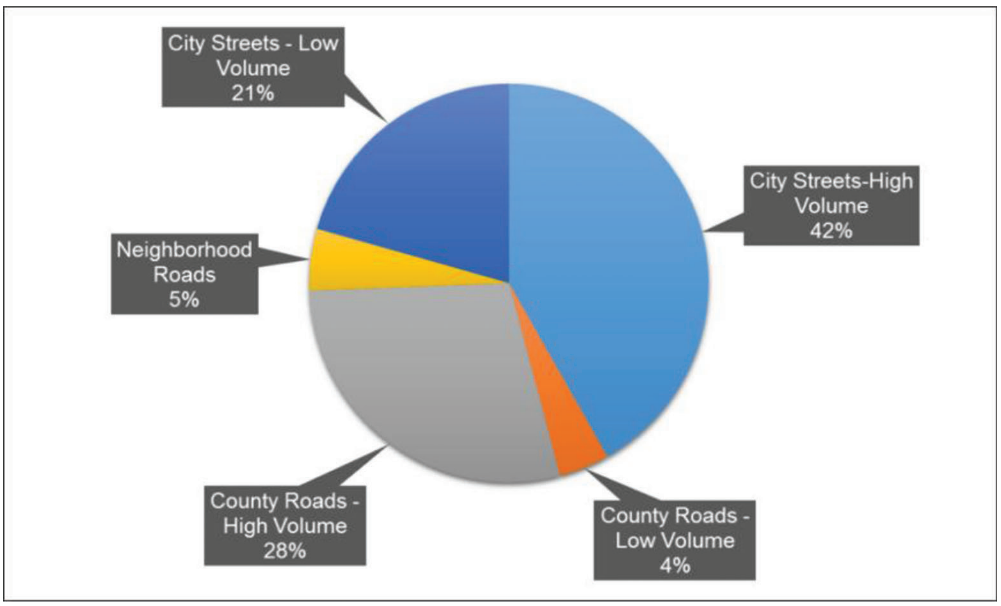


Figure 4.5 Tippecanoe County local VMT distribution.

TABLE 4.5
St. Joseph County estimation results by road class.

Road Classes	Network Links	Total Roadway Mileage	Average DVMT / Mile Per Group	Number of Traffic Counts	DVMT	AVMT
City Streets – High Volume	877	128.16	11,438	148	1,465,845	535,033,270
County Roads – Low Volume	933	516.53	559	116	288,632	105,350,681
County Roads – High Volume	431	138.05	2,180	80	300,960	109,850,407
Neighborhood Roads	5,319	511.46	200	22	102,292	37,336,666
City Streets – Low Volume	6,005	495.10	3,357	148	1,662,185	606,697,562
Totals	13,565	1789.30		514	3,819,914	1,394,268,586

Total VMT from Road Class Approach = 1,394,268,586
Total VMT from Average Approach = 4,039,912,656
Percent Difference = 189.751
Adjustment Factor = 2.898

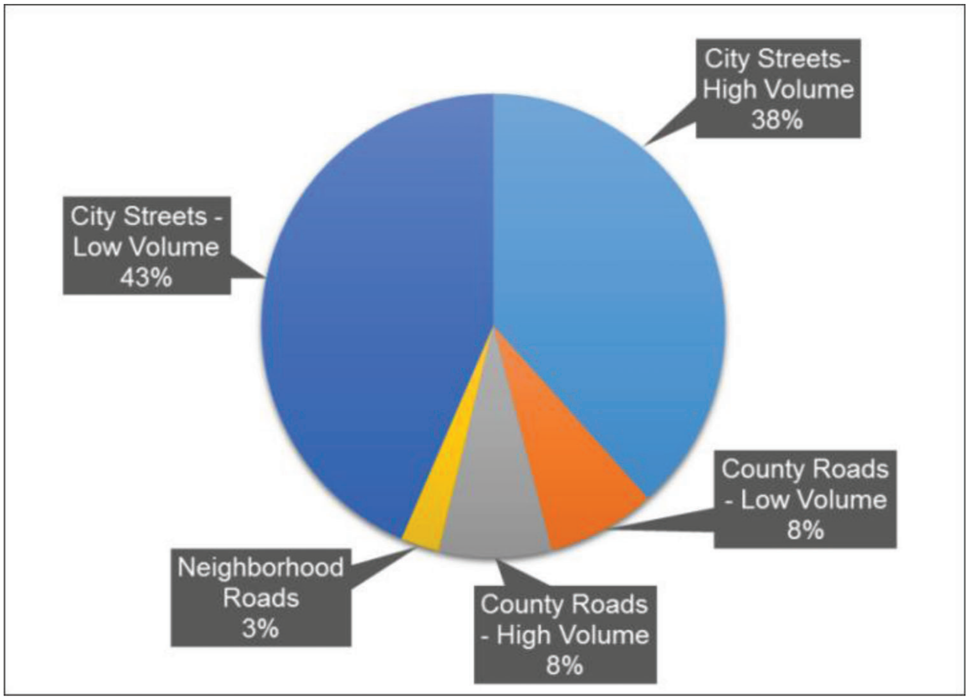


Figure 4.6 St. Joseph local VMT distribution.

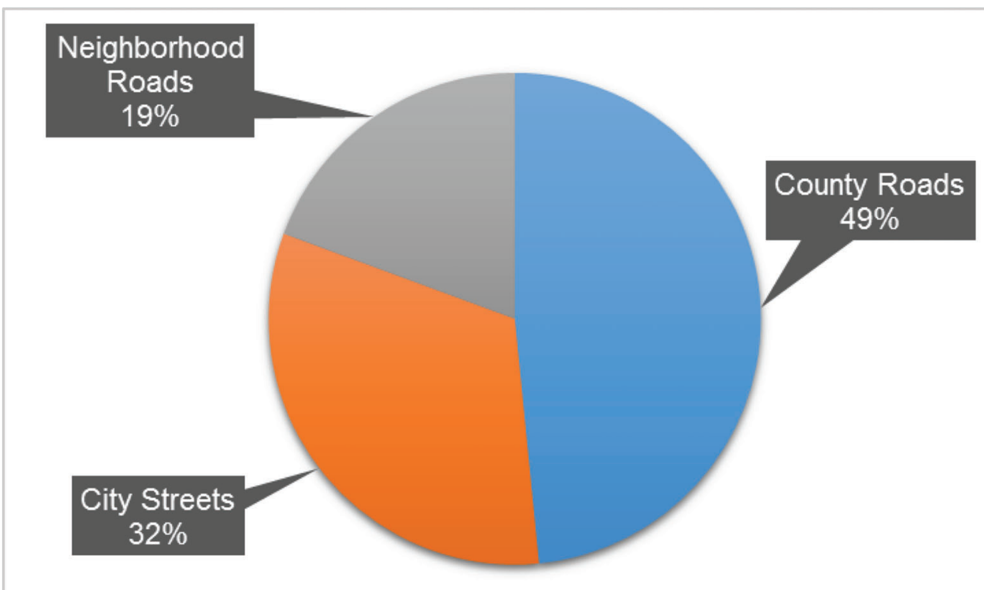


Figure 4.7 VMT distribution by road class for Jefferson County.

using the total local routes mileage. For example, the unadjusted unit VMT for Wayne County is 750,798, with an adjustment factor of 1.845 applied, becomes an adjusted unit VMT of 406,937.

4.3.6 Grouping Counties

The dendograms of Figure 4.8 and Figure 4.9 represent similarity between counties, with clusters one to seven (Figure 4.8) and cluster 8 (Figure 4.9). Cluster 8 consists of 64 predominantly rural counties, with a similarity of 94.88 percent. Cluster 1 contained Marion County by itself. Similarly, clusters 2 and 3 contained Lake and Allen County by themselves.

The listing of Indiana counties assigned to the eight unique cluster groups is given in Table 4.7. The similarity was determined from statistical analysis, using the complete linkage method. The highlighted counties are those that constituted the local roads traffic sample, with representation for each cluster group.

TABLE 4.6
Jefferson County estimation results by road class.

Road Classes	Network Links	Total Roadway Mileage	Average DVMT / Mile per Group	Number of Traffic Counts	DVMT	AVMT
County Roads	1,440	457.28	297	129	135,640	49,508,539
City Streets	359	40.40	2,232	51	90,175	32,914,030
Neighborhood Roads	1,742	271.27	200	0	54,255	19,802,969
Totals	3,541	768.96		180	280,070	102,225,537

Total VMT from Road Class Approach = 102,225,537
Total VMT from Average Approach = 188,590,095
Percent Difference = 84.484
Adjustment Factor = 1.845

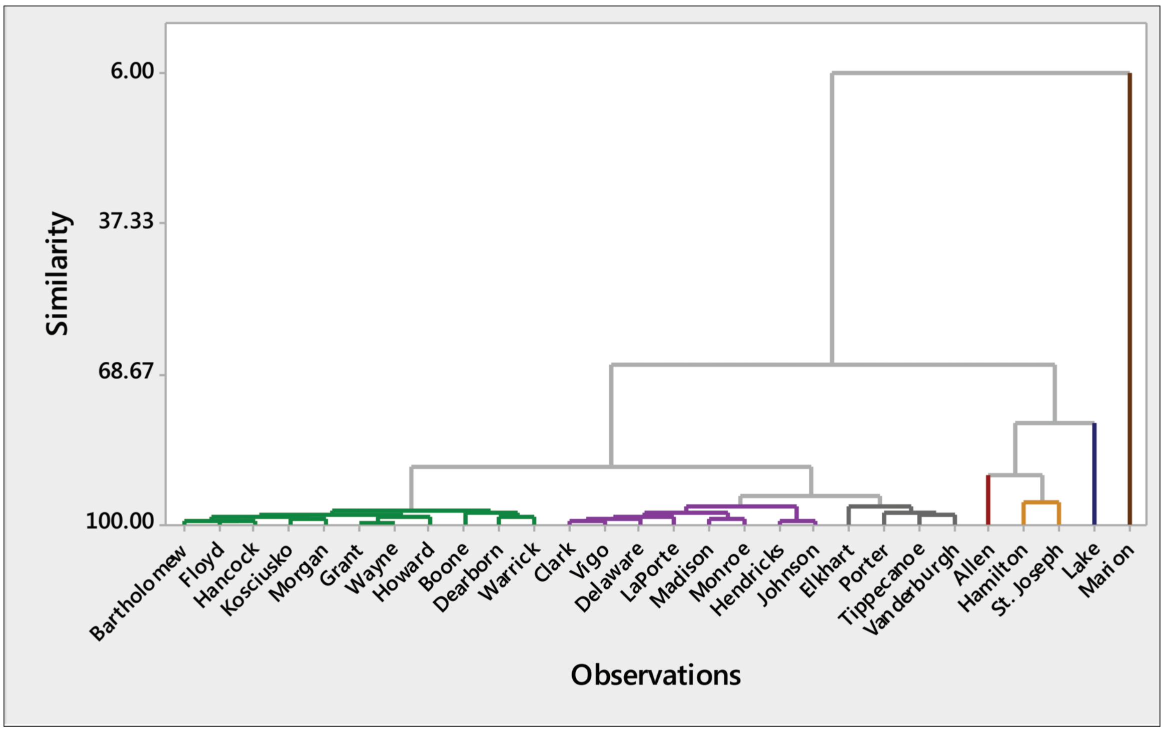


Figure 4.8 Clustering of Indiana counties based on VMT characteristics.

4.3.7 Expansion to Statewide Estimate

The fourteen counties comprising the local roads traffic sample were used to expand from clusters to a statewide estimate. The average annual per mile was adjusted based on the adjustment factors developed in Section 4.3.5. The adjusted annual VMT per mile was weighted for clusters with more than one representative county. For example, Cluster 8 has traffic data from five counties and a single unit value is needed to represent the annual VMT per mile.

The variation between the county estimates is shown in Table 4.8 is significant. Marion County has a VMT of 1,440,792 per mile, compared to rural counties with 95,919 to 339,827 per mile. The rural counties (with an adjustment factor of 1.85) were observed to require less adjustment compared to the urban counties (with an adjustment factor of 2.31).

The Total VMT per cluster group is shown in Table 4.9. The weighted average VMT per mile is needed because there are multiple counties representing each cluster group. The VMT estimates represent 2013 statewide annual VMT because the majority of the AADT counts used for estimation are from 2012 to 2014. The statewide VMT, from local routes, is estimated as 36.214 billion, with a local road network of over 85,000 miles.

The distribution of the road network by cluster group is shown in Figure 4.10. Cluster 8, containing the predominantly rural counties, has 55.0 percent of the total mileage, but accounts for only 25.2 percent of the total VMT. Cluster 1 has 4.2 percent of the total

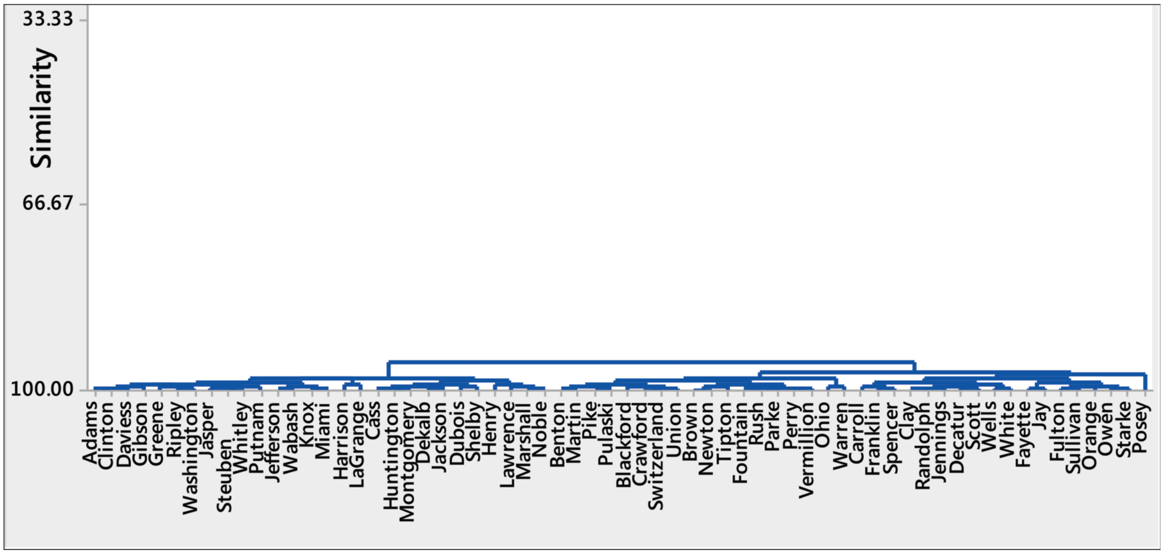


Figure 4.9 Clustering of Indiana counties (continued) based on VMT characteristics.

TABLE 4.7
Assignment of Indiana counties to cluster groups.

Cluster Group	Similarity (Complete Linkage)	Similarity (Average Linkage)	Number of Counties	Counties			
Cluster 1	100.0%	100.0%	1	Marion			
Cluster 2	100.0%	100.0%	1	Lake			
Cluster 3	95.1%	95.1%	2	St. Joseph	Hamilton		
Cluster 4	100.0%	100.0%	1	Allen			
Cluster 5	96.0%	96.3%	4	Vanderburgh	Tippecanoe	Porter	Elkhart
Cluster 6	95.1%	96.3%	8	Johnson	Hendricks	Monroe	Madison
				LaPorte	Delaware	Vigo	Clark
Cluster 7	94.9%	96.8%	11	Warrick	Dearborn	Boone	Howard
				Wayne	Grant	Morgan	Kosciusko
				Hancock	Bartholomew	Flyod	
Cluster 8	94.9%	97.6%	64	Posey	Randolph	Martin	Whitley
				Starke	Clay	Benton	Steuben
				Owen	Spencer	Noble	Jasper
				Orange	Franklin	Marshall	Washington
				Sullivan	Carroll	Lawrence	Ripley
				Fulton	Warren	Henry	Greene
				Jay	Ohio	Shelby	Gibson
				Fayette	Vermillion	Dubois	Daviees
				White	Perry	Jackson	Clinton
				Wells	Parke	Dekalb	Adams
				Scott	Rush	Montgomery	Wabash
				Decatur	Fountain	Huntington	Jefferson
				Jennings	Tipton	Cass	Putnam
				Brown	Newton	LaGrange	Pulaski
				Union	Switzerland	Harrison	Pike
				Crawford	Blackford	Miami	Knox

TABLE 4.8
Adjusted average VMT for local routes.

County	Principal Cities	Source	Years	Sample Size	Cluster Group	Average Annual VMT Per Mile	Adjustment Factor	Adjusted Annual VMT Per Mile
Marion	Indianapolis	TCDS	2014–2015	677	1	3,335,071	2.3147	1,440,792
Lake	Gary; E Chicago	TCDS	2014–2015	510	2	1,920,180	2.3147	829,542
St. Joseph	South Bend; Mishawaka	TCDS	2009–2015	455	3	2,159,094	2.3147	932,755
Allen	Fort Wayne	TCDS	2014–2015	192	4	2,228,682	2.3147	962,818
Tippecanoe	West Lafayette; Lafayette	APC	2006–2014	412	5	415,490	1.7320	239,893
		TCDS	2014–2015	199	5	1,980,083	1.7320	1,143,246
Madison	Anderson	TCDS	2014–2015	202	6	1,033,744	1.8448	560,343
Vigo	Terre Haute	TCDS	2014–2015	126	6	1,465,999	1.8448	794,647
Wayne	Richmond	TCDS	2014–2015	156	7	750,798	1.8448	406,971
Kosciusko	Warsaw; Syracuse	TCDS	2009–2015	236	7	783,618	1.8448	424,761
Jefferson	Madison; Hanover	TCDS	2014–2015	197	8	302,759	1.8448	164,111
Dubois	Jasper; Dubois	TCDS	2014–2015	102	8	626,927	1.8448	339,827
Jennings	North Vernon	TCDS	2014–2015	166	8	264,396	1.8448	143,316
Perry	Derby; Tell City	TCDS	2014–2015	63	8	176,955	1.8448	95,919
Lawrence	Bedford, Mitchell	TCDS	2014–2015	82	8	499,454	1.8448	270,730

TABLE 4.9
Summary of VMT per cluster group.

Cluster	Weighted Average VMT per Mile	Total Local Routes Mileage	Total Adjusted VMT per Cluster
1	1,440,792	3,579	5,156,554,922
2	829,542	2,503	2,076,304,376
3	932,755	3,743	3,491,348,625
4	962,818	2,71	2,475,793,220
5	534,111	5,761	3,077,201,286
6	650,350	10,291	6,692,942,130
7	417,681	9,832	4,106,514,170
8	195,124	46,829	9,137,465,330
Totals		**85,110**	**36,214,124,059**

mileage, yet contributes 14.2 percent of the total local VMT of the state.

A graphical representation of the total local roads mileage by county is given in Figure 4.11. The data is compiled from the published INDOT historical VMT by county and systems (INDOT, 2013), for local routes consisting of both city streets and county roads (INDOT, 2013). The product of adjusted average VMT per mile and the county-wide mileages shown below represent each county's contribution toward local VMT.

4.3.8 Comparison of Study and Literature Estimates

In this study, the estimated local routes VMT is 36.214 billion and the local road VMT from the literature (INDOT, 2013) is 38.508 billion, with data applicable for 2013. Thus, there is a 2.294 billion difference between the two estimates. However, there is significant variation when examining VMT for individual counties as seen from Figure 4.12. The negative deviations indicate an underestimate, and positive deviations indicate an overestimate. The findings for individual counties are given in Table 4.10.

The range of difference is from -56.0% (for Wayne County) to 62.4% (for Vanderburgh County). The reasons for such wide difference at the extremes may include the nature of assigning counties to the cluster groups and the adjusted VMT used to represent each county assigned to the cluster. Wayne and Vanderburgh, for example, are mixed urban counties which may not fit completely into one cluster. Marion County, assigned its own cluster only has a 21.0% difference between the study and reported estimates. Traffic counts and non-traffic data inputs for modeling were also extensive for Marion County. Overall, the statewide total for local roads is more reliable than estimating VMT at a disaggregate level, as may be expected.

4.3.9 Functional Class Distributions

One of the difficulties of estimating VMT by functional class is the variation within state routes and local routes for the FHWA functional class designations. Highway categories of US and State Highways have a mixture of principal arterials, minor arterials, collectors, and local designations on these roads. Based on link-level data, described in Section 3.5, the distribution of state

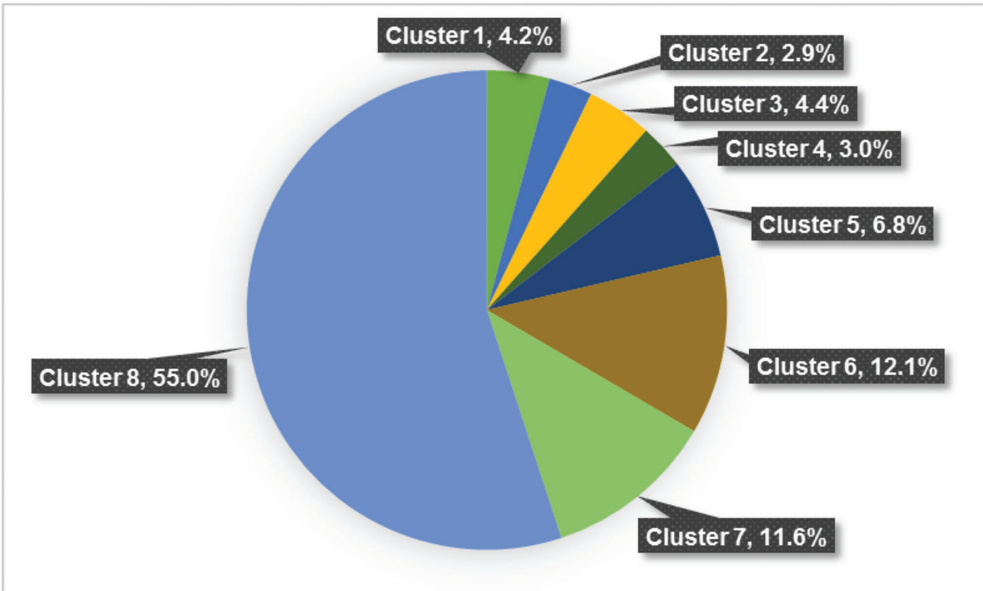


Figure 4.10 Distribution of local routes mileage per cluster group.

route VMT by FHWA functional class is provided in Table 4.11.

For local routes, which comprise city streets and county roads, the distribution of functional class VMT is not so straightforward. The results for local routes are provided in Table 4.12, based on the 14-county traffic sample used in this study. Functional class 7, "locals" was not the functional class noted for the majority of road sections in the sample. Instead, the distribution between principal arterials, minor arterials, collectors, and locals, varied greatly. A cluster average for the six functional classes (with all of FC 1 attributed to state routes) was used to estimate a statewide total for functional classes. Cluster 1, Marion County, had the highest local VMT attributed to principal arterials, as expected for an urban area.

4.4 Spatial Interpolation for VMT Estimation

This report identified a robust, comprehensive, and sustainable methodology framework for VMT estimation for all road types. Part of the framework involves comprehensive evaluation of VMT estimation techniques. Spatial interpolation techniques were investigated for use in VMT estimation. This approach assumes that the VMT at a given location is strongly and directly related to the VMT of its neighboring locations, and the strength of this relationship is proportional to the distance from its neighbors.

Weighted-distance algorithms were used to develop models that reliably interpolate the synthetic estimates of traffic volumes (AADT) for the road segments with unavailable, missing, or outdated data. To gauge the applicability for local jurisdictions and planning organizations, spatial interpolation was investigated in this study for a wide variety of road classes. This section discusses the motivation, review of techniques, implementation for Indiana, project level application, and suitability based on county type and local road class.

4.4.1 Motivation

Spatial interpolation may be more suitable for local roads VMT estimation because of the limited traffic counts and incomplete coverage available. This approach does not require additional traffic data, but uses existing counts warehoused by INDOT and maintained by local organizations. Therefore, no additional traffic counting resources and expense of field staff is required. The database can be updated easily when more recent or extensive traffic data becomes available. The procedure is implemented with readily-available GIS platforms (ESRI, 2013) using default user settings on that platform. Spatial interpolation can be viewed as a robust method of VMT estimation which is capable of providing comparative estimates from a variety of techniques.

4.4.2 Review of Techniques and Applications

Spatial interpolation techniques include support vector regression, inverse distance weighting (IDW), trend, topo-to-raster, spline, pointInterp, natural neighbor (NN), and Kriging (Mitas & Mitasova, 1999). PointInterp, spline, and topo-to-raster interpolation techniques were not implemented for this specific study because their underlying assumptions and the topographical challenges are not applicable. These techniques have been found to be very useful in applications related to mining, forestry, and other resource-oriented fields.

Therefore, IDW, Kriging, NN, and trend interpolation were investigated for this study. IDW is used where the parameter of interest is densely populated over the area of interest. NN is used when a clustered set of traffic count

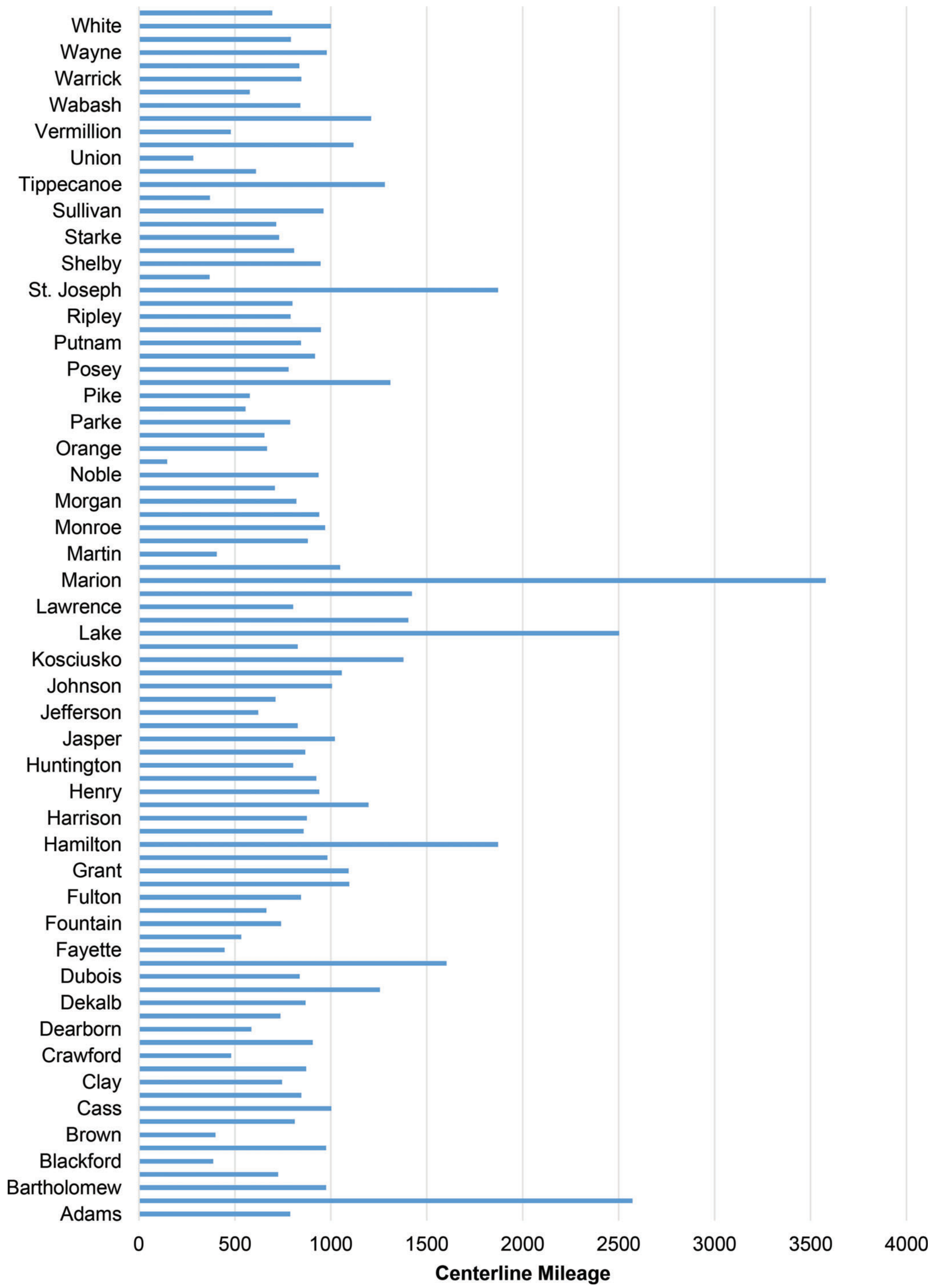


Figure 4.11 Total local routes mileage by Indiana counties.

data is available. Trend is an inexact estimation that uses least squares regression fitting and can be implemented only when there is minimal variation in the magnitude of the parameter of interest (Mitas & Mitasova, 1999). Where the parameter of interest is traffic count, the resulting surface from trend analysis may be appropriate only for a specific functional class of road network. Kriging is a popular geostatistical technique used in a wide range of fields such as mining (Delfiner, 1976), hydrosciences (Goovaerts, 2000), health sciences (Kelsall & Wakefield, 2002) and environmental sciences (Li & Heap, 2011).

There has been recent examination of the application of these type of techniques in the transportation engineering field. Researchers have applied Kriging algorithms for AADT prediction and vehicle class distributions (Eom et al., 2006; Volovski et al., 2015).

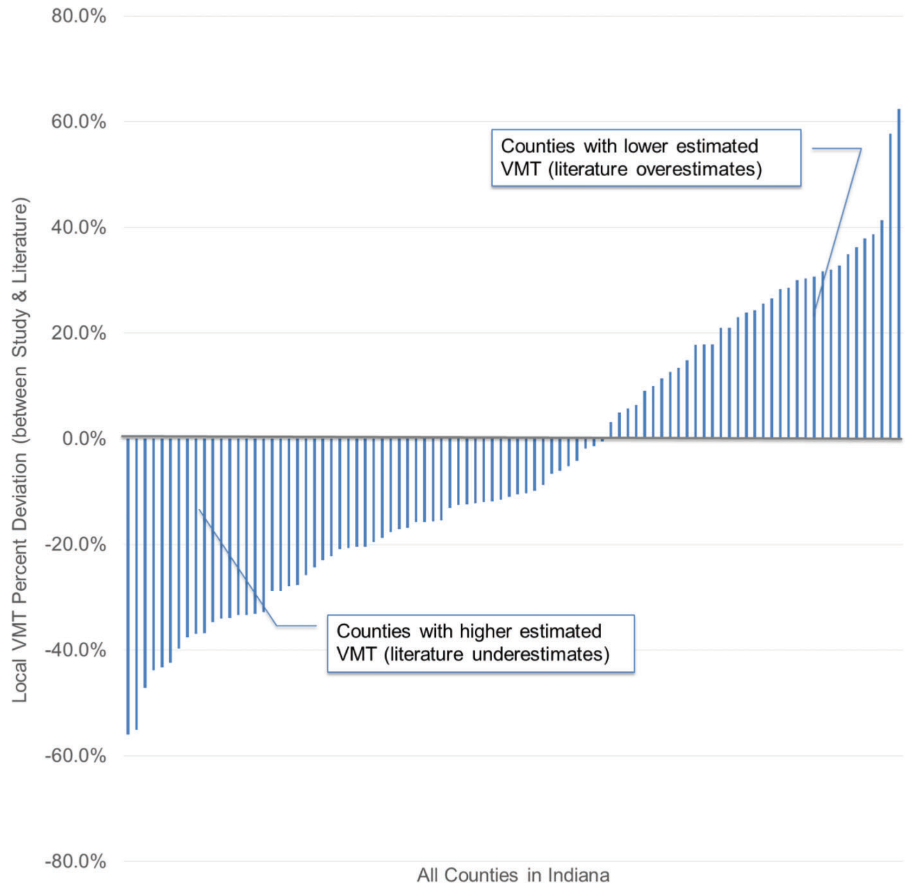


Figure 4.12 Percent deviations between study and literature local VMT.

Of the available spatial interpolation techniques, Kriging may be the most robust because it considers the mutual interactions of all the available data in the area of interest, within a pre-defined search radius (Myers, 1994). Thus, Kriging assumes spatial correlation using weighted average techniques. Of the types of Kriging, the Ordinary Kriging method is the most commonly applied for spatial interpolation because it does not assume an underlying trend in the data, unless the dataset exhibits a clearly defined trend.

4.4.3 Implementation for Indiana

Local road traffic data were collected for Tippecanoe, Jefferson, and St. Joseph County (Table 4.13), representing varying geographic areas and urbanization: Tippecanoe is mixed-urban, Jefferson is predominantly rural, and St. Joseph is predominantly urban. Each county and road class within the county has a different number of local AADT traffic counts. For example, the sample for St. Joseph, in this study, has 148, 80, 148, and 116 traffic counts for city streets high volume, county roads high volume, city streets low volume, and county roads low volume, respectively.

Spatial interpolation techniques produce raster surfaces for each road class at a time. Each technique uses the AADT value as the surface height or Z-value to produce a "rastervalue" which represents the interpolated AADT. To estimate VMT, the continuous variation of AADT across the study area is applied to the road networks. An example of Kriging interpolation for all road classes, to show variation of AADT across a county is illustrated from Figure 4.13. However, higher accuracy is expected when producing the interpolation surfaces for one road class at a time, with the traffic counts specific to the road class under consideration. As observed from Figure 4.13, the highest interpolated AADT value is 11,604 and the lowest is 41, with low traffic volumes typically seen as being representative of rural county roads. This is an example of the link between the continuous AADT surfaces from weighted distance analysis, and the county's road network. The same process could be followed for a specific city or township within the county, if the road network is defined by attributes allowing for selection within boundaries.

The VMT is estimated for every link in the road inventory by developing a centroid for every segment as shown in Figure 4.14 for Tippecanoe (top) and St. Joseph (bottom). This continuous VMT represents all centerline mileage of the road network.

