

# Methodology for Ranking Relative Importance of Structures to Virginia's Roadway Network

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<p>16. Abstract:</p> <p>In 2011, the Structure and Bridge Division of the Virginia Department of Transportation (VDOT) requested assistance from the Virginia Transportation Research Council to develop a structure scoring tool that would rank the relative importance of VDOT-maintained structures to the highway network and to the economy of Virginia. Although tools existed to rank structures by condition and age, no scoring tool existed that systematically incorporated non-condition-based structure features known to be relevant to decision-makers, such as intensity of travel demand for a structure relative to its capacity, the relative magnitude of user costs imposed by potential closure of the structure, and the relative impact of closure of a particular structure on key nearby facilities.</p> <p>The new tool produces a structure score dubbed the "Importance Factor" score (IF score) for all open structures in VDOT's current inventory database. IF scores are based on current data in the structure inventory database on which other structure scoring tools in current use are based, supplemented by geospatial data that identify schools, hospitals, and fire/rescue stations within half-mile increments of each eligible structure up to 3 miles. Beyond 3 miles, a structure is assumed to provide negligible mobilization options to these "key" facilities. IF scores are relative rankings; thus they have no inherent meaning at face value.</p> <p>The tool was statistically tested and adjusted to ensure that the structure characteristics selected to generate IF scores would have known and measurable impacts in accordance with the intentions of an expert panel composed of staff from VDOT's Structure and Bridge Division. Consequently, the relative influences of the factors that determine IF scores are assured by model specification.</p> <p>IF scores are relative rankings of eligible VDOT-maintained structures and may be updated each time a structure inventory database is refreshed. To existing structure scoring tools that measure relative funding need among structures based on condition and age factors, the IF score adds the critically important dimension of the structure's role in the highway system and the economy of Virginia.</p> <p>The study recommends that VDOT's Structure and Bridge Division include consideration of IF scores in making closure decisions and in the process of allocating funds; that VDOT's Structure and Bridge Division consider the new IF rankings, alongside condition and budget data, in decisions relating to bridge maintenance such as ranking structures for rehabilitation or replacement, restorative maintenance, and preventative maintenance actions when preparing the annual needs assessment; and that VDOT's Traffic Engineering Division and Information Technology Division provide support to VDOT's Structure and Bridge Division to automate the export of relevant data that are incorporated into the IF tool from data sources outside the Structure and Bridge Division.</p>					
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## ABSTRACT

In 2011, the Structure and Bridge Division of the Virginia Department of Transportation (VDOT) requested assistance from the Virginia Transportation Research Council to develop a structure scoring tool that would rank the relative importance of VDOT-maintained structures to the highway network and to the economy of Virginia. Although tools existed to rank structures by condition and age, no scoring tool existed that systematically incorporated non-condition-based structure features known to be relevant to decision-makers, such as intensity of travel demand for a structure relative to its capacity, the relative magnitude of user costs imposed by potential closure of the structure, and the relative impact of closure of a particular structure on key nearby facilities.

The new tool produces a structure score dubbed the “Importance Factor” score (IF score) for all open structures in VDOT’s current inventory database. IF scores are based on current data in the structure inventory database on which other structure scoring tools in current use are based, supplemented by geositional data that identify schools, hospitals, and fire/rescue stations within half-mile increments of each eligible structure up to 3 miles. Beyond 3 miles, a structure is assumed to provide negligible mobilization options to these “key” facilities. IF scores are relative rankings; thus they have no inherent meaning at face value.

The tool was statistically tested and adjusted to ensure that the structure characteristics selected to generate IF scores would have known and measurable impacts in accordance with the intentions of an expert panel composed of staff from VDOT’s Structure and Bridge Division. Consequently, the relative influences of the factors that determine IF scores are assured by model specification.

IF scores are relative rankings of eligible VDOT-maintained structures and may be updated each time a structure inventory database is refreshed. To existing structure scoring tools that measure relative funding need among structures based on condition and age factors, the IF score adds the critically important dimension of the structure’s role in the highway system and the economy of Virginia.

The study recommends that VDOT’s Structure and Bridge Division include consideration of IF scores in making closure decisions and in the process of allocating funds; that VDOT’s Structure and Bridge Division consider the new IF rankings, alongside condition and budget data, in decisions relating to bridge maintenance such as ranking structures for rehabilitation or replacement, restorative maintenance, and preventative maintenance actions when preparing the annual needs assessment; and that VDOT’s Traffic Engineering Division and Information Technology Division provide support to VDOT’s Structure and Bridge Division to automate the export of relevant data that are incorporated into the IF tool from data sources outside the Structure and Bridge Division.

