Using EPA MOVES to Build a Repository of Emissions Factors

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16. Abstract

This report synthesizes the findings of three technical assistance requests aimed at developing an emissions-accounting framework for integration into the North Carolina Department of Transportation's (NCDOT's) project prioritization process. Because current prioritization practices do not incorporate atmospheric pollution or air quality impacts, the research team established data sources, analytical methods, and emissions factor lookup tables—derived from EPA's MOVES model—to quantify emissions from both linear highway corridors and point-based operational projects. The resulting framework includes three Vehicle Miles Traveled (VMT) methodologies of increasing complexity for linear projects—Simple, V/C Equipped, and Induced Demand—as well as a Vehicle Hours Traveled (VHT) delay methodology for point projects that captures emissions tied to congestion and idling.

Applied to 1,441 projects in SPOT P.7, these methods reveal substantial differences in environmental outcomes across project types. Point projects generally produced emissions reductions due to notable decreases in delay, while many linear projects generated emissions increases linked to higher post-construction throughput and induced demand. Expanding the pollutant set beyond USDOT's standard criteria consistently elevated estimated environmental costs, though emissions impacts still represented a relatively small share of total project benefits, raising concerns that these effects may be "washed out" in existing scoring structures.

Overall, this work establishes a technically robust foundation for incorporating emissions into statewide transportation decision-making. It also identifies key implementation considerations.

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Executive Summary

North Carolina's process of prioritizing transportation projects for funding currently does not account for atmospheric pollution or air quality as part of its decision-making criteria. This technical assistance request is specifically designed to address this critical gap. The objective of this work is to develop data-driven methodologies that can accurately estimate emissions resulting from various highway projects. This effort seeks to lay the foundation for integrating environmental impacts into the North Carolina Department of Transportation's (NCDOT's) process for prioritizing highway projects.

To support this objective, three technical assistance requests (TARs) were executed and are referenced in Table 1. They established data sources, methodologies, case studies, and advanced a proof of concept on SPOT P.7. highway projects that could be used for estimating emissions quantities and associated costs or benefits.

Table 1. TARs Used to Explore Emissions Accounting in Highway Project Prioritization

Technical Assistance Request	Status
TA2024-15: Investigation of Environmental Measures for P8.0	Complete
TA2025-05: Investigation of Environmental Measures Using Delay	Complete
TAR2025-11: Using EPA MOVES to Build a Repository of Emissions Factors	Contents of this report

Source: ITRE, 2025

The Purpose of Each TAR

TA2024-15 explored the different models and methods state departments of transportation have used for emissions accounting. The core recommendation of TA2024-15 was to use the Environmental Protection Agency's (EPA's) Motor Vehicle Emissions Simulator (MOVES) model to generate a lookup table with emissions factors (similar to the process used by the Massachusetts Department of Transportation). This lookup table would be used to estimate auto and truck emissions on a grams per mile basis, accounting for carbon dioxide (CO2), nitrogen oxide (NO_x), sulfur dioxide (SO_2), and particulate matter ($PM_{2.5}$). **TA2024-15 developed a starter framework that could be used to estimate emissions stemming from changes in vehicle miles traveled** (VMT) and the associated emissions costs.

TA2025-05 expanded on the VMT starter framework and determined three (3) methodologies that could be used for emissions accounting. This allowed for emissions accounting for linear highway projects. Additionally, **TA2025-05 developed a delay methodology that enables emissions accounting for highway point projects**.

TA2025-11 refined the methodologies developed in the first two technical assistance requests. EPA MOVES was used to develop a final lookup table that estimated the emissions released per vehicle mile traveled and per minute of delay. Additionally, induced demand assumptions were refined through an expanded literature search. The third TAR reviewed emissions extending beyond those discussed in U.S. Department of Transportation's Benefit-Cost Analysis Guidance (USDOT's BCA Guidance) and tested the effect of including a wider set of emissions in the methodology.

Key Takeaways Related to Developing an Emissions Accounting Framework for Highways

The research team evaluated 1,441 highway projects in SPOT P.7. Of those projects, 1,009 require a VMT methodology, and 432 require a delay methodology. Emissions quantities and costs were evaluated over a 10-year period. The research team compared the environmental costs of pollutant categories that were monetized within USDOT's BCA Guidance to those plus an extended set of criteria pollutants identified in the EPA MOVES model.

Table 2 demonstrates the average and total environmental costs for all linear highway projects evaluated in the SPOT P.7 project cycle. These costs are derived using SPOT data that estimates existing and future traffic conditions over a 10-year period. Not all linear projects result in notable emissions costs. For example, 47 projects have costs totaling less than $10,000 over a 10-year period when using the simple methodology.

Table 2. Summary of Environmental Costs for Linear Highway Projects by VMT Methodology

Methodology	SPOT Specific Improvement Types (SITs)	Environmental Costs USDOT Pollutants Only [1]	Environmental Costs Extended List of Pollutants[2]
VMT - Simple	1-6, 11, 16-18, 22, 24, 26	**Average Project Environmental Cost: $596,400** Total Environmental Cost in P.7: $601,735,800	**Average Project Environmental Cost: $688,300** Total Environmental Cost in P.7l: $694,451,400
VMT - V/C Equipped	*same as above*	**Average Project Environmental Cost: $410,800** Total Environmental Cost in P.7: $389,066,600	**Average Project Environmental Cost: $470,300** Total Environmental Cost in P.7: $445,414,000
VMT - V/C & Induced Demand	*same as above*	**Average Project Environmental Cost: $727,100** Total Environmental Cost in P.7: $688,612,300	**Average Project Environmental Cost: $831,700** Total Environmental Cost in P.7: $787,656,900

Source: ITRE, 2025

[1]Pollutants evaluated include Nitrogen Oxide (NO_x), Sulfur Dioxide (SO_2), Carbon Dioxide (CO_2), Particulate Matter 2.5 Microns ($PM_{2.5}$).
[2]Pollutants evaluated include those above plus Particulate Matter 10 (PM_{10}), Methane (CH_4), Ethanol (C_2H_5OH), Naphthalene Particle ($C_{10}H_8$), 1,3-Butadiene (C_4H_6), Ammonium (NH_4^+), Ethyl Benzene (C_8H_{10}), Hexane (C_6H_{14}), Propionaldehyde (C_3H_6O), Styrene (C_8H_8), Toluene (C_7H_8), Arsenic Compounds (e.g., As_2O_3), Manganese Compounds (e.g., MnO_2)

Table 3 demonstrates the average total environmental costs for all point highway projects evaluated in the SPOT P.7 project cycle. These costs are anchored using SPOT travel time savings data, which estimates existing and future conditions over a 10-year period. Not all point projects result in emissions savings. For example, 102 of the 432 point projects have emissions costs, while 330 have emissions benefits.

Whether an intersection project results in an emissions benefit or an emissions cost depends on its existing operating conditions and the forecasted changes in travel time. Some intersection improvements are projected to generate travel time savings by reducing delay, improving signal coordination, or enhancing traffic flow. These reductions in delay typically decrease vehicle idling and overall travel time, leading to lower fuel consumption and net emissions benefits.

Other intersection projects, however, may introduce travel time costs—such as increased delay from new traffic controls, geometric changes, or altered turning movements—which cause vehicles to spend more time accelerating, decelerating, and idling. These added delays increase fuel use and therefore lead to higher emissions profiles. As a result, the emissions impact of each intersection project is closely tied to whether it decreases or increases travel time for users moving through the intersection.

Table 3. Summary of Environmental Costs for Point Highway Projects

Methodology	SPOT Specific Improvement Types (SITs)	Environmental Costs USDOT Pollutants Only [1]	Environmental Costs Extended List of Pollutants[2]
VHT - Delay	7-10, 12-15, 19-21, 23, 25	**Average Project Environmental Cost: -$2,340,300** Total Environmental Cost in P.7: -$1,011,001,700	**Average Project Environmental Cost: -$2,702,100** Total Environmental Cost in P.7l: -$1,167,328,700

Source: ITRE, 2025

[1]Pollutants evaluated include Nitrogen Oxide (NO_x), Sulfur Dioxide (SO_2), Carbon Dioxide (CO_2), Particulate Matter 2.5 Microns ($PM_{2.5}$).
[2]Pollutants evaluated include those above plus Particulate Matter 10 (PM_{10}), Methane (CH_4), Ethanol (C_2H_5OH), Naphthalene Particle ($C_{10}H_8$), 1,3-Butadiene (C_4H_6), Ammonium (NH_4^+), Ethyl Benzene (C_8H_{10}), Hexane (C_6H_{14}), Propionaldehyde (C_3H_6O), Styrene (C_8H_8), Toluene (C_7H_8), Arsenic Compounds (e.g., As_2O_3), Manganese Compounds (e.g., MnO_2)

Implications for Implementation

Currently, NCDOT does not formally account for emissions from highway projects within its project prioritization framework. While environmental reviews may estimate emissions for regulatory or NEPA purposes, those emissions are not integrated into the scoring or benefit-cost trade-offs used to decide which projects to fund. As a result, key externalities associated with highway construction, notably the long-term impacts from vehicle operations and infrastructure lifecycle emissions, remain under-reflected in decision-making.

Integrating emissions into the prioritization process can offer a more holistic representation of a project's full societal costs and benefits. By quantifying and monetizing the emissions impacts, decision-makers could more transparently compare trade-offs between capacity expansion, operations projects, or alternatives that reduce vehicle travel. In effect, such an approach brings previously hidden emissions costs into decision-making, helping ensure that investments better align with broader societal goals.

Prospective Unintended Consequences Associated with Implementation

One unintended consequence of incorporating an emissions-accounting methodology into highway project prioritization stems from the fundamental differences between vehicle miles traveled (VMT) and vehicle hours traveled (VHT) calculations. Because the VHT methodology captures operational improvements at point locations, and these projects typically generate notable travel time savings by reducing delay and idling, they often show net emissions reductions after implementation. An analysis of corridor projects using the VMT method results in increased cost, while the analysis of point projects using the VHT method yields an overall benefit.

Given these dynamics, it will be important for future work to consider strategies to address the imbalance created by the differing methodologies for linear versus corridor projects and the resulting boost in scores for point projects. This could include evaluating adjustments or normalization approaches that account for the structural differences between VMT and VHT methods.

It is also important to note that emissions costs remain relatively small compared to travel time savings and safety benefits. For the median linear project evaluated with the VMT method, estimated emissions costs are only about 2.14% of the combined value of travel time and safety benefits. For the median point project evaluated using the VHT method, emissions costs represent roughly 1.29% of those benefits. Because emissions represent such a small share of the total benefit-cost ratio, incorporating emissions into the analysis has the potential to be effectively “washed out,” exerting minimal influence on a project’s overall prioritization outcome (see Table 4 for median share of emissions costs or benefits when compared to safety and travel time benefits).

Approaches to combat the “washout” effect, where emissions costs are overshadowed by much larger travel time and safety benefits, should be explored in future research. Such efforts would help ensure that emissions remain a meaningful component of the prioritization process.