This allows the AADT from the surface to be assigned to the appropriate segment, creating a joined database of the entire county's local road network. The

TABLE 4.10
Comparison of county-wide local VMT from study and literature.

County	Study AVMT (millions)	Literature AVMT (millions)	Percent Difference	County	Study AVMT (millions)	Literature AVMT (millions)	Percent Difference
Adams	154.00	143.81	-6.6%	Madison	925.38	782.20	-15.5%
Allen	2475.79	3043.74	22.9%	Marion	5156.55	6240.04	21.0%
Bartholomew	407.57	468.30	14.9%	Marshall	204.55	223.02	9.0%
Benton	141.65	88.33	-37.6%	Martin	79.40	41.98	-47.1%
Blackford	75.44	98.55	30.6%	Miami	171.68	188.71	9.9%
Boone	407.77	390.92	-4.1%	Monroe	631.11	552.25	-12.5%
Brown	78.04	62.78	-19.6%	Montgomery	183.26	167.17	-8.8%
Carroll	158.39	117.53	-25.8%	Morgan	342.83	404.06	17.9%
Cass	195.66	263.90	34.9%	Newton	138.14	87.24	-36.9%
Clark	550.70	496.40	-9.9%	Noble	182.64	171.55	-6.1%
Clay	145.49	137.97	-5.2%	Ohio	28.77	20.81	-27.7%
Clinton	170.00	141.26	-16.9%	Orange	130.30	82.13	-37.0%
Crawford	93.86	56.58	-39.7%	Owen	127.68	90.89	-28.8%
Daviess	176.86	174.47	-1.4%	Parke	153.73	133.59	-13.1%
Dearborn	244.90	206.23	-15.8%	Perry	108.36	94.90	-12.4%
Decatur	143.85	178.85	24.3%	Pike	112.82	64.97	-42.4%
Dekalb	169.34	239.44	41.4%	Porter	700.06	921.99	31.7%
Delaware	816.73	672.33	-17.7%	Lawrence	156.74	161.70	3.2%
Dubois	349.75	198.56	-43.2%	Posey	152.23	128.48	-15.6%
Elkhart	855.94	1060.69	23.9%	Pulaski	179.14	118.26	-34.0%
Fayette	238.80	107.31	-55.1%	Putnam	164.73	163.89	-0.5%
Floyd	223.24	352.23	57.8%	Randolph	185.02	146.73	-20.7%
Fountain	144.74	94.54	-34.7%	Ripley	154.17	121.91	-20.9%
Franklin	129.75	116.07	-10.5%	Rush	156.36	121.55	-22.3%
Fulton	164.71	131.04	-20.4%	Scott	71.80	86.87	21.0%
Gibson	213.99	173.74	-18.8%	Shelby	184.77	256.23	38.7%
Grant	456.35	351.13	-23.1%	Spencer	157.85	119.36	-24.4%
Greene	191.59	158.78	-17.1%	St. Joseph	1745.29	1965.53	12.6%
Hamilton	1746.06	2245.12	28.6%	Starke	142.53	95.27	-33.2%
Hancock	358.48	488.37	36.2%	Steuben	139.76	192.72	37.9%
Harrison	170.75	121.55	-28.8%	Sullivan	187.82	126.29	-32.8%
Hendricks	778.17	1011.42	30.0%	Switzerland	72.38	47.82	-33.9%
Henry	183.57	192.72	5.0%	Tippecanoe	684.77	866.51	26.5%
Howard	386.28	512.83	32.8%	Tipton	119.02	104.76	-12.0%
Huntington	156.95	185.06	17.9%	Union	55.31	36.87	-33.4%
Jackson	169.11	188.34	11.4%	Vanderburgh	597.63	970.54	62.4%
Jasper	199.36	212.07	6.4%	Vermillion	93.57	83.95	-10.3%
Jay	161.53	142.35	-11.9%	Vigo	786.86	690.58	-12.2%
Jefferson	121.54	143.08	17.7%	Wabash	164.27	145.27	-11.6%
Jennings	139.05	183.60	32.0%	Warren	112.91	81.40	-27.9%
Johnson	654.88	840.23	28.3%	Warrick	353.60	297.84	-15.8%
Knox	206.28	233.97	13.4%	Washington	163.32	172.65	5.7%
Kosciusko	575.75	383.98	-33.3%	Wayne	636.39	279.96	-56.0%
LaGrange	161.42	128.48	-20.4%	Wells	154.59	137.61	-11.0%
Lake	2076.30	2706.84	30.4%	White	195.20	191.63	-1.8%
LaPorte	912.73	512.83	-43.8%	Whitley	135.76	170.46	25.6%

VMT is then calculated as the sum of the VMTs of individual links over the area of interest, in this case, the county in question.

As shown in Figure 4.15, a continuous traffic volume map can be developed for a specific road class from the interpolated AADT surface. The lowest interpolated AADT for high volume city streets is 4,260 and highest is 18,977. High-volume city streets are shown for a section of West Lafayette and Lafayette. One can assess areas of high VMT, such as the avenues and boulevards (high volume city streets) shown in Greater Lafayette, with the highest volume occurring on roads indicated with thick shading representing 15,500 to 18,977 AADT.

Similarly, interpolated VMT for a specific road class, high volume county roads, is presented in Figure 4.16 for Tippecanoe County. These county roads receive traffic from the low volume county roads, and are

TABLE 4.11
Distribution of state route VMT by FHWA functional class.

FHWA Functional Class	Principal Arterials – Interstate FC 1	Principal Arterials – Other Freeways FC 2	Principal Arterials – Other FC 3	Minor Arterials FC 4	Major Collectors FC 5	Minor Collectors FC 6	Locals FC 7
Interstates	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
US Highways	0.0%	7.1%	75.7%	11.7%	5.3%	0.1%	0.0%
State Highways	0.0%	4.4%	42.7%	25.0%	26.7%	1.1%	0.1%

TABLE 4.12
Distribution of local route VMT by FHWA functional class.

FHWA Functional Class	Principal Arterials – Other Freeways FC 2	Principal Arterials – Other FC 3	Minor Arterials FC 4	Major Collectors FC 5	Minor Collectors FC 6	Locals FC 7
Allen	0.0%	20.4%	44.6%	26.2%	1.1%	7.8%
Dubois	0.0%	0.0%	25.6%	69.4%	4.8%	0.3%
Jefferson	0.0%	0.3%	20.0%	51.2%	0.1%	28.3%
Jennings	0.0%	0.0%	20.4%	66.1%	1.2%	12.4%
Kosiusko	0.0%	5.4%	27.8%	50.8%	2.4%	13.7%
Lake	1.7%	10.0%	51.4%	36.9%	0.0%	0.1%
Lawrence	0.0%	16.2%	36.5%	46.7%	0.1%	0.6%
Madison	0.0%	29.6%	27.6%	42.6%	0.0%	0.2%
Marion	6.6%	39.3%	29.9%	24.1%	0.0%	0.1%
Marion (MPO)	4.0%	80.9%	7.0%	8.1%	0.0%	0.0%
Perry	0.0%	0.0%	8.0%	81.0%	10.0%	1.0%
St. Joseph	0.0%	26.3%	40.7%	20.3%	1.0%	11.7%
Tippecanoe	0.0%	7.6%	29.7%	40.9%	6.2%	15.5%
Vigo	0.0%	9.9%	34.7%	52.3%	2.4%	0.8%
Wayne	0.0%	7.8%	31.2%	60.6%	0.2%	0.2%
Cluster 1 Average	5.3%	60.1%	18.5%	16.1%	0.0%	0.1%
Cluster 2 Average	1.7%	10.0%	51.4%	36.9%	0.0%	0.1%
Cluster 3 Average	0.0%	26.3%	40.7%	20.3%	1.0%	11.7%
Cluster 4 Average	0.0%	20.4%	44.6%	26.2%	1.1%	7.8%
Cluster 5 Average	0.0%	7.6%	29.7%	40.9%	6.2%	15.5%
Cluster 6 Average	0.0%	19.8%	31.1%	47.4%	1.2%	0.5%
Cluster 7 Average	0.0%	6.6%	29.5%	55.7%	1.3%	6.9%
Cluster 8 Average	0.0%	3.3%	22.1%	62.9%	3.2%	8.5%

typically paved routes. The range of interpolated AADT is from 615 to 5,598, with grey shading representing transition areas and high volumes represented by lighter shading. As expected, higher traffic volumes are observed at areas close to the urban core of Greater Lafayette.

4.4.4 Segment Level VMT Estimation

Examination of VMT estimates at the segment level revealed significant differences in the predicted VMT. The known traffic attributes, including segment ID, link length, AADT, and daily VMT are provided in Table 4.14 for a sample of road segments; as well as the predicted daily VMT from each spatial interpolation technique. Depending on the local route road class, low and high volume city streets and county roads, the percent difference from the actual VMT varies among techniques. Trend interpolation has the highest deviation, indicating that this technique is not appropriate for local roads when no underlying trend is known or assumed.

4.4.5 County Level VMT Estimation

Aggregating VMT for all segments of each local road class, a total local VMT is estimated for three representative counties analyzed in this study. The results of these county level aggregate estimates are provided in

TABLE 4.13
Summary of traffic count sample and validation dataset.

Road Class	Average AADT	Number of AADT Counts	Validation Dataset
Tippecanoe County			
City Streets – High Volume	8,732	93	9
County Roads – High Volume	2,067	223	21
City Streets – Low Volume	2,119	71	7
County Roads – Low Volume	154	203	18
St. Joseph County			
City Streets – High Volume	11,438	148	15
County Roads – High Volume	2,180	80	8
City Streets – Low Volume	3,378	147	15
County Roads – Low Volume	559	116	11
Jefferson County			
County Roads – Low Volume	297	129	13
City Streets – Low Volume	2,232	51	5

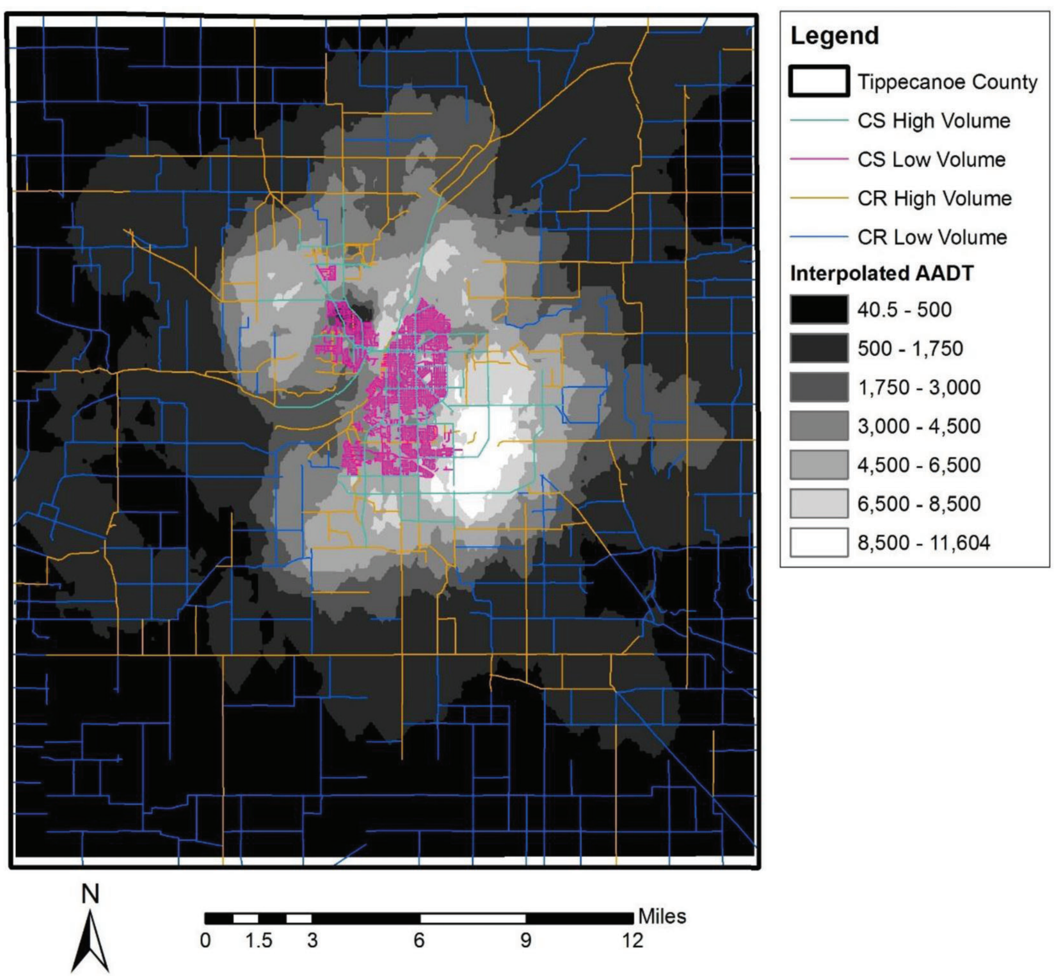


Figure 4.13 Interpolated AADT raster surface for Tippecanoe County.

Table 4.15 to Table 4.17, for Tippecanoe, St. Joseph, and Jefferson County, respectively.

Each spatial interpolation technique assessed in this study produces annual VMT (AVMT) values which are relatively similar to each other. For example, the predicted AVMT for Tippecanoe County is 644.0 to 695.9 million; St. Joseph County is estimated as 1,291 to 1,387 million; and Jefferson County is estimated as 94.8 to 101.6 million. On average, estimates from Kriging are higher and estimates from Natural Neighbor are

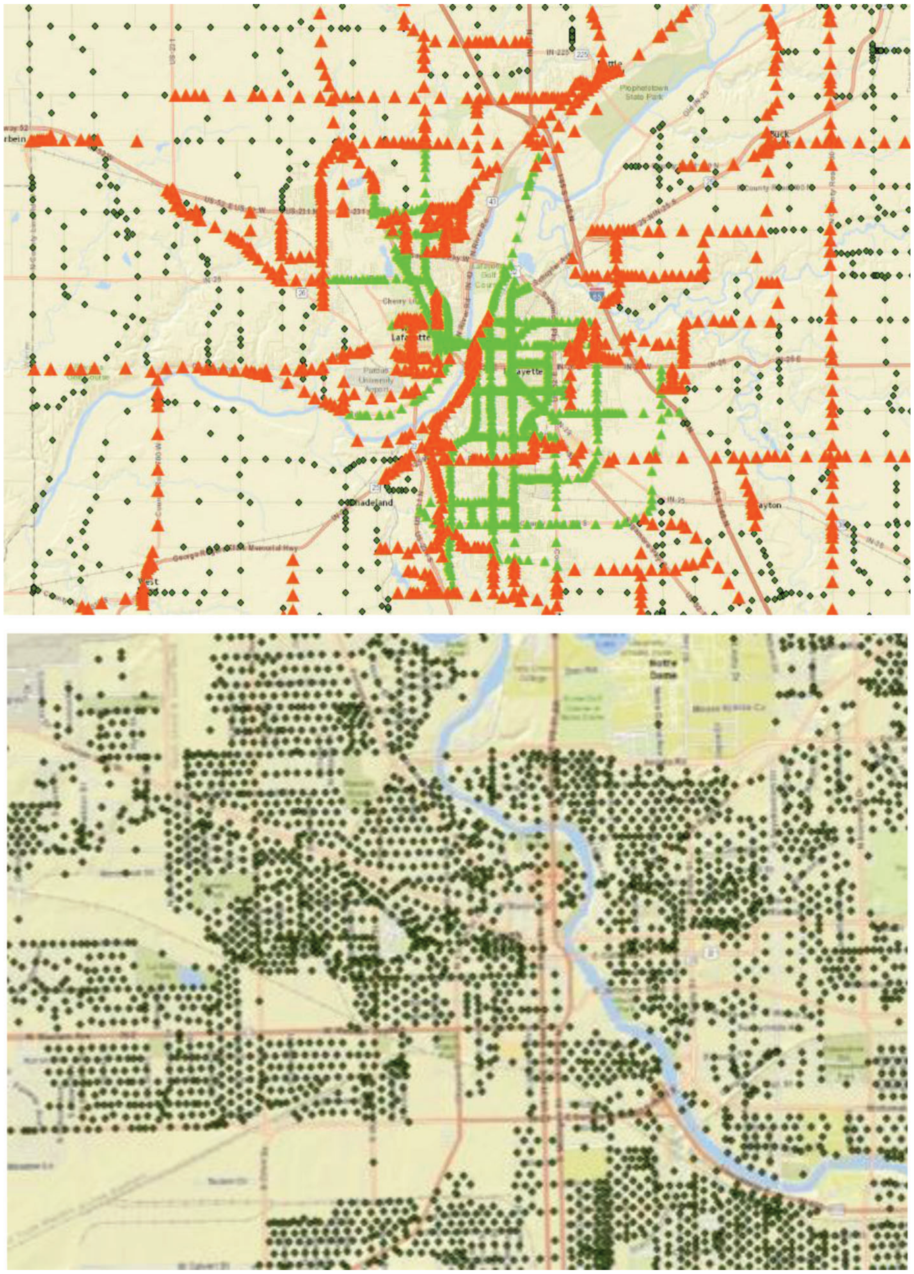


Figure 4.14 Assignment of interpolated AADT based on road class centroid.

lower, with relative standing depending on the county being analyzed.

4.4.6 Validation of the Estimated VMT

To gauge the accuracy and extent of suitability associated with each technique, a validation approach is used. To validate these techniques, 90% of the original AADT counts were used for modeling, with 10% of the dataset set aside for validation. The same validation dataset was used for comparing predicted and actual daily VMT. The technique with the lowest root mean square error (RMSE), shown in Equation 4.1, was identified as the best approach. The process was repeated for all techniques and each road class. Here, y_{pred} refers to the interpolated daily VMT, y_{actual} gives the known daily VMT and N is the number of observations in the validation dataset.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_{pred} - y_{actual})^2} \qquad (4.1)$$

Table 4.18 through Table 4.22 present the validation results by each county and technique, depending on the level of urbanization of the counties. These accuracy

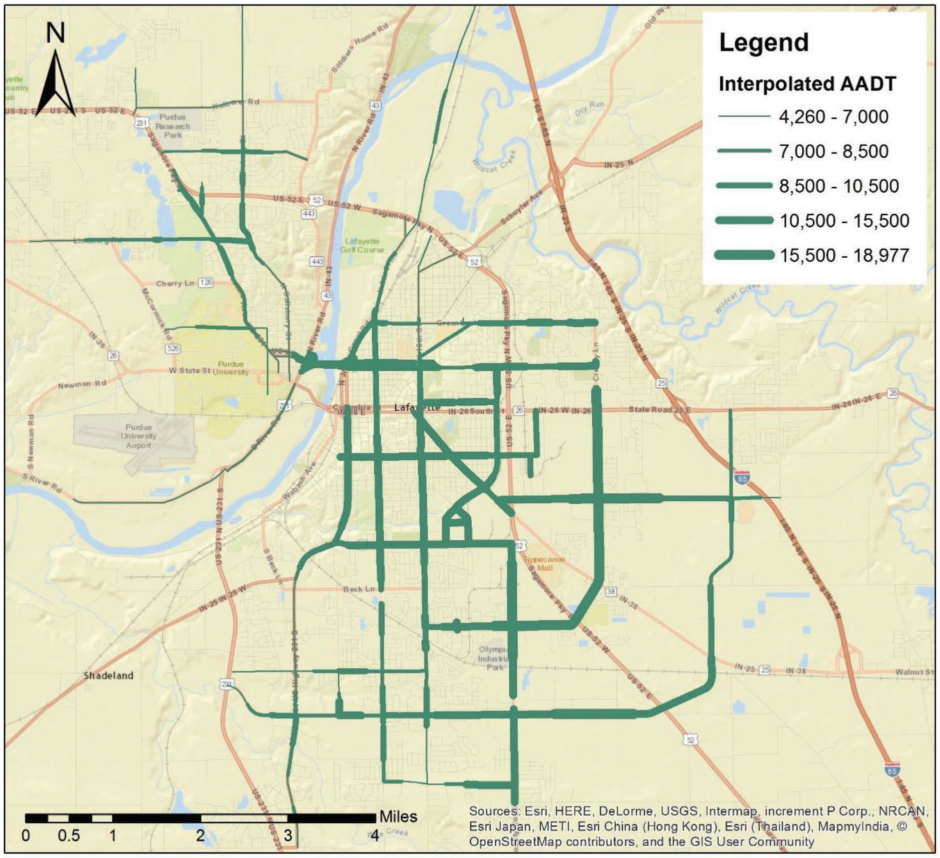


Figure 4.15 Flow map of interpolated traffic for high-volume city streets.

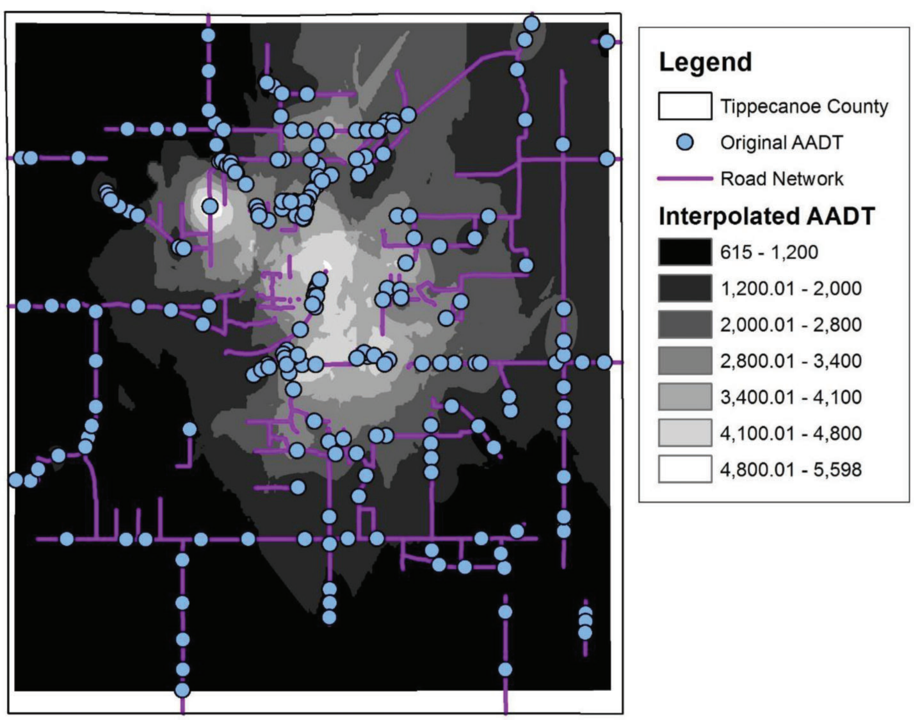


Figure 4.16 Interpolated VMT for high volume county roads (Tippecanoe County).

TABLE 4.14
Sample county segment level VMT estimation from spatial interpolation.

	Known Traffic Attributes				Predicted Daily VMT (Spatial Interpolation)				Percent Difference (Spatial Interpolation)			
Road Class	**Road Segment ID**	**Link Length (miles)**	**AADT**	**DVMT**	**Kriging**	**IDW**	**Natural Neighbor**	**Trend**	**Kriging**	**IDW**	**Natural Neighbor**	**Trend**
City Streets – High Volume	7558	0.07	18,247	1,258.6	539	528	537	551	-57.21%	-58.08%	-57.31%	-56.23%
City Streets – High Volume	1418	0.41	14,238	5,787.2	2,703	2,666	2,779	3,609	-53.29%	-53.93%	-51.98%	-37.64%
City Streets – High Volume	10425	0.11	12,224	1,311.6	1,178	1,056	1,270	1,316	-10.15%	-19.46%	-3.17%	0.33%
City Streets – High Volume	6246	0.25	10,964	2,775.8	2,113	2,042	1,753	3,032	-23.88%	-26.44%	-36.85%	9.23%
City Streets – High Volume	10,028	0.14	9,624	1,393.3	1,178	1,365	1,376	939	-15.44%	-2.02%	-1.27%	-32.64%
City Streets – High Volume	9509	0.10	7,926	795.1	695	670	825	833	-12.64%	-15.75%	3.81%	4.79%
City Streets – High Volume	8845	0.09	6,566	605.4	590	505	563	692	-2.57%	-16.59%	-7.01%	14.27%
Average Percent Difference									**-25.03%**	**-27.47%**	**-21.97%**	**-13.98%**
City Streets – Low Volume	5044	0.05	439.0	21.9	29.4	25.6	39.6	93.9	34.40%	17.31%	81.32%	329.61%
City Streets – Low Volume	8719	0.06	1,016.0	62.8	56.1	44.8	49.2	117.7	-10.63%	-28.74%	-21.65%	87.40%
City Streets – Low Volume	3446	0.06	2,021.0	128.1	95.6	73.7	70.3	127.9	-25.33%	-42.45%	-45.13%	-0.15%
City Streets – Low Volume	1763	0.10	2,806.0	270.3	209.4	241.8	292.7	246.0	-22.56%	-10.55%	8.27%	-9.02%
City Streets – Low Volume	2841	0.04	4,844.0	182.9	90.0	66.4	90.1	96.7	-50.78%	-63.69%	-50.74%	-47.13%
City Streets – Low Volume	3792	0.05	2,501.0	135.1	118.9	139.9	164.7	138.5	-12.00%	3.56%	21.95%	2.52%
City Streets – Low Volume	2211	0.06	737.0	47.2	73.7	74.6	72.3	156.4	56.31%	58.21%	53.32%	231.48%
Average Percent Difference									**-4.37%**	**-9.48%**	**6.76%**	**84.96%**
County Roads – High Volume	582	0.14	499.0	68.6	126.7	116.6	116.1	220.2	84.57%	69.94%	69.09%	220.79%
County Roads – High Volume	780	0.24	2,504.0	601.7	676.0	710.6	753.4	512.4	12.34%	18.08%	25.20%	-14.85%
County Roads – High Volume	1081	0.33	1,761.0	579.9	657.5	623.9	567.9	822.7	13.38%	7.60%	-2.06%	41.88%
County Roads – High Volume	1185	0.10	1,039.0	102.2	116.5	97.5	98.2	203.1	13.96%	-4.64%	-3.99%	98.64%
County Roads – High Volume	1198	0.25	870.0	219.9	234.7	240.5	242.8	460.2	6.76%	9.36%	10.40%	109.28%
County Roads – High Volume	3434	0.24	1,634.0	394.7	342.5	329.2	269.3	420.7	-13.22%	-16.59%	-31.75%	6.61%
County Roads – High Volume	3849	0.18	1,241.0	220.5	164.8	164.7	191.7	329.2	-25.25%	-25.30%	-13.08%	49.29%
Average Percent Difference									**13.22%**	**8.35%**	**7.69%**	**73.09%**
County Roads – Low Volume	249	1.36	25.0	33.9	81.3	84.1	73.2	164.0	140.00%	148.00%	116.00%	384.00%
County Roads – Low Volume	6660	0.77	40.0	30.7	40.7	44.5	28.4	76.8	32.50%	45.00%	-7.50%	150.00%
County Roads – Low Volume	5678	0.76	86.0	65.2	34.9	37.9	34.9	95.5	-46.51%	-41.86%	-46.51%	46.51%
County Roads – Low Volume	4764	0.53	519.0	276.9	83.2	60.8	109.4	59.8	-69.94%	-78.03%	-60.50%	-78.42%
County Roads – Low Volume	6605	0.28	335.0	92.8	72.3	54.0	72.3	44.6	-22.09%	-41.79%	-22.09%	-51.94%
County Roads – Low Volume	10870	0.26	303.0	79.8	74.5	94.8	109.3	41.6	-6.60%	18.81%	36.96%	-47.85%
County Roads – Low Volume	7700	0.48	272.0	131.4	226.1	271.5	237.2	107.2	72.06%	106.62%	80.51%	-18.38%
Average Percent Difference									**14.20%**	**22.39%**	**13.84%**	**54.84%**

TABLE 4.15
Total local VMT from spatial interpolation (Tippecanoe County).

Road Class	Total Length (miles)	Predicted AVMT			
		Kriging	IDW	Natural Neighbor	Trend
County Roads – High Volume	258.73	182,050,209	176,747,687	178,703,278	196,666,263
County Roads – Low Volume	497.50	33,140,117	31,752,328	35,715,880	28,554,652
City Streets – High Volume	89.81	302,909,260	298,864,673	291,544,077	289,123,522
City Streets – Low Volume	182.45	140,849,296	138,338,070	103,789,575	147,258,658
Neighborhood Roads	469.62	34,282,421			
Total Local Route VMT		**693,231,303**	**679,985,180**	**644,035,231**	**695,885,515**

TABLE 4.16
Total local VMT from spatial interpolation (Jefferson County).

Road Class	Total Length (miles)	Predicted AVMT			
		Kriging	IDW	Natural Neighbor	Trend
County Roads	457.28	44,058,846	42,167,736	38,843,412	45,421,262
City Streets	40.40	37,737,758	36,598,518	36,181,414	33,289,018
Neighborhood Roads	271.27	19,802,969			
Total Local Route VMT		**101,599,573**	**98,569,223**	**94,827,795**	**98,513,250**

TABLE 4.17
Total local VMT from spatial interpolation (St. Joseph County).

Road Class	Total Length (miles)	Predicted AVMT			
		Kriging	IDW	Natural Neighbor	Trend
County Roads – High Volume	138.05	97,221,130	98,430,796	95,095,767	105,738,226
County Roads – Low Volume	516.53	87,530,969	83,911,639	84,131,626	99,657,302
City Streets – High Volume	128.16	517,911,961	494,649,971	483,991,742	526,132,856
City Streets – Low Volume	495.10	592,352,090	576,447,480	608,978,923	617,739,107
Neighborhood Roads	511.46	37,336,666			
Total Local Route VMT		**1,332,352,817**	**1,290,776,552**	**1,309,534,724**	**1,386,604,156**

TABLE 4.18
Accuracy for all road classes.

All Local Routes Road Classes, RMSE		Jefferson County Rural	Tippecanoe County Mixed	St. Joseph County Urban
Spatial Interpolation Techniques	Kriging	139	557	1431
	Inverse Distance Weighting	92	404	1487
	Natural Neighbor	85	332	788
	Trend	175	1483	1567

TABLE 4.19
Accuracy for low-volume city streets.

City Streets – Low Volume RMSE		Jefferson County Rural	Tippecanoe County Mixed	St. Joseph County Urban
Spatial Interpolation Techniques	Kriging	42	45	281
	Inverse Distance Weighting	64	51	212
	Natural Neighbor	37	45	205
	Trend	82	63	269

TABLE 4.20
Accuracy for high-volume city streets.

City Streets – High Volume RMSE		Jefferson County Rural	Tippecanoe County Mixed	St. Joseph County Urban
Spatial Interpolation Techniques	Kriging	N/A	1087	1418
	Inverse Distance Weighting	N/A	1108	1174
	Natural Neighbor	N/A	1101	963
	Trend	N/A	787	1473

TABLE 4.21
Accuracy for low-volume county roads.

County Roads – Low Volume RMSE		Jefferson County Rural	Tippecanoe County Mixed	St. Joseph County Urban
Spatial Interpolation Techniques	Kriging	78	78	189
	Inverse Distance Weighting	76	83	183
	Natural Neighbor	103	87	136
	Trend	116	88	323

TABLE 4.22
Accuracy for high-volume county roads.

County Roads – High Volume RMSE		Jefferson County Rural	Tippecanoe County Mixed	St. Joseph County Urban
Spatial Interpolation Techniques	Kriging	N/A	304	415
	Inverse Distance Weighting	N/A	286	469
	Natural Neighbor	N/A	229	432
	Trend	N/A	648	548

tables help to identify the lowest RMSE, or the difference between the predicted and observed VMT values. This establishes the most appropriate spatial interpolation technique to select for a road class, accounting for different degrees of urbanization in a geographic setting. The highlighted values represent the best technique for each road class.

Table 4.18 presents the best technique for the combined road classes without segmentation. The best technique is shown for low-volume city streets, high-volume city streets, low-volume county roads, and high-volume county roads, respectively. These results show that the feasibility of spatial interpolation techniques for local route VMT estimation greatly depends on the type of county, rural, mixed, or urban, and road class under investigation.

A metropolitan planning organization (MPO) or highway agency may require project-level VMT estimates. This study methodology can be applied to estimate local AADT/VMT for individual segments or highway corridors with unavailable traffic counts. The validation process of this section enables the selection of the most appropriate spatial interpolation technique, depending on the road class. Using different techniques to develop each road class layer is expected to lead to more reliable VMT estimates.

4.5 Non-Traffic VMT Estimation Methods

This section provides additional intermediate inputs for non-traffic methods of VMT estimation such as fuel, statistical regression using socio-economic data, and travel surveys.

4.5.1 Intermediate Inputs

Vehicle fleet fuel efficiencies are weighted for each year of analysis. Table 4.23 presents the fuel efficiencies for gasoline (top row) and diesel (bottom row) vehicles, by VMT estimation approach. The average ranges from 21.59 to 21.88 MPG for vehicle

TABLE 4.23
Weighted vehicle fuel efficiencies by approach.

Fuel Approach	2009	2010	2011	2012
Estimated fuel revenues (disaggregate, link-level)	21.61	21.45	21.63	21.38
	6.78	6.68	7.99	6.90
Estimated fuel revenues (aggregate, FHWA)	22.13	22.13	22.14	21.73
	6.62	6.62	6.65	6.21
Reported fuel consumed (aggregate, link-level)	21.86	21.86	21.85	21.67
	7.57	7.57	7.96	6.43
Average for Fuel Method	21.87	21.81	21.88	21.59
	6.99	6.96	7.54	6.51

TABLE 4.24
Weighted average traffic for statewide estimation.