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## **INTRODUCTION**

### **Background**

In 2011, the development of a statewide methodology for ranking the importance of structures was initiated as a result of a break-out session during the annual Virginia Department of Transportation (VDOT) Structure and Bridge Leadership Forum. Researchers at the Virginia Transportation Research Council (VTRC) were asked to collaborate with colleagues in VDOT's Structure and Bridge Division to develop a methodology and guidance, to be documented in an advisory report, for objectively ranking structures to support decisions such as maintenance budget prioritization. An expert panel composed of staff from VDOT's Structure and Bridge Division determined that a new ranking of structure importance to the VDOT-maintained road network would be useful in prioritizing funding when VDOT does not have adequate funds for all maintenance, repairs, and replacements needs for its inventory of structures.

The ranking tool was developed from the premise that VDOT-maintained structures shall be closed only if no funds are available to repair or replace them, a situation that under the *Code of Virginia* would occur only after all other potential funding was allocated or reallocated from other purposes yet remained inadequate. In any case, however, the new methodology was envisioned to help determine the order in which structures would be assigned priority for expenditure. Through the use of scores of structure importance in conjunction with the cumulative estimated repair/rehabilitation costs for structures taken sequentially (i.e., according to rank) up to the limit of available funding, VDOT would be able to ensure greater public benefit from available funding by delaying repairs to some low-ranked structures in order to make timely repairs to higher ranked structures.

The new ranking tool was designed to preserve the functionality of the road system maintained by VDOT by means of a consistent rationale that links a structure's role in the VDOT-maintained road system with its "Importance Factor" (IF) score. The IF scoring tool differs from other structure scoring tools because it measures the relative importance of the structure in the movement of people and goods on VDOT-maintained roads and highways.

Generation of a "score" by means of standardized ranking criteria is done in other scoring tools such as that used in association with VDOT's Dedicated Bridge Fund (DBF). DBF rankings prioritize structures according to physical condition and daily traffic, and the score is used to indicate relative need for replacement. In contrast, the new ranking tool provides a measure of the spatial location and the designated role, if any, of each structure in the connectivity and functionality of the VDOT-maintained road system and, by those attributes, to the diverse highway-dependent activities of Virginia, without consideration of the condition (or age) of the structure. The new score informs decision-makers about how essential a link the structure provides in the system as a whole rather than about the urgency of its need for repairs. Therefore, its optimum use is to supplement physical condition scores (such as the DBF formula provides) by formally capturing geospatial and traffic information that is otherwise considered only anecdotally.

Consistency in distinctions between structures in their importance to the road system is a principal benefit of the new tool. Importance is defined uniformly between VDOT construction districts and within them, and structures are ranked with an automated spreadsheet macro module. In current practice, when a structure's condition becomes very poor or critical, the district bridge engineer (DBE) decides on an ad hoc basis whether to repair, replace, or close the specific structure to traffic. The outcome typically results from a case-by-case determination by the DBE based on a balance between practical knowledge of the situation and the informally and subjectively perceived importance of the structure. The new ranking tool is likely to assign a ranking that is consistent with a DBE's informal decision because the tool generates scores from factors that a DBE would normally consider, although qualitatively, in a funding decision. Preliminary results were determined satisfactory in a trial calibration test because consistently low IF scores were generated for a set of structures nominated earlier for closure in each VDOT construction district (i.e., at the initiation of the study before tool development).

The ranking tool developed in this study will add value by supplementing funding criteria in current use. When applied to all VDOT-maintained structures, the new ranking identifies the

structures for which funding continuation can be readily justified on the grounds of the linkages and connectivity they provide for travelers, commerce, and potential emergency mobilizations. In fiscal downturns, the scores can distinguish for policy-makers which structures will have greater or less impact on the functionality of the VDOT-maintained road system and thereby on the welfare, including the economic competitiveness, of Virginia.

### **Related Research in Other States**

Late in this study, the research team learned of related work undertaken at the University of Kansas sponsored by the Kansas Department of Transportation. The Kansas team investigated “advantages and/or disadvantages of closing a bridge on a rural low volume road” determined by comparing the costs of keeping a low-volume structurally deficient rural bridge in service with the increased vehicle operating costs of a driver detour if the bridge is taken out of service (Mulinazzi et al., 2013).

### **PURPOSE AND SCOPE**

This study was undertaken with the purpose of developing a methodology that would provide staff of VDOT’s Structure and Bridge Division, including district structure and bridge staff, with objective and consistent guidance about the relative importance of specific structures to the VDOT-maintained road system.

During the course of the study, it became clear that the desired guidance would be most useful in the form of numerical ranking information that would be compatible with the DBF scoring method and scale; that the methodology should employ data sources that are already familiar to district structure and bridge staff; and that the scores should be easily refreshed with timely supporting data for in-service and VDOT-maintained structures.

As is discussed in this report, existing indices used by VDOT, the Federal Highway Administration (FHWA), and others attempt to combine importance and condition data to produce a single measure for determining the appropriateness of repair or replacement for a particular structure. By decoupling the concepts of importance and condition, it was hoped that the current study would provide managers of bridge inventories with an additional tool to refine and standardize their decision-making process. Thus the new ranking methodology, when considered alongside condition and budget data, could be useful in a much broader spectrum of decisions relating to bridge maintenance.