Table 4. Median Share of Travel Time and Safety Benefits by Emissions Methodology

Statistic	VMT	VHT
Count	1,009	432
Median share	1.99%	1.29%

Source: ITRE, 2025

Table 5. Summary of Estimated Emissions Costs by Specific Improvement Type (VMT Methodology)

Specific Improvement Type	Count	Total Emissions Cost	Average Emissions Cost	Median Emissions Cost
1 - Widen Existing Roadway	394	$332,508,039	$843,929	$217,371
2 - Upgrade Arterial to Freeway/Expressway	26	$32,119,564	$1,235,368	$846,177
3 - Upgrade Expressway to Freeway	19	$21,159,307	$1,113,648	$973,013
4 - Upgrade Arterial to Signalized RCI Corridor	53	$31,868,907	$601,300	$405,939
5 - Construct Roadway on New Location	115	$54,874,294	$477,168	$85,769
6 - Widen Existing Roadway and Construct Part on New Location	33	$10,639,565	$322,411	$113,123
11 - Access Management	91	$33,658,303	$369,871	$219,067
16 - Modernize Roadway	180	$25,797,990	$143,322	$84,042
17 - Upgrade Freeway to Interstate Standards	17	$30,361,853	$1,785,991	$788,710
18 - Widen Existing Local (Non-State) Roadway	10	$1,485,262	$148,526	$41,426
22 - Construct Auxiliary Lanes or Other Operational Improvements	9	$11,004,707	$1,222,745	$742,319
24 - Implement Road Diet to Improve Safety	20	$9,205,014	$460,251	$68,574
26 - Upgrade Roadway	42	$7,053,002	$167,929	$131,656
Corridor Improvement Type	1009	$601,735,807		

Source: ITRE Analysis, 2025

Table 6. Summary of Estimated Costs by Specific Improvement Type (VHT Methodology)

Specific Improvement Type	Count	Total Emissions Cost	Average Emissions Cost	Median Emissions Cost
7 - Upgrade At-grade Intersection to Interchange or Grade Separation	33	-$48,785,948	-$1,478,362	-$126,675
8 - Improve Interchange	75	-$657,787,668	-$8,770,502	-$388,261
9 - Convert Grade Separation to Interchange	11	-$5,097	-$463	$0
10 - Improve Intersection	256	-$190,276,632	-$743,268	-$23,387
12 - Ramp Metering	4	-$57,191,740	-$14,297,935	-$12,801,225
13 - Citywide Signal System	8	-$48,036,384	-$6,004,548	-$1,964,197
14 - Closed Loop Signal System	2	-$2,567,571	-$1,283,785	-$1,283,785
19 - Improve Intersection on Local (Non-State) Roadway	3	$120,524	$40,175	$1,314
20 - Convert Grade Separation to Interchange to Relieve Existing Congested Interchange	4	-$947,685	-$236,921	-$80,817
21 - Realign Multiple Intersections	12	-$3,255,720	-$271,310	-$118,056
25 - Improve Multiple Intersections along Corridor	24	-$2,267,802	-$94,492	-$15,439
Point Improvement Type	432	-$1,011,001,722		

*Source: ITRE Analysis, 2025. *** Note, costs shown with negative values are depictions of benefits.*

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Project Context

Accounting for emissions in the transportation prioritization process is essential for creating sustainable and environmentally responsible infrastructure. As transportation is a major source of greenhouse gas (GHG) emissions, integrating emissions data into decision-making helps mitigate climate change and improve air quality. By prioritizing low-emission and energy-efficient projects, policymakers can reduce the environmental impact of transportation systems, promote public health, and align with global sustainability goals. Additionally, this approach encourages innovation in cleaner technologies and fosters a long-term shift toward greener transportation networks, which ensures that development is both economically and ecologically sound.

Emission Methodologies by Specific Improvement Types

NCDOT's highway prioritization process evaluates projects across 26 Specific Improvement Types (SITs), which define the full range of highway mobility projects considered under the agency's purview. These SITs serve as a standardized framework to categorize projects, ensuring that every proposal, from widening major corridors to upgrading small intersections, fits into a clearly documented improvement type.

Broadly, the 26 SITs can be grouped into two categories: linear segment projects and point projects. Linear projects include roadway widening, new capacity expansions, and auxiliary lane additions, all of which extend along a stretch of roadway. Point projects, on the other hand, focus on discrete locations such as intersection improvements, interchange upgrades, or spot safety enhancements.

Because of these structural differences, the methods used to assess environmental impacts, particularly emissions, must also differ. For linear projects, the primary concern is how changes affect overall vehicle miles traveled (VMT) across a corridor, making VMT-based methodologies most appropriate. For point projects, the impacts are better captured through changes in vehicle hours traveled (VHT) or traffic delay at a specific location, since the improvements primarily influence congestion and stop-and-go traffic rather than corridor-wide mileage. This distinction ensures that emissions analyses are tailored to the nature of the project, providing a more accurate measure of environmental outcomes in the prioritization process.

Table 7 provides an overview of the distinction between linear and point project segments. It mentions the emissions methodology and the project functions of linear and point highway projects. Table 8 provides a breakdown of each SIT and the emissions methodology needed for emissions accounting.

Table 7. Linear & Point Highway Projects and their Emissions Methodologies

Category	Examples of SITs	Emissions Methodology	Project Functions
Linear Segment Projects	- Roadway widening (general purpose lanes) - New location roadway / bypass- Managed lanes (HOV, HOT, toll) - Auxiliary lanes (climbing, truck, weaving) - Access management along corridors - Median/shoulder improvements	Vehicle Miles Traveled (VMT)	These projects affect **corridor length and capacity**, changing total miles driven and traffic distribution.
Point Projects	- Intersection upgrades (turn lanes, signal improvements) - Interchange upgrades (ramps, configurations) - Roundabouts - Grade separations (rail or road) - Spot safety/operational improvements	Vehicle Hours Traveled (VHT) "Delay"	These projects affect **bottlenecks and localized congestion**, changing idling, acceleration, and stop-and-go patterns.

Source: ITRE, 2025

Table 8. Highway Specific Improvement Types and Associated Methods (adapted from NCDOT, 2019 and 2024)

SIT	Description	Scoring Category (Mobility or Modernize)	Segment or Point Type	Method for Env. Measure
1	Widen Existing Roadway	Mobility	Segment	VMT
2	Upgrade Arterial to Freeway/Expressway	Mobility	Segment	VMT
3	Upgrade Expressway to Freeway	Mobility	Segment	VMT
4	Upgrade Arterial to Superstreet	Mobility	Segment	VMT
5	Construct Roadway on New Location	Mobility	Segment	VMT
6	Widen Existing Roadway (Part new location)	Mobility	Segment	VMT
7	Upgrade at-grade intersection to Interchange or Grade Separation	Mobility	Point(s)	DELAY
8	Improve Interchange	Mobility	Point(s)	DELAY
9	Convert Grade Separation to Interchange	Mobility	Point(s)	DELAY
10	Improve Intersection	Mobility	Point(s)	DELAY
11	Access Management	Mobility	Segment	VMT
12	Ramp Metering	Mobility	Point(s)	DELAY

SIT	Description	Scoring Category (Mobility or Modernize)	Segment or Point Type	Method for Env. Measure
13	Citywide Signal System	Mobility	Point(s)	DELAY
14	Closed Loop Signal System	Mobility	Point(s)	DELAY
15	Install Cameras and DMS	Mobility	Point(s)	DELAY
16	*Modernize Roadway*	Modernize	Segment	VMT
17	*Upgrade Freeway to Interstate Standards*	Modernize	Segment	VMT
18	Widen Existing or construct New Local (non-state) Road	Mobility	Segment	VMT
19	Improve Intersection on local (non-state) road	Mobility	Point(s)	DELAY
20	Convert Grade Separation to Interchange to relieve an existing interchange	Mobility	Point(s)	DELAY
21	Realign Multiple Intersections	Mobility	Point(s)	DELAY
22	Construct Auxiliary Lanes or Other Operational Improvements	Mobility	Segment	VMT
23	Improve Highway-Railroad Crossing	Mobility	Point(s)	DELAY
24	Implement Road Diet to Improve Safety	Mobility	Segment	VMT
25	Improve Multiple Intersections along a corridor	Mobility	Point(s)	DELAY
26	Upgrade Roadway	Mobility	Segment	VMT

Source: ITRE, 2025

Vehicle Miles Traveled Methodology

As part of TA2024-15, the research team developed an emissions framework that could be used to account for linear highway project emissions resulting from vehicle miles traveled (TA2024-15 is appended to this report, see Appendix A). That VMT framework was further developed as part of TA2025-05 and TA2025-11 to account for changes in emissions subject to vehicle speeds and induced demand. Ultimately, the TARs resulted in three VMT methodologies (simple, V/C equipped, and induced demand). These methodologies, including their data sources and formulas, are discussed in this section. The vehicle hours traveled, or VHT, methodology is discussed in the next section.

VMT Data Sources

To the greatest extent possible, the research team relied on existing SPOT data and fields within the Highway Project Mastersheet used for project prioritization. Leveraging data and processes already embedded in the SPOT framework provides two key advantages: (1) it builds on workflows and methodologies that have already been reviewed and approved by NCDOT, and (2) it draws from established, validated data sources that are familiar to both staff and stakeholders. This approach minimizes redundancy, enhances consistency with prior prioritization cycles, and streamlines integration of new environmental measures. For clarity and ease of understanding, the research team has documented the SPOT data sources used for emissions quantification in Table 9 and external data sources in Table 10.

Table 9. SPOT Data Sources for Emissions Quantification

Data Element	Column*	Highway Project Mastersheet Name
Project Length	DM	Grouped Project Length (Miles)
Base Year Project Volume	EH, FN	Existing Volume (AADT)
Future AADT	GC	TTS Future Year Existing Volume - CALC
Auto Percentage	ED	Auto %
Truck Percentage	EE	Truck % (FORMULA - DO NOT OVERRIDE)
Existing V/C Ratio	FR	Base Year V/C Ratio with Project
Future V/C Ratio	FS	Future Year V/C Ratio with Project

Source: ITRE, 2025

**Denotes the column in the Highway Master Sheet that contains data available for emissions quantification.*

Table 10. External Data Sources for Emissions Quantification

Data Element	Notes
EPA MOVES Emissions	USDOT BCA monetized pollutants[1] and a wider set of EPA MOVES pollutants[2] underwent a comparative analysis as part of this effort.
EPA MOVES Emissions by Vehicle Speed	For V/C method.
USDOT BCA Guidance	For monetization values.
Percent of Free Flow Speed Lookup	For speeds & associated emissions.
Induced Demand	Elasticity values for induced demand were sourced from a literature scan as part of this effort. These values and sources can be found in Table 21.

Source: ITRE, 2025

[1]Pollutants evaluated include Nitrogen Oxide (NO_x), Sulfur Dioxide (SO_2), Carbon Dioxide (CO_2), Particulate Matter 2.5 Microns ($PM_{2.5}$).
[2]Pollutants evaluated include those above plus Particulate Matter 10 (PM_{10}), Methane (CH_4), Ethanol (C_2H_5OH), Naphthalene Particle ($C_{10}H_8$), 1,3-Butadiene (C_4H_6), Ammonium (NH_4^+), Ethyl Benzene (C_8H_{10}), Hexane (C_6H_{14}), Propionaldehyde (C_3H_6O), Styrene (C_8H_8), Toluene (C_7H_8), Arsenic Compounds (e.g., As_2O_3), Manganese Compounds (e.g., MnO_2)

Overview of the Three VMT Approaches

The research team recognized the importance of developing methods that are nimble and adaptable to different policy objectives embedded within the prioritization workbook. To support this flexibility, the team designed a tiered set of emissions quantification methodologies that can be applied at varying levels of complexity depending on decision-making needs.