FHWA Vehicle Class	2009	2010	2011	2012	2013
Class 1	0.54%	0.54%	0.55%	0.55%	0.55%
Class 2	61.80%	61.86%	63.72%	62.67%	62.67%
Class 3	24.73%	24.74%	25.63%	24.98%	24.98%
Class 4	0.19%	0.19%	0.16%	0.22%	0.22%
Class 5	2.40%	2.38%	2.28%	3.02%	3.02%
Class 6	0.76%	0.76%	1.01%	1.28%	1.28%
Class 7	0.23%	0.23%	0.32%	0.41%	0.41%
Class 8	0.80%	0.80%	0.56%	0.60%	0.60%
Class 9	8.14%	8.09%	5.49%	5.95%	5.95%
Class 10	0.12%	0.12%	0.08%	0.09%	0.09%
Class 11	0.18%	0.18%	0.12%	0.14%	0.14%
Class 12	0.06%	0.06%	0.04%	0.05%	0.05%
Class 13	0.04%	0.04%	0.03%	0.03%	0.03%

class 1 to 3 (which mostly use gasoline) and 6.51 to 7.54 MPG for vehicle classes 4 to 13 (which mostly use diesel).

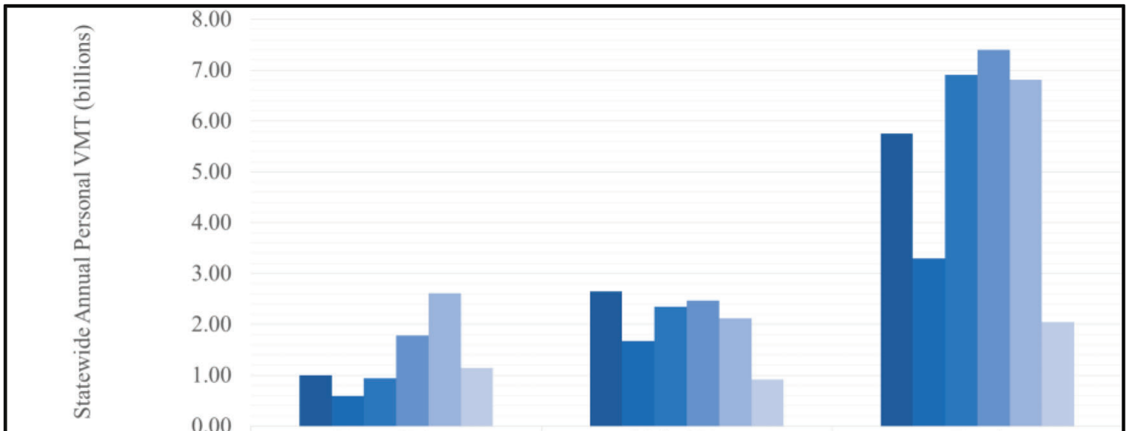
The traffic distributions used for statewide estimation are weighted between state and local routes. These vehicle class distributions are given in Table 4.24. As observed, Class 2 (automobiles), Class 3 (primarily light-duty trucks and SUVs), and Class 9 (heavy trucks) constitute the majority of the traffic stream, with 62.67%, 24.98%, and 5.95%, respectively for 2013.

Based on socioeconomic travel surveys, personal VMT (classes 1 to 3) is estimated by land-area groups shown in Figure 4.17. Dense Urban, Light Urban, and Rural represent all possible household locations. Based on reported household incomes, VMT is highest for dense urban, light urban, and rural, respectively, for household incomes of $20K-$40K; greater than $100K, and $40K-$60K. For example, from travel surveys, the distribution of personal VMT for dense-urban households is shown by Figure 4.18. Household incomes of $20K-$40K and $40–60K constitute a combined 55% of the total VMT for this type of household location in Indiana cities.

4.5.2 Trend Analysis

This section discusses the models investigated to predict VMT based on trend analysis. These functional forms differ greatly with respect to accuracy and predictive capabilities. Linear, polynomial, s-curve model, growth curve, and annual growth factors were investigated. The equations for the functional forms are given in Figure 4.19, for s-curve model, Figure 4.20 for growth curve model, and Figure 4.21 for linear trend. Index one represents 1992, the first year with historical statewide VMT data available. Index 18 represents 2009, the first year for predicted statewide VMT. The s-curve predicts the same VMT of around 74 billion in 2015, the growth curve predicts a VMT of around 85 billion in 2015, and the linear curve also predicts a VMT of around 85 billion in 2015.

The extent of prediction error from the actual, VMT from literature (INDOT, 2013) is provided in Table 4.25. As observed, the linear trend model consistently overestimated the VMT; whereas, the polynomial trend model underestimated for 2009 and progressively overestimated the VMT for the remain-



	Dense Urban	Light Urban	Rural
Greater than $100K	1.00	2.65	5.75
$80K - $100K	0.59	1.68	3.30
$60K - $80K	0.94	2.35	6.91
$40K - $60K	1.78	2.47	7.40
$20K - $40K	2.62	2.11	6.81
Less than $20K	1.14	0.92	2.05

Figure 4.17 Personal VMT by income and land-area groups.

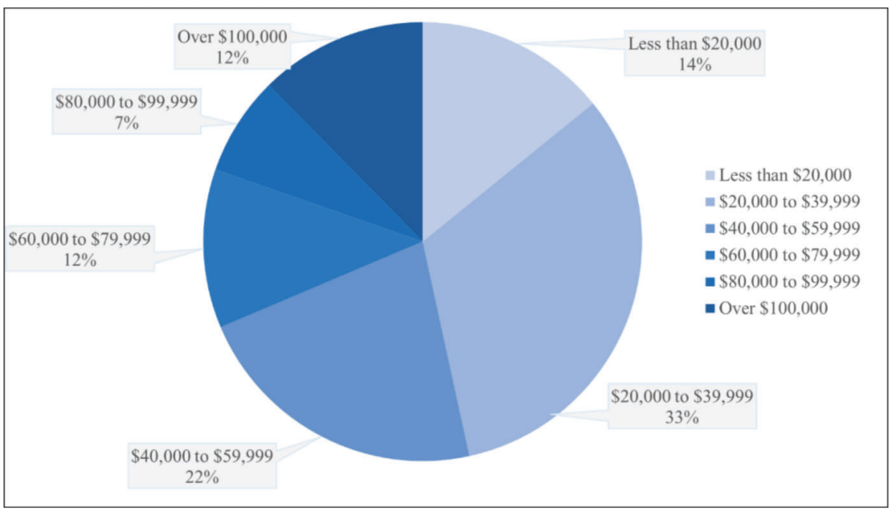


Figure 4.18 Distribution of personal VMT for dense-urban households.

ing analysis years. The S-curve trend model underestimated the VMT for all years except 2010. Finally, the growth factor method underestimated the VMT for 2009 and there was a small overestimate in 2010 to 2013. These findings indicate that the predictive capabilities of various techniques of trend analysis and growth factors greatly influence the accuracy of the results obtained.

4.6 Chapter Summary

This chapter built upon the Chapter 3 framework to carry out analysis and modeling for statewide VMT estimation for both local and state routes. To implement this framework and provide a platform for future use, a traffic count database was created. This database contains extensive link-level (highway segment) traffic count data, which were used for estimation and prediction of traffic volumes and consequently VMT estimates. In order to increase the reliability and consistency of local VMT estimates, the local VMT estimation approach was discussed in detail. A GIS platform was implemented to estimate the segment lengths, analyze the traffic count sample, more accurately estimate VMT using representative counties throughout the state, and create local road classes. To expand the traffic count sample used for local VMT estimation to the entire state of Indiana, cluster analysis was used

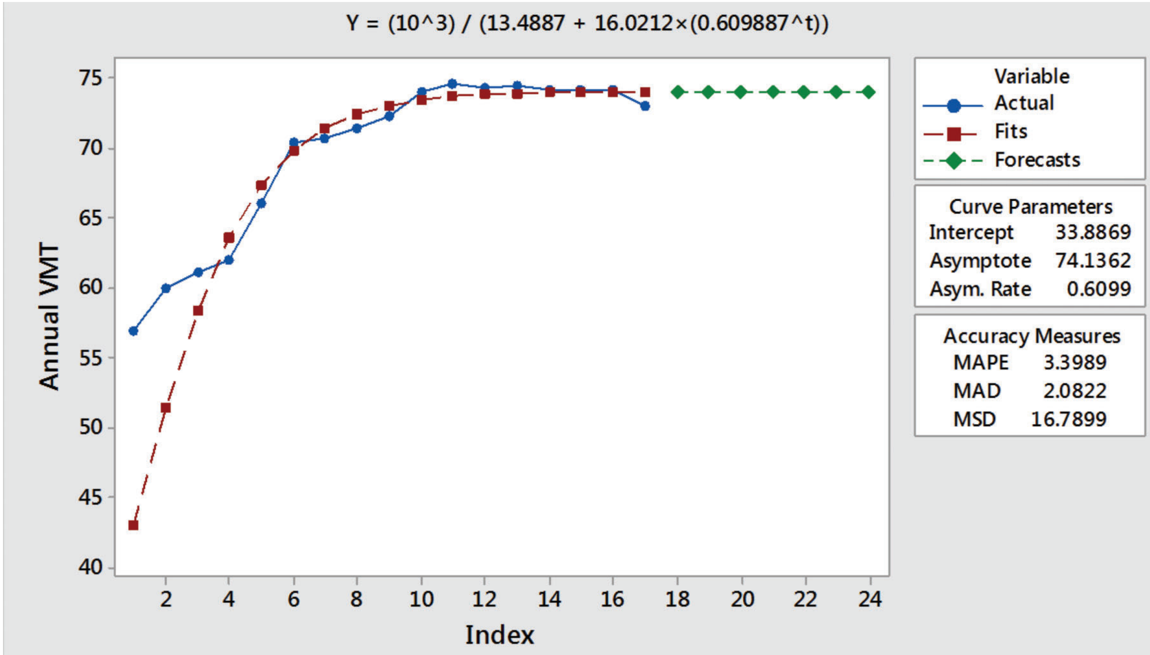


Figure 4.19 S-curve trend model for annual VMT prediction.

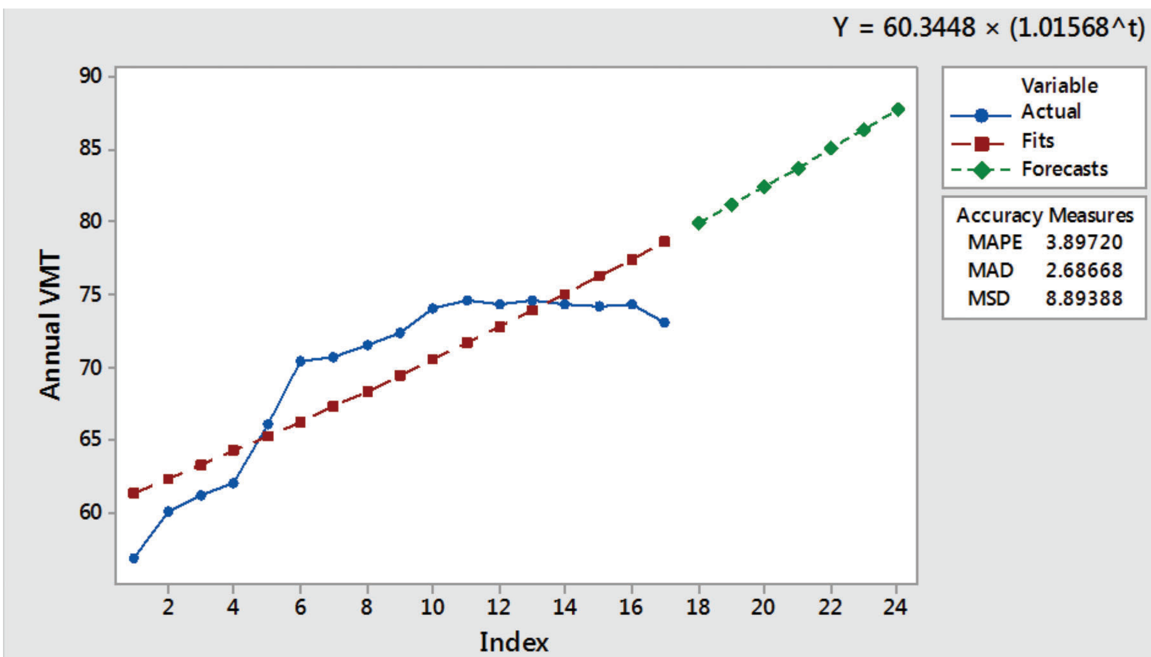


Figure 4.20 Growth curve model for annual VMT prediction.

to group counties, using VMT-related characteristics such as urban population, commute times, and vehicle registrations. Applications of spatial interpolation for local VMT estimation were presented, using existing traffic counts to estimate VMT by road class within a county. The techniques, implementation for Indiana, and the accuracy of each technique were discussed. Finally, analysis of the inputs and intermediate steps for non-traffic methods of VMT estimation were conducted, with emphasis on inputs and intermediate steps for the fuel-revenue and trend analysis methods.

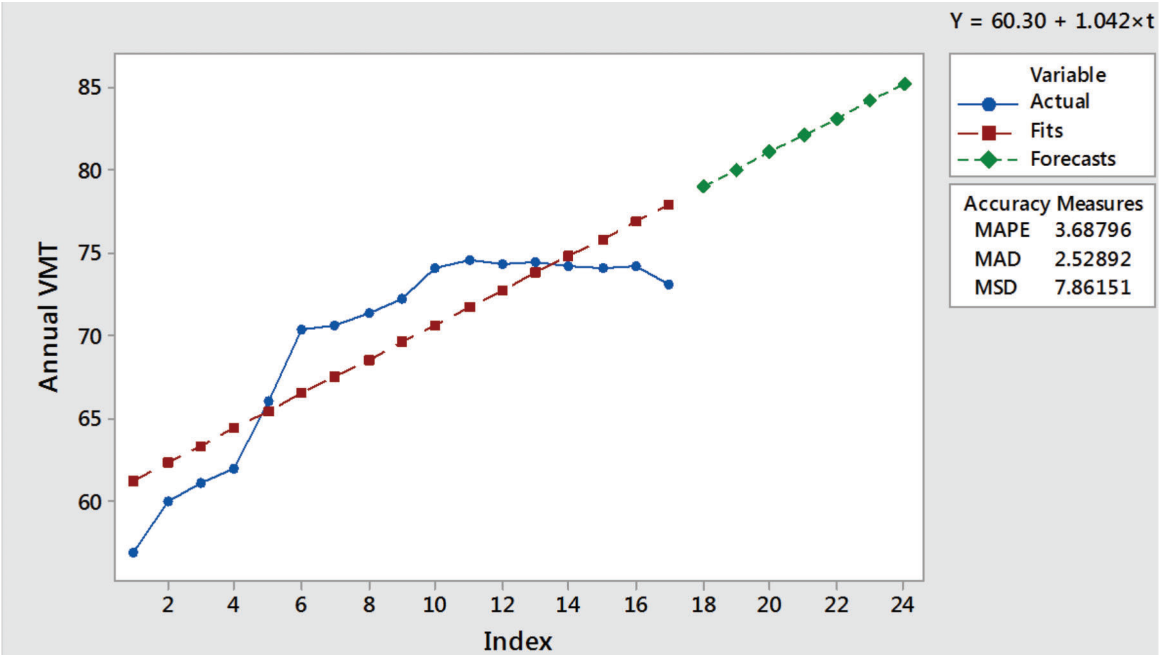


Figure 4.21 Linear trend model for annual VMT prediction.

TABLE 4.25
Extent of prediction error by trend analysis technique.

Analysis Years	Linear Trend	Polynomial Trend	Growth Curve Model	S-Curve Trend	Growth Factors
2009	2.0%	-6.9%	3.0%	-4.4%	-3.8%
2010	10.7%	4.0%	12.1%	2.4%	5.2%
2011	4.8%	1.0%	6.3%	-4.3%	0.3%
2012	4.5%	3.4%	6.4%	-5.7%	0.8%
2013	4.9%	6.3%	7.1%	-6.6%	1.9%

5. RESULTS AND DISCUSSION

5.1 Estimated Statewide VMT (Link-Level)

This section contains Indiana statewide VMT estimates, aggregated from the segment level using a comprehensive traffic database. These aggregated results represent the annual VMT, which is provided for varying scopes and users including the county-level, administrative district, road designation, economic region, and comparison to the HPMS. These aggregations assist policymakers with assessing the existing VMT conditions, as well as providing long-term predictions for applications necessitating VMT.

5.1.1 Aggregation by County

The local route VMT was based on data applicable for 2013 but is expected to be transferable across the years due to the limited variation in the observed growth rates. A summary of the county-wide VMT is shown in Table 5.1 and Table 5.2 for state and local routes, respectively. The table indicates each county's contribution to the statewide VMT. For example, Elkhart County had a VMT of 591.60 million on state routes and 855.94 million on local routes, for a county-wide total of 1,447.54 million. Note that the state routes and statewide total are for mainline segments and do not include ramps as they account for minimal VMT. Similarly, the percentages of VMT of local and state routes represent the proportion of travel that occurs on these road classes. For example, Allen County had 61.65% and 38.35% on local and state routes, respectively, indicating that more VMT was attributed to local roads. Counties without interstates and other high-volume roads tend to have a higher proportion of their total VMT from local routes.

For local routes, the county cluster group for statewide expansion, local routes centerline mileage, adjusted annual VMT, study VMT, reported VMT, and percent difference between study and reported, are shown in Table 5.3 and Table 5.4, respectively. The units of the study and VMT from the past literature are in millions. Most of the percent differences

TABLE 5.1
Summary of state and local VMT by county.

County ID	County Name	State Route Average (millions)	Local Route Average (millions)	Total (millions)	State Route (%)	Local Route (%)
01	Adams	161.62	154.00	315.62	51.21%	48.79%
02	Allen	1539.96	2475.79	4015.75	38.35%	61.65%
03	Bartholomew	772.34	407.57	1179.90	65.46%	34.54%
04	Benton	66.82	141.65	208.47	32.05%	67.95%
05	Blackford	53.10	75.44	128.55	41.31%	58.69%
06	Boone	761.86	407.77	1169.63	65.14%	34.86%
07	Brown	74.67	78.04	152.71	48.90%	51.10%
08	Carroll	140.71	158.39	299.10	47.05%	52.95%
09	Cass	164.08	195.66	359.73	45.61%	54.39%
10	Clark	644.75	550.70	1195.45	53.93%	46.07%
11	Clay	278.37	145.49	423.86	65.68%	34.32%
12	Clinton	341.53	170.00	511.53	66.77%	33.23%
13	Crawford	199.01	93.86	292.87	67.95%	32.05%
14	Daviess	167.51	176.86	344.37	48.64%	51.36%
15	Dearborn	434.79	244.90	679.68	63.97%	36.03%
16	Decatur	257.46	143.85	401.31	64.16%	35.84%
17	Dekalb	362.99	169.34	532.33	68.19%	31.81%
18	Delaware	573.51	816.73	1390.24	41.25%	58.75%
19	Dubois	248.49	349.75	598.24	41.54%	58.46%
20	Elkhart	591.60	855.94	1447.54	40.87%	59.13%
21	Fayette	83.11	238.80	321.91	25.82%	74.18%
22	Floyd	407.57	223.24	630.81	64.61%	35.39%
23	Fountain	172.55	144.74	317.28	54.38%	45.62%
24	Franklin	131.69	129.75	261.45	50.37%	49.63%
25	Fulton	129.69	164.71	294.40	44.05%	55.95%
26	Gibson	349.83	213.99	563.81	62.05%	37.95%
27	Grant	492.10	456.35	948.45	51.89%	48.11%
28	Greene	218.21	191.59	409.79	53.25%	46.75%
29	Hamilton	1256.76	1746.06	3002.82	41.85%	58.15%
30	Hancock	583.17	358.48	941.65	61.93%	38.07%
31	Harrison	350.92	170.75	521.66	67.27%	32.73%
32	Hendricks	764.59	778.17	1542.76	49.56%	50.44%
33	Henry	477.01	183.57	660.58	72.21%	27.79%
34	Howard	256.24	386.28	642.52	39.88%	60.12%
35	Huntington	447.54	156.95	604.49	74.04%	25.96%
36	Jackson	543.18	169.11	712.29	76.26%	23.74%
37	Jasper	574.11	199.36	773.47	74.23%	25.77%
38	Jay	121.80	161.53	283.32	42.99%	57.01%
39	Jefferson	183.24	121.54	304.79	60.12%	39.88%
40	Jennings	166.22	139.05	305.28	54.45%	45.55%
41	Johnson	757.92	654.88	1412.80	53.65%	46.35%
42	Knox	265.27	206.28	471.54	56.26%	43.74%
43	Kosciusko	367.10	575.75	942.86	38.94%	61.06%
44	LaGrange	174.13	161.42	335.55	51.89%	48.11%
45	Lake	2625.88	2076.30	4702.18	55.84%	44.16%
46	LaPorte	737.33	912.73	1650.06	44.69%	55.31%

were primarily between +/- 30%. Percent differences greater than +/-30% at certain counties may be due to the nature of the cluster assignment and the reliability and availability of traffic data.

5.1.2 Aggregation by District and Road Designation

This section provides the state route VMT at the six INDOT administrative districts and road designations of interstate, state, and US roads. The districts include Crawfordsville, Greenfield, Vincennes, Fort Wayne, Seymour, and LaPorte. The VMT (in millions) is shown in Table 5.5 for 2011. The variation in VMT distribution across districts is evident in Figure 5.1. The Greenfield district had the highest interstate VMT of 6,995 million; the Seymour district had the highest VMT from state highways at 2,801 million; and the LaPorte district had the highest VMT from US highways at 2,646 million.

TABLE 5.2
Summary of state and local VMT by county (continued).

County ID	County Name	State Route Average (millions)	Local Route Average (millions)	Total (millions)	State Route (%)	Local Route (%)
47	Lawrence	248.69	156.74	405.43	61.34%	38.66%
48	Madison	669.91	925.38	1595.29	41.99%	58.01%
49	Marion	4227.24	5156.55	9383.79	45.05%	54.95%
50	Marshall	349.61	204.55	554.17	63.09%	36.91%
51	Martin	93.65	79.40	173.06	54.12%	45.88%
52	Miami	237.61	171.68	409.29	58.05%	41.95%
53	Monroe	462.06	631.11	1093.17	42.27%	57.73%
54	Montgomery	326.89	183.26	510.15	64.08%	35.92%
55	Morgan	524.86	342.83	867.69	60.49%	39.51%
56	Newton	170.03	138.14	308.18	55.17%	44.83%
57	Noble	247.81	182.64	430.45	57.57%	42.43%
58	Ohio	26.42	28.77	55.19	47.87%	52.13%
59	Orange	122.87	130.30	253.18	48.53%	51.47%
60	Owen	119.23	127.68	246.91	48.29%	51.71%
61	Parke	94.69	153.73	248.42	38.12%	61.88%
62	Perry	152.10	108.36	260.46	58.40%	41.60%
63	Pike	117.29	112.82	230.10	50.97%	49.03%
64	Porter	985.21	700.06	1685.27	58.46%	41.54%
65	Posey	216.84	152.23	369.07	58.75%	41.25%
66	Pulaski	84.25	179.14	263.39	31.99%	68.01%
67	Putnam	419.18	164.73	583.91	71.79%	28.21%
68	Randolph	124.88	185.02	309.90	40.30%	59.70%
69	Ripley	258.17	154.17	412.34	62.61%	37.39%
70	Rush	108.04	156.36	264.40	40.86%	59.14%
71	St. Joseph	707.47	1745.29	2452.76	28.84%	71.16%
72	Scott	245.90	71.80	317.70	77.40%	22.60%
73	Shelby	451.60	184.77	636.37	70.97%	29.03%
74	Spencer	242.63	157.85	400.47	60.58%	39.42%
75	Starke	157.09	142.53	299.62	52.43%	47.57%
76	Steuben	288.94	139.76	428.70	67.40%	32.60%
77	Sullivan	147.19	187.82	335.01	43.94%	56.06%
78	Switzerland	57.39	72.38	129.76	44.22%	55.78%
79	Tippecanoe	808.02	684.77	1492.79	54.13%	45.87%
80	Tipton	170.21	119.02	289.23	58.85%	41.15%
81	Union	46.34	55.31	101.65	45.59%	54.41%
82	Vanderburgh	716.99	597.63	1314.62	54.54%	45.46%
83	Vermillion	172.52	93.57	266.09	64.84%	35.16%
84	Vigo	525.70	786.86	1312.57	40.05%	59.95%
85	Wabash	188.68	164.27	352.95	53.46%	46.54%
86	Warren	85.51	112.91	198.42	43.10%	56.90%
87	Warrick	353.12	353.60	706.72	49.97%	50.03%
88	Washington	144.63	163.32	307.94	46.97%	53.03%
89	Wayne	529.96	636.39	1166.34	45.44%	54.56%
90	Wells	137.41	154.59	291.99	47.06%	52.94%
91	White	326.85	195.20	522.05	62.61%	37.39%
92	Whitley	289.86	135.76	425.62	68.10%	31.90%

The proportion of commercial VMT by INDOT district is shown in Figure 5.2. The Greenfield district had the highest percentage, at 27.05, with the LaPorte district having the next highest percentage at 21.65. The Vincennes district had the lowest commercial VMT for 2011, with similar trends observed for other analysis years. The proportion of VMT attributed to NHS routes is shown in Figure 5.3. Again, the same observations as the commerical VMT were made, with Greenfield having highest VMT on NHS routes.

5.1.3 Aggregation by Economic Region

VMT can also be analyzed for groups of counties aggregated on the basis of economic growth regions (EGR). The 12 EGRs defined by the Indiana Department of Workforce Development (IDWD) are referenced in Figure 5.4 (IDWD, 2011). Marion County is an EGR by itself (EGR 12). Several counties in the greater Indianapolis metropolitan area, such as Hamilton (Carmel) and Boone (Zionsville) are part of EGR 5. The link-level

TABLE 5.3
Summary of local routes county-wide VMT estimates.

County ID	County Name	Cluster Group	Local Route Mileage	% Total as Local Mileage	Adjusted VMT per Mile	Study Annual VMT (millions)	Literature Annual VMT (millions)	% Difference
01	Adams	8	789.2	88.7	195,124	154.00	143.81	-6.6%
02	Allen	4	2571.4	90.9	962,818	2475.79	3043.74	22.9%
03	Bartholomew	7	975.8	82.6	417,681	407.57	468.30	14.9%
04	Benton	8	725.9	86.8	195,124	141.65	88.33	-37.6%
05	Blackford	8	386.7	89.9	195,124	75.44	98.55	30.6%
06	Boone	7	976.3	85.2	417,681	407.77	390.92	-4.1%
07	Brown	8	400.0	87.5	195,124	78.04	62.78	-19.6%
08	Carroll	8	811.7	88.0	195,124	158.39	117.53	-25.8%
09	Cass	8	1002.7	88.2	195,124	195.66	263.90	34.9%
10	Clark	6	846.8	75.5	650,350	550.70	496.40	-9.9%
11	Clay	8	745.6	85.8	195,124	145.49	137.97	-5.2%
12	Clinton	8	871.2	87.0	195,124	170.00	141.26	-16.9%
13	Crawford	8	481.1	79.0	195,124	93.86	56.58	-39.7%
14	Daviess	8	906.4	87.9	195,124	176.86	174.47	-1.4%
15	Dearborn	7	586.3	82.5	417,681	244.90	206.23	-15.8%
16	Decatur	8	737.2	89.4	195,124	143.85	178.85	24.3%
17	Dekalb	8	867.8	87.7	195,124	169.34	239.44	41.4%
18	Delaware	6	1255.8	90.3	650,350	816.73	672.33	-17.7%
19	Dubois	7	837.4	85.6	417,681	349.75	198.56	-43.2%
20	Elkhart	5	1602.5	90.2	534,111	855.94	1060.69	23.9%
21	Fayette	5	447.1	92.2	534,111	238.80	107.31	-55.1%
22	Floyd	7	534.5	89.3	417,681	223.24	352.23	57.8%
23	Fountain	8	741.8	84.1	195,124	144.74	94.54	-34.7%
24	Franklin	8	665.0	85.3	195,124	129.75	116.07	-10.5%
25	Fulton	8	844.1	89.4	195,124	164.71	131.04	-20.4%
26	Gibson	8	1096.7	86.4	195,124	213.99	173.74	-18.8%
27	Grant	7	1092.6	87.0	417,681	456.35	351.13	-23.1%
28	Greene	8	981.9	83.8	195,124	191.59	158.78	-17.1%
29	Hamilton	3	1871.9	93.3	932,755	1746.06	2245.12	28.6%
30	Hancock	7	858.3	89.5	417,681	358.48	488.37	36.2%
31	Harrison	8	875.1	84.1	195,124	170.75	121.55	-28.8%
32	Hendricks	6	1196.5	87,7	650,350	778.17	1011.42	30.0%
33	Henry	8	940.8	86.9	195,124	183.57	192.72	5.0%
34	Howard	7	924.8	90.4	417,681	386.28	512.83	32.8%
35	Huntington	8	804.3	79.6	195,124	156.95	185.06	17.9%
36	Jackson	8	866.7	81.9	195,124	169.11	188.34	11.4%
37	Jasper	8	1021.7	85.4	195,124	199.36	212.07	6.4%
38	Jay	8	827.8	89.7	195,124	161.53	142.35	-11.9%
39	Jefferson	8	622.9	73.5	195,124	121.54	143.08	17.7%
40	Jennings	8	712.6	87.9	195,124	139.05	183.60	32.0%
41	Johnson	6	1007.0	87.8	650,350	654.88	840.23	28.3%
42	Knox	8	1057.2	87.5	195,124	206.28	233.97	13.4%
43	Kosciusko	7	1378.5	90.8	417,681	575.75	383.98	-33.3%
44	LaGrange	8	827.3	89.8	195,124	161.42	128.48	-20.4%
45	Lake	2	2503.0	89.3	829,542	2076.30	2706.84	30.4%
46	LaPorte	6	1403.4	86.6	650,350	912.73	512.83	-43.8%
47	Lawrence	8	803.3	86.2	195,124	156.74	161.70	3.2%
48	Madison	6	1422.9	89.5	650,350	925.38	782.20	-15.5%
49	Marion	1	3579.0	92.7	1,440,792	5156.55	6240.04	21.0%
50	Marshall	8	1048.3	86.1	195,124	204.55	223.02	9.0%
51	Martin	8	406.9	43.1	195,124	79.40	41.98	-47.1%
52	Miami	8	879.9	86.6	195,124	171.68	188.71	9.9%
53	Monroe	6	970.4	88.6	650,350	631.11	552.25	-12.5%
54	Montgomery	8	939.2	85.2	195,124	183.26	167.17	-8.8%
55	Morgan	7	820.8	85.9	417,681	342.83	404.06	17.9%
56	Newton	8	708.0	85.2	195,124	138.14	87.24	-36.9%
57	Noble	8	936.0	89.2	195,124	182.64	171.55	-6.1%
58	Ohio	8	147.5	84.0	195,124	28.77	20.81	-27.7%
59	Orange	8	667.8	84.8	195,124	130.30	82.13	-37.0%

TABLE 5.3
(Continued)

County ID	County Name	Cluster Group	Local Route Mileage	% Total as Local Mileage	Adjusted VMT per Mile	Study Annual VMT (millions)	Literature Annual VMT (millions)	% Difference
60	Owen	8	654.4	88.1	195,124	127.68	90.89	-28.8%
61	Parke	8	787.9	89.1	195,124	153.73	133.59	-13.1%
62	Perry	8	555.4	76.7	195,124	108.36	94.90	-12.4%
63	Pike	8	578.2	81.8	195,124	112.82	64.97	-42.4%
64	Porter	5	1310.7	87.4	534,111	700.06	921.99	31.7%
65	Posey	8	780.2	87.8	195,124	152.23	128.48	-15.6%
66	Pulaski	8	918.1	90.7	195,124	179.14	118.26	-34.0%
67	Putnam	8	844.2	85.8	195,124	164.73	163.89	-0.5%
68	Randolph	8	948.2	87.9	195,124	185.02	146.73	-20.7%
69	Ripley	8	790.1	78.6	195,124	154.17	121.91	-20.9%
70	Rush	8	801.3	90.7	195,124	156.36	121.55	-22.3%
71	Scott	8	368.0	81.2	195,124	71.80	86.87	21.0%
72	Shelby	8	946.9	90.6	195,124	184.77	256.23	38.7%
73	Spencer	8	809.0	83.3	195,124	157.85	119.36	-24.4%
74	St. Joseph	3	1871.1	92.1	932,755	1745.29	1965.53	12.6%
75	Starke	8	730.5	87.4	195,124	142.53	95.27	-33.2%
76	Steuben	8	716.3	85.8	195,124	139.76	192.72	37.9%
77	Sullivan	8	962.6	90.0	195,124	187.82	126.29	-32.8%
78	Switzerland	8	370.9	80.9	195,124	72.38	47.82	-33.9%
79	Tippecanoe	5	1282.1	88.3	534,111	684.77	866.51	26.5%
80	Tipton	8	610.0	90.8	195,124	119.02	104.76	-12.0%
81	Union	8	283.5	84.0	195,124	55.31	36.87	-33.4%
82	Vanderburgh	5	1118.9	90.2	534,111	597.63	970.54	62.4%
83	Vermillion	8	479.5	73.7	195,124	93.57	83.95	-10.3%
84	Vigo	6	1209.9	89.7	650,350	786.86	690.58	-12.2%
85	Wabash	8	841.9	85.3	195,124	164.27	145.27	-11.6%
86	Warren	8	578.7	84.9	195,124	112.91	81.40	-27.9%
87	Warrick	7	846.6	85.9	417,681	353.60	297.84	-15.8%
88	Washington	8	837.0	87.8	195,124	163.32	172.65	5.7%
89	Wayne	6	978.5	86.6	650,350	636.39	279.96	-56.0%
90	Wells	8	792.3	88.5	195,124	154.59	137.61	-11.0%
91	White	8	1000.4	87.7	195,124	195.20	191.63	-1.8%
92	Whitley	8	695.8	83.8	195,124	135.76	170.46	25.6%

database has an indicator to assign each network link to the county and EGR in which it is located.