### **METHODS**

The study objectives were achieved in seven steps:

1. An expert panel composed of staff from VDOT’s Structure and Bridge Division was formed.

2. Scoring formulas in current use within VDOT were reviewed and analyzed for elements that would be useful in estimating the relative importance of each structure.
3. A concept was developed to model a structure's importance to VDOT's road network and to facilitate commerce and other activities in Virginia. The concept was summed up in the term "Importance Factor" (IF).
4. Explanatory variables to support the IF concept were developed for use in calculation of numerical IF scores, and coefficients and index formulas were developed for each explanatory variable.
5. A spreadsheet tool was developed to automate the batch calculation of final scores for a typical inventory of more than 19,000 structures, and an automated spreadsheet macro module was developed to generate and record all variable index values and structure IF scores for all subject structures in a given inventory database.
6. Preliminary IF scores were statistically evaluated to investigate the performance of the model and to guide adjustments to the model.
7. Adjustments were made to the coefficients on explanatory variables in the IF formula to ensure the original desired relative impacts of the variables on IF scores.

### **Formation of Expert Panel**

The VDOT bridge management experts who comprised the expert panel closely advised the researchers in order to expedite the scoring tool and ensure its practicality at the implementation level. The members of the expert panel were Adam Matteo (Assistant State Structure and Bridge Engineer for Maintenance), Jonathan Mallard (Load Rating Program Manager, VDOT Structure and Bridge Division), Jeff Milton (Bridge Preservation Specialist, VDOT Structure and Bridge Division), Prasad Nallapaneni (Assistant State Structure and Bridge Engineer for Engineering Services, VDOT Structure and Bridge Division), and Rex Pearce (Staunton District Structure and Bridge Engineer). The researchers and the expert panel met regularly throughout the duration of the project; the product is the direct result of extensive collaboration.

### **Review of Existing Structure Ranking Tools**

Prior to designing the new instrument for estimating a structure's relative importance, the researchers reviewed two scoring tools that have been used to rank VDOT-maintained structures for funding decisions. These are (1) the DBF ranking scoring tool, an internal VDOT tool, and (2) the Sufficiency Rating (SR) scoring tool, a federal tool that had been, prior to the passage of the Moving Ahead for Progress in the 21st Century Act (MAP-21) in nearly ubiquitous use nationally (FHWA, 2011). The SR currently has no officially established role in prioritization or use of federal funds.

The DBF ranking of a VDOT-maintained structure is calculated from 10 factors, 7 of which describe the structure's physical condition and 3 of which describe the structure's level of use and its location. The SR of a structure is 1 of these 10 factors, although the SR is itself a similar composite score derived mainly from physical condition data with minimal use of traffic and location data. The SR was developed by the FHWA as a comprehensive ranking criterion for states to use in federal funding allocations. The DBF and SR are considered unsatisfactory for the purpose of the current study.

The DBF ranking was, until 2013, computed as a simple discrete score. Each of the 10 components of the DBF score could take one of four discrete point values: 0.25, 0.50, 0.75, and 1.0. It was not mathematically possible for a structure to have a DBF ranking of 0.

A new DBF formula, developed in 2013, scores eligible structures according to continuous functions rather than discrete step functions, allowing granularity of scores and finer scoring distinctions between structures. Yet development of the new tool continued because DBF scores are "stews" of condition, age, and use data, with deliberate emphasis on age and physical condition measurements. Since SR is an input into the DBF score, and some structural characteristics considered within SR are also separately included in the DBF, some of these characteristics have multiple avenues of influence on the final DBF score. Such redundancy may stress relevant characteristics but impedes the comprehensibility of the resulting DBF score.

The SR is a numerical scoring instrument developed by the FHWA and, commensurate with the provision of federal funds for transportation, it was a universally referenced scoring tool in state departments of transportation prior to the adoption of MAP-21. Its use had been mandatory in the identification of bridges eligible for federal funding under the Federal Highway Bridge Program since the Federal-Aid Highway Act of 1978. The SR is calculated from four subsections: S1 or "Structural Adequacy and Safety" (weighted at a maximum of 55% of the total score); S2 or "Serviceability and Functional Obsolescence" (weighted at a maximum of 30% of the final score); S3 or "Essentiality for Public Use" (weighted at a maximum of 15% of the final score); and S4, allowing "Special Reductions" for bridges under certain circumstances (weighted at a maximum of 13% of the final score).

The SR for a given bridge is the sum of S1, S2, and S3 minus S4 when applicable. S1 and S2, together contributing a maximum of 85% of the final score, are calculated from 15 metrics of physical condition and 2 metrics of use (i.e., traffic) and location. S3 is composed of 3 metrics of use and location and may not contribute in excess of 15% to the final score.