At the simplest level, the team developed a VMT-based methodology that estimates emissions using existing and future Annual Average Daily Traffic (AADT) values, incorporating automobile and truck percentages. This approach does not account for forecasted changes in the highway network's volume-to-capacity (V/C) ratio resulting from a project, but it provides a straightforward, transparent method for initial evaluation.

To add nuance, the team introduced a V/C ratio–sensitive methodology, which incorporates changes in congestion levels to reflect a "truer-to-life" picture of highway conditions before and after a project. While more complex, this approach better captures how roadway improvements affect traffic flow and associated emissions.

Finally, the team developed a methodology that explicitly accounts for induced demand—the additional travel generated when roadway capacity is increased. Induced demand is important because it can offset some of the congestion relief benefits of a project, leading to higher long-term VMT and associated emissions. Although this is the most complex methodology, it provides the most realistic representation of future highway conditions and ensures that long-term environmental impacts are fully considered.

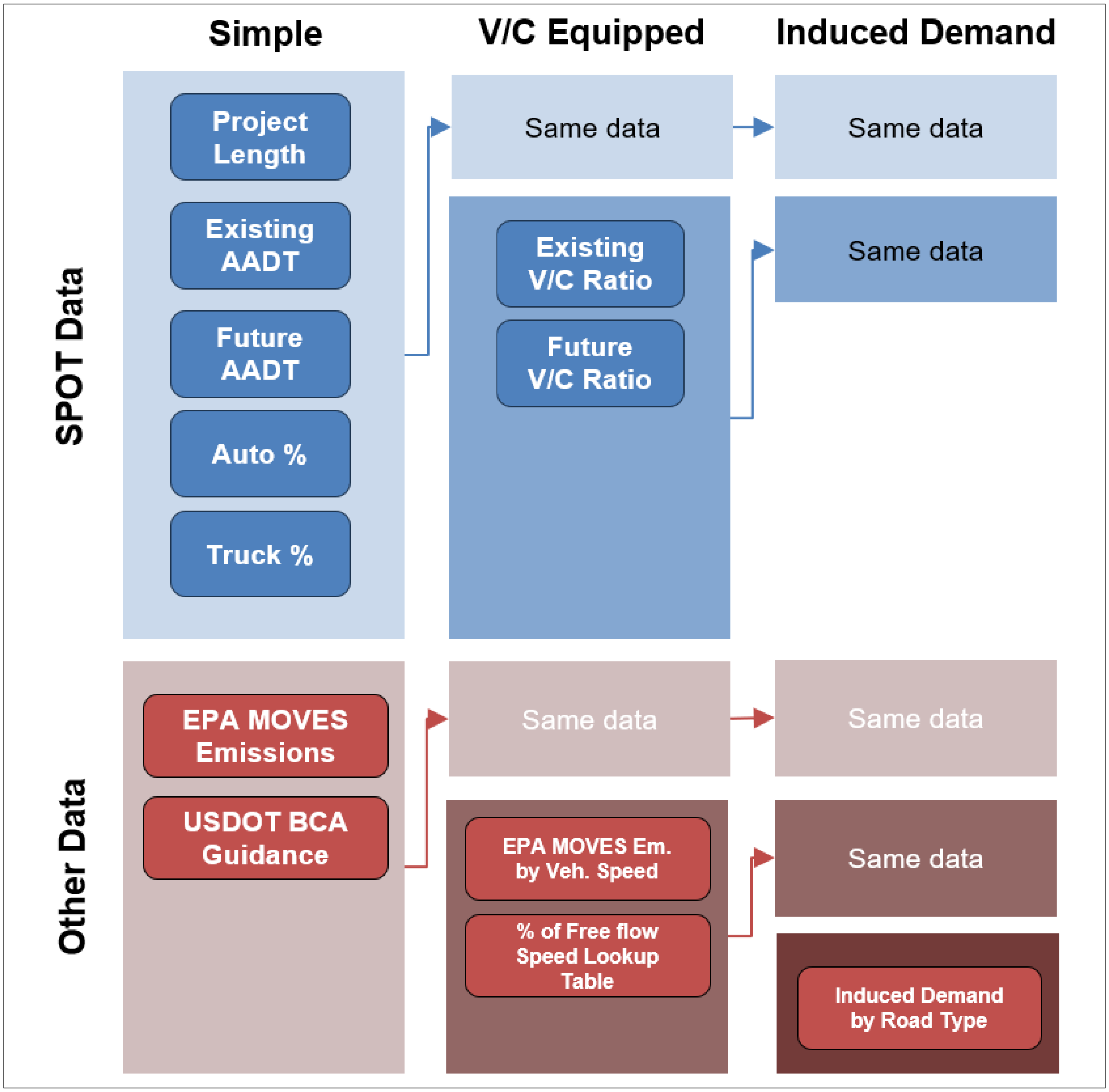


Figure 1. The Three Quantification Options for the VMT Methodology

Figure 1 demonstrates the simple, V/C equipped, and induced demand methodological approaches. Each approach builds on the previous one, using the same datasets at the core, but adding others to build nuance. For example, the volume to capacity equipped approach uses SPOT projections for existing and future V/C ratios and pairs those with a lookup table that crosswalks volume to capacity ratio and free flow speed. Thereafter, the induced demand approach uses the V/C equipped approach, but accounts for the induced demand, or the pent-up traffic that appears when road capacity is increased.

Simple VMT Approach

Description. The "simple" approach compares existing automobile and truck traffic to future automobile and truck traffic across highway corridor. Annual average daily traffic counts for existing and future years are converted to annual traffic counts. Emissions and their costs are estimated by determining the grams of emissions released by VMT for all vehicles on the corridor.

Limitations. This approach does not account for emissions benefits that stem from volume-to-capacity ratio improvements, nor does it account for emissions costs from induced demand that are likely to occur in linear highway projects.

Data Sources. Both SPOT and external data sources are used to estimate emissions using the "Simple" approach. Those data sources are shown in Table 11.

Table 11. Data Sources Used in the Simple VMT Approach

Data Source	Data Element Name
SPOT	Project Length, Existing AADT, Future AADT, Auto %, Truck %
External	EPA MOVES Average Emissions, USDOT BCA Guidance & Literature Review for Monetization Values

Source: ITRE, 2025

Formula. The formula for estimating emissions using the Simple VMT approach is shown in steps 1-7 below. An example showing these steps and resulting emissions values for SPOT ID, H090394-A, NC 191 (Brevard Road / Old Haywood Road) to NC 280 (Boylston Highway) is shown in Figure 2.

Step 1

(Base Year Project Volume) – (Future Year Project Volume) = Net Dif. in Daily Traffic

Step 2

(Net Difference in AADT) x (Project Length) x (Days of Year) = Net Dif. in Annual Traffic on the Corridor

Step 3

(Net Difference in Annual Traffic on the Corridor) x (Auto %) = Auto VMT

Step 4

(Net Difference in Annual Traffic on the Corridor) x (Truck %) = Truck VMT

Step 5

(Auto VMT) x (Ave. Emissions per Auto VMT) x (Emissions Cost per Auto VMT) = Auto Emissions Cost

Step 6

(Truck VMT) x (Ave. Emissions per Truck VMT) x (Emissions Cost per Truck VMT) = Truck Emissions Cost

Step 7

Auto Emissions Cost + Truck Emissions Cost = Total Emissions Cost

NC STATE UNIVERSITY

SPOT ID: H090394-A
TIP: U-3403A
Route: NC 191 (Brevard Road / Old Haywood Road)
Description: Widen to Multi-Lanes with Bicycle Lanes
SIT: 1 - Widen Existing Roadway

VMT Formula – Simple Method

Base Year Project Volume:
AADT: 8,888

Future Year Project Volume[1]:
AADT: 10,077

Net Dif. in AADT: 1,189

× **Project Length 3.69** × **Days of Year 365** = **Change in VMT 1,599,523**

→ **Auto % 95.3**

→ **Truck % 4.7**

Auto VMT: 1,524,835

Truck VMT: 74,698

Emissions Quantities in Grams per Vehicle Mile Traveled (VMT) | NO SPEED LIMIT DIFFERENTIATION

Item	NOx (grams)	SOx (grams)	CO_2 (grams)	$PM_{2.5}$ (grams)
Auto	0.48	0.00	440.16	0.02
Truck (4-13, SU + MU)	2.67	0.01	1633.91	0.07

Pollutant	Cost per Metric Ton	Cost per g
NO_x (Nitrogen Oxides)	$21,100	$0.021100
SO_x (Sulfur Oxides)	$56,800	$0.056800
CO_2 (Carbon Dioxide)	$246	$0.000246
$PM_{2.5}$ (Fine Particulate Matter)	$1,011,100	$1.011100

Source: USDOT BCA Guidance, November 2024 (adjusted to 2025 dollars)

Auto Em. Cost: $209,826
Truck Em. Cost: $39,519

Total Em. Cost: $249,345

[1]Future Year Project Volume accounts for NCSTM growth rates assumptions over a 10-year period. This value is can be sourced directly from SPOT derived values or calculated (8,888*(1+1.26%)^10)

Figure 2. Demonstration of How to Apply the "Simple" Approach Using a SPOT P.7 Project

V/C Equipped VMT Approach

Description. The "V/C Equipped" approach offers more precision than the "Simple" approach. It accounts for changes in vehicular speeds resulting from changes in the volume-to-capacity ratios of linear highway projects. For example, if a corridor experiences congestion relief after a project, the resulting improvement in the V/C ratio will increase average operating speeds.

Accounting for these changes in volume-to-capacity ratios is essential when estimating project-related emissions before and after construction. Relying solely on changes in VMT overlooks how improved operating conditions (particularly higher, more stable travel speeds) can reduce emissions on a per-mile basis along the corridor. By incorporating V/C ratios, the analysis captures the operational benefits of a project that directly influences emission rates, resulting in a more accurate and comprehensive understanding of both the environmental impacts and the true benefits of capacity-related improvements.

The "V/C Equipped" approach offers more precision than the "Simple" approach because it explicitly links corridor operating conditions to emissions. It uses a lookup table that serves as a crosswalk between volume-to-capacity (V/C) ratios and the percent of free flow speed expected under those conditions. For more information about how speed affects emission quantities, see Appendix B. The resulting percent of free flow speed is then multiplied by the corridor's free flow speed to estimate a representative operating speed for the segment. This representative speed is subsequently matched to the EPA MOVES emissions factor table, which reports emissions by vehicle speed, allowing the analysis to reflect how real-world congestion levels influence per-mile emission rates.