There is a historical relationship between relative economic activity (freight commodity flows, workplace commuting, and so on) and VMT. However, caution should be exercised when comparing between EGRs because bias could arise when comparing regions with major interstates and other routes that contribute to the regional VMT.

For state routes, the annual change in VMT from 2009 to 2012 is shown in Figure 5.5. EGR 5 had the highest VMT in 2009 and 2010 and EGR 1 had the highest VMT in 2011 and 2012, with both regions' VMT at 5.7 to 6.2 billion annually. Regions 2, 4, 6, and 11 had similar VMT at 2 to 3 billion annually. Both local routes and the statewide total per EGR are shown in Figure 5.6 and Table 5.6. The trends were similar to the state routes, with EGR 5 and EGR 1 having the highest VMT in Indiana. Regions 3 and 12 were the next highest at 9 to 9.2 billion.

Local route VMT was found to be the highest for EGR 5, with EGR 3 and EGR 1 having the next highest. The lowest local route VMT was EGR 7 and EGR 8 in southwestern Indiana. As may be expected, the urban areas of Lake, Marion, and Allen County contributed to a high VMT for regions containing these counties, along with regions containing major freeway corridors.

5.1.4 Aggregation by Link-Level Sample (HPMS)

To compare the results from estimation using the link-level sampling incorporated into the HPMS, data were compiled from HPMS submittals for 2009 to 2013 shown by FHWA functional class. These statewide VMT estimates are expected to be close to this study's estimates because they also are based on an extensive sample of traffic counts for each functional class. However, the local and collector classes have a lower reliability due to the limitations of relying solely on a single approach as discussed earlier. As shown for 2009 to 2013 (Table 5.7), the statewide VMT is shown by functional classes for interstates, principal arterials,

TABLE 5.4
Summary of local routes county-wide VMT estimates (continued).

County ID	County Name	Cluster Group	Local Route Mileage	% Total as Local Mileage	Adjusted VMT per Mile	Study Annual VMT (millions)	Literature Annual VMT (millions)	% Difference
47	Lawrence	8	803.3	86.2	195,124	156.74	161.70	3.2%
48	Madison	6	1422.9	89.5	650,350	925.38	782.20	-15.5%
49	Marion	1	3579.0	92.7	1,440,792	5156.55	6240.04	21.0%
50	Marshall	8	1048.3	86.1	195,124	204.55	223.02	9.0%
51	Martin	8	406.9	43.1	195,124	79.40	41.98	-47.1%
52	Miami	8	879.9	86.6	195,124	171.68	188.71	9.9%
53	Monroe	6	970.4	88.6	650,350	631.11	552.25	-12.5%
54	Montgomery	8	939.2	85.2	195,124	183.26	167.17	-8.8%
55	Morgan	7	820.8	85.9	417,681	342.83	404.06	17.9%
56	Newton	8	708.0	85.2	195,124	138.14	87.24	-36.9%
57	Noble	8	936.0	89.2	195,124	182.64	171.55	-6.1%
58	Ohio	8	147.5	84.0	195,124	28.77	20.81	-27.7%
59	Orange	8	667.8	84.8	195,124	130.30	82.13	-37.0%
60	Owen	8	654.4	88.1	195,124	127.68	90.89	-28.8%
61	Parke	8	787.9	89.1	195,124	153.73	133.59	-13.1%
62	Perry	8	555.4	76.7	195,124	108.36	94.90	-12.4%
63	Pike	8	578.2	81.8	195,124	112.82	64.97	-42.4%
64	Porter	5	1310.7	87.4	534,111	700.06	921.99	31.7%
65	Posey	8	780.2	87.8	195,124	152.23	128.48	-15.6%
66	Pulaski	8	918.1	90.7	195,124	179.14	118.26	-34.0%
67	Putnam	8	844.2	85.8	195,124	164.73	163.89	-0.5%
68	Randolph	8	948.2	87.9	195,124	185.02	146.73	-20.7%
69	Ripley	8	790.1	78.6	195,124	154.17	121.91	-20.9%
70	Rush	8	801.3	90.7	195,124	156.36	121.55	-22.3%
71	Scott	8	368.0	81.2	195,124	71.80	86.87	21.0%
72	Shelby	8	946.9	90.6	195,124	184.77	256.23	38.7%
73	Spencer	8	809.0	83.3	195,124	157.85	119.36	-24.4%
74	St. Joseph	3	1871.1	92.1	932,755	1745.29	1965.53	12.6%
75	Starke	8	730.5	87.4	195,124	142.53	95.27	-33.2%
76	Steuben	8	716.3	85.8	195,124	139.76	192.72	37.9%
77	Sullivan	8	962.6	90.0	195,124	187.82	126.29	-32.8%
78	Switzerland	8	370.9	80.9	195,124	72.38	47.82	-33.9%
79	Tippecanoe	5	1282.1	88.3	534,111	684.77	866.51	26.5%
80	Tipton	8	610.0	90.8	195,124	119.02	104.76	-12.0%
81	Union	8	283.5	84.0	195,124	55.31	36.87	-33.4%
82	Vanderburgh	5	1118.9	90.2	534,111	597.63	970.54	62.4%
83	Vermillion	8	479.5	73.7	195,124	93.57	83.95	-10.3%
84	Vigo	6	1209.9	89.7	650,350	786.86	690.58	-12.2%
85	Wabash	8	841.9	85.3	195,124	164.27	145.27	-11.6%
86	Warren	8	578.7	84.9	195,124	112.91	81.40	-27.9%
87	Warrick	7	846.6	85.9	417,681	353.60	297.84	-15.8%
88	Washington	8	837.0	87.8	195,124	163.32	172.65	5.7%
89	Wayne	6	978.5	86.6	650,350	636.39	279.96	-56.0%
90	Wells	8	792.3	88.5	195,124	154.59	137.61	-11.0%
91	White	8	1000.4	87.7	195,124	195.20	191.63	-1.8%
92	Whitley	8	695.8	83.8	195,124	135.76	170.46	25.6%

other freeways and expressways, minor arterials, major collectors, minor collectors, and locals. Interstates, FC 1, and Locals, FC 7, had the highest VMT based on the HPMS. The statewide annual VMT is 76.628, 75.761, 76.485, 78.923, and 78.851 billion for 2009, 2010, 2011, 2012, and 2013, respectively.

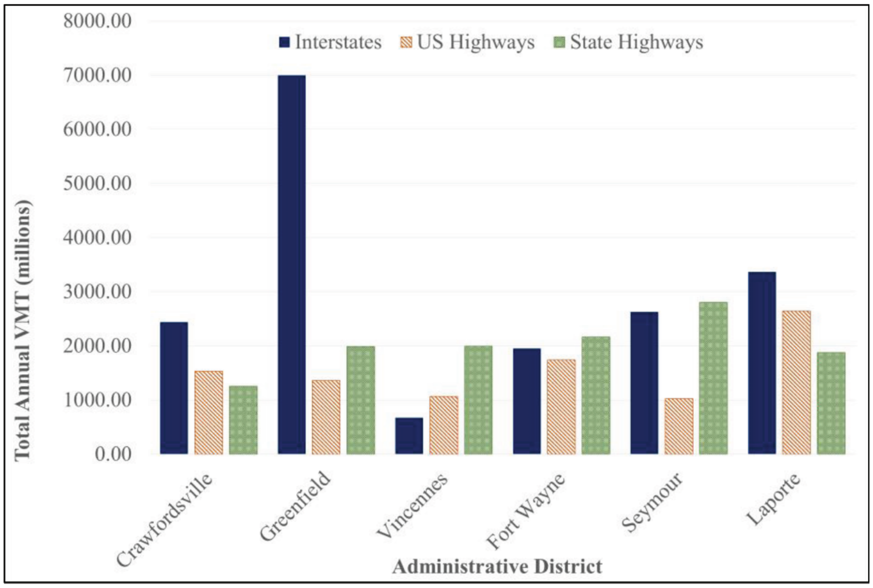


Figure 5.1 Proportion of state route VMT by INDOT administrative district.

TABLE 5.5
State route VMT aggregation by INDOT administrative district.

Annual State Route VMT by Administrative District (millions)			
Crawfordsville	Total	NHS Road Class	Commercial Vehicles
Interstates	2439.46	2439.46	517.99
US Highways	1530.54	946.65	113.53
State Highways	1253.04	450.12	107.33
Total	**5223.05**	**3836.23**	**738.85**
Greenfield	Total	NHS Road Class	Commercial Vehicles
Interstates	6994.81	6994.81	1171.66
US Highways	1359.17	1097.29	108.60
State Highways	1989.76	1133.28	148.52
Total	**10343.75**	**9225.38**	**1428.79**
Vincennes	Total	NHS Road Class	Commercial Vehicles
Interstates	674.72	674.72	144.85
US Highways	1064.31	1042.28	122.73
State Highways	1992.87	927.00	161.38
Total	**3731.89**	**2644.00**	**428.95**
Fort Wayne	Total	NHS Road Class	Commercial Vehicles
Interstates	1952.99	1952.99	367.08
US Highways	1738.55	1433.69	231.16
State Highways	2162.59	637.53	193.83
Total	**5854.13**	**4024.21**	**792.07**
Seymour	Total	NHS Road Class	Commercial Vehicles
Interstates	2627.00	2627.00	462.65
US Highways	1023.04	726.17	84.38
State Highways	2801.30	1351.80	202.40
Total	**6451.35**	**4704.97**	**749.43**
Laporte	Total	NHS Road Class	Commercial Vehicles
Interstates	3368.53	3368.53	622.98
US Highways	2645.69	2139.75	350.98
State Highways	1875.87	915.84	169.77
Total	**7890.10**	**6424.12**	**1143.73**

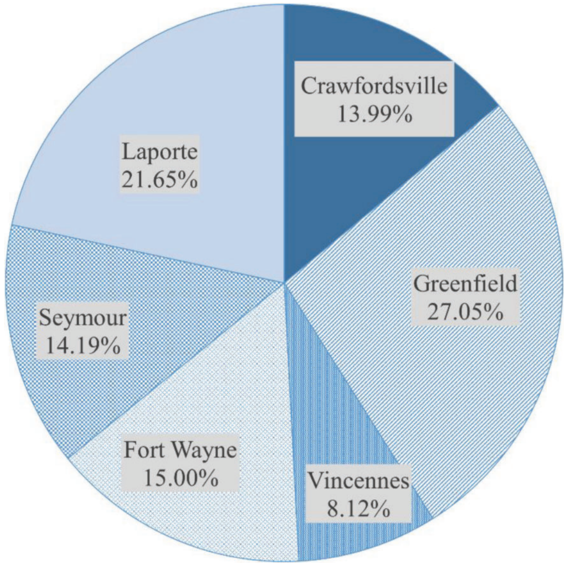


Figure 5.2 Proportion of commercial VMT by INDOT administrative district.

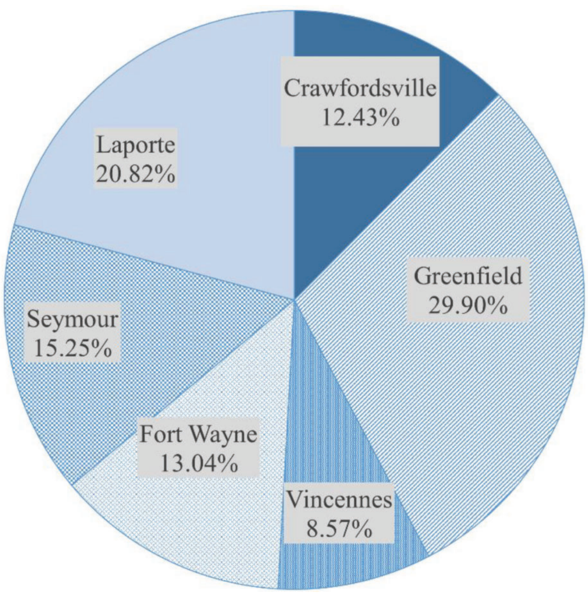


Figure 5.3 Proportion of NHS VMT by INDOT administrative district.

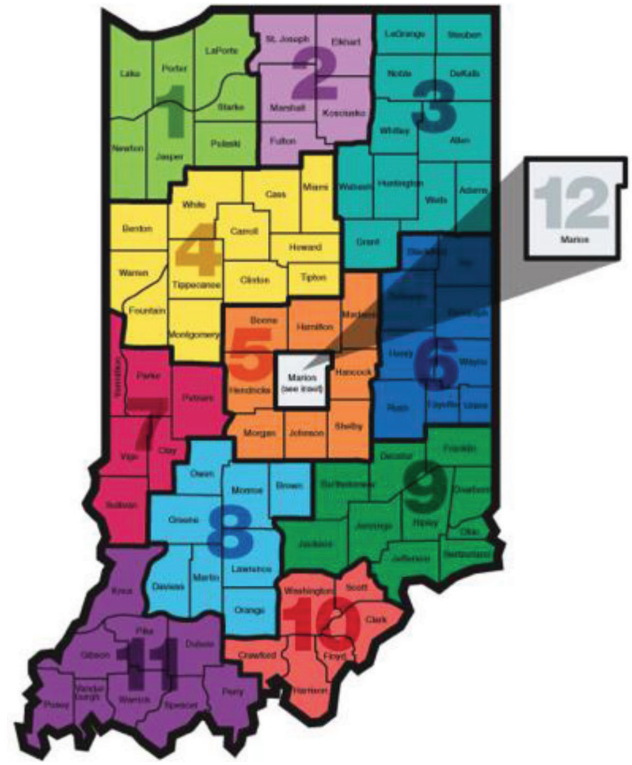


Figure 5.4 Counties comprising of Indiana growth regions.

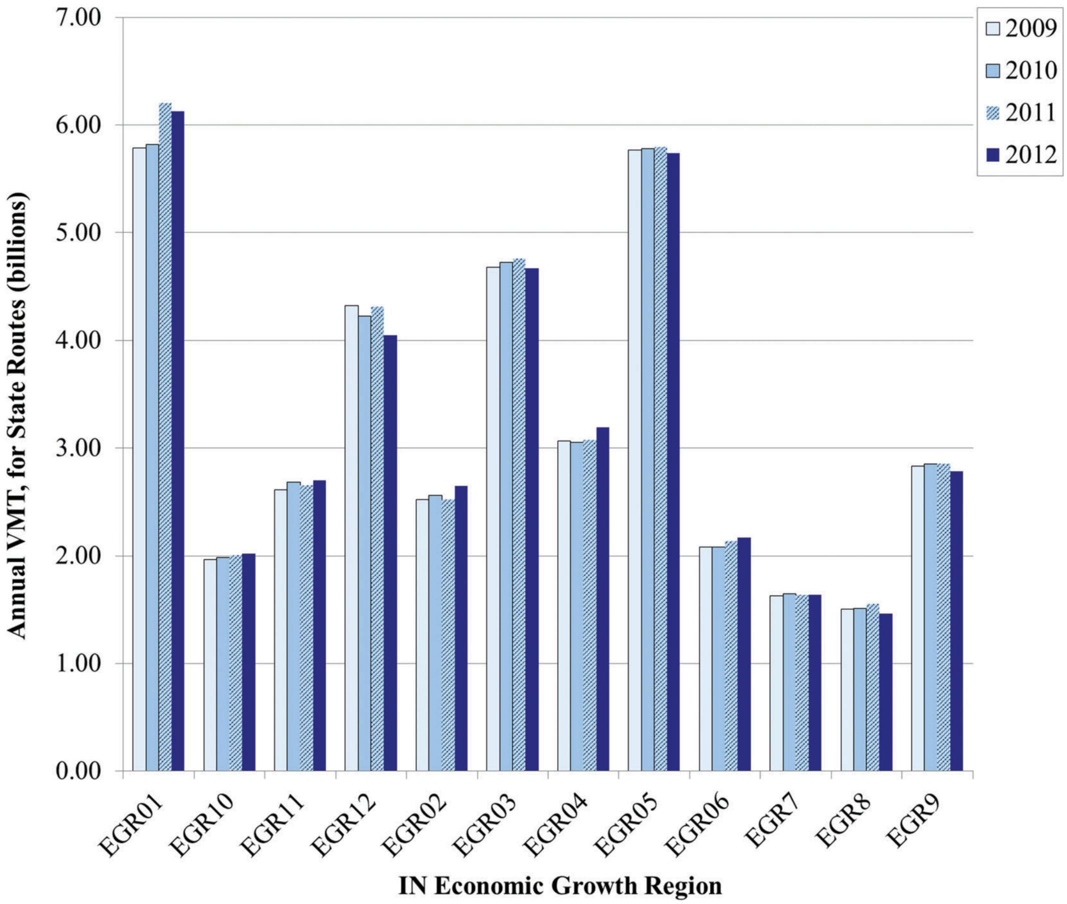


Figure 5.5 Estimated state route VMT by Indiana economic growth region.

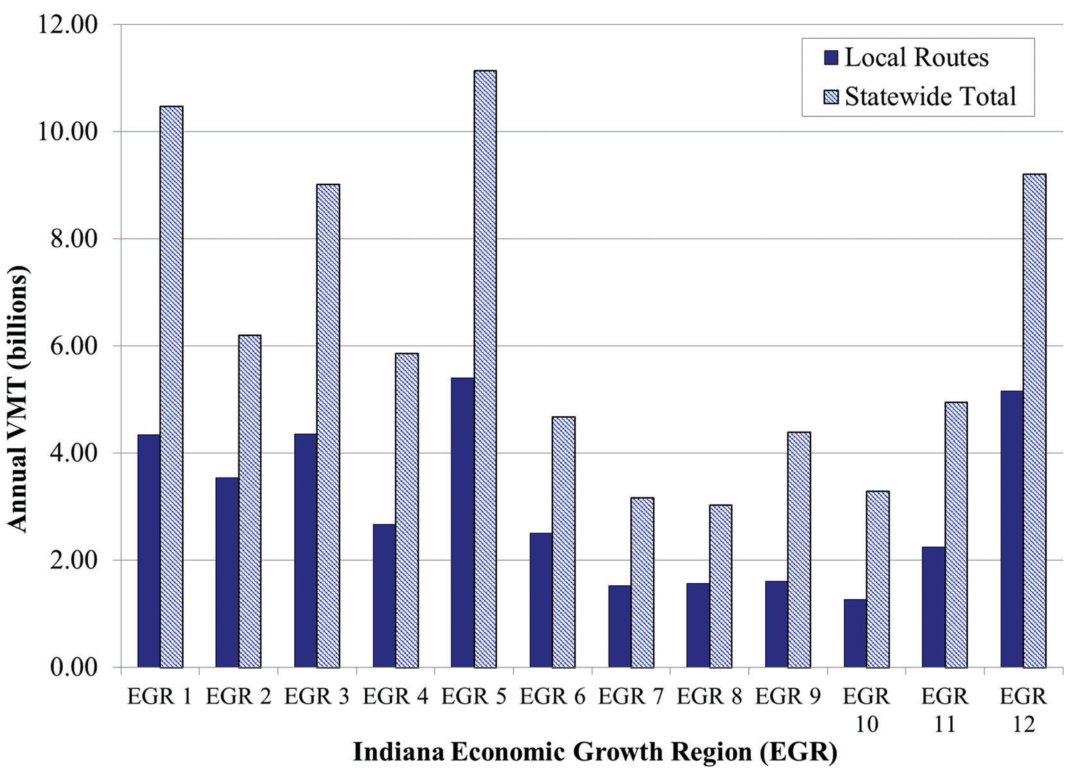


Figure 5.6 Share of local route VMT by Indiana economic growth region.

TABLE 5.6
Annual local and state VMT by Indiana economic growth region. 7

Indiana Economic Growth Region	Local Routes VMT (billions)	Statewide Total VMT (billions)
EGR 1	4.348	10.477
EGR 2	3.546	6.197
EGR 3	4.351	9.022
EGR 4	2.664	5.858
EGR 5	5.398	11.139
EGR 6	2.509	4.679
EGR 7	1.532	3.169
EGR 8	1.572	3.031
EGR 9	1.611	4.396
EGR 10	1.274	3.292
EGR 11	2.253	4.953
EGR 12	5.157	9.202

TABLE 5.7
Statewide VMT by FHWA functional classes from HPMS submittals.

Statewide VMT by FHWA Functional Class	2009	2010	2011	2012	2013
Interstates (FC 1)	16.726	16.506	17.130	17.238	17.440
Principal Arterials – Other Freeways/Expressways (FC2)	1.304	1.339	1.288	1.347	1.339
Principal Arterials – Other (FC3)	15.280	15.055	15.216	15.877	15.845
Minor Arterial (FC4)	11.007	11.818	11.858	12.191	12.617
Major Collector (FC5)	12.818	11.286	11.291	11.214	10.450
Minor Collector (FC6)	1.916	1.916	1.883	2.385	2.368
Locals (FC 7)	17.577	17.840	17.819	18.670	18.791
Totals	76.628	75.761	76.485	78.923	78.851

5.2 Predicted Statewide VMT (Link-Level)

This section contains the predicted Indiana annual VMT at the link-level. Aggregations are provided by statewide totals, route, vehicle class, and functional class.

5.2.1 Aggregation by Year (Statewide)

The predicted aggregated statewide VMT is presented in Table 5.8 for 2009 to 2035, with 2009 to 2012 as the benchmark estimation years. All units are shown in billions. The low, medium, and high growth ranges are shown for state and local routes as well as the statewide total.

In 2035, the statewide VMT was estimated as 90.180 to 100.571 billion (average of 95.224 billion): of this total, state routes are expected to contribute 49.277 to 56.225 billion and local routes, 40.903 to 44.346 billion (Figure 5.7) the bottom curve represents the low growth rate scenario, the middle curve represents a moderate growth rate scenario, and the top curve represents the high growth rate scenario. The range of VMT remains close until 2022 and then the gap widens far into the future, indicating the stochastic nature of long-term traffic forecasting. It is noted that economic changes, population shifts, and other exogenous factors may greatly influence these predictions. Therefore, these predictions should be used to gauge the trends in statewide VMT but must be updated as additional traffic data become available.

5.2.2 Aggregation by Year and Route

A comparison of current and future interstate VMT is shown in Table 5.9. This aggregation is for all interstate routes in Indiana, including the Indiana Toll Road with 2011 link-level data. The four-year weighted average traffic distributions by vehicle classes were applied for aggregating by routes. The route aggregations are for mainline roads and do not contain ramps. Based on the projections shown for 2035, I-65 had the highest total VMT, and then I-70, followed closely by I-69. With the major I-69 construction underway, this may lead to I-69 having the second highest interstate VMT. Additionally, I-465 has the fourth highest interstate VMT.

The distribution for vehicle classes along interstate route is shown in Table 5.10. Motorcycles were consistently at 0.4–0.5% for all routes. Automobiles varied from 50.4% for I-70 to 65.6% for I-265. Light-duty trucks varied from 17.1% for I-70 to 22.2% for I-265. Buses were consistent across all the routes at 0.2 to 0.4%. Class 5 trucks varied from 2.4 to 4.6% on the I-94 route. Single-unit trucks were consistent across most interstate routes. The distribution of class 9 trucks varied greatly, with I-70 containing the highest (23.8%) and I-275 and I-265 containing the lowest (9.7% and 7.3%). Finally, combination trucks were consistently below 1.0% for all interstate routes, with I-64 and I-74 containing the highest percentages.

The combined distribution of single-unit truck classes 5–7 is shown in Figure 5.8 for interstate routes in

TABLE 5.8
Summary of predicted aggregate statewide VMT.

	State Routes Annual VMT (billions)			Local Routes Annual VMT (billions)			State Total Annual VMT (billions)		
Year	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
2009	39.240	39.921	40.602	34.840	35.154	35.468	74.080	75.075	76.069
2010	39.098	39.779	40.460	35.102	35.416	35.730	74.201	75.195	76.190
2011	39.911	40.592	41.273	35.367	35.680	35.994	75.277	76.272	77.266
2012	39.665	40.346	41.027	35.633	35.946	36.260	75.298	76.292	77.287
2013	40.588	40.702	40.817	36.214	36.214	36.214	76.802	76.917	77.031
2014	40.942	41.174	41.407	36.415	36.482	36.549	77.357	77.656	77.956
2015	41.300	41.652	42.007	36.617	36.752	36.887	77.917	78.404	78.894
2016	41.662	42.137	42.616	36.820	37.024	37.228	78.482	79.161	79.844
2017	42.027	42.627	43.234	37.025	37.298	37.573	79.052	79.925	80.807
2018	42.396	43.124	43.863	37.230	37.574	37.920	79.626	80.698	81.783
2019	42.769	43.627	44.501	37.437	37.852	38.271	80.205	81.479	82.772
2020	43.145	44.136	45.149	37.645	38.132	38.625	80.790	82.269	83.775
2021	43.525	44.653	45.808	37.854	38.414	38.982	81.379	83.067	84.791
2022	43.909	45.176	46.478	38.064	38.699	39.343	81.973	83.874	85.821
2023	44.297	45.705	47.158	38.275	38.985	39.707	82.572	84.690	86.865
2024	44.689	46.242	47.849	38.487	39.273	40.074	83.176	85.516	87.923
2025	45.085	46.786	48.551	38.701	39.564	40.445	83.786	86.350	88.996
2026	45.485	47.337	49.264	38.916	39.857	40.819	84.401	87.194	90.083
2027	45.889	47.895	49.989	39.132	40.152	41.197	85.021	88.047	91.186
2028	46.297	48.460	50.725	39.349	40.449	41.578	85.646	88.909	92.303
2029	46.710	49.033	51.474	39.567	40.748	41.962	86.277	89.781	93.436
2030	47.126	49.613	52.234	39.787	41.050	42.350	86.913	90.663	94.585
2031	47.548	50.201	53.007	40.008	41.354	42.742	87.555	91.555	95.749
2032	47.973	50.797	53.792	40.230	41.660	43.137	88.203	92.457	96.930
2033	48.403	51.401	54.590	40.453	41.968	43.536	88.856	93.369	98.127
2034	48.838	52.013	55.401	40.678	42.278	43.939	89.515	94.291	99.340
2035	49.277	52.633	56.225	40.903	42.591	44.346	90.180	95.224	100.571

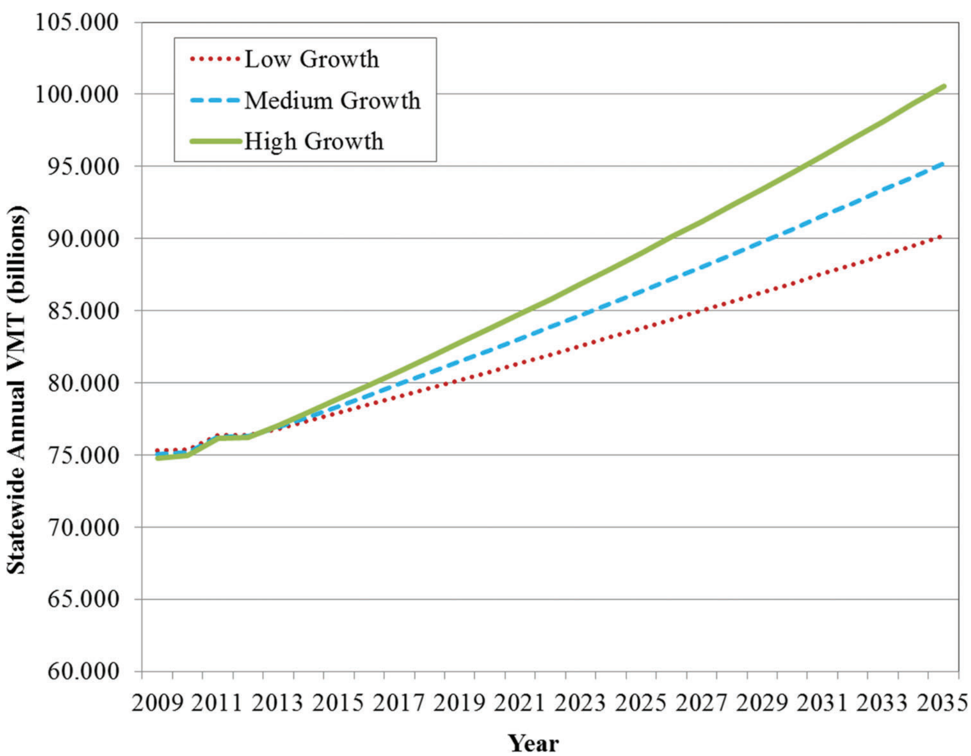


Figure 5.7 Predicted statewide VMT for varying traffic growth rate scenarios.

TABLE 5.9
Comparison of current and projected interstate VMT by route.

	Annual VMT (millions)												
Year	**I-265**	**I-275**	**I-465**	**I-469**	**I-64**	**I-65**	**I-69**	**I-70**	**I-74**	**I-80**	**I-865**	**I-90**	**I-94**
2009	119.72	41.75	2195.50	231.33	776.04	4659.68	2303.28	2496.74	1253.95	680.61	47.37	1447.92	497.92
2010	120.19	39.62	2199.13	242.03	839.71	4568.20	2295.73	2479.85	1203.10	760.79	47.55	1447.92	499.91
2011	121.35	39.72	2113.81	245.68	863.05	4706.30	2324.79	2649.97	1180.99	897.54	50.55	1447.92	607.13
2012	119.66	39.79	2045.35	243.13	885.96	4764.30	2319.65	2398.38	1167.64	760.76	50.65	1447.92	609.35
2013	122.49	40.19	2066.30	245.62	895.03	4813.08	2343.41	2422.94	1179.60	768.55	51.17	1462.75	615.59
2014	123.74	40.61	2087.46	248.13	904.20	4862.37	2367.40	2447.75	1191.68	776.42	51.69	1477.73	621.89
2015	125.01	41.02	2108.83	250.67	913.46	4912.16	2391.65	2472.82	1203.88	784.37	52.22	1492.86	628.26
2016	126.29	41.44	2130.43	253.24	922.81	4962.46	2416.14	2498.14	1216.21	792.40	52.76	1508.15	634.69
2017	127.58	41.87	2152.24	255.83	932.26	5013.28	2440.88	2523.72	1228.66	800.51	53.30	1523.59	641.19
2018	128.89	42.29	2174.28	258.45	941.81	5064.61	2465.87	2549.56	1241.24	808.71	53.84	1539.19	647.76
2019	130.21	42.73	2196.55	261.10	951.45	5116.47	2491.12	2575.67	1253.95	816.99	54.39	1554.95	654.39
2020	131.54	43.17	2219.04	263.77	961.20	5168.87	2516.63	2602.05	1266.80	825.36	54.95	1570.88	661.09
2021	132.89	43.61	2241.76	266.47	971.04	5221.80	2542.40	2628.69	1279.77	833.81	55.51	1586.96	667.86
2022	134.25	44.05	2264.72	269.20	980.98	5275.27	2568.44	2655.61	1292.87	842.35	56.08	1603.21	674.70
2023	135.63	44.50	2287.91	271.96	991.03	5329.29	2594.74	2682.80	1306.11	850.97	56.66	1619.63	681.61
2024	137.02	44.96	2311.34	274.74	1001.18	5383.86	2621.31	2710.28	1319.49	859.69	57.24	1636.21	688.59
2025	138.42	45.42	2335.00	277.56	1011.43	5438.99	2648.15	2738.03	1333.00	868.49	57.82	1652.97	695.64
2026	139.84	45.89	2358.91	280.40	1021.78	5494.68	2675.27	2766.07	1346.65	877.38	58.41	1669.89	702.76
2027	141.27	46.36	2383.07	283.27	1032.25	5550.95	2702.66	2794.39	1360.44	886.37	59.01	1686.99	709.96
2028	142.71	46.83	2407.47	286.17	1042.82	5607.79	2730.34	2823.00	1374.37	895.44	59.62	1704.27	717.23
2029	144.18	47.31	2432.13	289.10	1053.50	5665.21	2758.30	2851.91	1388.44	904.61	60.23	1721.72	724.57
2030	145.65	47.79	2457.03	292.06	1064.28	5723.23	2786.54	2881.12	1402.66	913.88	60.84	1739.35	731.99
2031	147.14	48.28	2482.19	295.05	1075.18	5781.83	2815.08	2910.62	1417.02	923.23	61.47	1757.16	739.49
2032	148.65	48.78	2507.61	298.07	1086.19	5841.04	2843.90	2940.42	1431.53	932.69	62.10	1775.16	747.06
2033	150.17	49.28	2533.29	301.13	1097.31	5900.85	2873.02	2970.53	1446.19	942.24	62.73	1793.33	754.71
2034	151.71	49.78	2559.23	304.21	1108.55	5961.27	2902.44	3000.95	1461.00	951.89	63.37	1811.70	762.44
2035	153.26	50.29	2585.43	307.32	1119.90	6022.32	2932.16	3031.68	1475.96	961.64	64.02	1830.25	770.25

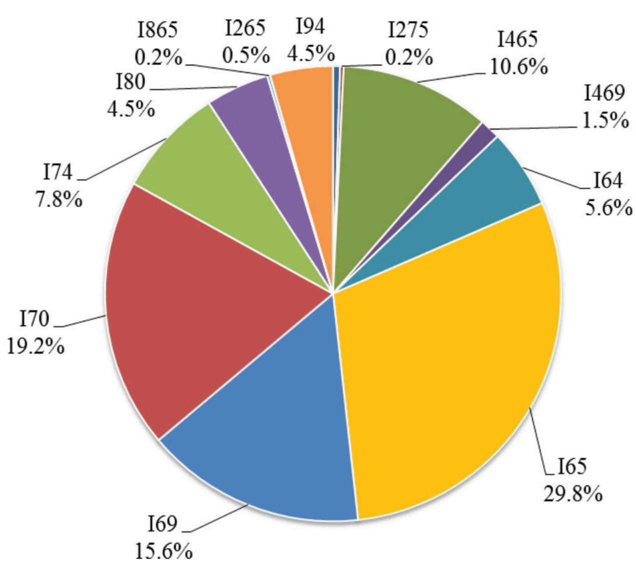


Figure 5.8 Distribution of single-unit truck VMT by interstate route.