Altogether it is apparent from its construction that the SR is intentionally a measure primarily of a structure's physical condition weighted by limited consideration of the traffic it carries rather than a measure of the relative magnitude of the structure's role in directly supporting the roadway system of which it is part.

It was relevant to the current study that federal transportation legislation implemented in 2005 (Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users [SAFETEA-LU]) "freed" the federal Highway Bridge Program "from the requirement that bridges must be considered 'significantly important'" in order to receive (federal) funding

(FHWA, 2005). Consistent with this ruling, the FHWA continued in the 2008 *Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance* to use the SR extensively as a performance measure of alternative bridge management strategies (and funding priorities). The instruction that the “importance” of a structure could be overlooked while the problematic SR continued to be recommended, if not required, for funding decisions effectively endorses VDOT’s search for a scoring tool for funding decisions that ranks bridges primarily according to their importance to the state highway system, a core consideration that no physical condition measure currently captures formally.

A third scoring tool called the Rating Factor (RF), introduced in 1983 for the selective award of discretionary Highway Bridge Replacement and Rehabilitation Program funds, was briefly reviewed to determine whether its formula could inform the present study (FHWA, 1994). Like the DBF ranking, the RF employs the structure’s SR as a major factor in the score, although the formula also juxtaposes project cost against the average daily traffic (ADT) to give a score result that favors bridges that require relatively inexpensive projects and carry high traffic volumes. The RF was disregarded in the current study on the grounds that in the desired scoring tool, project cost is not an exogenous influence on the decision to keep a structure in service or to close it. Rather, project cost in the new guidance is an outcome of the determination that one bridge is of higher importance than another, therefore, meriting the expenditures required to keep it fully in service. Thus the internal logic of the RF is at odds with a valuable benefit anticipated with the new tool, which is the identification of bridges deserving of maintenance or replacement funding on grounds of their importance relative to other VDOT-maintained structures.

### **Development of a Concept for Estimating Relative Structure Importance**

The IF was a new concept for estimating a structure’s importance relative to other structures. The IF score estimates the relative importance of a structure to the road system and to users by means of structure inventory items pertaining to the structure’s use and location. In general, a relative importance ranking (IF score) will be higher with higher traffic volumes and greater bypass detour lengths; a higher number of key (as defined here) facilities within 3 miles of the structure (particularly in combination with a greater bypass detour length); high annualized growth rate of ADT; and location on designated systems. Lower travel demand for the structure, fewer key facilities within 3 miles, location off the designated systems identified here, and a shorter bypass detour length will result in a lower IF score. Several of the explanatory variables in the IF component are constructed from functions of two or more structure inventory items because the functions provide information beyond what individual items can provide. The IF score results from the interplay of use and location features, which are nearly unique for each structure.

The ranking methodology developed in this study purposely draws on readily available data held in federal or state structure inventory databases that track a structure’s location, traffic levels, and physical condition. IF scores reflect the accuracy of those data, and a valid comparison of structures on the basis of IF scores is wholly dependent upon the completeness of the data and the availability of timely updates to the data.

## **Explanatory Variables Supporting the IF Concept**

The unique information desired from the baseline IF score consists of a measure of the importance of a structure's role in the VDOT-maintained system and its relative contribution to facilitation of commerce and other activities of Virginia. The new decision tool is consistent with all existing decision tools that use, in some form, variables for total ADT and the percent of ADT that is composed of trucks. In addition, a structure's status on or off the four designated highway networks (i.e., Base Highway Network, Strategic Highway Network, Surface Transportation Authorization Act [STAA] Highway Network, and the Virginia Highway System) is considered by the expert panel to be directly relevant to the structure's importance in specific transportation objectives of the Commonwealth as represented by these systems. Thus routine structure inventory items are capable of providing current data for six variables in the IF score for a structure.

More complex structure characteristics were developed for three variables in the IF score: the annualized growth rate of ADT, the "Bypass Impact" variable, and the "Access Impact" variable, the latter two of which measure how much traffic is affected by a specific structure closure and how much access a specific structure provides to key facilities (identified as hospitals, schools, and emergency response stations) within 3 miles of the structure. These variables are functions, i.e., combinations, of data items routinely entered into the structure inventory database except in the case of Access Impact. In this case, data from the VDOT Geographical Information System (GIS) are joined to inventory items to provide the variable values for each VDOT-maintained structure.

Structure inventory items that contribute to these nine variables are recorded in the structure inventory database under a wide range of disparate units and so cannot be combined algebraically in raw numerical form. For this reason, the possible range of values for each final explanatory variable is converted into index values on a 0 to 1 scale. In other words, all explanatory variable index values are calculated on a consistent numerical scale. Nevertheless, to ensure the model produced IF scores as intended, a simple statistical adjustment was needed, as described later.

In addition, it was considered desirable, for purposes of differentiation of IF scores, to calculate index values according to continuous functions to the extent possible. To meet this objective, a unique function for each explanatory variable was developed to determine the index value contributed by the variable to the structure's IF score.