By contrast, the "Simple" method relies on a single assumed average speed that does not change with corridor congestion or project-induced operational improvements. This fails to capture how reductions in V/C can increase travel speeds and thereby lower emissions on a per-mile basis. Because the "V/C Equipped" approach ties emissions directly to speed changes derived from V/C ratios, it provides a far more accurate and nuanced estimate of pre- and post-project emissions than the simple average-speed method.

Limitations. Despite the added precision gained by accounting for V/C ratios and their associated operational speeds, this method remains limited because it does not account for induced vehicle demand. Induced demand refers to the well-documented phenomenon in which increasing roadway capacity reduces travel times in the short term, which then encourages additional travel over the medium and long term—either through more frequent trips, longer trips, shifts in travel time, or new travelers entering the system. As a result, even if congestion initially improves and speeds increase, overall VMT along the corridor may rise, partially or fully offsetting the operational and emissions benefits. Because the V/C Equipped method does not model these demand responses, its emissions estimates may understate longer-term project impacts.

Data Sources. Both SPOT and external data sources are used to estimate emissions using the "V/C Equipped" approach. Those data sources are shown in Table 12.

Table 12. Data Sources Used in the V/C Equipped VMT Approach

Data Source	Data Element Name
SPOT	Project Length, Existing AADT, Future AADT, Auto %, Truck %, Existing V/C Ratio, Future V/C Ratio
External	Volume-to-Capacity and Percentage of Free Flow Speed Lookup Table, EPA MOVES Emissions by Vehicular Speed, EPA MOVES USDOT BCA Guidance & Literature Review for Monetization Values

Source: ITRE, 2025

Table 13 shows the EPA MOVES emissions table for automobiles and trucks. The two light blue rows demonstrate the average vehicular emissions for autos and trucks without accounting for vehicle speed. These two rows represent the auto and truck emissions factors used for the "Simple" VMT approach. By contrast, the "V/C Equipped" VMT approach uses the emissions associated with a specific highway corridor and its free flow speed and V/C context.

Table 14 and Table 15 show the emissions factors for pollutants extending beyond those monetized in USDOT's BCA guidance. USDOT accounts for Nitrogen Oxide (NO_x), Sulfur Dioxide (SO_2), Carbon Dioxide (CO_2), and Particulate Matter 2.5 Microns ($PM_{2.5}$). Meanwhile, the EPA MOVES emissions model accounts for dozens more pollutants that are released during vehicular travel. The research team was able to find monetization values for 13 additional pollutants, including Particulate Matter 10 (PM_{10}), Methane (CH_4), Ethanol (C_2H_5OH), Naphthalene Particle ($C_{10}H_8$), 1,3-Butadiene (C_4H_6), Ammonium (NH_4^+), Ethyl Benzene (C_8H_{10}), Hexane (C_6H_{14}), Propionaldehyde (C_3H_6O), Styrene (C_8H_8), Toluene (C_7H_8), Arsenic Compounds (e.g., As_2O_3), and Manganese Compounds (e.g., MnO_2).

Table 16 shows a lookup table for volume-to-capacity ratios and free flow speed. This table provides a direct link between a corridor's volume-to-capacity (V/C) ratio and the percentage of free-flow speed expected under those operating conditions. To estimate the representative speed for a highway segment, the corridor's free-flow speed is multiplied by the percent of free-flow speed associated with its V/C ratio.

Using these adjusted speed estimates improves the emissions profile for a highway segment because vehicle emissions vary significantly with speed, especially under congested or unstable flow conditions. By grounding the analysis in V/C-based speeds rather than a single assumed average speed, the method more accurately captures how real-world congestion affects per-mile emissions.

Formula. The "V/C Equipped" VMT approach is an enhanced version of the simple method. Instead of using average speed, speed is estimated using volume-to-capacity ratios, percent of free flow speed estimates, and the corridor speed limit. The formula for estimating emissions using the "V/C Equipped" approach is shown in steps 1-7 below. An example showing these steps and resulting emissions values for SPOT ID, H090394-A, NC 191 (Brevard Road / Old Haywood Road) to NC 280 (Boylston Highway) is shown in Figure 3.

Step 1

(Base Year Project Volume) – (Future Year Project Volume) = Net Dif. in Daily Traffic

Step 2

(Net Difference in AADT) x (Project Length) x (Days of Year) = Net Dif. in Annual Traffic on the Corridor

Step 3

(Net Difference in Annual Traffic on the Corridor) x (Auto %) = Auto VMT

Step 4

(Net Difference in Annual Traffic on the Corridor) x (Truck %) = Truck VMT

Step 5 – V/C Equipped Enhancement

Use the future year V/C ratio (from SPOT data) and crosswalk it with the percent of free flow speed lookup table value (see Table 16). Then multiply the lookup table value by the project corridor speed limit to get the estimated corridor speed of the project.

Future Year V/C Ratio → % of Free Flow Speed

(% of Free Flow Speed) x (Project Speed Limit) = Estimated Corridor Speed

Step 6 – V/C Equipped Enhancement

Use the Estimated Corridor Speed to determine the EPA MOVES emissions factors for autos and trucks. These emissions factors vary by speed and can be found in Table 13 for the criteria pollutants monetized within the USDOT BCA Guidance. For criteria pollutants monetized with methods beyond those provided in USDOT's BCA Guidance, see Table 14 and Table 15. The monetization values for the criteria pollutants not included in USDOT's BCA Guidance can be found in Table 17. These emissions factors and monetization values will be used in steps 7, 8, and 9.

Step 7

(Auto VMT) x (Ave. Emissions per Auto VMT) x (Emissions Cost per Auto VMT) = Auto Emissions Cost

Step 8

(Truck VMT) x (Ave. Emissions per Truck VMT) x (Emissions Cost per Truck VMT) = Truck Emissions Cost

Step 9

Auto Emissions Cost + Truck Emissions Cost = Total Emissions Cost

Table 13. Emissions in Grams per Vehicle Mile Traveled by USDOT Category Pollutant and Speed

Vehicle Type	Speed Bin	Nitrogen Oxide	Sulfur Dioxide	Carbon Dioxide	PM 2.5	Emissions Cost per Mile
Auto (Class 1-3)	0≤Speed<2.5	1.820	0.012	1573.469	0.077	$0.50
Auto (Class 1-3)	2.5≤Speed<7.5	1.027	0.007	890.827	0.044	$0.29
Auto (Class 1-3)	7.5≤Speed<12.5	0.623	0.004	550.763	0.026	$0.18
Auto (Class 1-3)	12.5≤Speed<17.5	0.473	0.003	439.845	0.020	$0.14
Auto (Class 1-3)	17.5≤Speed<22.5	0.385	0.003	374.776	0.016	$0.12
Auto (Class 1-3)	22.5≤Speed<27.5	0.346	0.003	336.846	0.013	$0.10
Auto (Class 1-3)	27.5≤Speed<32.5	0.317	0.002	307.398	0.012	$0.09
Auto (Class 1-3)	32.5≤Speed<37.5	0.310	0.002	296.373	0.011	$0.09
Auto (Class 1-3)	37.5≤Speed<42.5	0.308	0.002	289.855	0.011	$0.09
Auto (Class 1-3)	42.5≤Speed<47.5	0.306	0.002	284.836	0.010	$0.09
Auto (Class 1-3)	47.5≤Speed<52.5	0.302	0.002	279.718	0.010	$0.09
Auto (Class 1-3)	52.5≤Speed<57.5	0.297	0.002	276.181	0.010	$0.08
Auto (Class 1-3)	57.5≤Speed<62.5	0.295	0.002	274.875	0.010	$0.08
Auto (Class 1-3)	62.5≤Speed<67.5	0.299	0.002	278.799	0.010	$0.08
Auto (Class 1-3)	67.5≤Speed<72.5	0.305	0.002	287.574	0.010	$0.09
Auto (Class 1-3)	72.5≤Speed	0.315	0.002	300.368	0.010	$0.09
Auto (Class 1-3)	**Average**	**0.4830**	**0.0034**	**440.1563**	**0.0187**	**$0.14**
Truck (Class 4-13)	0≤Speed<2.5	11.070	0.025	5872.461	0.242	$1.92
Truck (Class 4-13)	2.5≤Speed<7.5	5.931	0.014	3405.955	0.137	$1.10
Truck (Class 4-13)	7.5≤Speed<12.5	3.546	0.009	2111.096	0.089	$0.68
Truck (Class 4-13)	12.5≤Speed<17.5	2.825	0.007	1721.091	0.078	$0.56
Truck (Class 4-13)	17.5≤Speed<22.5	2.364	0.006	1476.332	0.071	$0.49
Truck (Class 4-13)	22.5≤Speed<27.5	2.061	0.006	1305.343	0.066	$0.43
Truck (Class 4-13)	27.5≤Speed<32.5	1.931	0.006	1242.937	0.064	$0.41
Truck (Class 4-13)	32.5≤Speed<37.5	1.633	0.005	1095.822	0.051	$0.36
Truck (Class 4-13)	37.5≤Speed<42.5	1.531	0.005	1047.945	0.048	$0.34
Truck (Class 4-13)	42.5≤Speed<47.5	1.453	0.005	1011.391	0.045	$0.32
Truck (Class 4-13)	47.5≤Speed<52.5	1.386	0.005	979.622	0.041	$0.31
Truck (Class 4-13)	52.5≤Speed<57.5	1.328	0.005	950.388	0.037	$0.30
Truck (Class 4-13)	57.5≤Speed<62.5	1.324	0.005	932.797	0.035	$0.29
Truck (Class 4-13)	62.5≤Speed<67.5	1.396	0.005	965.717	0.035	$0.30
Truck (Class 4-13)	67.5≤Speed<72.5	1.460	0.005	996.849	0.036	$0.31
Truck (Class 4-13)	72.5≤Speed	1.534	0.005	1026.748	0.037	$0.32
Truck (Class 4-13)	**Average**	**2.673**	**0.007**	**1633.906**	**0.070**	**$0.53**

Source: ITRE Analysis of EPA MOVES, 2025

Table 14. Emissions in Grams per Vehicle Mile Traveled by Monetizable Category Pollutant and Speed (Part I)