Indiana. It was observed that I-65 contributed most of the total single truck VMT (29.8%), and I-70 had the next highest share of single-unit truck VMT (19.2%). Interstates 74, 80, 865, 94, 265, 275, 469, and 64 all had less than 10.0% of the VMT share for single-unit trucks.

The distribution of single-trailer truck VMT for classes 8–10, is shown by the interstate route in Figure 5.9. Again, I-65 contributed the majority (31.4%), with I-70 as the second highest (20.5%), followed by I-69 (14.2%). A relatively similar distribution was observed between single-unit and single-trailer trucks. Finally, the distribution of combination truck VMT classes 11–13 is shown by the interstate route in Figure 5.10. Similar distributions to single-unit trucks are seen with I-65 (29.4%), I-70 (19.6%), and I-69 (15.6%), with these routes containing 64.6% of the total combination truck VMT.

The commercial VMT was analyzed for each interstate route between 2009 and 2012, as presented in Figure 5.11. On average, I-65 contains the highest commercial trucking VMT, estimated as approximately 1.4 billion in 2009 and 2010, 0.8 billion in 2011, and 1.0 billion in 2012. The routes in order from the highest to the lowest commercial VMT were as follows: I-70, I-69, I-465, I-74, I-64, I-80, I-469, and I-265. Note that three routes, I-65, I-70, and I-70, had an average annual commercial VMT exceeding 0.4 billion.

Aggregations of the annual VMT by US highway route are provided in Table 5.11 with all units in millions for the 20 US routes, which were based on the link-level AADT. The highest VMT was attributed to US-31, at 2,244 million in 2035, with US-41 next highest at 1,649 million. Similarly, aggregated results for

TABLE 5.10
Interstate vehicle class distribution by route.

4-Year Weighted Average Traffic Distribution by Route													
Route	**Class 1**	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**Class 13**
I-265	0.45%	65.58%	22.23%	0.21%	2.38%	0.40%	0.06%	0.74%	7.29%	0.12%	0.37%	0.14%	0.04%
I-275	0.42%	61.28%	20.77%	0.31%	3.46%	0.58%	0.09%	1.80%	9.69%	0.28%	0.89%	0.34%	0.09%
I-865	0.41%	59.88%	20.30%	0.22%	2.41%	0.40%	0.06%	0.63%	15.13%	0.10%	0.31%	0.12%	0.03%
I-69	0.39%	55.84%	18.93%	0.37%	4.08%	0.68%	0.11%	1.28%	17.20%	0.20%	0.63%	0.24%	0.06%
I-469	0.39%	55.77%	18.91%	0.32%	3.58%	0.59%	0.10%	0.95%	18.54%	0.15%	0.47%	0.18%	0.05%
I-80	0.39%	55.70%	18.88%	0.30%	3.30%	0.55%	0.09%	1.07%	18.78%	0.17%	0.53%	0.20%	0.05%
I-65	0.37%	53.76%	18.24%	0.35%	3.87%	0.64%	0.10%	1.19%	20.42%	0.19%	0.59%	0.22%	0.06%
I-74	0.37%	53.32%	18.14%	0.35%	3.93%	0.65%	0.10%	1.60%	20.10%	0.25%	0.79%	0.30%	0.08%
I-64	0.36%	52.64%	17.85%	0.35%	3.89%	0.65%	0.10%	1.62%	21.10%	0.26%	0.80%	0.30%	0.08%
I-94	0.35%	50.83%	17.25%	0.42%	4.61%	0.77%	0.12%	1.34%	23.12%	0.21%	0.66%	0.25%	0.07%
I-70	0.35%	50.42%	17.11%	0.39%	4.38%	0.73%	0.12%	1.43%	23.80%	0.23%	0.71%	0.27%	0.07%

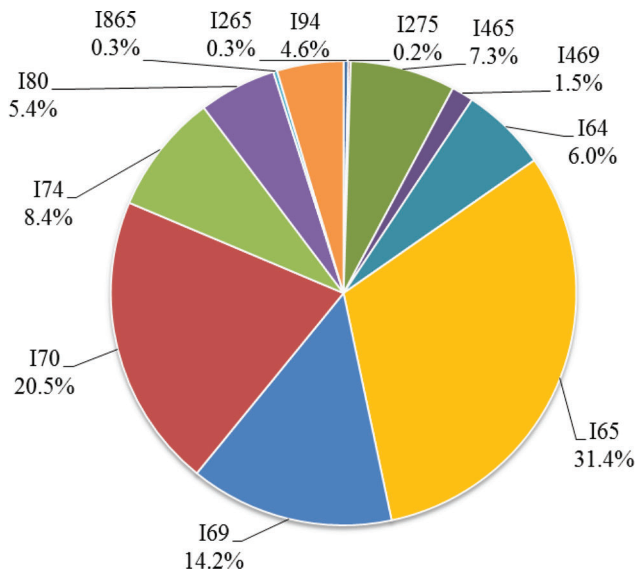


Figure 5.9 Distribution of single-trailer truck VMT by interstate route.

select state roads are given in Table 5.12. There are over 200 state roads in Indiana, and about 20 of the routes with a predicted 2035 VMT of above 300 million were chosen to represent the highest state road VMT in Indiana. SR-37 is predicted to have the highest 2035 VMT of around 1,253 million. Other state roads with significant future VMT include SR-3 and SR-62.

5.2.3 Aggregation by Year and Vehicle Class

Aggregation by vehicle classes is important for many agency applications, specifically cost allocation and revenue forecasting. The aggregations shown in this section may help users at INDOT, MPOs, and other organizations, obtain more reliable inputs for a wide-range of applications. However, predictions of over 20 years based on observed data are meant to provide the user with the trends and a coarse estimate of VMT. Economic and demographic shifts and other exogenous factors may greatly affect the resulting annual VMT estimate. These aggregations include both mainline and ramp segments. The predicted statewide VMT for vehicle classes 1 to 3 is shown in Table 5.13, vehicle classes 4 to 6 is shown in Table 5.14, vehicle classes 7 to 9 in Table 5.15, vehicle classes 10 to 11 in Table 5.16, and vehicle classes 12 to 13 in Table 5.17. The low, medium, and high ranges are given for each vehicle class shown, representing the annual VMT for 2009 to 2035, with all units in millions within Table 5.13 to Table 5.17.

The results for the grouped annual VMT for single-trailer trucks and combination trucks are presented in Table 5.18. Single-trailer trucks represent truck classes 8 to 10, and multi-trailer trucks represent truck classes 11 to 13. In 2009, single-trailer truck VMT ranged from 6,718 to 6,738 million and combination trucks was approximately 218 million. By 2035, the single-trailer truck VMT was estimated to be 7,015 to 7,929 million

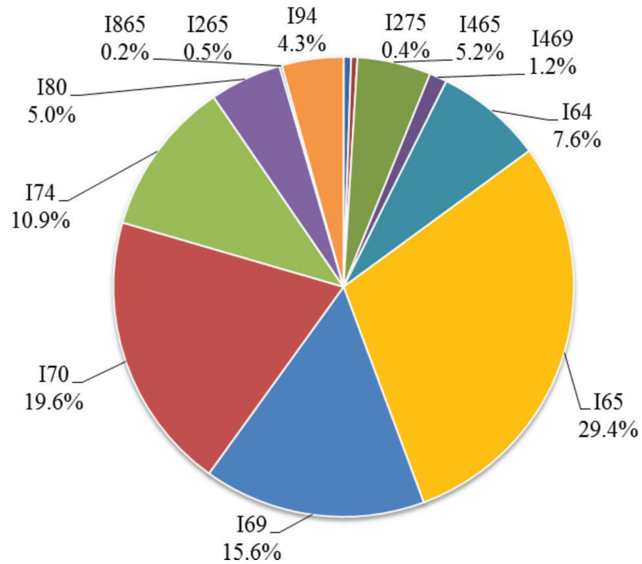


Figure 5.10 Distribution of combination truck VMT by interstate route.

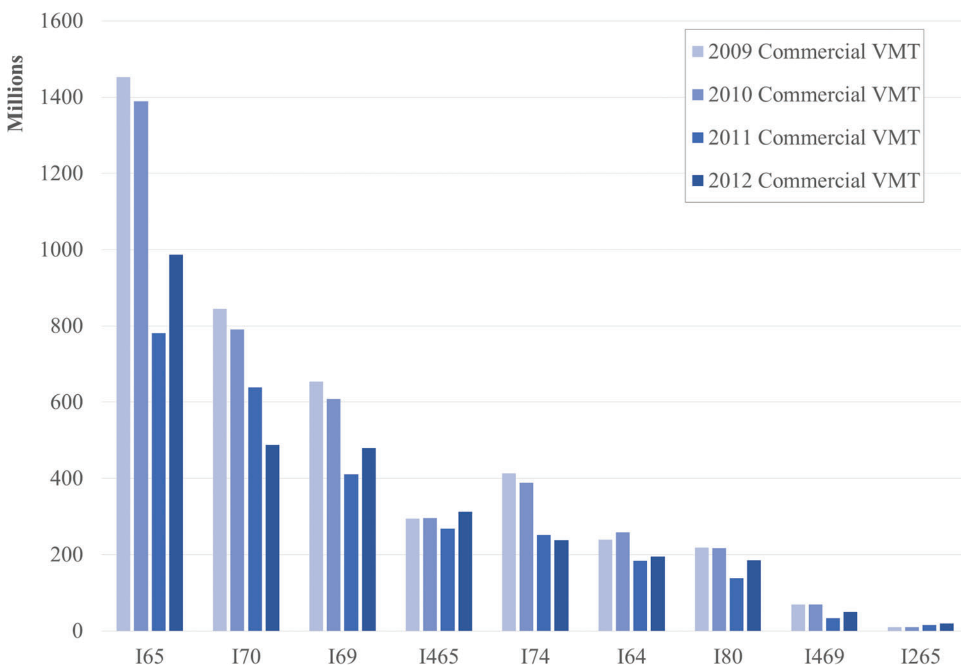


Figure 5.11 Distribution of commercial VMT at interstates.

and combination truck VMT is estimated to range from 241 to 274 million.

5.2.4 Aggregation by Year and Road Type

This section provides additional aggregations for state routes by road type or major road designation. The Interstate VMT total shown in Table 5.19 includes mainline, ramps, and the Indiana Toll Road (I-90). The totals provided for US and state roads also include all mainline and ramp segments. The interstate VMT for 2015 ranged from 18.146 to 18.410 billion, the US Roads VMT was from 10.303 to 10.493 billion, and the State Roads VMT was from 12.850 to 13.103 billion.

Local routes are comprised of multiple FHWA functional classes; therefore, individual functional class totals, such as for major and minor collectors, cannot be determined using this aggregation. Instead, this study provides the cluster VMT, or grouped counties VMT (2009 to 2035) to allow for regional assessment of VMT across Indiana. The city and county road VMT given in Table 5.20 (units in billions) represents the annual local route VMT.

TABLE 5.11
Comparison of current and projected US road VMT.

Year	US Road Annual VMT (millions)																			
	US 12	US 131	US 136	US 150	US 20	US 224	US 231	US 24	US 27	US 30	US 31	US 33	US 35	US 36	US 40	US 41	US 421	US 50	US 52	US 6
2009	164.08	2.06	113.43	154.09	711.51	63.83	672.61	472.47	362.59	1048.21	1704.13	219.43	395.35	389.26	508.73	1196.27	376.17	560.68	356.61	347.06
2010	164.42	1.60	114.22	154.13	699.04	63.98	668.79	474.70	354.85	1075.13	1709.92	231.68	397.78	395.26	519.59	1195.76	378.15	571.38	356.39	333.09
2011	193.50	1.88	114.53	163.78	684.17	95.63	671.07	398.06	331.15	1066.15	1746.20	135.89	395.36	404.83	501.58	1194.85	448.07	590.31	328.78	347.95
2012	200.14	2.15	115.22	160.78	710.03	67.61	694.98	406.24	337.43	1014.03	1671.74	242.21	398.38	407.14	537.87	1235.44	423.73	601.22	357.63	363.06
2013	202.79	2.18	116.78	163.11	716.50	68.58	704.14	410.46	341.70	1025.05	1693.25	245.31	403.52	412.70	544.90	1250.99	429.41	608.56	362.48	367.58
2014	205.46	2.21	118.36	165.48	723.05	69.57	713.42	414.74	346.02	1036.22	1715.04	248.45	408.74	418.33	552.03	1266.75	435.16	616.00	367.39	372.15
2015	208.17	2.24	119.96	167.88	729.70	70.57	722.82	419.08	350.40	1047.53	1737.11	251.63	414.03	424.03	559.25	1282.71	441.00	623.53	372.37	376.78
2016	210.92	2.27	121.59	170.32	736.44	71.58	732.35	423.47	354.84	1058.99	1759.47	254.85	419.40	429.82	566.57	1298.87	446.91	631.15	377.43	381.47
2017	213.70	2.29	123.23	172.79	743.27	72.61	742.01	427.92	359.33	1070.59	1782.13	258.11	424.85	435.68	573.98	1315.25	452.90	638.88	382.55	386.22
2018	216.52	2.32	124.90	175.30	750.20	73.66	751.80	432.42	363.88	1082.34	1805.07	261.41	430.38	441.63	581.49	1331.84	458.97	646.71	387.73	391.03
2019	219.38	2.35	126.59	177.84	757.23	74.71	761.72	436.99	368.49	1094.24	1828.32	264.76	435.98	447.65	589.09	1348.64	465.13	654.63	393.00	395.90
2020	222.28	2.38	128.30	180.43	764.36	75.79	771.77	441.60	373.16	1106.29	1851.87	268.15	441.67	453.76	596.80	1365.67	471.37	662.66	398.33	400.84
2021	225.21	2.41	130.04	183.05	771.58	76.88	781.96	446.28	377.88	1118.49	1875.73	271.58	447.43	459.96	604.61	1382.91	477.69	670.80	403.73	405.84
2022	228.19	2.45	131.80	185.71	778.92	77.98	792.29	451.02	382.67	1130.85	1899.90	275.06	453.28	466.23	612.52	1400.38	484.10	679.04	409.21	410.90
2023	231.20	2.48	133.58	188.40	786.35	79.11	802.76	455.82	387.52	1143.37	1924.39	278.58	459.22	472.60	620.53	1418.08	490.59	687.38	414.77	416.03
2024	234.25	2.51	135.39	191.14	793.89	80.24	813.37	460.68	392.43	1156.05	1949.19	282.14	465.24	479.05	628.65	1436.01	497.18	695.84	420.39	421.23
2025	237.35	2.54	137.22	193.92	801.53	81.40	824.13	465.60	397.41	1168.88	1974.32	285.75	471.35	485.59	636.88	1454.17	503.85	704.40	426.10	426.49
2026	240.48	2.57	139.08	196.74	809.29	82.57	835.03	470.58	402.44	1181.89	1999.77	289.41	477.54	492.22	645.21	1472.56	510.61	713.07	431.89	431.82
2027	243.66	2.61	140.97	199.60	817.15	83.76	846.08	475.63	407.54	1195.06	2025.56	293.12	483.82	498.95	653.65	1491.20	517.46	721.86	437.75	437.22
2028	246.87	2.64	142.87	202.50	825.12	84.96	857.28	480.74	412.71	1208.39	2051.68	296.87	490.20	505.76	662.20	1510.08	524.41	730.76	443.69	442.68
2029	250.14	2.67	144.81	205.44	833.21	86.19	868.63	485.92	417.95	1221.90	2078.15	300.67	496.66	512.67	670.87	1529.20	531.44	739.78	449.72	448.22
2030	253.44	2.71	146.77	208.43	841.41	87.43	880.14	491.16	423.25	1235.58	2104.96	304.52	503.22	519.67	679.64	1548.58	538.58	748.91	455.82	453.83
2031	256.79	2.74	148.76	211.46	849.73	88.69	891.80	496.47	428.61	1249.43	2132.12	308.41	509.88	526.77	688.54	1568.20	545.81	758.16	462.01	459.51
2032	260.18	2.78	150.77	214.53	858.17	89.96	903.63	501.85	434.05	1263.46	2159.63	312.36	516.63	533.97	697.55	1588.08	553.14	767.53	468.29	465.27
2033	263.62	2.81	152.81	217.65	866.72	91.26	915.61	507.30	439.56	1277.67	2187.51	316.36	523.47	541.26	706.67	1608.22	560.57	777.02	474.65	471.10
2034	267.10	2.85	154.88	220.82	875.40	92.57	927.76	512.81	445.13	1292.06	2215.74	320.41	530.42	548.66	715.92	1628.63	568.09	786.64	481.10	477.00
2035	270.63	2.89	156.98	224.03	884.19	93.91	940.08	518.40	450.78	1306.63	2244.35	324.51	537.46	556.16	725.29	1649.29	575.72	796.38	487.63	482.98

TABLE 5.12
Comparison of selected high-volume state road VMT.

	State Road (SR) Annual VMT (millions)																
Year	**SR1**	**SR13**	**SR135**	**SR15**	**SR19**	**SR2**	**SR25**	**SR3**	**SR32**	**SR37**	**SR39**	**SR46**	**SR56**	**SR62**	**SR66**	**SR67**	**SR9**
2009	289.64	215.74	271.17	270.86	235.52	266.12	255.49	507.87	343.72	940.79	188.14	366.55	265.96	542.92	344.98	329.12	486.75
2010	294.95	217.89	275.97	278.06	242.55	270.37	260.36	518.90	345.00	941.77	188.41	368.39	265.81	554.94	345.54	333.26	484.92
2011	301.60	218.52	272.58	276.26	244.25	277.60	245.00	511.18	339.17	965.18	195.64	409.16	256.46	537.89	344.60	346.91	494.07
2012	304.46	233.93	284.97	271.82	252.15	274.13	267.27	523.32	343.01	1009.55	214.86	366.39	247.19	481.07	360.71	373.98	472.27
2013	308.74	237.28	289.04	275.72	255.97	278.09	270.87	530.08	347.71	1018.72	218.05	371.23	250.60	487.28	365.43	378.89	478.68
2014	313.09	240.68	293.16	279.68	259.85	282.10	274.52	536.93	352.47	1028.02	221.28	376.13	254.05	493.58	370.21	383.88	485.19
2015	317.49	244.14	297.35	283.70	263.79	286.17	278.22	543.88	357.31	1037.44	224.57	381.09	257.56	499.97	375.05	388.93	491.78
2016	321.96	247.64	301.59	287.78	267.80	290.30	281.96	550.92	362.20	1046.98	227.91	386.13	261.11	506.45	379.96	394.06	498.47
2017	326.48	251.20	305.90	291.92	271.88	294.49	285.76	558.06	367.17	1056.65	231.31	391.23	264.71	513.01	384.93	399.26	505.25
2018	331.08	254.81	310.27	296.12	276.02	298.74	289.61	565.30	372.20	1066.43	234.76	396.40	268.36	519.67	389.97	404.53	512.13
2019	335.74	258.47	314.70	300.38	280.24	303.06	293.51	572.63	377.31	1076.35	238.27	401.63	272.07	526.43	395.08	409.88	519.10
2020	340.46	262.19	319.19	304.71	284.53	307.43	297.47	580.07	382.48	1086.39	241.84	406.94	275.82	533.27	400.25	415.30	526.17
2021	345.25	265.97	323.75	309.10	288.89	311.87	301.47	587.60	387.73	1096.57	245.46	412.31	279.63	540.22	405.49	420.80	533.34
2022	350.11	269.80	328.37	313.55	293.33	316.37	305.54	595.24	393.05	1106.87	249.15	417.76	283.49	547.26	410.80	426.38	540.61
2023	355.04	273.69	333.06	318.07	297.84	320.94	309.65	602.98	398.44	1117.31	252.90	423.28	287.40	554.39	416.17	432.04	547.99
2024	360.04	277.64	337.82	322.66	302.43	325.58	313.83	610.83	403.90	1127.88	256.70	428.87	291.37	561.63	421.62	437.77	555.46
2025	365.11	281.65	342.65	327.32	307.10	330.28	318.06	618.78	409.45	1138.60	260.58	434.54	295.39	568.98	427.14	443.59	563.04
2026	370.25	285.72	347.55	332.05	311.85	335.05	322.34	626.85	415.06	1149.45	264.52	440.28	299.47	576.42	432.73	449.49	570.73
2027	375.46	289.85	352.51	336.85	316.69	339.89	326.69	635.02	420.76	1160.44	268.52	446.10	303.61	583.97	438.40	455.47	578.53
2028	380.75	294.05	357.55	341.72	321.60	344.81	331.09	643.30	426.54	1171.57	272.59	451.99	307.80	591.62	444.14	461.53	586.43
2029	386.11	298.31	362.66	346.66	326.61	349.79	335.56	651.70	432.39	1182.84	276.73	457.97	312.05	599.39	449.95	467.69	594.45
2030	391.55	302.63	367.85	351.68	331.70	354.84	340.08	660.21	438.33	1194.27	280.94	464.02	316.36	607.26	455.85	473.92	602.57
2031	397.07	307.02	373.11	356.77	336.88	359.97	344.66	668.84	444.34	1205.84	285.23	470.15	320.73	615.24	461.82	480.25	610.82
2032	402.66	311.48	378.44	361.94	342.15	365.18	349.31	677.58	450.45	1217.56	289.58	476.37	325.16	623.34	467.86	486.67	619.17
2033	408.34	316.01	383.85	367.18	347.51	370.46	354.02	686.45	456.63	1229.43	294.01	482.66	329.65	631.55	473.99	493.17	627.65
2034	414.09	320.60	389.34	372.51	352.97	375.81	358.80	695.44	462.90	1241.46	298.52	489.05	334.21	639.88	480.20	499.77	636.24
2035	419.93	325.27	394.91	377.91	358.53	381.25	363.64	704.54	469.26	1253.64	303.10	495.51	338.83	648.32	486.49	506.47	644.96

TABLE 5.13
Predicted statewide VMT for class 1 to class 3 vehicles.

	Class 1 AVMT (billions)			Class 2 AVMT (billions)			Class 3 AVMT (billions)		
Year	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
2009	0.409	0.407	0.406	46.656	46.483	46.311	18.648	18.575	18.502
2010	0.409	0.408	0.407	46.654	46.523	46.393	18.666	18.611	18.556
2011	0.423	0.422	0.422	48.683	48.596	48.510	19.591	19.554	19.517
2012	0.417	0.417	0.416	47.861	47.818	47.774	19.084	19.065	19.047
2013	0.420	0.420	0.421	48.042	48.111	48.180	19.231	19.257	19.283
2014	0.423	0.424	0.426	48.386	48.570	48.754	19.367	19.438	19.509
2015	0.426	0.428	0.431	48.734	49.033	49.335	19.504	19.621	19.739
2016	0.429	0.432	0.436	49.084	49.502	49.924	19.642	19.806	19.972
2017	0.432	0.436	0.441	49.437	49.976	50.520	19.782	19.993	20.207
2018	0.435	0.441	0.446	49.793	50.455	51.125	19.922	20.182	20.446
2019	0.438	0.445	0.452	50.152	50.939	51.738	20.064	20.374	20.688
2020	0.441	0.449	0.457	50.514	51.428	52.359	20.207	20.567	20.933
2021	0.444	0.453	0.462	50.879	51.923	52.988	20.351	20.762	21.181
2022	0.447	0.458	0.468	51.247	52.423	53.626	20.496	20.959	21.433
2023	0.451	0.462	0.473	51.618	52.928	54.272	20.643	21.159	21.688
2024	0.454	0.466	0.479	51.992	53.439	54.928	20.790	21.360	21.947
2025	0.457	0.471	0.485	52.369	53.956	55.592	20.939	21.564	22.209
2026	0.460	0.475	0.491	52.750	54.478	56.265	21.090	21.770	22.474
2027	0.464	0.480	0.497	53.134	55.006	56.947	21.241	21.979	22.743
2028	0.467	0.484	0.503	53.521	55.540	57.639	21.394	22.189	23.016
2029	0.470	0.489	0.509	53.912	56.080	58.340	21.548	22.402	23.292
2030	0.474	0.494	0.515	54.306	56.625	59.050	21.703	22.617	23.572
2031	0.477	0.499	0.521	54.703	57.177	59.771	21.860	22.835	23.856
2032	0.481	0.503	0.527	55.104	57.735	60.501	22.018	23.055	24.143
2033	0.484	0.508	0.534	55.508	58.300	61.241	22.177	23.277	24.435
2034	0.488	0.513	0.540	55.916	58.870	61.991	22.338	23.502	24.730
2035	0.491	0.518	0.547	56.328	59.447	62.752	22.500	23.729	25.030

TABLE 5.14
Predicted statewide VMT for class 4 to class 6 vehicles.

	Class 4 AVMT (billions)			Class 5 AVMT (billions)			Class 6 AVMT (billions)		
Year	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
2009	0.142	0.141	0.141	1.788	1.785	1.781	0.569	0.567	0.566
2010	0.142	0.142	0.141	1.793	1.791	1.788	0.574	0.573	0.571
2011	0.129	0.129	0.128	1.777	1.774	1.772	0.787	0.786	0.784
2012	0.168	0.168	0.168	2.305	2.303	2.302	0.977	0.976	0.975
2013	0.147	0.147	0.147	1.938	1.941	1.945	0.735	0.736	0.737
2014	0.148	0.149	0.149	1.953	1.961	1.970	0.740	0.743	0.746
2015	0.149	0.150	0.151	1.968	1.981	1.995	0.745	0.750	0.755
2016	0.150	0.152	0.153	1.983	2.002	2.021	0.751	0.757	0.763
2017	0.151	0.153	0.155	1.998	2.022	2.047	0.756	0.764	0.773
2018	0.153	0.155	0.157	2.014	2.043	2.073	0.762	0.772	0.782
2019	0.154	0.157	0.159	2.029	2.064	2.100	0.767	0.779	0.791
2020	0.155	0.158	0.161	2.045	2.086	2.127	0.773	0.786	0.800
2021	0.156	0.160	0.164	2.061	2.107	2.155	0.778	0.794	0.810
2022	0.158	0.162	0.166	2.077	2.129	2.183	0.784	0.801	0.820
2023	0.159	0.163	0.168	2.093	2.151	2.211	0.789	0.809	0.830
2024	0.160	0.165	0.170	2.110	2.174	2.240	0.795	0.817	0.839
2025	0.161	0.167	0.172	2.126	2.196	2.269	0.801	0.825	0.850
2026	0.163	0.169	0.175	2.143	2.219	2.298	0.806	0.833	0.860
2027	0.164	0.170	0.177	2.160	2.242	2.328	0.812	0.841	0.870
2028	0.165	0.172	0.179	2.177	2.266	2.359	0.818	0.849	0.881
2029	0.167	0.174	0.182	2.194	2.290	2.390	0.824	0.857	0.891
2030	0.168	0.176	0.184	2.211	2.314	2.421	0.830	0.865	0.902
2031	0.169	0.178	0.187	2.229	2.338	2.453	0.836	0.874	0.913
2032	0.171	0.180	0.189	2.246	2.363	2.485	0.842	0.882	0.924
2033	0.172	0.182	0.192	2.264	2.387	2.518	0.848	0.891	0.935
2034	0.173	0.184	0.194	2.282	2.413	2.551	0.855	0.899	0.947
2035	0.175	0.186	0.197	2.300	2.438	2.585	0.861	0.908	0.958

TABLE 5.15
Predicted statewide VMT for class 7 to class 9 vehicles.

	Class 7 AVMT (billions)			Class 8 AVMT (billions)			Class 9 AVMT (billions)		
Year	**Low**	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
2009	0.170	0.169	0.169	0.600	0.599	0.598	6.049	6.040	6.032
2010	0.173	0.172	0.172	0.602	0.601	0.600	6.081	6.074	6.068
2011	0.252	0.251	0.251	0.389	0.388	0.388	4.124	4.120	4.116
2012	0.316	0.315	0.315	0.458	0.458	0.458	4.536	4.535	4.534
2013	0.230	0.230	0.231	0.519	0.520	0.521	5.264	5.276	5.288
2014	0.232	0.233	0.233	0.523	0.525	0.528	5.306	5.333	5.359
2015	0.233	0.235	0.236	0.527	0.531	0.535	5.349	5.390	5.431
2016	0.235	0.237	0.239	0.531	0.537	0.542	5.393	5.448	5.504
2017	0.237	0.239	0.242	0.536	0.542	0.549	5.437	5.507	5.578
2018	0.238	0.241	0.244	0.540	0.548	0.557	5.481	5.567	5.654
2019	0.240	0.244	0.247	0.544	0.554	0.564	5.526	5.627	5.730
2020	0.242	0.246	0.250	0.549	0.560	0.572	5.571	5.688	5.808
2021	0.243	0.248	0.253	0.553	0.566	0.579	5.617	5.750	5.887
2022	0.245	0.250	0.256	0.558	0.572	0.587	5.663	5.813	5.967
2023	0.247	0.253	0.259	0.562	0.578	0.595	5.709	5.876	6.048
2024	0.248	0.255	0.262	0.567	0.584	0.603	5.756	5.940	6.130
2025	0.250	0.258	0.265	0.571	0.591	0.611	5.803	6.005	6.214
2026	0.252	0.260	0.268	0.576	0.597	0.619	5.851	6.071	6.299
2027	0.254	0.262	0.271	0.581	0.604	0.628	5.899	6.138	6.386
2028	0.256	0.265	0.275	0.585	0.610	0.636	5.948	6.205	6.473
2029	0.257	0.267	0.278	0.590	0.617	0.645	5.997	6.273	6.562
2030	0.259	0.270	0.281	0.595	0.624	0.654	6.047	6.342	6.652
2031	0.261	0.272	0.284	0.600	0.630	0.663	6.097	6.412	6.744
2032	0.263	0.275	0.288	0.605	0.637	0.672	6.148	6.483	6.837
2033	0.265	0.278	0.291	0.610	0.644	0.681	6.199	6.555	6.932
2034	0.267	0.280	0.295	0.615	0.651	0.690	6.251	6.627	7.028
2035	0.269	0.283	0.298	0.620	0.658	0.699	6.303	6.701	7.125

TABLE 5.16
Predicted statewide VMT for class 10 to class 11 vehicles.

	Class 10 AVMT (billions)			Class 11 AVMT (billions)		
Year	**Low**	**Med**	**High**	**Low**	**Med**	**High**
2009	0.090	0.089	0.089	0.141	0.141	0.141
2010	0.090	0.089	0.089	0.136	0.136	0.136
2011	0.058	0.058	0.058	0.085	0.085	0.085
2012	0.068	0.068	0.068	0.108	0.108	0.108
2013	0.077	0.078	0.078	0.119	0.120	0.120
2014	0.078	0.078	0.079	0.120	0.121	0.122
2015	0.079	0.079	0.080	0.121	0.122	0.123
2016	0.079	0.080	0.081	0.122	0.124	0.125
2017	0.080	0.081	0.082	0.123	0.125	0.127
2018	0.081	0.082	0.083	0.124	0.126	0.129
2019	0.081	0.083	0.084	0.125	0.128	0.130
2020	0.082	0.084	0.085	0.127	0.129	0.132
2021	0.082	0.084	0.086	0.128	0.131	0.134
2022	0.083	0.085	0.088	0.129	0.132	0.136
2023	0.084	0.086	0.089	0.130	0.134	0.138
2024	0.085	0.087	0.090	0.131	0.135	0.140
2025	0.085	0.088	0.091	0.132	0.137	0.142
2026	0.086	0.089	0.092	0.133	0.139	0.144
2027	0.087	0.090	0.094	0.134	0.140	0.146
2028	0.087	0.091	0.095	0.136	0.142	0.148
2029	0.088	0.092	0.096	0.137	0.143	0.150
2030	0.089	0.093	0.098	0.138	0.145	0.153
2031	0.089	0.094	0.099	0.139	0.147	0.155
2032	0.090	0.095	0.100	0.140	0.148	0.157
2033	0.091	0.096	0.102	0.142	0.150	0.159
2034	0.092	0.097	0.103	0.143	0.152	0.162
2035	0.092	0.098	0.104	0.144	0.154	0.164

TABLE 5.17
Predicted statewide VMT for class 12 to class 13 vehicles.

	Class 12 AVMT (billions)			Class 13 AVMT (billions)		
Year	**Low**	**Med**	**High**	**Low**	**Med**	**High**
2009	0.049	0.049	0.049	0.028	0.028	0.028
2010	0.047	0.047	0.047	0.028	0.028	0.028
2011	0.029	0.029	0.029	0.078	0.078	0.078
2012	0.038	0.038	0.038	0.021	0.021	0.021
2013	0.042	0.042	0.042	0.039	0.039	0.039
2014	0.042	0.042	0.042	0.040	0.040	0.040
2015	0.042	0.043	0.043	0.040	0.040	0.041
2016	0.043	0.043	0.044	0.040	0.041	0.041
2017	0.043	0.044	0.044	0.041	0.041	0.042
2018	0.043	0.044	0.045	0.041	0.042	0.042
2019	0.044	0.045	0.045	0.041	0.042	0.043
2020	0.044	0.045	0.046	0.042	0.043	0.043
2021	0.044	0.046	0.047	0.042	0.043	0.044
2022	0.045	0.046	0.047	0.042	0.043	0.045
2023	0.045	0.047	0.048	0.043	0.044	0.045
2024	0.046	0.047	0.049	0.043	0.044	0.046
2025	0.046	0.048	0.050	0.043	0.045	0.047
2026	0.046	0.048	0.050	0.044	0.045	0.047
2027	0.047	0.049	0.051	0.044	0.046	0.048
2028	0.047	0.049	0.052	0.044	0.046	0.049
2029	0.048	0.050	0.052	0.045	0.047	0.049
2030	0.048	0.051	0.053	0.045	0.048	0.050
2031	0.049	0.051	0.054	0.046	0.048	0.051
2032	0.049	0.052	0.055	0.046	0.049	0.051
2033	0.049	0.052	0.056	0.046	0.049	0.052
2034	0.050	0.053	0.056	0.047	0.050	0.053
2035	0.050	0.054	0.057	0.047	0.050	0.054

TABLE 5.18
Predicted statewide VMT for single-trailer and combination trucks.