The coefficients on variables in the IF formula effectively assign weight to the respective variables in accordance with opinions among the expert panelists. For example, an explanatory variable coefficient of 0.2 means that the variable should have twice the impact on the IF score as a variable with a coefficient of 0.1. All coefficients sum to 1.0 so that the IF formula produces scores on a 0 to 1.0 scale, where 0 is the least important and 1.0 is the most important.

## **Spreadsheet Tool and Macro for Batch Calculations**

Given that more than 19,000 in-service VDOT-maintained structures are typically eligible at any time for an IF ranking, a spreadsheet tool was created to perform the algebra of IF score generation from structure inventory data. In final form, the spreadsheet tool has preserved the option of calculating a single structure score in situations where structure inventory data are determined to be inaccurate (or missing) but can be supplied manually. This direct calculation option requires only that the federal structure number (FSN) be entered in the appropriate cell. If the structure is in service (i.e., in the inventory list that populates the spreadsheet tool), the data are drawn from the database to populate the column directly below the structure number automatically. Missing or inaccurate data may be manually altered in that column. The inputs from that column automatically determine the variable index values in the tool cells and instantaneously generate an IF score in the IF score output cell.

For batch calculations, an automated macro calculates IF scores and variable sub-scores for around 19,500 structures in less than 2 hours and records them for analysis in the same spreadsheet with the inventory data and tool. In other words, the macro generates a total of 10 scores for each structure and places them in a row alongside the input data corresponding to the FSN. This spreadsheet of results permits inspection and analysis of structure characteristics that may cause a specific structure to be more or less highly ranked in importance than expected.

## **Statistical Evaluation of Preliminary Results**

The IF score is intended to be calculated by means of a fully determined model, meaning that it will rank structures according to the model specification and the variables selected, with (literally) no (or negligible) element of “chance.” In other words, a surprising result should be traceable to the explanatory variable at its root. Although it is outside the scope of this study to discover every relationship within the data used in the IF ranking tool, it is well within the scope to ascertain whether the model was adequately specified for this objective of transparency. Consequently, several questions about the raw data and the IF scores were investigated, including the following:

- Do any raw data underlying the (indexed) variables have a problematically high correlation with IF scores?
- Do any raw data underlying the (indexed) variables have a problematically high collinearity with other raw data?
- Does regression analysis indicate that any raw data dominate the magnitude of the IF score?
- Do any variables have a problematically high correlation with IF scores?
- Do any variables have a problematically high collinearity with other variables?

- Does statistical analysis indicate that indexed variables have their intended weights (i.e., according to their initially assigned coefficients) in determining the IF score?

The answers to these questions would determine necessary model adjustments, if any.

### **Model Adjustments**

The IF score model is deterministic and transparent in that the impacts of the variables on IF scores are intended to be consistent with the weights assigned to the variables in the IF formula. Yet there was no assurance that the explanatory variables as ultimately developed would function interactively in the IF formula according to the weights assigned in the concept stage since they were employed in a statistically nonstandardized form. To check for this and remedy it if possible, a statistical evaluation of the formula would be performed to confirm (or not) that the variables were actually influencing IF scores as originally intended, in accordance with the original model specification. If it was found that they were not, new coefficients for the IF formula would be determined and tested by the same criterion of matching the intended relative impacts of the original coefficients.

## **RESULTS**

### **The IF Ranking: Variables, Coefficients, and Index Values**

#### **Variables**

The IF score is calculated using variables that are based on the structure inventory database fields shown in Table 1. Item numbers and descriptions are as given in the *Federal and State Structure Inventory Coding Guide* (VDOT, 2009a).

The 11 inventory items are arranged in nine explanatory variables to determine a structure's importance ranking relative to other structures in the same database. Five of the nine variables are combinations of inventory items listed in Table 1, and the remaining four are designated networks. The reasoning of the expert panel for choosing these nine variables is discussed briefly here:

- *Variable A (Total Average Daily Traffic per Lane, ADT/LN), Variable B (Average Daily Truck Traffic per Lane, ADTT/LN).* The two variables ADT/LN and ADTT/LN are intended to compare demand for the structure relative to its capacity and, by derivation, for the inventory route on which the structure lies. Traffic per lane signals intensity of travel demand for the structure relative to structure capacity, a quality that the metric of ADT cannot capture alone. Analysis of VSYS and ADT show that Virginia highway system designation (secondary, primary, interstate) is a serviceable proxy for simple ADT on a structure, in effect providing an avenue of impact for simple ADT on the IF score. (The correlation between VSYS designation and ADT is examined further later.) (Federal Inventory Items 29, 109, and 28A.)