VEHICLE TYPE	SPEED BIN	Omitted Increment of CO_2	PM10	Methane	Ethanol	Napthalene Particle	1,3-Butadiene	Ammonium
Auto (Class 1-3)	0≤Speed<2.5	1573.469348	0.084459185	0.140	0.014	0.000	0.002	0.001
Auto (Class 1-3)	2.5≤Speed<7.5	890.8266912	0.047626638	0.078	0.008	0.000	0.001	0.000
Auto (Class 1-3)	7.5≤Speed<12.5	550.7633312	0.02887851	0.047	0.005	0.000	0.001	0.000
Auto (Class 1-3)	12.5≤Speed<17.5	439.8449071	0.021986767	0.037	0.004	0.000	0.000	0.000
Auto (Class 1-3)	17.5≤Speed<22.5	374.7755726	0.01729961	0.031	0.003	0.000	0.000	0.000
Auto (Class 1-3)	22.5≤Speed<27.5	336.8463237	0.014634674	0.027	0.003	0.000	0.000	0.000
Auto (Class 1-3)	27.5≤Speed<32.5	307.3976912	0.012909911	0.024	0.002	0.000	0.000	0.000
Auto (Class 1-3)	32.5≤Speed<37.5	296.3727559	0.012206764	0.022	0.002	0.000	0.000	0.000
Auto (Class 1-3)	37.5≤Speed<42.5	289.854899	0.011775827	0.021	0.002	0.000	0.000	0.000
Auto (Class 1-3)	42.5≤Speed<47.5	284.8360134	0.01144699	0.020	0.002	0.000	0.000	0.000
Auto (Class 1-3)	47.5≤Speed<52.5	279.7177639	0.011067441	0.019	0.002	0.000	0.000	0.000
Auto (Class 1-3)	52.5≤Speed<57.5	276.1805363	0.010723406	0.018	0.002	0.000	0.000	0.000
Auto (Class 1-3)	57.5≤Speed<62.5	274.8747356	0.010534552	0.018	0.002	0.000	0.000	0.000
Auto (Class 1-3)	62.5≤Speed<67.5	278.7991848	0.01062392	0.017	0.002	0.000	0.000	0.000
Auto (Class 1-3)	67.5≤Speed<72.5	287.5739679	0.010827682	0.018	0.002	0.000	0.000	0.000
Auto (Class 1-3)	72.5≤Speed	300.3678226	0.011234592	0.018	0.002	0.000	0.000	0.000
Auto (Class 1-3)	**Average**	**440.1563466**	**0.020514779**	**0.0346**	**0.0034**	**0.0000**	**0.0004**	**0.0002**
Truck (Class 4-13)	0≤Speed<2.5	5872.461281	0.263901836	40.775	0.005	0.000	0.002	0.001
Truck (Class 4-13)	2.5≤Speed<7.5	3405.95545	0.149798095	24.445	0.003	0.000	0.001	0.001
Truck (Class 4-13)	7.5≤Speed<12.5	2111.096359	0.097531324	13.538	0.002	0.000	0.001	0.000
Truck (Class 4-13)	12.5≤Speed<17.5	1721.090927	0.085404008	9.712	0.002	0.000	0.000	0.000
Truck (Class 4-13)	17.5≤Speed<22.5	1476.332273	0.077492213	7.369	0.001	0.000	0.000	0.000
Truck (Class 4-13)	22.5≤Speed<27.5	1305.342727	0.071642735	6.080	0.001	0.000	0.000	0.000
Truck (Class 4-13)	27.5≤Speed<32.5	1242.936909	0.069955503	5.088	0.001	0.000	0.000	0.000
Truck (Class 4-13)	32.5≤Speed<37.5	1095.821545	0.056087002	4.498	0.001	0.000	0.000	0.000
Truck (Class 4-13)	37.5≤Speed<42.5	1047.945182	0.052144506	3.811	0.001	0.000	0.000	0.000
Truck (Class 4-13)	42.5≤Speed<47.5	1011.391091	0.048996356	3.272	0.001	0.000	0.000	0.000
Truck (Class 4-13)	47.5≤Speed<52.5	979.6223636	0.044843224	2.802	0.001	0.000	0.000	0.000
Truck (Class 4-13)	52.5≤Speed<57.5	950.3881818	0.040926507	2.409	0.000	0.000	0.000	0.000
Truck (Class 4-13)	57.5≤Speed<62.5	932.7966407	0.038292552	2.133	0.000	0.000	0.000	0.000
Truck (Class 4-13)	62.5≤Speed<67.5	965.7166696	0.038844554	1.997	0.001	0.000	0.000	0.000
Truck (Class 4-13)	67.5≤Speed<72.5	996.8490909	0.039447085	1.885	0.001	0.000	0.000	0.000
Truck (Class 4-13)	72.5≤Speed	1026.748409	0.040798982	1.806	0.001	0.000	0.000	0.000
Truck (Class 4-13)	**Average**	**1633.905944**	**0.076006655**	**4.540**	**0.002**	**0.000**	**0.000**	**0.000**

Source: ITRE Analysis of EPA MOVES, 2025

Table 15. Emissions in Grams per Vehicle Mile Traveled by Monetizable Category Pollutant and Speed (Part II)

VEHICLE TYPE	SPEED BIN	Ethyl Benzene	Hexane	Propionaldehyde	Styrene	Toluene	Arsenic Compounds	Manganese Compounds
Auto (Class 1-3)	0≤Speed<2.5	0.012	0.016	0.003	0.001	0.047482569	0.0000018	0.0000012
Auto (Class 1-3)	2.5≤Speed<7.5	0.006	0.009	0.001	0.001	0.025345266	0.0000018	0.0000012
Auto (Class 1-3)	7.5≤Speed<12.5	0.004	0.005	0.001	0.000	0.014376965	0.0000018	0.0000012
Auto (Class 1-3)	12.5≤Speed<17.5	0.003	0.004	0.001	0.000	0.010915129	0.0000018	0.0000012
Auto (Class 1-3)	17.5≤Speed<22.5	0.002	0.003	0.001	0.000	0.009025906	0.0000018	0.0000012
Auto (Class 1-3)	22.5≤Speed<27.5	0.002	0.003	0.000	0.000	0.00781757	0.0000018	0.0000012
Auto (Class 1-3)	27.5≤Speed<32.5	0.002	0.002	0.000	0.000	0.006983321	0.0000018	0.0000012
Auto (Class 1-3)	32.5≤Speed<37.5	0.002	0.002	0.000	0.000	0.006462137	0.0000018	0.0000012
Auto (Class 1-3)	37.5≤Speed<42.5	0.001	0.002	0.000	0.000	0.006082528	0.0000018	0.0000012
Auto (Class 1-3)	42.5≤Speed<47.5	0.001	0.002	0.000	0.000	0.005788051	0.0000018	0.0000012
Auto (Class 1-3)	47.5≤Speed<52.5	0.001	0.002	0.000	0.000	0.005559011	0.0000018	0.0000012
Auto (Class 1-3)	52.5≤Speed<57.5	0.001	0.002	0.000	0.000	0.005388778	0.0000018	0.0000012
Auto (Class 1-3)	57.5≤Speed<62.5	0.001	0.002	0.000	0.000	0.005257512	0.0000018	0.0000012
Auto (Class 1-3)	62.5≤Speed<67.5	0.001	0.002	0.000	0.000	0.005170465	0.0000018	0.0000012
Auto (Class 1-3)	67.5≤Speed<72.5	0.001	0.002	0.000	0.000	0.005122497	0.0000018	0.0000012
Auto (Class 1-3)	72.5≤Speed	0.001	0.002	0.000	0.000	0.005069532	0.0000018	0.0000012
Auto (Class 1-3)	**Average**	**0.0026**	**0.0036**	**0.0006**	**0.0002**	**0.010740452**	**0.0000018**	**0.0000012**
Truck (Class 4-13)	0≤Speed<2.5	0.008	0.007	0.006	0.001	0.034922739	0.0000017	0.0000011
Truck (Class 4-13)	2.5≤Speed<7.5	0.005	0.005	0.003	0.000	0.021914904	0.0000017	0.0000011
Truck (Class 4-13)	7.5≤Speed<12.5	0.003	0.003	0.002	0.000	0.013187212	0.0000017	0.0000011
Truck (Class 4-13)	12.5≤Speed<17.5	0.002	0.002	0.002	0.000	0.009946189	0.0000017	0.0000011
Truck (Class 4-13)	17.5≤Speed<22.5	0.002	0.002	0.001	0.000	0.007748581	0.0000017	0.0000011
Truck (Class 4-13)	22.5≤Speed<27.5	0.001	0.001	0.001	0.000	0.006256791	0.0000017	0.0000011
Truck (Class 4-13)	27.5≤Speed<32.5	0.001	0.001	0.001	0.000	0.005386249	0.0000017	0.0000011
Truck (Class 4-13)	32.5≤Speed<37.5	0.001	0.001	0.001	0.000	0.004620438	0.0000017	0.0000011
Truck (Class 4-13)	37.5≤Speed<42.5	0.001	0.001	0.001	0.000	0.003981874	0.0000017	0.0000011
Truck (Class 4-13)	42.5≤Speed<47.5	0.001	0.001	0.001	0.000	0.003486894	0.0000017	0.0000011
Truck (Class 4-13)	47.5≤Speed<52.5	0.001	0.001	0.001	0.000	0.003097415	0.0000017	0.0000011
Truck (Class 4-13)	52.5≤Speed<57.5	0.001	0.001	0.001	0.000	0.00277451	0.0000017	0.0000011
Truck (Class 4-13)	57.5≤Speed<62.5	0.001	0.001	0.001	0.000	0.002670065	0.0000017	0.0000011
Truck (Class 4-13)	62.5≤Speed<67.5	0.001	0.001	0.001	0.000	0.003134374	0.0000017	0.0000011
Truck (Class 4-13)	67.5≤Speed<72.5	0.001	0.001	0.001	0.000	0.003574627	0.0000017	0.0000011
Truck (Class 4-13)	72.5≤Speed	0.001	0.001	0.001	0.000	0.003858188	0.0000017	0.0000011
Truck (Class 4-13)	**Average**	**0.002**	**0.003**	**0.001**	**0.000**	**0.00932124**	**0.0000017**	**0.0000011**