	Classes 8–10: Single-Trailer Truck AVMT (billions)			Classes 11–13: Combination Truck AVMT (billions)		
Year	**Low**	**Med**	**High**	**Low**	**Med**	**High**
2009	6.738	6.729	6.719	0.219	0.218	0.218
2010	6.772	6.764	6.757	0.212	0.212	0.212
2011	4.571	4.566	4.562	0.193	0.193	0.193
2012	5.063	5.062	5.060	0.168	0.168	0.168
2013	5.860	5.873	5.886	0.200	0.201	0.201
2014	5.907	5.936	5.965	0.202	0.203	0.204
2015	5.955	6.000	6.045	0.203	0.205	0.207
2016	6.003	6.065	6.127	0.205	0.207	0.210
2017	6.052	6.130	6.209	0.207	0.210	0.213
2018	6.102	6.197	6.293	0.209	0.212	0.216
2019	6.151	6.264	6.378	0.210	0.215	0.219
2020	6.201	6.332	6.465	0.212	0.217	0.222
2021	6.252	6.401	6.552	0.214	0.219	0.225
2022	6.303	6.470	6.641	0.216	0.222	0.228
2023	6.355	6.541	6.732	0.218	0.224	0.231
2024	6.407	6.612	6.823	0.220	0.227	0.235
2025	6.460	6.684	6.916	0.222	0.230	0.238
2026	6.513	6.757	7.011	0.223	0.232	0.241
2027	6.567	6.831	7.107	0.225	0.235	0.245
2028	6.621	6.906	7.204	0.227	0.238	0.248
2029	6.675	6.982	7.303	0.229	0.240	0.252
2030	6.731	7.059	7.404	0.231	0.243	0.256
2031	6.786	7.136	7.505	0.233	0.246	0.259
2032	6.843	7.215	7.609	0.235	0.249	0.263
2033	6.900	7.295	7.714	0.237	0.252	0.267
2034	6.957	7.376	7.821	0.239	0.255	0.271
2035	7.015	7.457	7.929	0.242	0.258	0.275

TABLE 5.19
Predicted statewide VMT by road type.

Year	Interstates VMT (billions)			US Roads VMT (billions)			State Roads VMT (billions)			Local Roads VMT (billions)		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
2009	17.782	17.782	17.782	9.876	9.876	9.876	12.263	12.263	12.263	35.417	35.154	34.893
2010	17.492	17.492	17.492	9.916	9.916	9.916	12.371	12.371	12.371	35.614	35.416	35.218
2011	18.057	18.057	18.057	9.954	9.954	9.954	12.581	12.581	12.581	35.813	35.680	35.547
2012	17.864	17.864	17.864	10.015	10.015	10.015	12.468	12.468	12.468	36.013	35.946	35.879
2013	17.884	17.927	17.970	10.110	10.141	10.171	12.594	12.635	12.676	36.214	36.214	36.214
2014	18.015	18.102	18.189	10.206	10.268	10.331	12.721	12.804	12.888	36.415	36.482	36.549
2015	18.146	18.278	18.410	10.303	10.398	10.493	12.850	12.977	13.103	36.617	36.752	36.887
2016	18.279	18.456	18.635	10.402	10.529	10.658	12.981	13.151	13.323	36.820	37.024	37.228
2017	18.413	18.636	18.862	10.501	10.662	10.825	13.113	13.328	13.547	37.025	37.298	37.573
2018	18.548	18.818	19.092	10.602	10.797	10.996	13.246	13.508	13.774	37.230	37.574	37.920
2019	18.683	19.002	19.326	10.704	10.934	11.170	13.381	13.690	14.006	37.437	37.852	38.271
2020	18.820	19.188	19.562	10.807	11.073	11.346	13.518	13.875	14.242	37.645	38.132	38.625
2021	18.958	19.375	19.801	10.911	11.214	11.526	13.656	14.063	14.482	37.854	38.414	38.982
2022	19.097	19.565	20.043	11.016	11.357	11.708	13.796	14.254	14.726	38.064	38.699	39.343
2023	19.237	19.756	20.288	11.123	11.502	11.894	13.937	14.447	14.975	38.275	38.985	39.707
2024	19.378	19.949	20.537	11.230	11.649	12.083	14.080	14.643	15.229	38.487	39.273	40.074
2025	19.521	20.145	20.788	11.339	11.798	12.276	14.225	14.843	15.487	38.701	39.564	40.445
2026	19.664	20.342	21.043	11.450	11.950	12.471	14.371	15.045	15.750	38.916	39.857	40.819
2027	19.808	20.542	21.301	11.561	12.103	12.670	14.520	15.250	16.017	39.132	40.152	41.197
2028	19.954	20.743	21.563	11.674	12.259	12.873	14.669	15.458	16.290	39.349	40.449	41.578
2029	20.100	20.946	21.827	11.788	12.417	13.079	14.821	15.670	16.567	39.567	40.748	41.962
2030	20.248	21.152	22.096	11.904	12.577	13.289	14.975	15.884	16.850	39.787	41.050	42.350
2031	20.397	21.359	22.367	12.021	12.739	13.502	15.130	16.102	17.138	40.008	41.354	42.742
2032	20.547	21.569	22.642	12.139	12.904	13.719	15.287	16.324	17.431	40.230	41.660	43.137
2033	20.698	21.781	22.921	12.259	13.072	13.940	15.447	16.548	17.730	40.453	41.968	43.536
2034	20.850	21.995	23.203	12.380	13.241	14.165	15.608	16.776	18.034	40.678	42.278	43.939
2035	21.004	22.211	23.488	12.502	13.414	14.393	15.771	17.008	18.343	40.903	42.591	44.346

TABLE 5.20
Local route VMT forecast by cluster group.

Year	Cluster Group VMT (billions)								City and County Roads VMT (billions)		
	#1	#2	#3	#4	#5	#6	#7	#8	Low	Med.	High
2009	5.01	2.02	3.39	2.40	2.99	6.50	3.99	8.87	35.42	35.15	34.89
2010	5.04	2.03	3.41	2.42	3.01	6.55	4.02	8.94	35.61	35.42	35.22
2011	5.08	2.05	3.44	2.44	3.03	6.59	4.05	9.00	35.81	35.68	35.55
2012	5.12	2.06	3.47	2.46	3.05	6.64	4.08	9.07	36.01	35.95	35.88
2013	5.16	2.08	3.49	2.48	3.08	6.69	4.11	9.14	36.21	36.21	36.21
2014	5.19	2.09	3.52	2.49	3.10	6.74	4.14	9.21	36.42	36.48	36.55
2015	5.23	2.11	3.54	2.51	3.12	6.79	4.17	9.27	36.62	36.75	36.89
2016	5.27	2.12	3.57	2.53	3.15	6.84	4.20	9.34	36.82	37.02	37.23
2017	5.31	2.14	3.60	2.55	3.17	6.89	4.23	9.41	37.02	37.30	37.57
2018	5.35	2.15	3.62	2.57	3.19	6.94	4.26	9.48	37.23	37.57	37.92
2019	5.39	2.17	3.65	2.59	3.22	7.00	4.29	9.55	37.44	37.85	38.27
2020	5.43	2.19	3.68	2.61	3.24	7.05	4.32	9.62	37.64	38.13	38.63
2021	5.47	2.20	3.70	2.63	3.26	7.10	4.36	9.69	37.85	38.41	38.98
2022	5.51	2.22	3.73	2.65	3.29	7.15	4.39	9.76	38.06	38.70	39.34
2023	5.55	2.24	3.76	2.67	3.31	7.21	4.42	9.84	38.27	38.98	39.71
2024	5.59	2.25	3.79	2.68	3.34	7.26	4.45	9.91	38.49	39.27	40.07
2025	5.63	2.27	3.81	2.70	3.36	7.31	4.49	9.98	38.70	39.56	40.44
2026	5.68	2.29	3.84	2.72	3.39	7.37	4.52	10.06	38.92	39.86	40.82
2027	5.72	2.30	3.87	2.74	3.41	7.42	4.55	10.13	39.13	40.15	41.20
2028	5.76	2.32	3.90	2.77	3.44	7.48	4.59	10.21	39.35	40.45	41.58
2029	5.80	2.34	3.93	2.79	3.46	7.53	4.62	10.28	39.57	40.75	41.96
2030	5.85	2.35	3.96	2.81	3.49	7.59	4.65	10.36	39.79	41.05	42.35
2031	5.89	2.37	3.99	2.83	3.51	7.64	4.69	10.43	40.01	41.35	42.74
2032	5.93	2.39	4.02	2.85	3.54	7.70	4.72	10.51	40.23	41.66	43.14
2033	5.98	2.41	4.05	2.87	3.57	7.76	4.76	10.59	40.45	41.97	43.54
2034	6.02	2.42	4.08	2.89	3.59	7.81	4.79	10.67	40.68	42.28	43.94
2035	6.06	2.44	4.11	2.91	3.62	7.87	4.83	10.75	40.90	42.59	44.35

5.3 Estimated Statewide VMT (Non-Traffic Methods)

This section contains the results from the methods of VMT estimation other than the link-level method. These results are briefly discussed for each method and a summary of the aggregations from all the methods is provided in Subsection 5.3.2. These values represent a statewide annual estimate, with most estimates applicable to all vehicle classes with further disaggregation not possible. The exception is some socioeconomic travel surveys which represent only personal (non-commercial) vehicles. One of the main objectives of this study is to reconcile the non-traffic methods with the benchmark from the selected link-level method. To gauge the extent of the errors associated with each method, a discussion of percent deviations is provided in Section 5.3.2, and the quantifiable limitations of the non-traffic approach for statewide VMT estimation are also identified.

5.3.1 Aggregation by Estimation Method

The results based on the fuel-revenue method are shown in Table 5.21 to Table 5.23, with varying assumptions affecting estimation results. Table 5.21 assumes that the fuel is distributed to all vehicle classes with a disaggregate approach. For example, based on the distribution of diesel and gasoline vehicles, each vehicle class shows the fuel consumption in gallons for both diesel and fuel, with around 99% of automobiles running on gasoline. Table 5.22 assumes that the fuel is distributed with an aggregate approach. For example, vehicle classes 1 to 3 all run on gasoline and classes 4–13 all run on diesel. This is expected to be less accurate than a disaggregate approach. Table 5.23 shows the results when using a different traffic distribution, specifically the FHWA distribution.

The VMT estimation results shown for each year in Table 5.21 to Table 5.23 are provided for two scenarios. The first scenario (indicated by "VMT from fuel revenue") uses the Indiana Department of Revenue annual reports (IDOR, 2014) and current fuel tax rate to estimate VMT for all vehicle classes. The second scenario (indicated by "VMT from transportation sector fuel consumption") uses the Energy Information Administration (EIA, 2014b) transportation sector fuel consumption data to estimate VMT for all vehicle classes. All the fuel revenue-based results were found to be similar to the statewide totals ranging from 70 to 76 billion annually, with gasoline-powered vehicles contributing around 61 to 67 billion of the statewide total VMT.

These results are presented graphically in Figure 5.12 and Figure 5.13 for the fuel-revenue based approaches. Consistent estimates were obtained for 2009 to 2013, with 2012 showing lower estimates of total annual VMT.

The statewide VMT results based on licensed drivers and demographics surveys are shown for 2009 to 2013 in Table 5.24 and graphically in Figure 5.14. The annual VMT by age group was aggregated for a state total and ranged from 73.189 billion (2009) to 78.208 billion (2013). Irrespective of the sample used, the bell-shaped curve for the distribution of VMT by age groups is shown in Figure 5.14. The highest VMT was attribute to ages 25 to 55, which was expected because

TABLE 5.21
Fuel distributed disaggregate by vehicle class (link-level vehicle distribution).

	VMT from Fuel Revenue			VMT from Transportation Sector Fuel Consumption		
	Disaggregate by Vehicle Classes (Link-Level Distribution)					
Year	**Gasoline**	**Diesel**	**Total**	**Gasoline**	**Diesel**	**Total**
2009	64.336	6.897	71.232	64.553	9.085	73.637
2010	64.373	6.987	71.360	65.756	8.869	74.625
2011	65.257	8.902	74.159	63.417	10.987	74.404
2012	63.506	7.920	71.425	61.794	9.220	71.014
2013	62.902	7.311	70.212	64.546	10.303	74.849

TABLE 5.22
Fuel distributed aggregate by vehicle class (link-level vehicle distribution).

	VMT from Fuel Revenue			VMT from Transportation Sector Fuel Consumption		
	Aggregate by Vehicle Classes (Link-Level Distribution)					
Year	**Gasoline**	**Diesel**	**Total**	**Gasoline**	**Diesel**	**Total**
2009	65.082	7.703	72.785	65.301	9.084	74.386
2010	65.297	6.394	71.691	67.320	7.541	74.861
2011	66.695	8.100	74.795	65.460	9.552	75.012
2012	65.211	6.537	71.748	63.516	7.709	71.225
2013	64.032	6.537	70.568	67.314	7.709	75.023

TABLE 5.23
Fuel distributed aggregate by vehicle class (FHWA vehicle distribution).

	VMT from Fuel Revenue			VMT from Transportation Sector Fuel Consumption		
	Aggregate by Vehicle Classes (FHWA Distribution)					
Year	**Gasoline**	**Diesel**	**Total**	**Gasoline**	**Diesel**	**Total**
2009	66.068	6.740	72.808	66.102	7.948	74.050
2010	66.131	6.295	72.425	68.162	7.423	75.585
2011	67.445	6.764	74.209	67.445	6.764	74.209
2012	65.372	6.322	71.694	63.670	7.455	71.126
2013	64.209	6.322	70.531	67.443	7.455	74.899

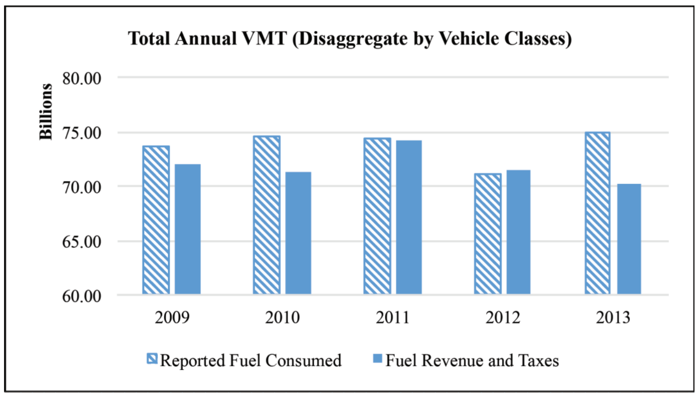


Figure 5.12 Disaggregate fuel consumption VMT estimate.

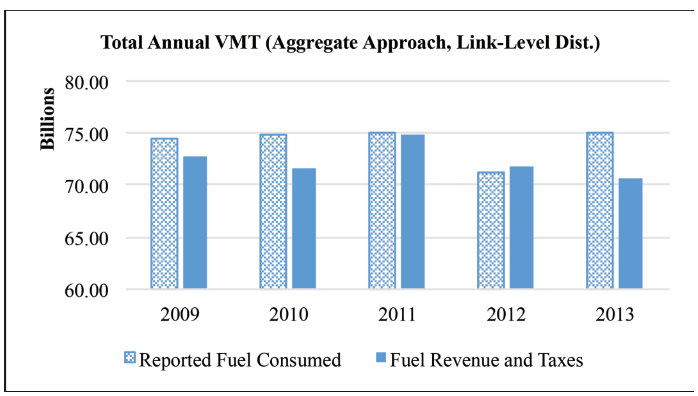


Figure 5.13 Aggregate fuel consumption VMT estimate.

that age group comprises drivers in the workforce who make more business trips annually. Ages 16 to 19 contributed the least to the statewide VMT at around 1 billion, and ages 70 and over contribute 4–5 billion to the statewide VMT.

An analysis of the different samples of licensed drivers showed that the average of IN, IA, WI, OH, and KY drivers produces a higher statewide VMT of 73.19 to 76.59 billion, compared to that of the Indiana sample from 70.79 to 74.25 billion (Figure 5.15). This shows how a different annual mileage obtained from travel surveys can and does significantly affect the statewide VMT. The statewide VMT was also estimated using vehicle registration data obtained from the BMV and classified by gross vehicle weight (BMV, 2015). An example of the 2011 annual VMT for the eight categories of vehicle weight is shown in Table 5.25. Motorcycles and passenger cars comprised the majority at 51.411 billion and light-duty trucks at 14.093 billion. Overall, for all vehicles, a statewide VMT of 69.751 billion was obtained.

Based on socioeconomic regression models, the statewide VMT for the predicted and the actual economic conditions was assessed, as shown in Table 5.26 and Table 5.27, respectively. The predicted economic conditions are reflected in a statewide VMT exceed that of the actual economic conditions. For example, based on predicted economic inputs, the VMT ranges from 78.513 to 81.423 billion and from actual economic inputs, VMT ranges from 67.080 to 79.988 billion over the analysis period of 2009 to 2013. The predicted economic model does not fully account for economic recession, with VMT stabilizing from both approaches for 2012 and 2013. Irrespective of whether the actual or predicted conditions were used, the vehicle class proportions remained relatively unchanged.

This trend toward stabilization as the analysis period progresses is evident in Figure 5.16 for statewide VMT and in Figure 5.17 for automobile VMT (dark shading in both cases represents the results of the analysis that used the actual economic conditions). The year 2016 represents a predicted future year using both of the identified socioeconomic regression models techniques. Economic downturns affect the amount of personal and commercial travel and thus can be measured as VMT. Caution is advised when using models based heavily on economic conditions, such as incomes and GDP as there is a tendency to misrepresent VMT for unforeseen changes in the economic climate.

Based on socioeconomic travel surveys, personal VMT (non-commercial) was estimated by land-area and household income groups. The findings are shown in Table 5.28, with the results in billions and are for 2009. For all income groups, the land-area

TABLE 5.24
VMT by licensed drivers age groups for surrounding states.

Annual VMT by Age Group	2009	2010	2011	2012	2013
16–19	1.310	1.010	0.756	1.144	1.098
20–24	4.809	4.988	5.165	2.762	4.619
25–29	6.948	7.848	8.684	6.627	7.823
30–34	8.463	8.808	9.175	8.776	9.148
35–39	7.784	7.599	7.476	7.932	8.002
40–44	8.119	8.103	8.143	8.897	8.638
45–49	9.540	9.188	8.931	9.688	9.705
50–54	7.293	7.398	7.533	8.091	7.873
55–59	5.906	6.220	6.524	6.973	6.653
60–64	4.921	5.309	5.674	5.887	5.657
65–69	3.261	3.624	3.950	4.043	3.863
70–74	1.842	1.989	2.128	2.266	2.135
75 and over	2.994	2.656	2.370	3.506	2.994
State Total	73.189	74.739	76.510	76.593	78.208

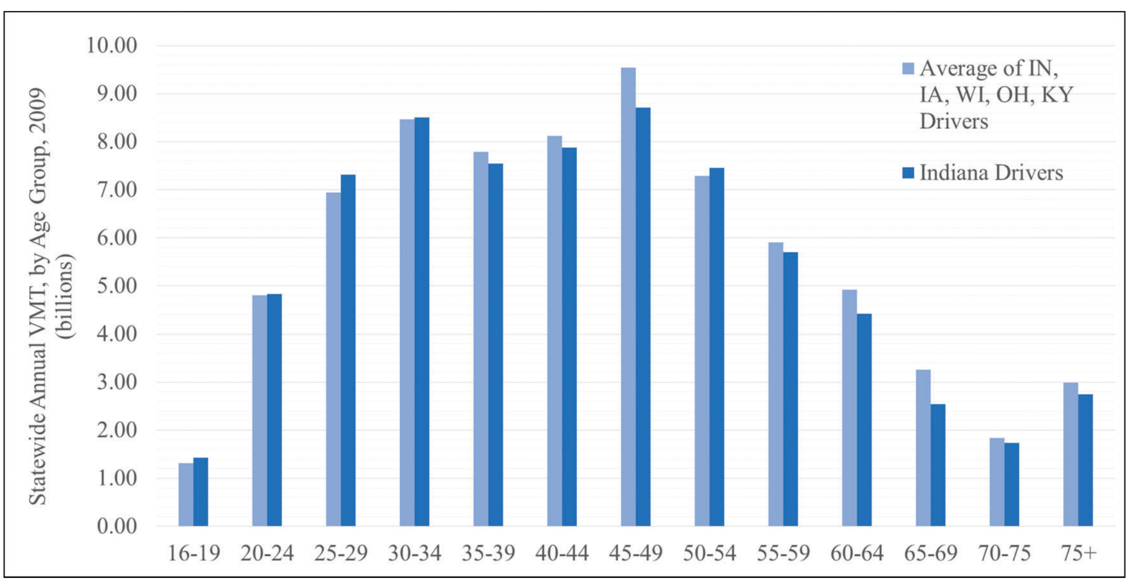


Figure 5.14 Statewide VMT by age group of licensed drivers.

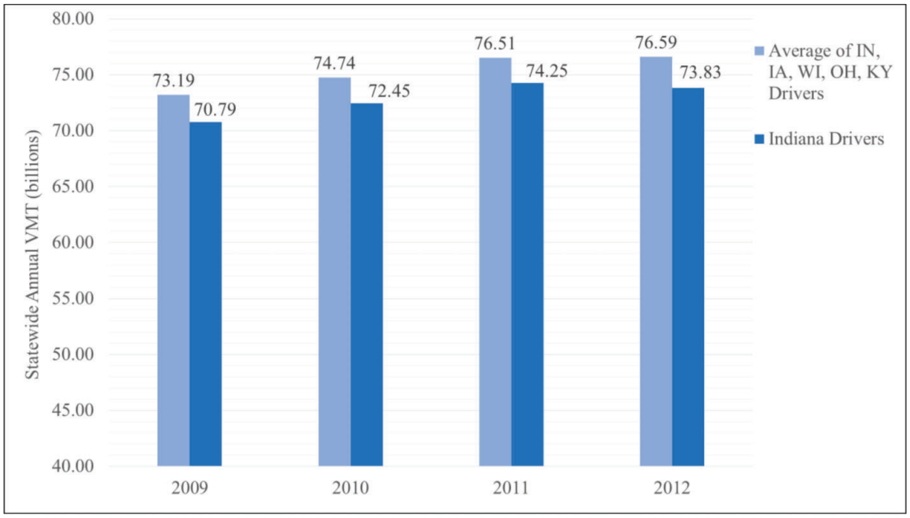


Figure 5.15 Statewide VMT for varying licensed drivers samples.

TABLE 5.25
Statewide VMT by gross vehicle weight category.

Annual VMT from Vehicle Registration (2011) (units in billions)		
Gross Weight Category 1	Motorcycles and Passenger Cars	51.411
Gross Weight Category 2	Light-Duty Trucks	14.093
Gross Weight Category 3	Trucks 11–16K lbs	0.808
Gross Weight Category 4	Trucks 16–20K lbs and School Buses	0.112
Gross Weight Category 5	RVs, Recovery Vehicles and Other	0.921
Gross Weight Category 6	Minibuses and Trucks 20–26K lbs	0.247
Gross Weight Category 7	City/ Commercial Buses, Trucks Over 26K lbs	1.264
Gross Weight Category 8	Long-Haul Commercial Trucks	0.895
All Vehicles		69.751

TABLE 5.26
Statewide VMT from predicted economic conditions.

VMT Estimates based on Predicted Economic Conditions (units in billions)					
Statewide Annual VMT by Vehicle Classes	**2009**	**2010**	**2011**	**2012**	**2013**
Class 1 (Motorcycle), VMT	0.451	0.466	0.480	0.495	0.509
Class 2 (Automobile), VMT	51.091	51.224	51.357	51.490	51.623
Class 3 (Light-duty trucks), VMT	17.266	17.810	18.349	18.884	19.414
Class 4 (Buses), VMT	0.006	0.006	0.006	0.005	0.005
Classes 5–8 (Single-unit trucks), VMT	2.439	2.444	2.449	2.454	2.459
Classes 9–13 (Multi-unit trucks), VMT	7.260	7.299	7.339	7.378	7.417
Classes 1–13 (All Vehicles) VMT	**78.513**	**79.249**	**79.979**	**80.706**	**81.428**

TABLE 5.27
Statewide VMT from actual economic conditions.

VMT Estimates based on Actual Economic Conditions (units in billions)					
Statewide Annual VMT by Vehicle Classes	**2009**	**2010**	**2011**	**2012**	**2013**
Class 1 (Motorcycle), VMT	0.514	0.531	0.546	0.556	0.569
Class 2 (Automobile), VMT	49.060	49.325	50.139	50.850	51.390
Class 3 (Light-duty trucks), VMT	8.325	9.562	13.227	16.269	18.480
Class 4 (Buses), VMT	0.006	0.006	0.006	0.006	0.005
Classes 5–8 (Single-unit trucks), VMT	2.364	2.374	2.404	2.430	2.450
Classes 9–13 (Multi-unit trucks), VMT	6.810	6.912	6.992	7.096	7.093
Classes 1–13 (All Vehicles) VMT	**67.080**	**68.710**	**73.315**	**77.207**	**79.988**

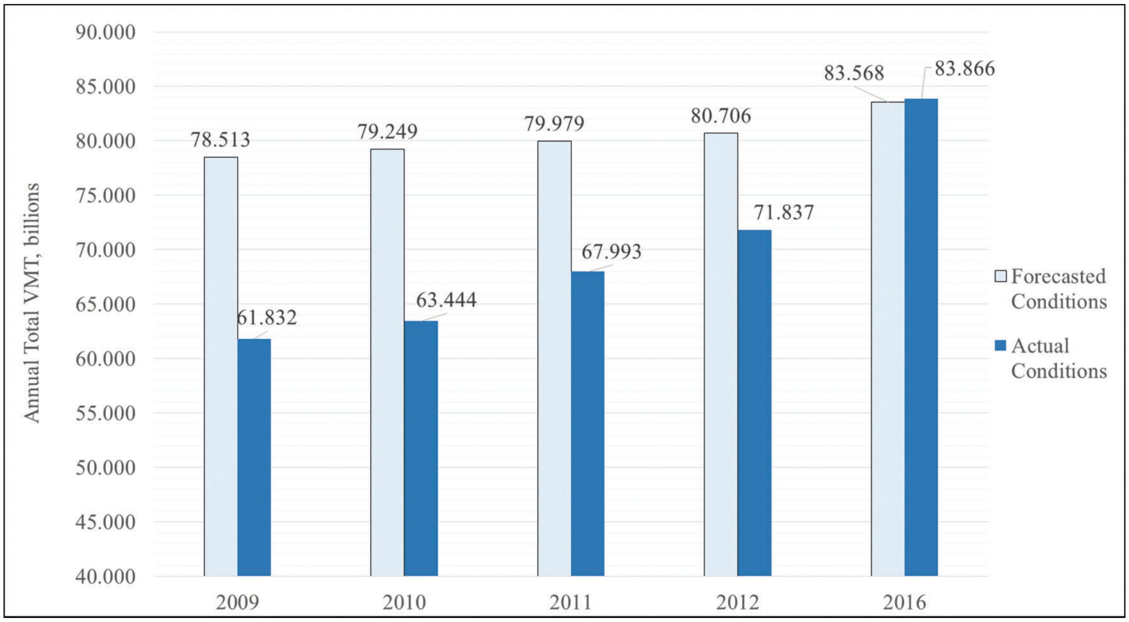


Figure 5.16 Statewide VMT estimate for varying economic conditions.

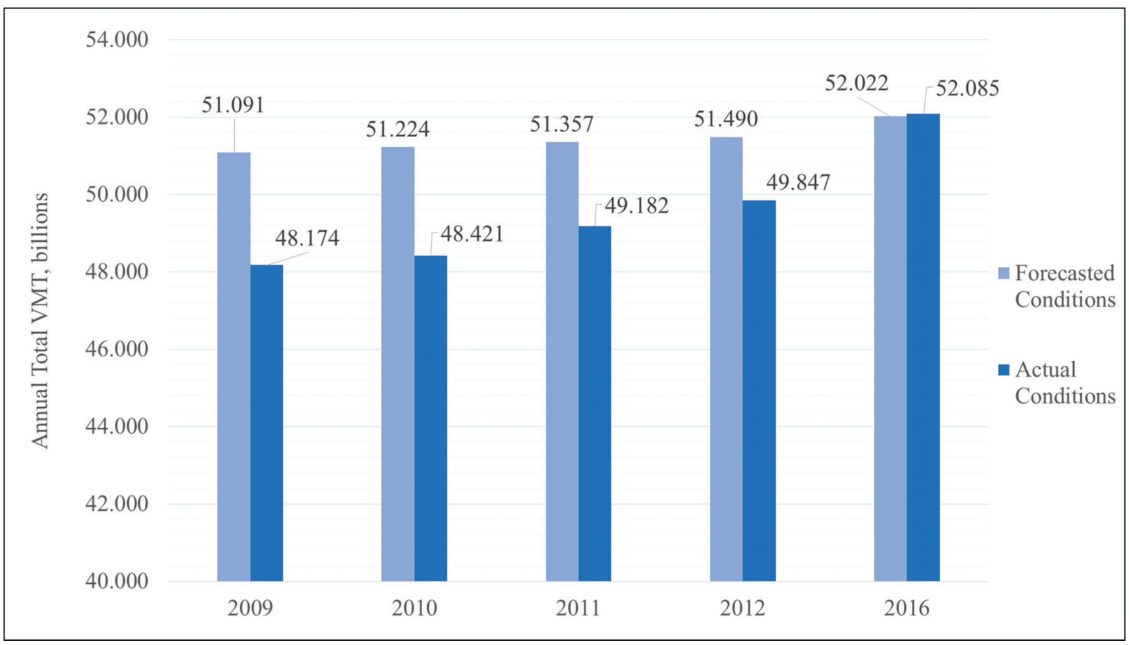


Figure 5.17 Automobile VMT estimate for varying economic conditions.

TABLE 5.28
Personal VMT by household income and land-area.

Personal VMT by Household Income and Land-Area	Dense Urban	Light Urban	Rural	All
Less than $20,000	1.144	0.916	2.046	4.106
$20,000 to $39,999	2.616	2.115	6.807	11.538
$40,000 to $59,999	1.780	2.473	7.397	11.650
$60,000 to $79,999	0.945	2.352	6.910	10.207
$80,000 to $99,999	0.589	1.677	3.297	5.563
Over $100,000	0.999	2.654	5.753	9.405
All	8.073	12.185	32.211	52.469

TABLE 5.29
Summary of predicted statewide VMT from trend analysis.

Analysis Years	Linear Trend	Polynomial Trend	Growth Curve Model	S-Curve Trend	Growth Factors	Reported ("Actual")
2009	79.056	72.180	79.848	74.124	74.601	77.517
2010	80.098	75.220	81.100	74.129	76.116	72.357
2011	81.140	78.260	82.372	74.132	77.660	77.456
2012	82.182	81.300	83.663	74.133	79.236	78.646
2013	83.224	84.340	84.975	74.134	80.844	79.363

TABLE 5.30
Summary of estimation approaches within methods.

Method	Code	Specific Approach and Assumptions	Coverage
Fuel-Revenue	F-1	Fuel distributed with *disaggregate* approach; gallonage from *EIA estimates*	Statewide
Fuel-Revenue	F-2	Fuel distributed with *disaggregate* approach; gallonage from *tax revenues*	Statewide
Fuel-Revenue	F-3	Fuel distributed with *aggregate* approach; galloange from *EIA estimates*	Statewide
Fuel-Revenue	F-4	Fuel distributed with *aggregate* approach; gallonage from *tax revenues*	Statewide
Fuel-Revenue	F-5	Fuel distributed with *aggregate* approach; gallonage from *EIA estimates* (FHWA distribution)	Statewide
Fuel-Revenue	F-6	Fuel distributed with *aggregate* approach; gallonage from *tax revenues* (FHWA distribution)	Statewide
Socioeconomic Regression	SE-1	Actual economic conditions as model inputs	Statewide
Socioeconomic Regression	SE-2	Predicted economic conditions as model inputs	Statewide
Vehicle Registrations	VR-1	Higher estimate of annual passenger automobile mileage	Statewide
Vehicle Registrations	VR-2	Lowest estimate of annual passenger automobile mileage	Statewide
Socioeconomic Travel Surveys	STS-1	Sample of households in Indiana	Statewide (Non-Commercial)
Socioeconomic Travel Surveys	STS-2	Sample of households in neighboring states (IN, KY, OH, WI, IA)	Statewide (Non-Commercial)
Licensed Drivers Surveys	LDD-1	Sample of households in Indiana	Statewide
Licensed Drivers Surveys	LDD-2	Sample of households in neighboring states (IN, KY, OH, WI, IA)	Statewide
HPMS	HPMS-1	Reported from the HPMS for all functional classes (AADT sampling)	Statewide
Trend Analysis	TA-1	Linear trend functional form	Statewide
Trend Analysis	TA-2	Polynomial trend functional form	Statewide
Trend Analysis	TA-3	Growth curve model functional form	Statewide
Trend Analysis	TA-4	S-curve trend functional form	Statewide
Trend Analysis	TA-5	Growth factors approach (without regression or curve fitting)	Statewide
Link-Specific	LS-1	Link-specific method for state and local routes	Statewide
Link-Specific	LS-2	Link-specific method for state and local routes	Statewide (Non-Commercial)

VMT are as follows: dense urban, 8.073 billion; light urban, 12.185 billion; and rural, 32.211 billion. A total of 52.469 billion VMT was estimated for vehicle classes 1 to 3.

Based on the trend analysis and growth factor approaches, the predictive capabilities of different functional forms were investigated. The reported or “actual” VMT were used for validating the functional forms.

TABLE 5.31
Summary of statewide VMT results by estimation approach.