**Table 1. Field Items and Item Descriptions in the Importance Factor**

Federal Inventory Item No.	State Inventory Item No.	Inventory Item Title	Inventory Item and Abbreviation	Explanatory Variable Related to Inventory Item
F29		ADTTOTAL	Total Average Daily Traffic (ADT)	ADT/LN, ADTT/LN, AGR(ADT), Bypass Impact
F30		ADTYEAR	Year of Average Daily Traffic (YADT)	AGR(ADT)
F114		ADTFUTURE	Future Average Daily Traffic (FADT)	
F115		ADTFUTYEAR	Year of Future Average Daily Traffic (YFADT)	
F109		TRUCKPCT	Average Daily Truck Traffic Percentage (ADTT)	ADTT/LN
F19		BYPASSLEN	Bypass Detour Length (BYP)	Bypass Impact, Access Impact
F12		ONBASENET	Base Highway Network (BHN)	Designated Networks
F100		DEFHWY	Strategic Highway Designation (STRAHNET)	
F110		TRUCKNET	Designated National Network (STAA)	
	S185	VA_HWY__SYS	Virginia Highway System (VSYs)	
F28A		LANES	Lanes on the Structure (LN)	

Source: Federal and State Structure Inventory Coding Guide (VDOT, 2009a).

- Variable C (Annualized Growth Rate of ADT, AGR(ADT)).* The researchers thought that growth of traffic on a structure is an indicator of the structure's relative importance. Since future traffic estimates for VDOT-maintained structures do not share a base year or extend to a common out-year, the inventory item of Future ADT (FADT) at face value is incomparable between structures. For this reason, Variable C values were calculated based on ADT and FADT inventory items. (Federal Inventory Items 29, 30, 114, and 115.)
- Variable D (Bypass Impact).* The Bypass Detour Length (BYP) around a structure is paired with the structure's current ADT in Variable D to quantify the relative inconvenience to drivers of vehicles that would be diverted by the structure's closure. It may be argued that trucks should be considered separately from other traffic on the assumption that payload causes the cost of detour to be higher than for passenger vehicles. Weigh-in-motion station data show, however, that trucks frequently travel with reduced or no payload. Moreover, it can also be argued that the human capital in passenger vehicles in some regions may be more valuable on average than the commercial goods in trucks. For these reasons a distinction between traffic types forced to detour by closure (or posting) of a structure was thought to be too speculative to pursue in this study. (Federal Inventory Items 19 and 29.)

- *Variable E (Access Impact)*. Data from the VDOT GIS are joined to BYP data in Variable E to suggest a structure’s potential serviceability to key facilities located nearby. Specifically, the BYP around a structure is paired with the number of key public facilities within a 3-mile radius of the structure. “Key facilities” are defined as locations of concentrations of potentially vulnerable populations (schools and hospitals) or of providers of emergency services (fire and rescue stations). The value of this variable for any structure depends directly on the number of key facilities that lie within a 3-mile radius, and therefore a given structure may have a value of 0 for Variable E if no key facility is located within that proximity. (Federal Inventory Items 19, 29, and 28A; additional database of key facilities within a 3-mile radius around a structure from the VDOT GIS.)
- *Variables F through I*, the four designated networks, affect IF scores “as is” and are entered as 1 for “on” the network and 0 for “off” the network. Structures on connector routes and non-interstate routes of the Strategic Highway system provide connectivity for fulfillment of the purpose of the designated system and are therefore included as “on” the system. (Federal Items 12, 100, 110; State Item 185.)

The IF score is calculated according to Equation 1 where all variables are nonstandardized:

$$IFscore = (0.2 \cdot V_A) + (0.1 \cdot V_B) + (0.15 \cdot V_C) + (0.25 \cdot V_D) + (0.10 \cdot V_E) + (0.05 \cdot V_F) + (0.05 \cdot V_G) + (0.05 \cdot V_H) + (0.05 \cdot V_I) \quad [Eq. 1]$$

where

- $V_A$  = Index of Variable A (ADT/LN)
- $V_B$  = Index of Variable B (ADTT/LN)
- $V_C$  = Index of Variable C (AGR(ADT))
- $V_D$  = Index of Variable D (Bypass Impact)
- $V_E$  = Index of Variable E (Access Impact)
- $V_F$  = Index of Variable F (BHN)
- $V_G$  = Index of Variable G (STRAHNET)
- $V_H$  = Index of Variable H (STAA) (Surface Transportation Authorization Act Network)
- $V_I$  = Index of Variable I (VSYS).

Every variable value derived from inventory data was normalized to an index scale of 0 to 1.0 and weighted as shown in Equation 1 in the calculation of a preliminary IF score for a particular structure. The formulas for translation of values of Variables A through I to index values  $V_A$  through  $V_I$  are discussed in detail in the following sections.

Equation 1 provides the guiding concept and formula for the IF ranking of VDOT-maintained structures. Specifically, a structure’s relative importance to the VDOT-maintained road network and to Virginia’s transportation-dependent activities can be estimated by demand for the structure (current traffic volumes); annualized growth rate of ADT on the inventory route served by the structure; traffic volumes and bypass detour lengths impacted by the structure’s

closure; key facilities that could depend on the structure to be in service during a private or public emergency; and the structure's presence on (or lack of presence on) designated networks that require all structures to be in service in order for the network to fulfill its designated function.