Source: ITRE Analysis of EPA MOVES, 2025

Table 16. Volume to Capacity and Free Flow Speed Lookup Table

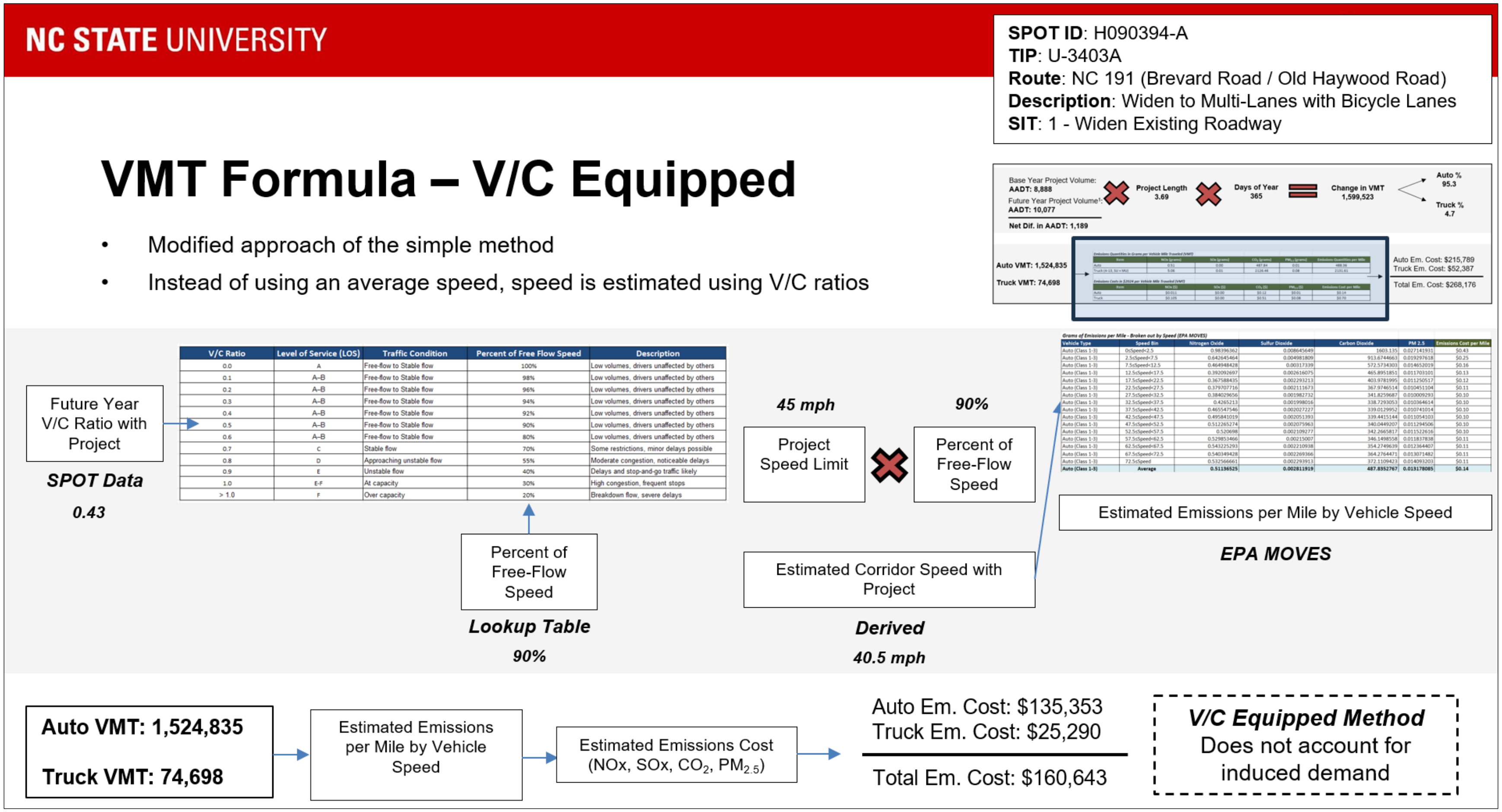
V/C Ratio	Level of Service (LOS)	Traffic Condition	Percent of Free Flow Speed	Description
0.0	A	Free flow to Stable flow	100%	Low volumes, drivers unaffected by others
0.1	A–B	Free flow to Stable flow	98%	Low volumes, drivers unaffected by others
0.2	A–B	Free flow to Stable flow	96%	Low volumes, drivers unaffected by others
0.3	A–B	Free flow to Stable flow	94%	Low volumes, drivers unaffected by others
0.4	A–B	Free flow to Stable flow	92%	Low volumes, drivers unaffected by others
0.5	A–B	Free flow to Stable flow	90%	Low volumes, drivers unaffected by others
0.6	A–B	Free flow to Stable flow	80%	Low volumes, drivers unaffected by others
0.7	C	Stable flow	70%	Some restrictions, minor delays possible
0.8	D	Approaching unstable flow	55%	Moderate congestion, noticeable delays
0.9	E	Unstable flow	40%	Delays and stop-and-go traffic likely
1.0	E-F	At capacity	30%	High congestion, frequent stops
> 1.0	F	Over capacity	20%	Breakdown flow, severe delays

Source: ITRE, 2025 (Adapted from a V/C ratio, LOS, Traffic Condition, and Free Flow Speed Literature Scan)

Table 17. Monetization Factors for Pollutants not Included in USDOT's BCA Guidance (Linear Projects)

Cost Factor	Omitted CO_2 Cost Increment	PM10	Methane	Ethanol	Napthalene Particle	1,3-Butadiene	Ammonium	Ethyl Benzene	Hexane	Propionaldehyde	Styrene	Toluene	Arsenic Compounds	Manganese Compounds
cost per kg		$34.54	$0.73	$0.86	$1.76	$685.22	$0.38	$4.60	$1.60	$728.00	$0.92	$0.85	$1.50	$2.13
cost per g	$0.000045	$0.03	$0.0007	$0.0009	$0.0018	$0.6852	$0.0004	$0.0046	$0.0016	$0.7280	$0.0009	$0.0009	$0.0015	$0.0021

Source: ITRE, 2025 (Adapted from Emissions Literature Scan)



V/C Ratio	Level of Service (LOS)	Traffic Condition	Percent of Free Flow Speed	Description
0.0	A	Free-flow to Stable flow	100%	Low volumes, drivers unaffected by others
0.1	A–B	Free-flow to Stable flow	98%	Low volumes, drivers unaffected by others
0.2	A–B	Free-flow to Stable flow	96%	Low volumes, drivers unaffected by others
0.3	A–B	Free-flow to Stable flow	94%	Low volumes, drivers unaffected by others
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0.7	C	Stable flow	70%	Some restrictions, minor delays possible
0.8	D	Approaching unstable flow	55%	Moderate congestion, noticeable delays
0.9	E	Unstable flow	40%	Delays and stop-and-go traffic likely
1.0	E-F	At capacity	30%	High congestion, frequent stops
> 1.0	F	Over capacity	20%	Breakdown flow, severe delays

Figure 3. Demonstration of How to Apply the "V/C Equipped" Approach Using a SPOT P.7 Project

Table 18. Monetization Factors for Pollutants not Included in USDOT's BCA Guidance (Point Projects - Automobiles)

VEHICLE TYPE	SPEED BIN	Omitted CO_2 Cost Increment	PM10	Methane	Ethanol	Napthalene Particle	1,3-Butadiene	Ammonium	Ethyl Benzene	Hexane	Propionaldehyde	Styrene	Toluene	Arsenic Compounds	Manganese Compounds
Auto (Class 1-3)	Cost per minute	0.07081	0.00292	0.00010	0.00001	0.00000	0.00129	0.00000	0.00005	0.00003	0.00201	0.00000	0.00004	0.00000	0.00000
Auto (Class 1-3)	Cost per hour	$4.25	$0.18	$0.01	$0.00	$0.00	$0.08	$0.00	$0.00	$0.00	$0.12	$0.00	$0.00	$0.00	$0.00

Source: ITRE, 2025 (Adapted from Emissions Literature Scan)

Table 19. Monetization Factors for Pollutants not Included in USDOT's BCA Guidance (Point Projects - Trucks)

VEHICLE TYPE	SPEED BIN	Omitted CO_2 Cost Increment	PM10	Methane	Ethanol	Napthalene Particle	1,3-Butadiene	Ammonium	Ethyl Benzene	Hexane	Propionaldehyde	Styrene	Toluene	Arsenic Compounds	Manganese Compounds
Truck (Class 4-13)	Cost per minute	0.26426	0.00912	0.02977	0.00000	0.00000	0.00117	0.00000	0.00004	0.00001	0.00419	0.00000	0.00003	0.00000	0.00000
Truck (Class 4-13)	Cost per hour	$15.86	$0.55	$1.79	$0.00	$0.00	$0.07	$0.00	$0.00	$0.00	$0.25	$0.00	$0.00	$0.00	$0.00

Source: ITRE, 2025 (Adapted from Emissions Literature Scan)

Induced Demand VMT Approach

Description. The "Induced Demand" VMT Approach builds on the "V/C Equipped" approach by explicitly accounting for the additional vehicle travel that may be generated after a project is constructed. While the "V/C Equipped" method adjusts emissions based on improved operating speeds, it does not capture how increased capacity can attract new trips over time. To address this gap, the "Induced Demand" approach calculates the net difference in vehicle volume over a ten-year period, comparing conditions before and after the project, and multiplies that change by the elasticity of demand associated with the specific highway facility type. This produces an estimated increment of induced AADT that reflects additional travel not otherwise accounted for in the baseline analysis.

Auto and truck splits are then applied to the induced AADT, enabling emission factors to be assigned separately to passenger vehicles and trucks. The resulting induced-demand-related emissions are added to the corridor's total emissions estimate, providing a more complete picture of the project's long-term environmental impacts. By incorporating the behavioral response to added capacity, the "Induced Demand" approach offers greater precision than methods that only consider operational improvements. It helps ensure that emission estimates reflect not only faster speeds but also the additional travel that projects may generate, strengthening the accuracy and credibility of the emissions accounting process.

Data Sources. Both SPOT and external data sources are used to estimate emissions using the "Induced Demand" approach. Those data sources are shown in Table 20.

Table 20. Data Sources Used in the Induced Demand VMT Approach

Data Source	Data Element Name
SPOT	Project Length, Existing AADT, Future AADT, Auto %, Truck %, Existing V/C Ratio, Future V/C Ratio
External	Volume-to-Capacity and Percentage of Free Flow Speed Lookup Table, Induced Demand Elasticities by Road Type, EPA MOVES Emissions by Vehicular Speed, EPA MOVES USDOT BCA Guidance & Literature Review for Monetization Values

Source: ITRE, 2025

Formula. The formula for estimating emissions using the "Induced Demand" approach is shown in steps 1-6 below. An example showing these steps and resulting emissions values for SPOT ID, H090394-A, NC 191 (Brevard Road / Old Haywood Road) to NC 280 (Boylston Highway) is shown in Figure 5.

Step 1

Calculate the difference in vehicle volume before & after project implementation (difference after 10 years)

$AADT_{Difference} = AADT_{Project} - AADT_{Existing}$

Step 2

Multiply by induced demand elasticity to arrive at an estimated induced AADT increment that is not currently accounted for in SPOT.

$AADT_{Difference} \text{ x } Elasticit_{Induced\ Demand} = AADT_{Induced\ Increment}$

Step 3

Add the induced demand increment (not currently accounted for) to the difference in vehicle volume to obtain volume with induced demand.

$AADT_{Induced\ Increment} + AADT_{Difference} = AADT_{Difference\ With\ Induced\ Demand}$

Step 4

Multiply the difference in vehicle volume, accounting for induced demand, times the project length, and times 365 to get project VMT with induced demand.