		Annual VMT Estimates (units in billions)					
Code	**Estimation Methodology**	**2009**	**2010**	**2011**	**2012**	**2013**	**4–5 Year Average**
F-1	Fuel-Revenue	73.637	74.625	74.404	71.014	74.849	73.706
F-2	Fuel-Revenue	71.232	71.360	74.159	71.425	70.212	71.678
F-3	Fuel-Revenue	74.386	74.861	75.012	71.225	75.023	74.101
F-4	Fuel-Revenue	72.785	71.691	74.795	71.748	70.568	72.318
F-5	Fuel-Revenue	74.050	75.585	74.209	71.126	74.899	73.974
F-6	Fuel-Revenue	72.808	72.425	74.209	71.694	70.531	72.333
SE-1	Socioeconomic Regression	67.080	68.710	73.315	77.207	79.988	73.260
SE-2	Socioeconomic Regression	78.513	79.249	79.979	80.706	81.428	79.975
VR-1	Vehicle Registrations	N/A	69.260	69.751	70.625	71.322	70.239
VR-2	Vehicle Registrations	N/A	60.986	61.386	62.129	62.707	61.802
STS-1	Socioeconomic Travel Surveys	52.469	53.256	54.055	54.865	55.688	53.661
STS-2	Socioeconomic Travel Surveys	51.587	52.361	53.146	53.944	54.753	52.760
LDD-1	Licensed Drivers/ Demographics	70.786	72.451	74.245	73.831	N/A	72.828
LDD-2	Licensed Drivers/ Demographics	73.189	74.739	76.510	76.593	N/A	75.258
HPMS-1	HPMS	76.628	75.761	76.485	78.923	78.311	77.222
TA-1	Trend Analysis	79.056	80.098	81.140	82.182	83.224	81.140
TA-2	Trend Analysis	72.180	75.220	78.260	81.300	84.340	78.260
TA-3	Trend Analysis	79.848	81.100	82.372	83.663	84.975	82.392
TA-4	Trend Analysis	74.124	74.129	74.132	74.133	74.134	74.130
TA-5	Trend Analysis	74.601	76.116	77.660	79.236	80.844	77.692
LS-1	Link-Specific (Benchmark)	75.313	75.375	76.393	76.353	76.825	76.052
LS-2	Link-Specific (Benchmark)	65.689	65.711	68.686	67.356	67.712	65.689

TABLE 5.32
Percent deviations from link-level benchmark by VMT estimation method.

Code	Estimation Methodology	2009 (% Dev)	2010 (% Dev)	2011 (% Dev)	2012 (% Dev)	2013 (% Dev)	4–5 Year (% Dev)
F-1	Fuel-Revenue	-2.2%	-1.0%	-2.6%	-7.0%	-2.6%	-3.1%
F-2	Fuel-Revenue	-5.4%	-5.3%	-2.9%	-6.5%	-8.6%	-5.8%
F-3	Fuel-Revenue	-1.2%	-0.7%	-1.8%	-6.7%	-2.3%	-2.6%
F-4	Fuel-Revenue	-3.4%	-4.9%	-2.1%	-6.0%	-8.1%	-4.9%
F-5	Fuel-Revenue	-1.7%	0.3%	-2.9%	-6.8%	-2.5%	-2.7%
F-6	Fuel-Revenue	-3.3%	-3.9%	-2.9%	-6.1%	-8.2%	-4.9%
SE-1	Socioeconomic Regression	-10.9%	-8.8%	-4.0%	1.1%	4.1%	-3.7%
SE-2	Socioeconomic Regression	4.2%	5.1%	4.7%	5.7%	6.0%	5.2%
VR-1	Vehicle Registrations	N/A	-8.1%	-8.7%	-7.5%	-7.2%	-7.6%
VR-2	Vehicle Registrations	N/A	-19.1%	-19.6%	-18.6%	-18.4%	-18.7%
STS-1	Socioeconomic Travel Surveys	-20.1%	-19.0%	-21.3%	-18.5%	-17.8%	-19.3%
STS-2	Socioeconomic Travel Surveys	-21.5%	-20.3%	-22.6%	-19.9%	-19.1%	-20.7%
LDD-1	Licensed Drivers/ Demographics	-6.0%	-3.9%	-2.8%	-3.3%	N/A	-4.2%
LDD-2	Licensed Drivers/ Demographics	-2.8%	-0.8%	0.2%	0.3%	N/A	-1.0%
HPMS-1	HPMS	1.7%	0.5%	0.1%	3.4%	1.9%	1.5%
TA-1	Trend Analysis	5.0%	6.3%	6.2%	7.6%	8.3%	6.7%
TA-2	Trend Analysis	-4.2%	-0.2%	2.4%	6.5%	9.8%	2.9%
TA-3	Trend Analysis	6.0%	7.6%	7.8%	9.6%	10.6%	8.3%
TA-4	Trend Analysis	-1.6%	-1.7%	-3.0%	-2.9%	-3.5%	-2.5%
TA-5	Trend Analysis	-0.9%	1.0%	1.7%	3.8%	5.2%	2.2%

Growth factors obtain a statewide VMT of 74.601 billion (2009) to 80.844 billion (2013), as presented in Table 5.29.

5.3.2 Reconciliation of Non-Traffic Methods

A summary of the approaches within each estimation method analyzed is provided in Table 5.30, with codes used to identify each method's different analysis and assumptions. These codes are referenced later in this section. The coverage level is indicated as well with the majority of the methods capable of representing statewide VMT and socioeconomic travel surveys representing the personal component (Classes 1–3) of the statewide VMT. The link-specific method (LS-1 and LS-2) is the study's selected method and the benchmark

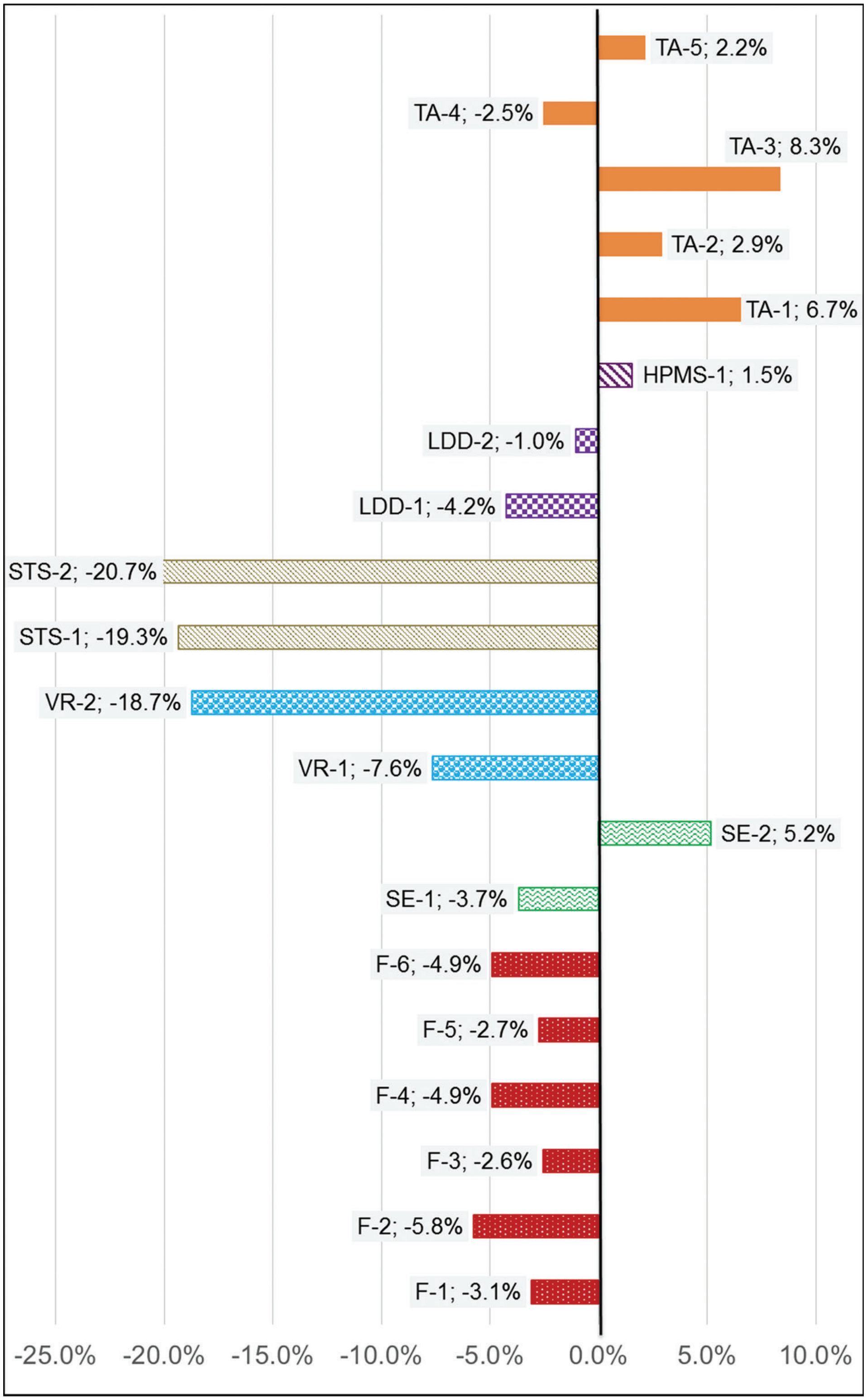


Figure 5.18 Comparison of percent deviations by VMT estimation method (refer to Table 5.30 for codes).

for comparison of the identified non-link-level estimation methods.

Based on all the estimation methods, a summary of the estimated statewide VMT values is given in Table 5.31. The four to five-year average is used for discussion and later a comparison of the percent deviations from the benchmark. LS-1, the link-specific benchmark, is 76.052 billion, and LS-2, the link-specific benchmark for non-commercial component, is 65.689 billion. The range of statewide AVMT (total) is from 61.802 billion to 82.393 billion, based on a four or five-year average, depending on the estimation method. As observed, this nearly 20 billion range to too wide, is suggestive of poor reliability and accuracy of the obtained VMT estimates, and impairs confidence in the VMT application.

The percent deviations from the link-level benchmark are given in Table 5.32. These deviations can be thought of as adjustment factors from the "actual" or ground-truth control based on an extensive traffic-data approach. Negative percent deviations indicate that the obtained results are an underestimate, whereas a positive sign indicates that the result is an overestimate. As seen from Table 5.32, the majority of the percent deviations are an underestimate, with vehicle registrations and socioeconomic travel surveys showing the highest discrepancies from the benchmark estimate. It was observed that vehicle registrations underestimated VMT by 18.7% to 7.6%. Socioeconomic travel surveys underestimated VMT by 19.3% to 20.7%. Trend analysis techniques can produce both under and overestimates of statewide VMT, more precisely, within a range of -2.5% to 8.3%. Fuel revenue-based approaches underestimate the VMT within a more precise range of 5.8% to 2.6%. The licensed drivers and demographics approach is close to the actual with underestimates of 4.2% to 1.0%. The HPMS is close to the benchmark, with an overestimate of 1.5%. Finally, socioeconomic regression models underestimate and overestimate but are close to the benchmark with percent deviations of -3.7% to 5.2%.

These adjustment factors, from the solid black line indicated as the benchmark VMT estimation method (segment-level), are graphically presented in Figure 5.18. For example, the percentage represents the extent of deviation from the actual VMT from each VMT estimation method. Trend analysis techniques both over and underestimate within a +/-10% range. Similar findings for all the investigated methods of VMT estimation are provided in Figure 5.18.

5.4 Chapter Summary

This chapter provided the results from statewide VMT estimations at the link level, aggregated over different geographic and analysis scopes. Aggregations based on available link-level traffic data were provided by county, administrative district, road designation, economic region, and HPMS. In addition, the predicted statewide VMT at the link level were provided for future years. Coverage for statewide, route, vehicle class, and road designation was provided for the statewide VMT estimates. Finally, the results from the preferred non-traffic-based approach of VMT estimation, particularly, the non-link-level method, were discussed. The findings indicated significant variations among the estimation methods and approaches within those methods, based on a comparison of the obtained estimates to the link-level benchmark VMT adopted for this study. Overall, commercial VMT is underrepresented by non-traffic-based VMT estimation methods and may contribute to the trend of underestimating statewide VMT.

6. SUMMARY AND CONCLUSIONS

6.1 Summary

This section provides a summary of the study motivation, problem statement, and framework developed for statewide VMT estimation and key numerical findings for different methods and the link-level (benchmark) method selected to reconcile estimates and to provide for future VMT estimation.

6.1.1 Problem Statement and Motivation

The primary purpose of this study was to improve the consistency, reliability, and accuracy of VMT estimates at present and future times for INDOT by developing a consistent framework intended for VMT estimation at the various divisions and hierarchical levels of INDOT. Such a need is underscored by the realization that VMT estimates play a critical role in INDOT's various functions and business processes. For example, with declining highway revenue from fuel taxes and the subsequent imminent move to VMT-based user fees, the need for reliable VMT estimates is critical. Also, VMT data are useful inputs in the evaluation of the Indiana highway network (or parts thereof) on the basis of different highway performance criteria, including crash and mobility performance at the overall network level. Furthermore, VMT data are reported annually to federal oversight agencies. Other end applications include highway revenue forecasting, traffic and energy impact assessments, and highway cost allocation. The current impaired ability of INDOT to readily produce consistent VMT estimates by functional and vehicle class hinders the several agency business processes for which VMT estimates are critical. In this regard, the lack of a central and consistent source for retrieving VMT information for specific corridors or at any level of system-wide aggregation is problematic for VMT-stakeholders.

VMT estimation methods are generally classified as traffic-based and non-traffic-based. The existing methods for VMT estimation are often non-traffic-based, that is, they do not use data on highway traffic volume; for example, in a few of these methods, VMT is estimated using data from travel surveys, fuel revenue, fleet efficiency, demographics, and socioeconomic conditions. However, the resulting VMT estimates from these methods often do not match the total aggregate VMT reported to the FHWA. Also, these methods tend to be data-intensive and require significant data processing efforts, which have proved to be worrisome, considering the multitude and critical nature of applications that require VMT estimates. On the other hand, traffic-based methods of VMT estimation use traffic volume data and section length information; however, these methods are applicable only to highway networks for which traffic data and inventory (section length) data are available. As such, traffic-based methods are typically not used for VMT estimation on local roads. Recognizing that local routes constitute a significant share of the entire road inventory in Indiana, this study carried out a detailed analysis of the local VMT to increase the reliability and accuracy of the VMT estimates for this traditionally-overlooked road class.

6.1.2 Study Framework

The first task in the study was a comprehensive review of the literature and qualitative analysis of the VMT estimation methods appropriate for different application levels. Also, a survey of the VMT stakeholders at INDOT was carried out in order to identify the challenges they face with VMT estimation and to identify the preferred outputs of any platform for VMT estimation. These first steps were undertaken to streamline the study effort, to categorize the different methods of VMT estimation, and to identify their limitations.

The non-traffic methods were deemed inadequate for meeting the entirety of INDOT's needs because these methods do not readily provide VMT estimates at the preferred levels of aggregation, including vehicle class, functional class, route, and spatial area. Due to the inherent nature of its VMT estimation procedure, the segment-level or link-level method was selected as the best method and therefore its VMT estimates were used as the benchmark estimates not only for reconciling any inconsistencies in the VMTs estimated using the other VMT methods but also for developing quantitative calibration factors for the other methods.

The benchmark method uses the traffic counts at the segment level to provide full coverage of the road inventory. This method is implemented in a series of Microsoft Excel spreadsheets, providing a platform for present and future VMT information as well as allowing for data updatability and scenario-based traffic growth analysis. Using the traffic volume data for the entire population of Indiana's state highways (interstates and US and state roads) and also a representative sample of local routes (city streets and county roads), these comprehensive databases facilitated extensive aggregations including the corridor level, region (district, county, etc.), highway class, route type, NHS class, and vehicle class. These spreadsheets are accompanied by a user's manual.

To facilitate VMT prediction at a future year, growth factors were developed based on the observed traffic data. These growth factors were developed by functional class and were applied at the segment level to represent any time-horizon selected in the spreadsheet system. To account better for the stochastic nature of long-term traffic forecasting, a range of VMT estima tes (low, medium, and high) were provided for each of the several levels and types of VMT aggregations, allowing for a scenario-based analysis of traffic growth to quickly assess possible future VMT conditions.

In view of the importance of spatial relationships in travel distributions, the use of spatial interpolation techniques was investigated to provide a more reliable characterization of the VMTs for the individual local roads. For local segments with unknown AADTs, the traffic counts from neighboring segments were used as a basis to spatially interpolate the AADTs and, subsequently, the VMT. Different spatial interpolation techniques within the ArcGIS software were investigated for this purpose, including kriging, natural neighbor, inverse distance weighting, and trend. Each interpolation technique produced a raster surface of the continuous variation in the AADT across each county under investigation. To assess the accuracy and appropriateness of each technique for local road VMT estimation, the techniques were validated by road class for each of the representative counties that were analyzed. Also, a county-wide total VMT was developed, thereby establishing benchmark values for future use. The capabilities of spatial interpolation were demonstrated quantitatively for the purpose of estimating the VMT of local roads in Indiana.

TABLE 6.1
Summary of total VMT across different estimation methods.

Annual VMT Estimates (units in billions)		
Code	**Estimation Methodology**	**4–5 Year Average**
F-1	Fuel-Revenue	73.706
F-2	Fuel-Revenue	71.678
F-3	Fuel-Revenue	74.101
F-4	Fuel-Revenue	72.318
F-5	Fuel-Revenue	73.974
F-6	Fuel-Revenue	72.333
SR-1	Socioeconomic Regression	73.260
SR-2	Socioeconomic Regression	79.975
VR-1	Vehicle Registrations	70.239
VR-2	Vehicle Registrations	61.802
STS-1	Socioeconomic Travel Surveys	53.661
STS-2	Socioeconomic Travel Surveys	52.760
LDD-1	Licensed Drivers/ Demographics	72.828
LDD-2	Licensed Drivers/ Demographics	75.258
HPMS-1	HPMS	77.222
TA-1	Trend Analysis	81.140
TA-2	Trend Analysis	78.260
TA-3	Trend Analysis	82.392
TA-4	Trend Analysis	74.130
TA-5	Trend Analysis	77.692
LS-1	Link-Specific (Benchmark)	76.052
LS-2	Link-Specific (Benchmark)	65.689

6.1.3 Findings across Different Methods

The results from the different non-traffic VMT estimation methods varied greatly, not only across methods, but with respect to the assumptions and specific techniques within each. This variation is illustrated in Table 6.1, for the four to five year (2009–2013) data-average, with the link level benchmark developed for this study as 76.05 billion for statewide VMT (classes 1–13) and 65.69 billion for personal vehicle VMT (classes 1–3).

TABLE 6.2
Summary of vehicle-class VMT across different estimation methods.

Annual VMT Estimates (units in billions)													
	FHWA Vehicle Class												
VMT Estimation Method	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Socieconomic Regression (SR-1)	0.569	51.390	18.48	0.005	2.450				7.093				
Socieconomic Regression (SR-2)	0.509	51.623	19.414	0.005	2.459				7.417				
Fuel-Revenue (F-1)	0.801	49.945	14.613	0.219	2.219	1.145	0.370	0.428	4.856	0.073	0.116	0.041	0.023
Fuel-Revenue (F-2)	0.780	48.419	14.166	0.156	1.652	0.828	0.268	0.310	3.454	0.052	0.083	0.029	0.016
Fuel-Revenue (F-3)		75.023	7.709										
Fuel-Revenue (F-6)		70.531	6.322										

TABLE 6.3
Calibrator factor table for VMT estimation methods.

Method	Technique	Percent Deviation	Calibration Factor
Trend Analysis	TA-1	6.70	0.933
	TA-2	2.90	0.971
	TA-3	0.30	0.997
	TA-4	-2.50	1.025
	TA-5	-3.10	1.031
	TA-6	-2.90	1.029
	TA-7	2.20	0.978
HPMS	HPMS-1	1.50	0.985
Licensed Drivers and Demographics	LDD-1	-1.00	1.010
	LDD-2	-4.20	1.042
Socioeconomic Travel Surveys	STS-1	-20.70	1.207
	STS-2	-19.30	1.193
Vehicle Registrations	VR-1	-7.60	1.076
	VR-2	-18.70	1.187
Socioeconomic Regression	SR-1	-3.70	1.037
	SR-2	5.20	0.948
Fuel-Revenue	F-1	-3.10	1.031
	F-2	-5.80	1.058
	F-3	-2.60	1.026
	F-4	-4.90	1.049
	F-5	-2.70	1.027
	F-6	-4.90	1.049

For example, fuel revenues and fleet efficiency yielded statewide VMT estimates in the range of 71.68 to 74.10 billion. These VMT estimates are underestimates of 1.95 to 4.37 billion compared to the benchmark developed in this study. The fuel-revenue method was found to be less accurate for estimating individual vehicle class VMT and may underrepresent commercial VMT. For socioeconomic regression models, the data and assumptions selected on economic conditions affected the results. Applying the actual economic conditions led to a value of 73.26 billion, while using the predicted economic conditions led to a higher value of 79.98 billion, indicating that VMT derived from socio-economic regression techniques are susceptible to

TABLE 6.4
Summary of key VMT estimates (medium growth range).

Aggregation	Category	Average % of Total	Annual VMT Estimates (units in billions) 2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Jurisdiction	All	100.0%	78.404	79.161	79.925	80.698	81.479	82.269	83.067	83.874	84.690	85.516	86.350
	State Routes	53.7%	41.652	42.137	42.627	43.124	43.627	44.136	44.653	45.176	45.705	46.242	46.786
	Local Routes	46.3%	36.752	37.024	37.298	37.574	37.852	38.132	38.414	38.699	38.985	39.273	39.564
Highway Route Type	Interstates	23.3%	18.278	18.456	18.636	18.818	19.002	19.188	19.375	19.565	19.756	19.949	20.145
	US Highways	13.5%	10.398	10.529	10.662	10.797	10.934	11.073	11.214	11.357	11.502	11.649	11.798
	State Highways	16.9%	12.977	13.151	13.328	13.508	13.690	13.875	14.063	14.254	14.447	14.643	14.843
	Local Roads	46.3%	36.752	37.024	37.298	37.574	37.852	38.132	38.414	38.699	38.985	39.273	39.564
FHWA Functional Class	FC 1	23.3%	18.278	18.456	18.636	18.818	19.002	19.188	19.375	19.565	19.756	19.949	20.145
	FC 2	2.1%	1.629	1.648	1.668	1.688	1.709	1.729	1.750	1.771	1.792	1.814	1.836
	FC 3	26.2%	20.396	20.623	20.852	21.085	21.320	21.559	21.800	22.045	22.293	22.545	22.799
	FC 4	19.6%	15.380	15.519	15.660	15.803	15.946	16.092	16.239	16.387	16.537	16.688	16.841
	FC 5	24.9%	19.654	19.823	19.993	20.165	20.339	20.514	20.691	20.870	21.050	21.232	21.416
	FC 6	1.1%	0.844	0.851	0.858	0.865	0.873	0.880	0.888	0.895	0.903	0.910	0.918
	FC 7	2.8%	2.223	2.240	2.256	2.273	2.290	2.307	2.324	2.342	2.359	2.377	2.394
Administrative District (State Routes Only)	Crawfordsville	13.2%	5.508	5.572	5.637	5.703	5.770	5.837	5.905	5.974	6.044	6.115	6.187
	Fort Wayne	14.8%	6.174	6.246	6.318	6.392	6.467	6.542	6.619	6.696	6.775	6.854	6.935
	Greenfield	26.2%	10.909	11.036	11.164	11.294	11.426	11.560	11.695	11.832	11.970	12.111	12.253
	Laporte	20.0%	8.321	8.418	8.516	8.615	8.716	8.818	8.921	9.025	9.131	9.238	9.347
	Seymour	16.3%	6.804	6.883	6.963	7.044	7.126	7.210	7.294	7.379	7.466	7.554	7.642
	Vincennes	9.4%	3.936	3.982	4.028	4.075	4.122	4.171	4.219	4.269	4.319	4.370	4.421
Commercial	All	100.0%	9.322	9.420	9.519	9.620	9.722	9.825	9.929	10.035	10.142	10.250	10.359
	State Routes	74.9%	6.943	7.024	7.105	7.188	7.272	7.357	7.443	7.530	7.619	7.708	7.799
	Local Routes	25.1%	2.379	2.396	2.414	2.432	2.450	2.468	2.486	2.505	2.523	2.542	2.561

economic fluctuations and unforeseen demographic changes. Using vehicle registrations and an assumed average annual travel per vehicle, VMT estimates of 61.80 to 70.24 billion were observed, underrepresenting statewide VMT by 5.81 to 14.25 billion. Socioeconomic travel surveys, considering personal vehicle VMT only (classes 1–3), yielded estimates of 52.76 to 53.66 billion. These values are significant underestimates of 12.03 to 12.93 billion. Travel surveys with licensed driver and demographic data yielded estimates of 72.83 to 75.26 billion. While this method underestimates VMT by 0.79 to 3.22 billion, the inputs derived from self-reported mileage may be prone to misrepresentation and infrequent updating. Based on the FHWA's HPMS reports, a statewide VMT estimate of 77.22 billion was determined, overestimating VMT by 1.17 billion, based on this study. The trend analysis and growth factor method yielded a range of statewide VMT estimates, from 74.13 to 82.39 billion. Trend analysis techniques were found to both underestimate and overestimate statewide VMT, depending on the estimation approach used.

One of the limitations of most non-traffic methods is that, due to their aggregate nature, it is often not possible to develop a VMT estimate for each vehicle class. Exceptions are the fuel-revenue method (which can provide VMT for each of the 13 FHWA vehicle classes) and socioeconomic regression (which can provide VMT by groups of vehicle classes) as shown in Table 6.2.

To aid with reconciling the VMT values across the different methods, calibrations factors were developed based on the percent deviation of each method and technique, relative to the benchmark method. In Table 6.3, the codes representing each technique are explained in Table 5.30. For example, for VMT obtained using a linear trend analysis (TA-1) such as forecasting using historical data, a calibration factor of

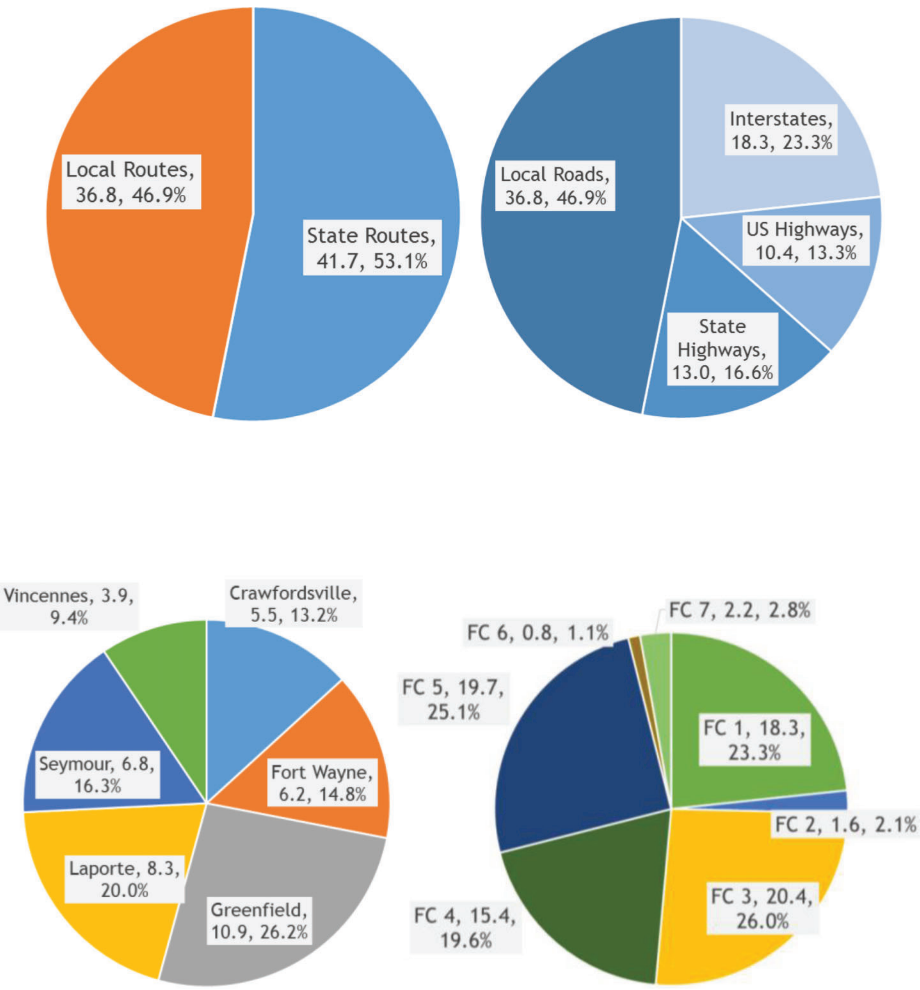


Figure 6.1 Distribution of statewide VMT by selected aggregations.

0.933 can be used. That is, the VMT estimate produced by the method is multiplied by 0.933 to obtain the "true" VMT (i.e., the VMT obtained using the benchmark method).

6.1.4 Findings using Link-Level Method

Table 6.4 presents an aggregation of the VMT estimates by jurisdiction, highway route type, FHWA functional class, administrative district, and commercial travel. The distributions of these key statewide VMT aggregations are visually represented in Figure 6.1. The medium range of observed traffic growth was applied for these aggregations, with the annual values provided in billions. Also, an average percentage of the total, for each aggregation category, was estimated for the 2015–2025 period (Table 6.4). With regard to VMT by highway category, it was determined that interstates, US highways, state highways, and local roads account for 23.3%, 13.5%, 16.9%, and 46.3%, respectively, of the total statewide VMT. Similarly, for assessing VMT by FHWA functional classes, using the distributions developed in this study based on an extensive link-level traffic sample, FC 1, FC 2, FC 3, FC 4, FC 5, FC 6, and FC 7, account for 23.3%, 2.1%, 26.2%, 19.6%, 24.9%, 1.1%, and 2.8%, respectively. For state highway VMT by INDOT administrative districts, the results indicate that on average, Crawfordsville, Fort Wayne, Greenfield, LaPorte, Seymour, and Vincennes contribute 13.2%, 14.8%, 26.2%, 20.0%, 16.3%, and 9.4%, of the state highway VMT. Aggregations for VMT by vehicle classes for the primary highway systems of state and local routes are provided in Table 6.5 for 2015–2035. Over the analysis period, as expected, vehicle class 2 (automobiles) represents the highest VMT, with vehicle class 3, light-duty vehicles, having the second highest VMT. Class 9 trucks have the highest commercial VMT, primarily on state routes, with the combination truck VMT predominately on state routes.

Figure 6.2 presents the statewide annual VMT growth for 2009 to 2035 (Figure 6.2). Three traffic growth scenarios (low, medium, and high) are provided. After 2025, the gaps between the predicted VMTs widens significantly. These long-term predictions should be used cautiously because of the influence of economic conditions and effect of changing

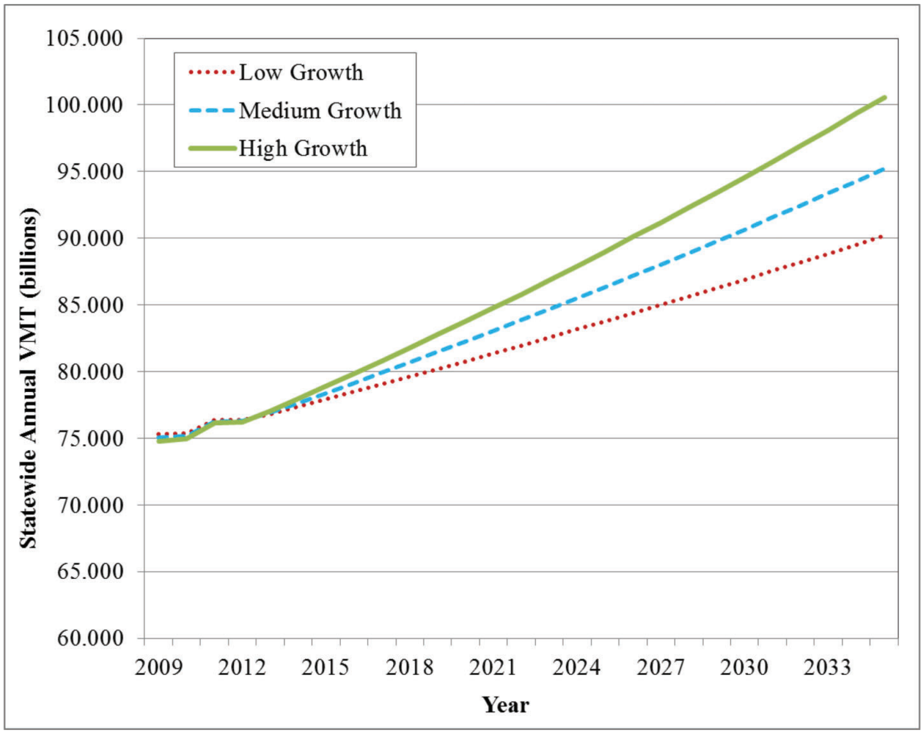


Figure 6.2 VMT growth (2009–2035) for statewide total.

technologies. The VMT estimates by highway category, for interstates, US and state roads, and local roads (medium growth) from 2015 to 2023 are presented in Figure 6.3.

The VMT growth scenarios by FHWA vehicle class from 2015 to 2035 are presented in Figure 6.4 to Figure 6.10. Classes 1 to 3 vehicles are primarily non-commercial and class 4 to 13 vehicles are primarily commercial. The widest gap in the prediction range was observed for vehicle class 2 (automobiles). Note that the y-axis represents annual VMT in billions and does not start at zero for any of the VMT estimate plots, except for vehicle class.

6.2 Problems Encountered

In this study, the county-level traffic sampling for local routes (using a sample of 14 counties to represent the 92 counties in Indiana) has inherent limitations. For example, it can be questioned whether the sample obtained adequately represents the distribution of the state's rural, mixed urban, and urban counties. For rural counties, the traffic counts from the sample used to represent the 50+ counties in this cluster (rural counties) are assumed to be representative of all rural counties. Likewise, the traffic counts collected for Marion County, where Indianapolis is located, is assumed to be representative of all local roads within this region.