The intended weight of each variable in determining a structure's IF score is indicated in the coefficient applied to the variable in Equation 1. It should be noted that the coefficients can be readily altered to reflect altered priorities (with the effect of producing different IF scores), but simple statistical adjustments are required to do so, as discussed later.

#### *Variable A (ADT/LN) and $V_A$*

Variable A is an estimate of travel demand for the structure relative to its capacity. It is also a reasonable estimate of user cost caused by diversions of traffic to detours if the structure is taken out of service. In the IF tool, the relative importance of a structure was assumed to be directly proportional to structure use as measured by Variable A. (To repeat, the structure inventory item F29 includes truck traffic as well as traffic from passenger and other vehicles.)

The expert panel assigned a weight of 0.2 to Variable A, as shown in Equation 1. The panel knew that other variables in the IF formula are positively correlated with ADT. Therefore the effect of high ADT on a structure's relative importance ranking is not confined to the coefficient of 0.2 on ADT/LN but will enter through other variables as well.

To relate Variable A values to index value  $V_A$ , Variable A values were organized into 10th percentiles from raw ADT/LN values, and index values from 0 to 1.0 were assigned to each of the 10 bins. From the trend line, a continuous function for increasing index values was developed to correspond to increasing Variable A values, as shown in Figure 1. Based on the March 2016 structure inventory database, values of Variable A below 23 were assigned an index value of 0 (these structures carry less than 1 vehicle per hour per 24-hour period) and Variable A values in excess of 8,500 were assigned an index value of 1.0. A step-function was adopted at the uppermost percentile because of the enormous range of ADT/LN above 8,500, which still comprised only 10% of structures. This simple percentile method of determining an appropriate index value function for Variable A should be adaptable to all inventory databases.

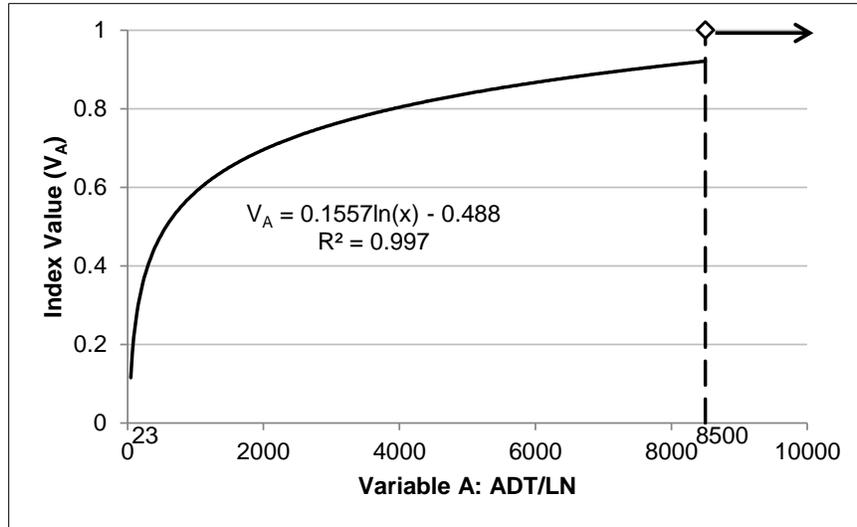


Figure 1. Index Value Function for Variable A: ADT/LN (Total Average Daily Traffic per Lane)

*Variable B (ADTT/LN) and  $V_B$*

Variable B conveys the importance of the structure for commerce relative to its capacity and, secondarily, infers the magnitude of potential negative impacts caused by truck traffic on detour routes if the structure was taken out of service. The expert panel reasoned that the relative importance of a structure specifically for commerce is directly proportional to Variable B.

Index values for  $V_B$  for Variable B were calculated according to the function shown in Figure 2. Because calculated values of Variable B below 4 resulted in negative points under the trend-line function in the graph (which otherwise fit the majority of the data very well), it was decided that the integer value of 4 (i.e., 4 trucks per lane per day on average) is the lower bound for the index value formula corresponding to Variable B.