$AADT_{Difference\ with\ Induced\ Demand} \text{ x Project Length x } 365 = VMTw_{ith\ Induced\ Demand}$

Step 5

Derive Auto and Truck split percentages (use existing SPOT splits)

$VMT_{With\ Induced\ Demand} \text{ x Auto \%} = \text{Auto } VMT_{with\ Induced\ Demand}$

$VMT_{With\ Induced\ Demand} \text{ x Truck \%} = \text{Truck } VMT_{with\ Induced\ Demand}$

Step 6

Derive Project V/C Ratio Including Induced Demand

VOLUME: $(AADT_{Project} + AADT_{Induced\ Demand\ Increment} = AADT_{With\ Induced\ Demand})$ / CAPACITY: $(AADT_{Project} / V/C_{Project})$

Table 21. Induced Demand Assumptions from the Literature

Author	Roadway Types	Short Run Elasticity	Long Run Elasticity
Fulton et al. (2000)	Interstate Highways, state highways, other primary roads (class 1-3)	0.46-0.51	
Nolan & Cowart (2000)	Interstate Highways, state highways, other primary roads... (class 1-4)	0.28-0.76	
Cervero & Hansen (2002)	Class 1-3	0.59	0.79
Duranton & Turner (2011)	Interstates (class 1)		1.03
Su (2011)	All roads (class 1-7)	0.7	0.26
Graham et al. (2014)	Class 1-4		0.77
Hymel (2019)	Freeways and limited access roads (class 1-3)	0.32-0.37	0.89-1.06
Gonzalez & Marrero (2012)	All roads (class 1-7)	0.11-0.17	0.27-0.31
Melo et al. (2012)	Principal arterials, minor arterials (class 3-4)		0.989
Noland (2001)	Interstates, arterials, collector roads by urban and rural (class 1-6)	0.3-0.6	0.7-1.0
Hymel et al. (2010)	States (class 1-7)	0.037	0.186
Hsu & Zhang (2014)	National expressways in Japan (in lane-kilometers) (class 1)		1.24-1.34
Noland (2025)	Urban and rural local roads (class 7)	0.056-0.279	

Source: ITRE, 2025

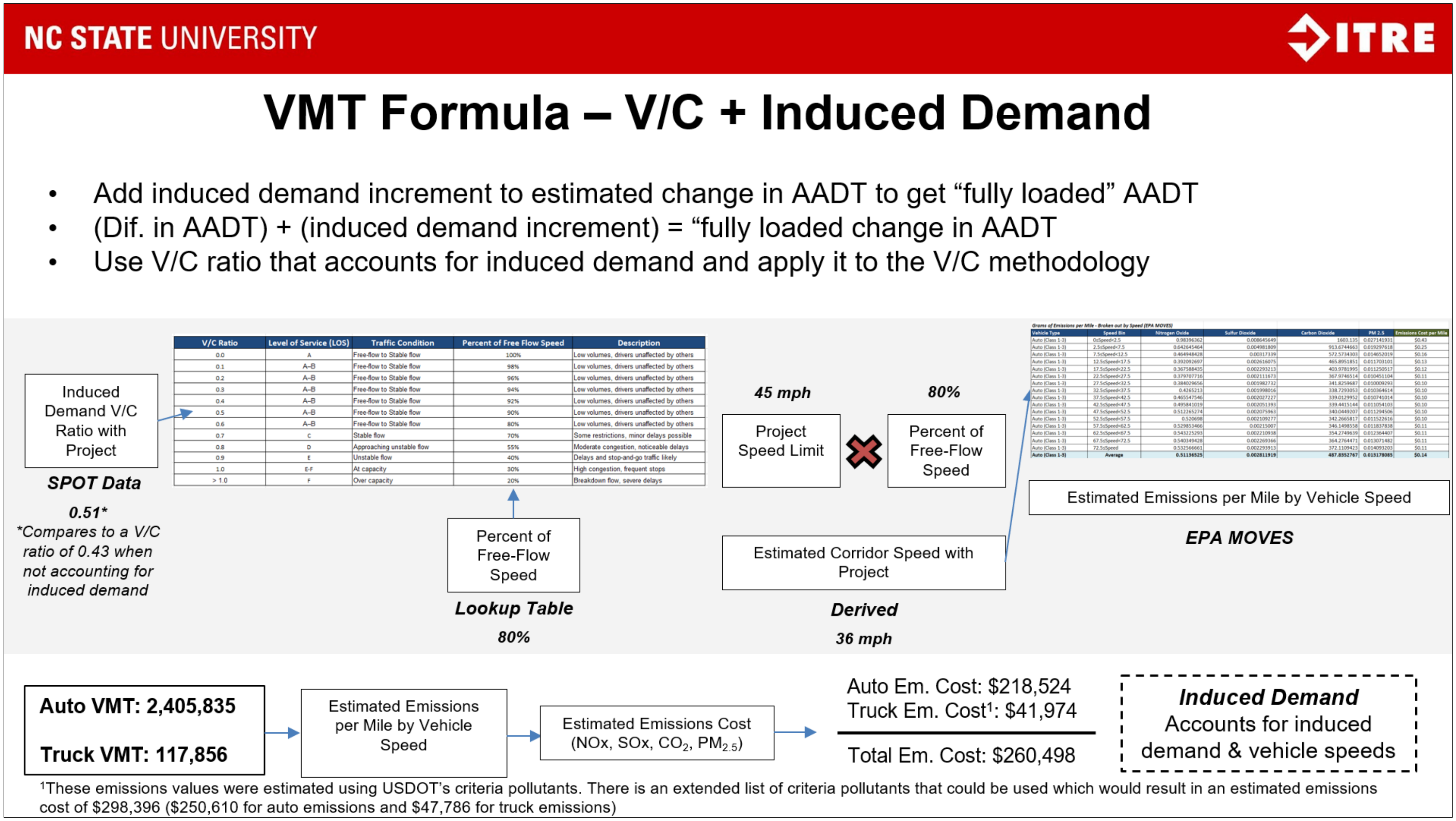
Induced Demand: the extra traffic that appears when road capacity is increased. People might drive more often, choose longer routes, shift trips to peak hours, or even relocate because driving is easier.

If the elasticity of induced demand is 0.5, then a 10% increase in road capacity would lead to a 5% increase in vehicle travel.

Search Term	Highway Type	Elasticity
I-	Interstate	0.70
US	US Highway	0.62
NC	NC Highway	0.60
SR	State Route	0.44
All Other	All Other Roads	0.27

Search Term	Highway Type	Elasticity
I-	Interstate	0.68
US	US Highway	0.62
NC	NC Highway	0.58
SR	State Route	0.44
All Other	All Other Roads	0.23

Figure 4. Changes in Induced Demand Assumptions from TA2025-05 to TA2025-11



V/C Ratio	Level of Service (LOS)	Traffic Condition	Percent of Free Flow Speed	Description
0.0	A	Free-flow to Stable flow	100%	Low volumes, drivers unaffected by others
0.1	A–B	Free-flow to Stable flow	98%	Low volumes, drivers unaffected by others
0.2	A–B	Free-flow to Stable flow	96%	Low volumes, drivers unaffected by others
0.3	A–B	Free-flow to Stable flow	94%	Low volumes, drivers unaffected by others
0.4	A–B	Free-flow to Stable flow	92%	Low volumes, drivers unaffected by others
0.5	A–B	Free-flow to Stable flow	90%	Low volumes, drivers unaffected by others
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0.9	E	Unstable flow	40%	Delays and stop-and-go traffic likely
1.0	E-F	At capacity	30%	High congestion, frequent stops
> 1.0	F	Over capacity	20%	Breakdown flow, severe delays

Figure 5. Demonstration of How to Apply the “Induced Demand” Approach Using a SPOT P.7 Project

Delay Methodology

The delay methodology differs from the three VMT methodologies discussed in the previous section (“Simple”, “V/C Equipped”, and “Induced Demand”). The delay methodology focuses on quantifying emissions resulting from point highway projects such as intersection upgrades (turn lanes, signal improvements), interchange upgrades (ramps, configurations), roundabouts, grade separations (rail or road), or spot safety/operational improvements.

The delay methodology relies on the travel time savings data and processes already embedded within the Highway Project Mastersheet, specifically the CMT and CALC methodologies. These approaches generate estimates of annual hours of delay by comparing traffic conditions before and after the implementation of a point project. This allows the emissions analysis to build on established and validated prioritization processes while ensuring consistency with existing project evaluation frameworks.

Once annual hours of delay are calculated, the methodology applies idle emissions rates (grams per hour) for each relevant pollutant and vehicle type. By multiplying the total annual hours of delay by these emission factors, the process yields an estimate of the quantity of emissions reduced or increased due to the project. This approach provides a straightforward way of linking travel time outcomes directly to air quality impacts.

After total emissions quantities are derived, the methodology incorporates monetization to translate emission reductions into economic terms. Using values from USDOT’s BCA Guidance, each pollutant is assigned a dollar value per ton reduced or emitted. This step allows environmental impacts to be expressed in a way that is directly comparable to other project benefits considered in the prioritization process.

Overall, this methodology provides a structured and practical means of accounting for the emissions benefits of point projects, which primarily influence congestion and delay rather than total vehicle miles traveled. As an important note, approximately three-fourths of the point projects tested using SPOT P.7 data (330 of 432) resulted in emissions benefits, while approximately one-fourth (102 of 432) resulted in emissions costs.[1]

Data Sources. Both SPOT and external data sources are used to estimate emissions using the “Delay” methodology. Those data sources are shown in Table 22.

[1] The VHT methodology generally targets operational improvements at specific locations, where projects reduce delay and idling, resulting in net emissions reductions. By contrast, corridor projects evaluated using VMT often exhibit increased emissions, as the higher traffic volumes enabled by post-construction throughput can outweigh emissions savings from reduced idling.

Table 22. Data Sources Used in the Delay Methodology

Data Source	Data Element Name
SPOT	TTS Total Base Year: CMT & CALC (hrs), TTS Future Year - CMT & CALC (hrs), Auto %, Truck %
External	Volume-to-Capacity and Percentage of Free Flow Speed Lookup Table, EPA MOVES Emissions by Vehicular Speed, EPA MOVES USDOT BCA Guidance & Literature Review for Monetization Values

Source: ITRE, 2025

Formula. The formula for estimating emissions using the "Delay" methodology is shown in steps 1-3 below. An example that demonstrates how to apply this methodology is shown in Figure 6.

Step 1

Account for changes in travel time savings before and after a point project. Use Travel Time Savings (TTS) methodologies derived by CMT and CALC to get annual hours of TTS.

$\Delta TTS = \text{Travel Time Savings}_{ProjectYear} - \text{Travel Time Savings}_{ExistingYear}$