The estimation of section lengths, which is necessary to transform from AADT to a VMT estimate, is not directly established for local roads and therefore requires a proximity analysis in GIS to connect with the existing road network. For example, the proximity analysis often identified segments which were from intersection to intersection, but that may not be the exact representation of the traffic count. It is assumed that the nearest road segment matching the traffic count represents the segment or link-level VMT estimate. Also, adding a new road or changing a road may not be reflected in the GIS network used for analysis. These are some of the inherent limitations in the determination of segment lengths for traffic data of this magnitude.

In assessing non-traffic VMT estimation methods, the study assumed that data, such as measures of highway travel in the FHWA *Highway Statistics* were complete and reliable. However, a few discrepancies were observed may be worrisome and may somewhat limit the confidence in this data, and hence for the resulting VMT estimates used in business processes. Also, the annual mileage compiled from the NHTS is often self-reported and statistically adjusted; however, the reliability of this adjusted data may be questionable.

6.3 The Future of VMT Estimation

VMT is a dynamic performance measure of the amount of travel on the highway system within a given spatial area. VMT has been linked strongly to technology and the economy. The nature of the long-term VMT estimates developed in this study are subject to much uncertainty and provided to facilitate revenue forecasting, transportation planning, and other appli-

TABLE 6.5
Summary of VMT by highway system and vehicle class (medium growth range).

FHWA Vehicle Class	Primary Highway Systems	VMT Estimates by Year (units in billions)																				
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
1	State Routes	0.209	0.211	0.214	0.216	0.219	0.221	0.224	0.226	0.229	0.232	0.234	0.237	0.240	0.243	0.246	0.249	0.252	0.255	0.258	0.261	0.264
	Local Routes	0.220	0.221	0.223	0.224	0.226	0.228	0.229	0.231	0.233	0.235	0.236	0.238	0.240	0.242	0.243	0.245	0.247	0.249	0.251	0.253	0.254
2	State Routes	25.046	25.337	25.632	25.930	26.233	26.539	26.850	27.164	27.483	27.805	28.132	28.464	28.799	29.139	29.483	29.832	30.186	30.544	30.907	31.275	31.648
	Local Routes	23.988	24.165	24.344	24.524	24.706	24.889	25.073	25.258	25.445	25.634	25.823	26.014	26.207	26.401	26.596	26.793	26.991	27.191	27.392	27.595	27.799
3	State Routes	9.455	9.565	9.676	9.789	9.903	10.019	10.136	10.255	10.375	10.497	10.620	10.745	10.872	11.001	11.131	11.262	11.396	11.531	11.668	11.807	11.948
	Local Routes	10.166	10.241	10.317	10.393	10.470	10.548	10.626	10.704	10.784	10.863	10.944	11.025	11.106	11.189	11.271	11.355	11.439	11.523	11.609	11.695	11.781
4	State Routes	0.111	0.112	0.113	0.115	0.116	0.117	0.119	0.120	0.122	0.123	0.125	0.126	0.127	0.129	0.130	0.132	0.134	0.135	0.137	0.138	0.140
	Local Routes	0.039	0.040	0.040	0.040	0.040	0.041	0.041	0.041	0.042	0.042	0.042	0.043	0.043	0.043	0.044	0.044	0.044	0.045	0.045	0.045	0.046
5	State Routes	1.355	1.370	1.386	1.402	1.419	1.435	1.452	1.469	1.486	1.504	1.521	1.539	1.558	1.576	1.595	1.613	1.633	1.652	1.672	1.691	1.712
	Local Routes	0.627	0.632	0.636	0.641	0.646	0.650	0.655	0.660	0.665	0.670	0.675	0.680	0.685	0.690	0.695	0.700	0.705	0.711	0.716	0.721	0.727
6	State Routes	0.371	0.376	0.380	0.384	0.389	0.394	0.398	0.403	0.408	0.412	0.417	0.422	0.427	0.432	0.437	0.442	0.448	0.453	0.458	0.464	0.469
	Local Routes	0.379	0.381	0.384	0.387	0.390	0.393	0.396	0.399	0.402	0.405	0.408	0.411	0.414	0.417	0.420	0.423	0.426	0.429	0.432	0.436	0.439
7	State Routes	0.105	0.106	0.108	0.109	0.110	0.112	0.113	0.114	0.116	0.117	0.118	0.120	0.121	0.122	0.124	0.125	0.127	0.128	0.130	0.131	0.133
	Local Routes	0.129	0.130	0.131	0.132	0.133	0.134	0.135	0.136	0.137	0.138	0.139	0.140	0.141	0.142	0.143	0.145	0.146	0.147	0.148	0.149	0.150
8	State Routes	0.410	0.415	0.420	0.425	0.430	0.435	0.440	0.445	0.450	0.456	0.461	0.466	0.472	0.478	0.483	0.489	0.495	0.501	0.507	0.513	0.519
	Local Routes	0.121	0.121	0.122	0.123	0.124	0.125	0.126	0.127	0.128	0.129	0.130	0.131	0.132	0.133	0.134	0.135	0.136	0.137	0.138	0.139	0.140
9	State Routes	4.338	4.389	4.440	4.492	4.544	4.597	4.651	4.705	4.761	4.817	4.873	4.931	4.989	5.048	5.107	5.168	5.229	5.291	5.354	5.418	5.482
	Local Routes	1.052	1.059	1.067	1.075	1.083	1.091	1.099	1.107	1.115	1.124	1.132	1.140	1.149	1.157	1.166	1.175	1.183	1.192	1.201	1.210	1.219

TABLE 6.5
(Continued)

FHWA Vehicle Class	Primary Highway Systems	VMT Estimates by Year (units in billions)																				
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
10	State Routes	0.062	0.063	0.063	0.064	0.065	0.066	0.066	0.067	0.068	0.069	0.070	0.070	0.071	0.072	0.073	0.074	0.075	0.076	0.076	0.077	0.078
	Local Routes	0.017	0.017	0.017	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.020	0.020	0.020	0.020
11	State Routes	0.115	0.116	0.118	0.119	0.120	0.122	0.123	0.125	0.126	0.128	0.129	0.131	0.132	0.134	0.135	0.137	0.138	0.140	0.142	0.143	0.145
	Local Routes	0.007	0.007	0.007	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.009
12	State Routes	0.040	0.041	0.041	0.042	0.042	0.043	0.043	0.044	0.044	0.045	0.045	0.046	0.047	0.047	0.048	0.048	0.049	0.049	0.050	0.051	0.051
	Local Routes	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
13	State Routes	0.035	0.035	0.035	0.036	0.036	0.037	0.037	0.038	0.038	0.038	0.039	0.039	0.040	0.040	0.041	0.041	0.042	0.042	0.043	0.043	0.044
	Local Routes	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006

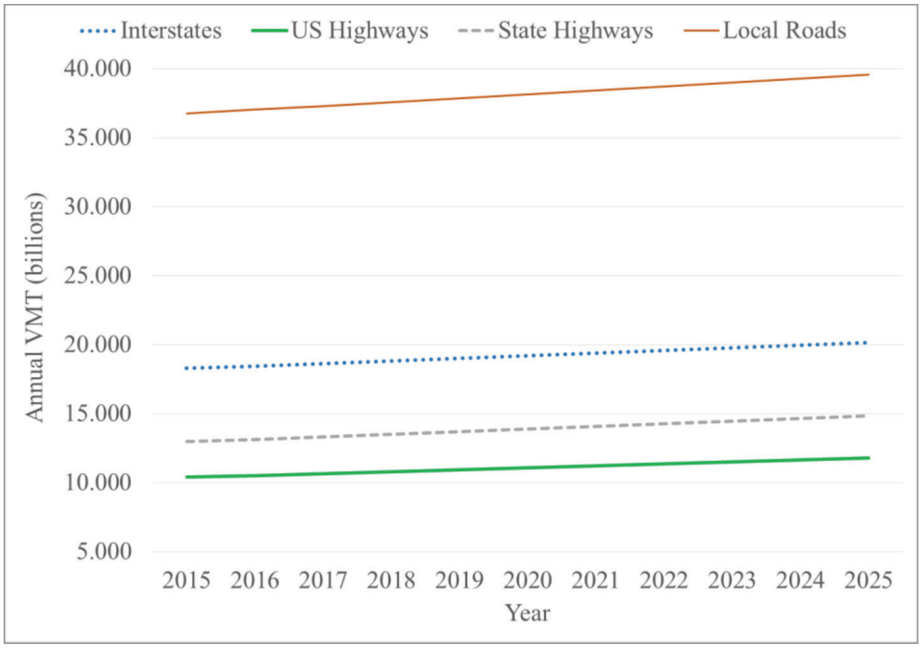


Figure 6.3 VMT growth (2015–2025) by highway jurisdiction and class.

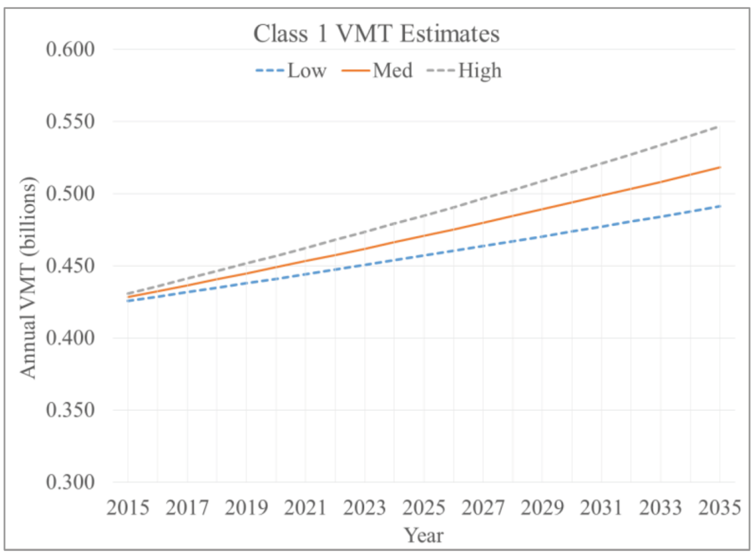


Figure 6.4 VMT growth (2015–2035) for class 1 vehicles.

cations that decision-makers may face within highway management. The future of travel in Indiana and the US depends largely on advances in technology and the current economic conditions. For example, emerging transportation technologies, such as autonomous vehicles driving on freeways, transport pods in dense urban centers, or the possibility of hyperloop trains connecting cities, are a few transportation modes which may dramatically alter the magnitude of VMT occurring in a given region. Changing modal shares, such as an increase in air travel or light-rail usage, may affect the VMT. Fluctuating oil prices may also affect the amount of travel by motorists, and subsequently VMT. Through this report, we hopefully provide a reliable statewide framework, the integrity of which hinges on the of consistent and reliable traffic counts. That way, users can be confident that the VMT estimates produced more accurately represent travel conditions in the state.

6.4 Conclusions

This report recommends the adoption of the benchmark method (segment or link level) for statewide VMT estimation. The framework developed for this study is implemented in a spreadsheet system, for the primary highway systems of state routes and local routes to allow for consistent and reliable VMT estimation at the segment or link level.

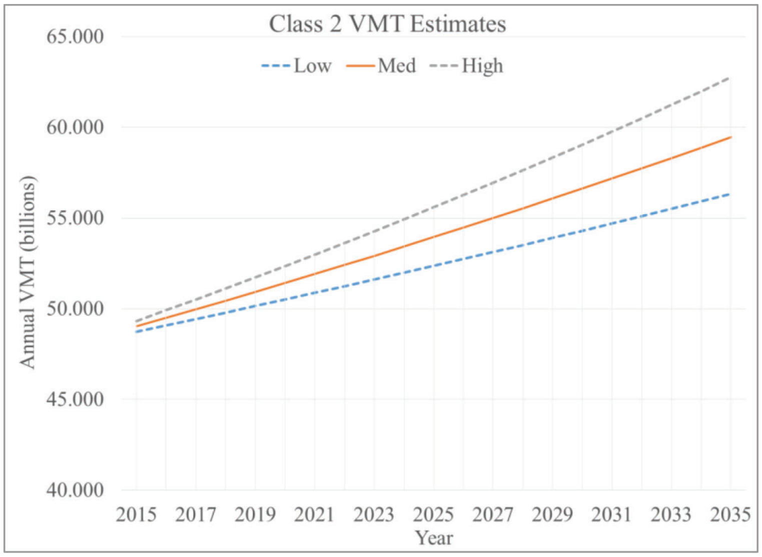


Figure 6.5 VMT growth (2015–2035) for class 2 vehicles.

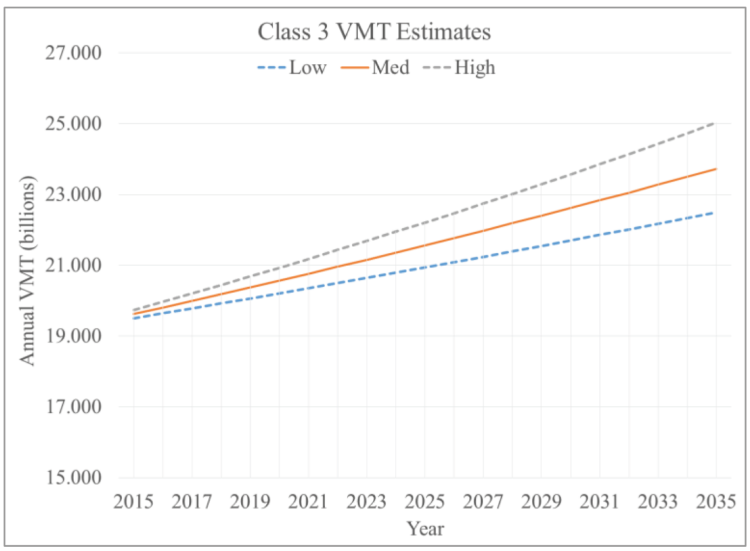


Figure 6.6 VMT growth (2015–2035) for class 3 vehicles.

To ensure maximum benefit from this study, the spreadsheet should be fully managed and updated by INDOT as and when more recent data on traffic volumes and inventory become available. The spreadsheet permits easy addition of new roads or deletion of decommissioned roads so that the estimated VMT can reliably reflect the current inventory and extent of travel by vehicle class, highway class, state/local class, district, sub-district, and other specified spatial, functional, or administrative jurisdiction or in Indiana.

6.5 Avenues for Future Study

A possible future study could include comprehensive evaluation and analysis of VMT-user fees as an alternative highway funding mechanism for INDOT, which was outside the scope of the present study. However, this is a topic of critical concern, considering the widening gap between highway revenue and expenditures. Also, a future study task could be to build upon the database developed in this study by implementing it with an interactive platform, such as a querying system. This system may be able to quickly provide the general public with VMT information in report form, as well as traffic statistics, depending on the application desired, such as a specific jurisdiction, corridor, or road class. Finally, future study could further assess the reliability and integrity of the use of spatial interpolation techniques for local VMT estimation.

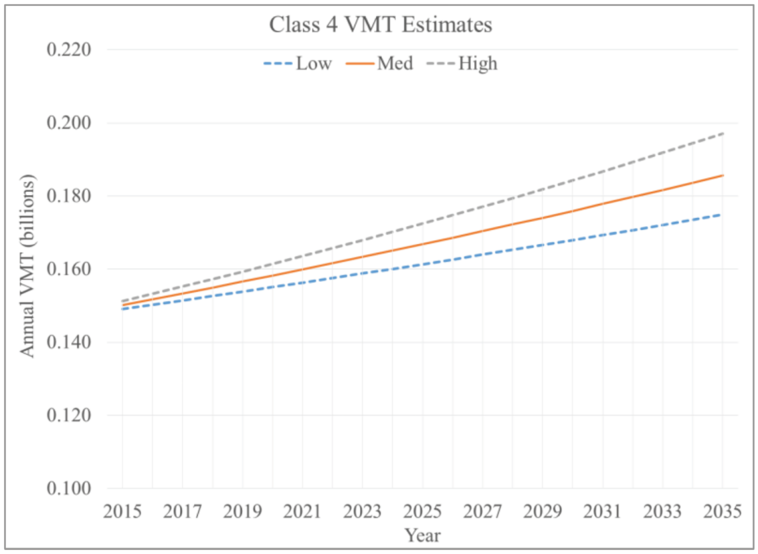


Figure 6.7 VMT growth (2015–2035) for class 4 vehicles.

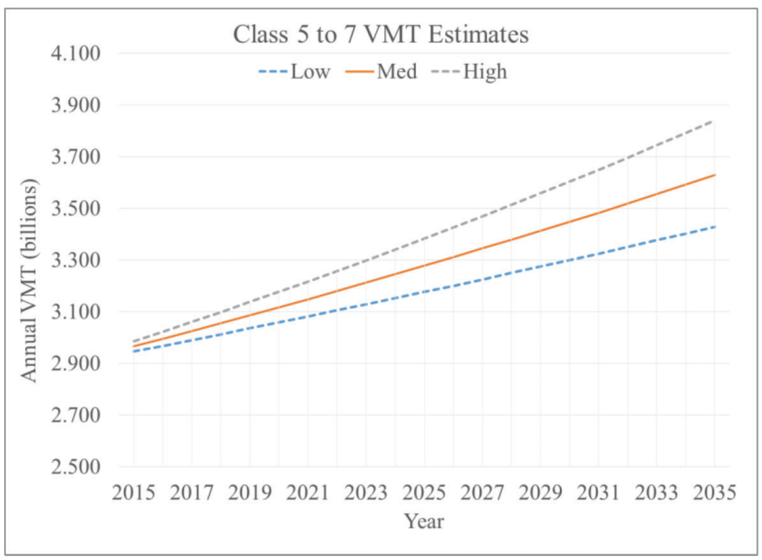


Figure 6.8 VMT growth (2015–2035) for class 5–7 vehicles.

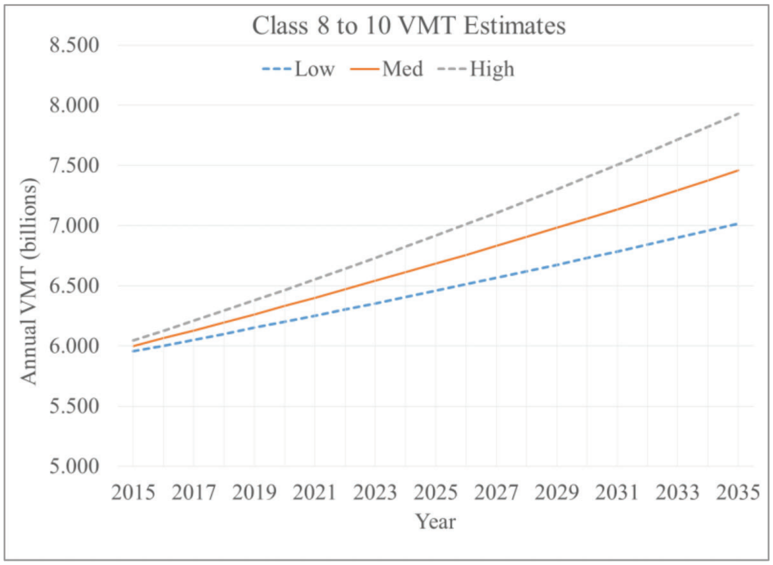


Figure 6.9 VMT growth (2015–2035) for class 8–10 vehicles.

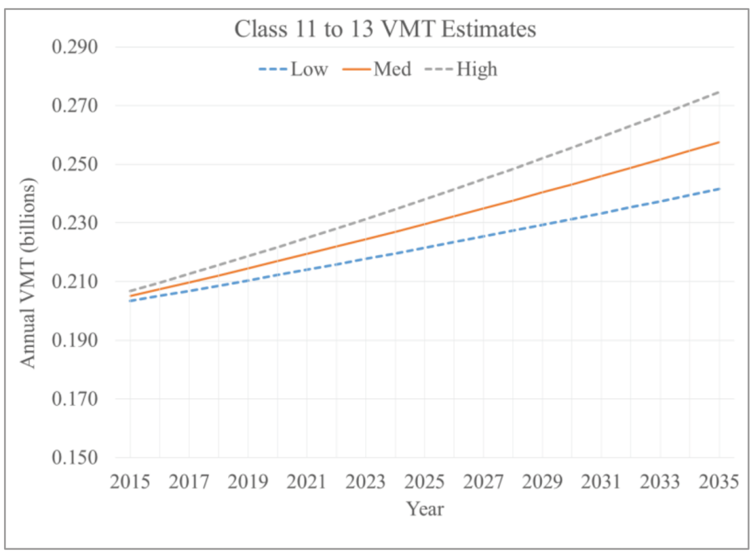


Figure 6.10 VMT growth (2015–2035) for class 11–13 vehicles.

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ADDENDUM A. DEVELOPED GROWTH FACTORS

TABLE A.1
Growth factors for state routes: Interstates (medium growth rate).

State Routes		FC 1 – Interstates										
		To AADT Year										
AGR = 1.02%		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
From AADT Year	2010	–	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.10	1.11
	2011	0.99	–	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.10
	2012	0.98	0.99	–	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08
	2013	0.97	0.98	0.99	–	1.01	1.02	1.03	1.04	1.05	1.06	1.07
	2014	0.96	0.97	0.98	0.99	–	1.01	1.02	1.03	1.04	1.05	1.06
	2015	0.95	0.96	0.97	0.98	0.99	–	1.01	1.02	1.03	1.04	1.05

TABLE A.2
Growth factors for state routes: Principal arterials (medium growth rate).

State Routes		FC 3 – Principal Arterials – Other										
		To AADT Year										
AGR = 1.28%		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
From AADT Year	2010	–	1.01	1.03	1.04	1.05	1.07	1.08	1.09	1.11	1.12	1.14
	2011	0.99	–	1.01	1.03	1.04	1.05	1.07	1.08	1.09	1.11	1.12
	2012	0.97	0.99	–	1.01	1.03	1.04	1.05	1.07	1.08	1.09	1.11
	2013	0.96	0.97	0.99	–	1.01	1.03	1.04	1.05	1.07	1.08	1.09
	2014	0.95	0.96	0.97	0.99	–	1.01	1.03	1.04	1.05	1.07	1.08
	2015	0.94	0.95	0.96	0.97	0.99	–	1.01	1.03	1.04	1.05	1.07

TABLE A.3
Growth factors for state routes: Major arterials (medium growth rate).

State Routes		FC 4 – Major Arterials										
		To AADT Year										
AGR = 1.53%		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
From AADT Year	2010	–	1.02	1.03	1.05	1.06	1.08	1.10	1.11	1.13	1.15	1.16
	2011	0.98	–	1.02	1.03	1.05	1.06	1.08	1.10	1.11	1.13	1.15
	2012	0.97	0.98	–	1.02	1.03	1.05	1.06	1.08	1.10	1.11	1.13
	2013	0.96	0.97	0.98	–	1.02	1.03	1.05	1.06	1.08	1.10	1.11
	2014	0.94	0.96	0.97	0.98	–	1.02	1.03	1.05	1.06	1.08	1.10
	2015	0.93	0.94	0.96	0.97	0.98	–	1.02	1.03	1.05	1.06	1.08

TABLE A.4
Growth factors for state routes: Minor arterials (medium growth rate).

State Routes		FC 5 – Minor Arterials										
		To AADT Year										
AGR = 1.35%		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
From AADT Year	2010	–	1.01	1.03	1.04	1.06	1.07	1.08	1.10	1.11	1.13	1.14
	2011	0.99	–	1.01	1.03	1.04	1.06	1.07	1.08	1.10	1.11	1.13
	2012	0.97	0.99	–	1.01	1.03	1.04	1.06	1.07	1.08	1.10	1.11
	2013	0.96	0.97	0.99	–	1.01	1.03	1.04	1.06	1.07	1.08	1.10
	2014	0.95	0.96	0.97	0.99	–	1.01	1.03	1.04	1.06	1.07	1.08
	2015	0.94	0.95	0.96	0.97	0.99	–	1.01	1.03	1.04	1.06	1.07

TABLE A.5
Growth factors for state routes: Major collectors and locals (medium growth rate).

State Routes		FC 6 & 7 – Major Collectors and Locals										
		To AADT Year										
AGR = 3.20%		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
From AADT Year	2010	–	1.03	1.07	1.10	1.13	1.17	1.21	1.25	1.29	1.33	1.37
	2011	0.97	–	1.03	1.07	1.10	1.13	1.17	1.21	1.25	1.29	1.33
	2012	0.94	0.97	–	1.03	1.07	1.10	1.13	1.17	1.21	1.25	1.29
	2013	0.91	0.94	0.97	–	1.03	1.07	1.10	1.13	1.17	1.21	1.25
	2014	0.88	0.91	0.94	0.97	–	1.03	1.07	1.10	1.13	1.17	1.21
	2015	0.85	0.88	0.91	0.94	0.97	–	1.03	1.07	1.10	1.13	1.17

TABLE A.6
Growth factors for local routes: City streets and county roads (medium growth rate).

Local Routes		City Streets and County Roads										
		To AADT Year										
AGR = 0.74%		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
From AADT Year	2010	–	1.01	1.01	1.02	1.03	1.04	1.05	1.05	1.06	1.07	1.08
	2011	0.99	–	1.01	1.01	1.02	1.03	1.04	1.05	1.05	1.06	1.07
	2012	0.99	0.99	–	1.01	1.01	1.02	1.03	1.04	1.05	1.05	1.06
	2013	0.98	0.99	0.99	–	1.01	1.01	1.02	1.03	1.04	1.05	1.05
	2014	0.97	0.98	0.99	0.99	–	1.01	1.01	1.02	1.03	1.04	1.05
	2015	0.96	0.97	0.98	0.99	0.99	–	1.01	1.01	1.02	1.03	1.04

ADDENDUM B. SUPPLEMENTAL TABLES

TABLE B.1
Predicted annual VMT by FHWA vehicle class, given medium growth factor (units in billions).

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
CLASS 1: MOTORCYCLES												
	0.407	0.408	0.422	0.417	0.420	0.424	0.428	0.432	0.436	0.441	0.445	0.449
CLASS 2: PASSENGER CARS												
	46.483	46.523	48.596	47.818	48.111	48.570	49.033	49.502	49.976	50.455	50.939	51.428
CLASS 3: PICKUPS, PANELS, VANS												
	18.575	18.611	19.554	19.065	19.257	19.438	19.621	19.806	19.993	20.182	20.374	20.567
CLASS 4: BUSES												
	0.141	0.142	0.129	0.168	0.147	0.149	0.150	0.152	0.153	0.155	0.157	0.158
CLASS 5: SINGLE UNIT 2 AXLE TRUCKS												
	1.785	1.791	1.774	2.303	1.941	1.961	1.981	2.002	2.022	2.043	2.064	2.086
CLASS 6: SINGLE UNIT 3 AXLE TRUCKS												
	0.567	0.573	0.786	0.976	0.736	0.743	0.750	0.757	0.764	0.772	0.779	0.786
CLASS 7: SINGLE UNIT 4 AXLE+ TRUCKS												
	0.169	0.172	0.251	0.315	0.230	0.233	0.235	0.237	0.239	0.241	0.244	0.246
CLASS 8: SINGLE TRAILER 3–4 AXLE TRUCKS												
	0.599	0.601	0.388	0.458	0.520	0.525	0.531	0.537	0.542	0.548	0.554	0.560
CLASS 9: SINGLE TRAILER 5 AXLE TRUCKS												
	6.040	6.074	4.120	4.535	5.276	5.333	5.390	5.448	5.507	5.567	5.627	5.688
CLASS 10: SINGLE TRAILER 6 AXLE TRUCKS												
	0.089	0.089	0.058	0.068	0.078	0.078	0.079	0.080	0.081	0.082	0.083	0.084
CLASS 11: MULTI TRAILER 5 AXLE TRUCKS												
	0.141	0.136	0.085	0.108	0.120	0.121	0.122	0.124	0.125	0.126	0.128	0.129
CLASS 12: MULTI TRAILER 6 AXLE TRUCKS												
	0.049	0.047	0.029	0.038	0.042	0.042	0.043	0.043	0.044	0.044	0.045	0.045
CLASS 13: MULTI TRAILER 7 AXLE TRUCKS												
	0.028	0.028	0.078	0.021	0.039	0.040	0.040	0.041	0.041	0.042	0.042	0.043
State Routes & Local Routes Total	**75.075**	**75.195**	**76.272**	**76.292**	**76.917**	**77.656**	**78.404**	**79.161**	**79.925**	**80.698**	**81.479**	**82.269**

TABLE B.2
Predicted annual VMT by highway system and FHWA vehicle class, given low growth factor (units in billions).

FHWA Vehicle Class	Primary Highway Systems	VMT Estimates by Year (units in billions)																				
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
1	State Routes	0.207	0.209	0.211	0.212	0.214	0.216	0.218	0.220	0.222	0.224	0.226	0.228	0.230	0.232	0.234	0.236	0.238	0.240	0.243	0.245	0.247
	Local Routes	0.219	0.220	0.221	0.222	0.224	0.225	0.226	0.227	0.229	0.230	0.231	0.232	0.234	0.235	0.236	0.238	0.239	0.240	0.242	0.243	0.244
2	State Routes	24.834	25.051	25.271	25.493	25.717	25.943	26.172	26.403	26.636	26.871	27.110	27.350	27.593	27.838	28.086	28.337	28.590	28.846	29.105	29.366	29.630
	Local Routes	23.900	24.033	24.166	24.300	24.435	24.571	24.707	24.844	24.982	25.121	25.260	25.400	25.541	25.683	25.825	25.969	26.113	26.258	26.404	26.550	26.697
3	State Routes	9.375	9.457	9.540	9.624	9.709	9.794	9.880	9.967	10.056	10.144	10.234	10.325	10.417	10.510	10.603	10.698	10.793	10.890	10.988	11.086	11.186
	Local Routes	10.129	10.185	10.241	10.298	10.355	10.413	10.471	10.529	10.587	10.646	10.705	10.765	10.824	10.884	10.945	11.005	11.067	11.128	11.190	11.252	11.314
4	State Routes	0.110	0.111	0.112	0.113	0.114	0.115	0.116	0.117	0.118	0.119	0.120	0.121	0.122	0.123	0.124	0.125	0.127	0.128	0.129	0.130	0.131
	Local Routes	0.039	0.039	0.040	0.040	0.040	0.040	0.040	0.041	0.041	0.041	0.041	0.042	0.042	0.042	0.042	0.043	0.043	0.043	0.043	0.044	0.044
5	State Routes	1.343	1.355	1.367	1.379	1.391	1.403	1.415	1.428	1.441	1.453	1.466	1.479	1.492	1.506	1.519	1.533	1.546	1.560	1.574	1.588	1.602
	Local Routes	0.625	0.628	0.632	0.635	0.639	0.642	0.646	0.649	0.653	0.657	0.660	0.664	0.668	0.671	0.675	0.679	0.682	0.686	0.690	0.694	0.698
6	State Routes	0.368	0.371	0.375	0.378	0.381	0.385	0.388	0.392	0.395	0.398	0.402	0.406	0.409	0.413	0.416	0.420	0.424	0.428	0.432	0.435	0.439
	Local Routes	0.377	0.379	0.381	0.384	0.386	0.388	0.390	0.392	0.394	0.396	0.399	0.401	0.403	0.405	0.408	0.410	0.412	0.414	0.417	0.419	0.421
7	State Routes	0.104	0.105	0.106	0.107	0.108	0.109	0.110	0.111	0.112	0.113	0.114	0.115	0.116	0.117	0.118	0.119	0.120	0.121	0.122	0.123	0.125
	Local Routes	0.129	0.130	0.130	0.131	0.132	0.133	0.133	0.134	0.135	0.136	0.136	0.137	0.138	0.139	0.139	0.140	0.141	0.142	0.142	0.143	0.144
8	State Routes	0.407	0.411	0.414	0.418	0.421	0.425	0.429	0.433	0.437	0.440	0.444	0.448	0.452	0.456	0.460	0.464	0.469	0.473	0.477	0.481	0.486
	Local Routes	0.120	0.121	0.121	0.122	0.123	0.123	0.124	0.125	0.126	0.126	0.127	0.128	0.128	0.129	0.130	0.130	0.131	0.132	0.133	0.133	0.134
9	State Routes	4.302	4.339	4.378	4.416	4.455	4.494	4.534	4.574	4.614	4.655	4.696	4.738	4.780	4.822	4.865	4.909	4.953	4.997	5.042	5.087	5.133
	Local Routes	1.048	1.053	1.059	1.065	1.071	1.077	1.083	1.089	1.095	1.101	1.107	1.113	1.120	1.126	1.132	1.138	1.145	1.151	1.157	1.164	1.170
10	State Routes	0.061	0.062	0.063	0.063	0.064	0.064	0.065	0.065	0.066	0.066	0.067	0.068	0.068	0.069	0.069	0.070	0.071	0.071	0.072	0.073	0.073
	Local Routes	0.017	0.017	0.017	0.017	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.019	0.019	0.019	0.019	0.019	0.019	0.019
11	State Routes	0.114	0.115	0.116	0.117	0.118	0.119	0.120	0.121	0.122	0.123	0.124	0.125	0.127	0.128	0.129	0.130	0.131	0.132	0.133	0.135	0.136
	Local Routes	0.007	0.007	0.007	0.007	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
12	State Routes	0.040	0.040	0.041	0.041	0.042	0.042	0.042	0.043	0.043	0.043	0.044	0.044	0.045	0.045	0.045	0.046	0.046	0.047	0.047	0.047	0.048
	Local Routes	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
13	State Routes	0.034	0.035	0.035	0.035	0.036	0.036	0.036	0.037	0.037	0.037	0.038	0.038	0.038	0.039	0.039	0.039	0.040	0.040	0.040	0.041	0.041
	Local Routes	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006

STUDY DELIVERABLES

The Excel file and user's manual discussed in this report are available on the report landing page: http://dx.doi.org/10.5703/1288284316349.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

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