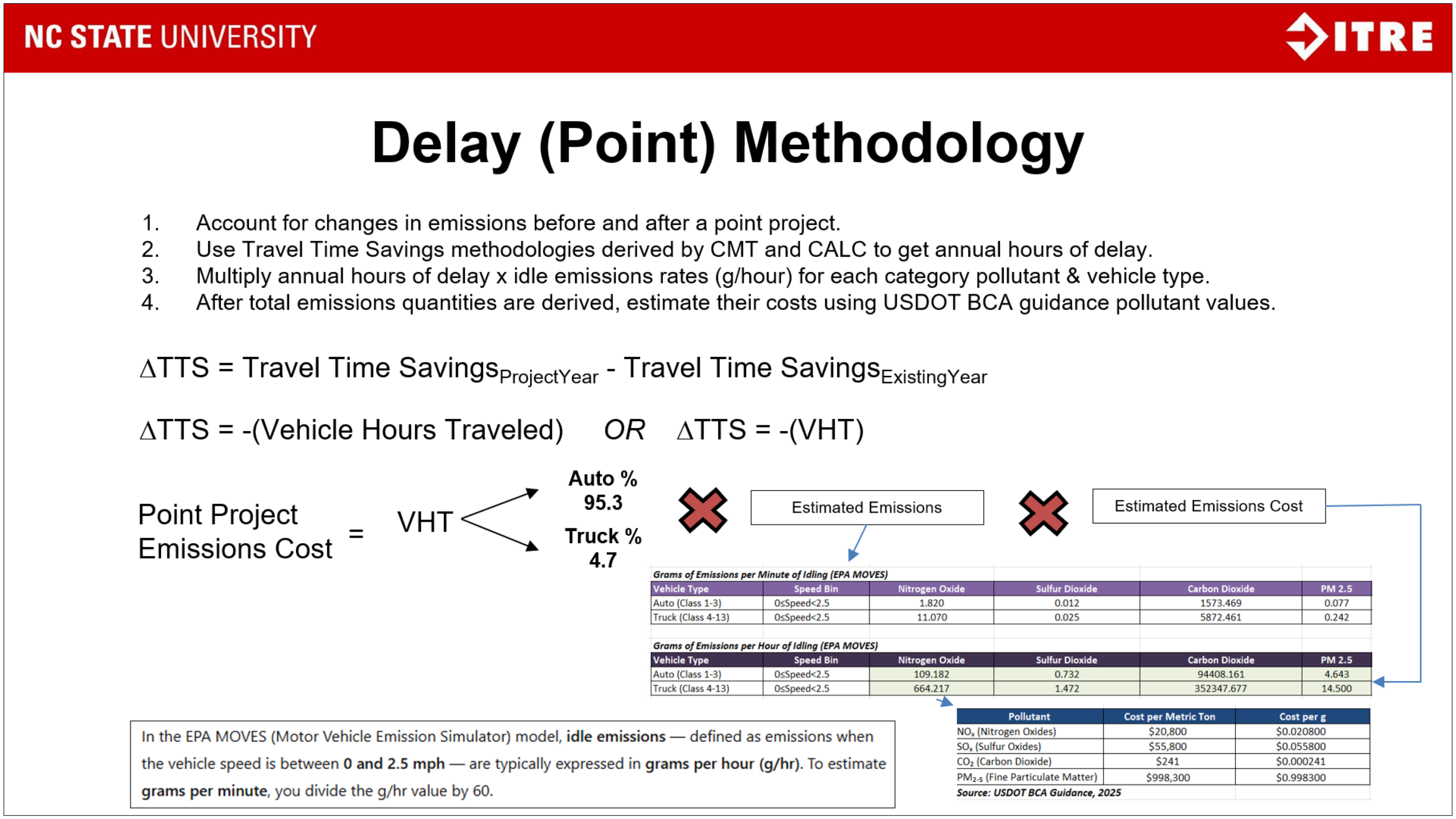
Step 2

Vehicle Hours Traveled (VHT) from a highway point investment is the opposite (negative) of TTS. Multiply ΔTTS times negative one to obtain VHT avoided from the investment. (Please note that not all point projects alleviate hours of travel. In some instances [for example, 102 of 432 in SPOT P.7], TTS is less after project implementation than at the current date.)

$\Delta TTS = -(VHT)$

Step 3

Multiply annual hours of delay times by idle emissions rates (g/hour) for each category pollutant & vehicle type.
Point Project Emissions Cost = [(VHT x Auto%) x emissions quantities x emissions costs] + [(VHT x Truck%) x emissions quantities x emissions costs]



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Delay (Point) Methodology

1. Account for changes in emissions before and after a point project.
2. Use Travel Time Savings methodologies derived by CMT and CALC to get annual hours of delay.
3. Multiply annual hours of delay x idle emissions rates (g/hour) for each category pollutant & vehicle type.
4. After total emissions quantities are derived, estimate their costs using USDOT BCA guidance pollutant values.

$$\Delta TTS = \text{Travel Time Savings}_{ProjectYear} - \text{Travel Time Savings}_{ExistingYear}$$

$$\Delta TTS = -(\text{Vehicle Hours Traveled}) \quad OR \quad \Delta TTS = -(VHT)$$

Point Project Emissions Cost = VHT (Auto % 95.3; Truck % 4.7) × Estimated Emissions × Estimated Emissions Cost

Grams of Emissions per Minute of Idling (EPA MOVES)

Vehicle Type	Speed Bin	Nitrogen Oxide	Sulfur Dioxide	Carbon Dioxide	PM 2.5
Auto (Class 1-3)	0≤Speed<2.5	1.820	0.012	1573.469	0.077
Truck (Class 4-13)	0≤Speed<2.5	11.070	0.025	5872.461	0.242

Grams of Emissions per Hour of Idling (EPA MOVES)

Vehicle Type	Speed Bin	Nitrogen Oxide	Sulfur Dioxide	Carbon Dioxide	PM 2.5
Auto (Class 1-3)	0≤Speed<2.5	109.182	0.732	94408.161	4.643
Truck (Class 4-13)	0≤Speed<2.5	664.217	1.472	352347.677	14.500

Pollutant	Cost per Metric Ton	Cost per g
NO_x (Nitrogen Oxides)	$20,800	$0.020800
SO_x (Sulfur Oxides)	$55,800	$0.055800
CO_2 (Carbon Dioxide)	$241	$0.000241
$PM_{2.5}$ (Fine Particulate Matter)	$998,300	$0.998300

Source: USDOT BCA Guidance, 2025

In the EPA MOVES (Motor Vehicle Emission Simulator) model, **idle emissions** — defined as emissions when the vehicle speed is between **0 and 2.5 mph** — are typically expressed in **grams per hour (g/hr)**. To estimate **grams per minute**, you divide the g/hr value by 60.

Figure 6. Demonstration of How to Apply the "Delay" Methodology

Prioritization Considerations

Legislative action by the North Carolina General Assembly would be required to create a new, standalone statutory criterion that explicitly measures and weights vehicular emissions. Changing the statute is necessary only when the State's prioritization framework must be altered to add a separate legal criterion. By contrast, no new legislation is required to account for emissions within an existing criterion. For example, the SPOT scoring framework can incorporate additional metrics or sub-measures under an already-authorized criterion, such as adding an emissions component to the benefit-cost analysis criterion.

Because of that distinction, the most practical and legally straightforward place to house an emissions-focused measure is within the existing benefit-cost criterion. Nesting an emissions component inside benefit-cost allows NCDOT to: (1) quantify emissions impacts alongside other economic and social benefits and costs, (2) apply consistent monetization or scoring methods, and (3) avoid the need for a separate statutory change to create an entirely new prioritization criterion. However, this method could result in emissions impacts being washed out relative to travel time savings and safety benefits. Further study focused on managing wash-out could be valuable.

Implementing emissions accounting in the SPOT process will require policy buy-in and agreement from SPOT governance, specifically the SPOT Workgroup. This will likely follow the SPOT practice of advancing new measures through a targeted Workgroup strike-team (a small, focused subgroup) to develop methodology, test data inputs, and recommend score weighting and documentation before full Workgroup consideration. The SPOT Prioritization (Workgroup) process and Prioritization 8.0 activities schedule show that key P.8 activities (including local input and Division Needs work) occur in the October–December 2026 window, so engaging the SPOT Workgroup and any strike-team in October 2026 would align with the established P.8 calendar.

Implementation Plan

This section presents the plan for putting the project's tools and findings into practice at NCDOT. It details the final deliverables, implementation steps, and metrics that will guide successful integration into agency workflows.

Explanation of Deliverables. The final deliverables include a written report that outlines the research conducted to evaluate including the emissions resulting from vehicular delay into the prioritizaiton process. It is part of a series of three deliverables (1) *TA2024-015: Investigation of Environmental Measures for P8.0*, (2) *TA2025-005: Investigation of Environmental Measures Using Delay (this report)*, and (3) *TA2025-11: Using EPA MOVES to Build a Repository of Emissions Factors*, that will be used to help integrate an environmental measure into the prioritization and scoring of North Carolina's highway projects.

Influence on NCDOT. This project will help provide NCDOT's Office of Strategic Initiatives and Program Support with a process that can be used to estimate emissions costs or benefits stemming from highway projects evaluated in NCDOT's prioritization process.

Implementation Process. The research team is currently in the process of coordinating with NCDOT's Office of Strategic Initiatives and Program Support on a implementing findings from this work.

Measures of Success. This research can be used to demonstrate emissions costs or benefits resulting from highway projects that are evaluated in NCDOT's prioritization process.

Additional Assistance. The research team plans to work with the Office of Strategic Initiatives and Program Support on continued research to fine-tune the research approach used for the induced demand component of this research discussed in this report.

Conclusions and Next Steps

This series of technical assistance requests (TARs) demonstrates the feasibility and value of incorporating emissions accounting into NCDOT's highway project prioritization process. Throughout *TA2024-15: Investigation of Environmental Measures for P8.0*, *TA2025-05: Investigation of Environmental Measures Using Delay*, and *TA2025-11: Using EPA MOVES to Build a Repository of Emissions Factors*, the research team established a robust foundation for estimating environmental impacts by assembling county-level emissions factors, testing multiple methodological approaches, and evaluating the emissions outcomes of more than 1,400 SPOT P.7 projects. Collectively, these efforts show that emissions can be quantified using existing SPOT data, established EPA MOVES tools, and monetization values from USDOT's Benefit-Cost Analysis guidance, thereby providing a defensible pathway for integrating environmental externalities into NCDOT's project evaluation framework.

The work also highlights several important dynamics that should be considered as NCDOT advances toward implementation. In particular, the differences between VMT-based and VHT-based methodologies create asymmetrical outcomes for linear and point projects, with the latter more frequently demonstrating emissions benefits due to delay reduction. Likewise, the incorporation of induced demand has a meaningful effect on long-term emissions outcomes for corridor projects, emphasizing the importance of including behavioral responses when evaluating added capacity. Finally, results from SPOT P.7 reveal that emissions costs tend to represent a small share of overall benefits compared to travel time savings and safety improvements, an effect that risks minimizing the influence of emissions metrics in prioritization unless carefully addressed.

Looking ahead, additional refinement and policy-focused exploration will be essential to ensure that emissions accounting can be adopted in a way that is transparent, equitable, and aligned with NCDOT's strategic goals. The scoring for emissions cost-benefit should ultimately be normalized or weighted to ensure the emission scoring does not get overshadowed by larger benefit categories. This may include developing scaling factors, alternative scoring structures, or threshold-based approaches that ensure emissions remain a meaningful component of prioritization.

An approach could be normalizing the overall scoring to ensure the proper level of point allocations by designating a weight for each of the three benefit scoring categories. Scoring categories, or "buckets", for the cost-benefit calculation are (1) Travel Time Savings, (2) Safety, and (3) Environment. The cost-benefit scoring accounts for 25% of the final project score. That percentage could be allocated based on the three scoring categories, and the score could be weighted to ensure each category carries the desired amount of impact in project prioritization. For example, Travel Time Savings could be allocated 10%, Safety could also be allocated 10%, and Environment could be allocated 5%. That would ensure a set number of available points for each of the cost-benefit categories.

Future research could be used to refine this weighting or explore the impact of different weights on project scoring results. However, this decision would ultimately be a stakeholder decision to ensure the criterion reflects transportation infrastructure investment policy and the desired policy-based outcomes.

Further work is also warranted to refine induced demand assumptions, align elasticity values more closely with North Carolina-specific contexts, and test alternative ways of integrating V/C and speed-based emissions profiles. Finally, as other state DOTs continue to evolve their approaches, NCDOT may benefit from continued engagement with peer agencies to track emerging best practices and evaluate opportunities for methodological harmonization. Together, these next steps will help NCDOT advance toward a more comprehensive and environmentally responsive prioritization framework—one that more fully captures the true societal costs and benefits of transportation investments while supporting statewide goals for sustainability, air quality, and long-term mobility resilience.

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