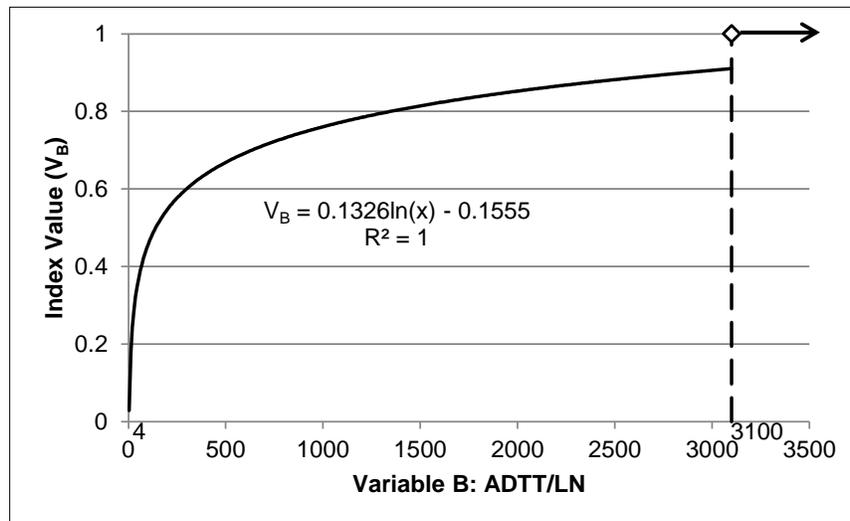


Figure 2. Index Value Function for Variable B: ADTT/LN (Average Daily Truck Traffic per Lane)

In fact, 50% of all IF-ranked structures have 4 or fewer trucks per day in the March 2016 structure inventory. The other 50% of structures are relatively evenly divided into 10th percentiles, with values of Variable B above 3,100 comprising the highest 10th percentile, receiving the maximum index value  $V_B$  of 1.0. As with Variable A, the enormous range of Variable B in the highest 10th percentile suggested a step-function as a logical device.

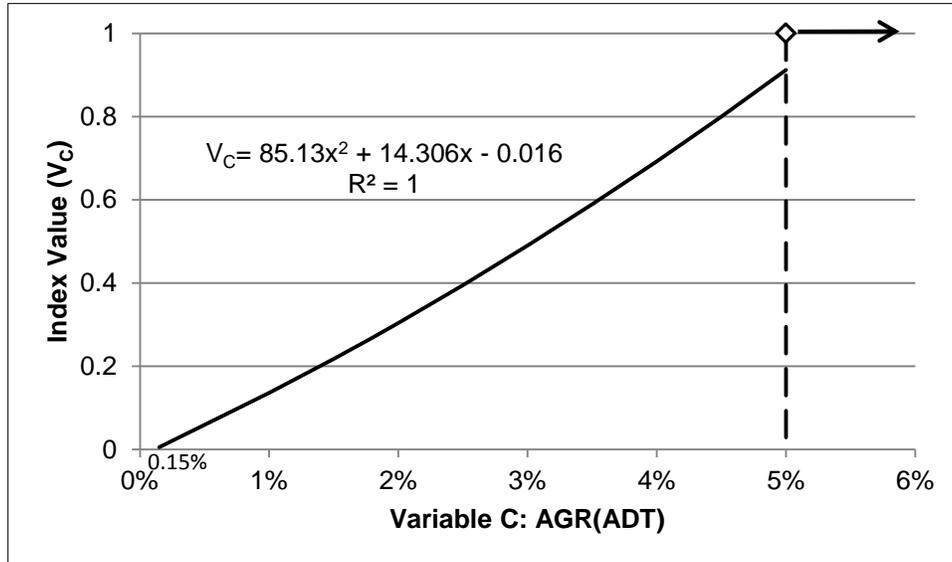
*Variable C (AGR(ADT)) and  $V_C$*

If satisfactory forecasting methods are assumed, a metric of ADT growth will reflect the expected effects of land use planning and zoning as well as (recognized) potential for unplanned development, exogenous regional transportation flows, and numerous other local conditions. However, FADT inventory item values are inherently incomparable between structures because the federal coding requirements allow for estimates of traffic demand to range from 17 to 22 years ahead of the year in which information is submitted to the National Bridge Inventory (although data must be updated if future estimates are effective within 17 years). Thus structures have a wide variety of base years for “current” ADT (VDOT, 2009a). In addition, estimates of ADT levels expected to exist decades in the future are inherently imprecise, which limits their utility.

To create a variable that reflects ADT growth, which at least moderates speculation about distant out-years and is comparable between structures in the present year, the AGR(ADT) for a structure was calculated in Variable C for each eligible structure. With reference to the abbreviations for inventory items shown in Table 1, the formula for Variable C is given in Equation 2:

$$AGR(ADT) = \left[ \frac{FADT}{ADT} \right]^{(1/(YFADT - YADT + 1))} - 1 \quad [Eq. 2]$$

Unlike for Variables A and B, the framework for an index value function for Variable C follows a “rule” that awards an index value increment of 0.1 for each half percentage point increase in Variable C from 1% to 5%. The polynomial function shows that at levels of Variable C between 0% and 1%, index values for  $V_C$  increase slightly more slowly; at all levels of Variable C above 5%, the maximum index value of 1.0 is assigned on the basis of the opinion of the expert panel that any structure with an annual ADT growth of 5% has an exceptionally high travel demand relative to other structures. A trend line was fit to the framework for Variable C to provide a continuous index value function for  $V_C$ , as shown in Figure 3. An AGR(ADT) of 0.15% is the lower bound on the index value function shown for Variable C.



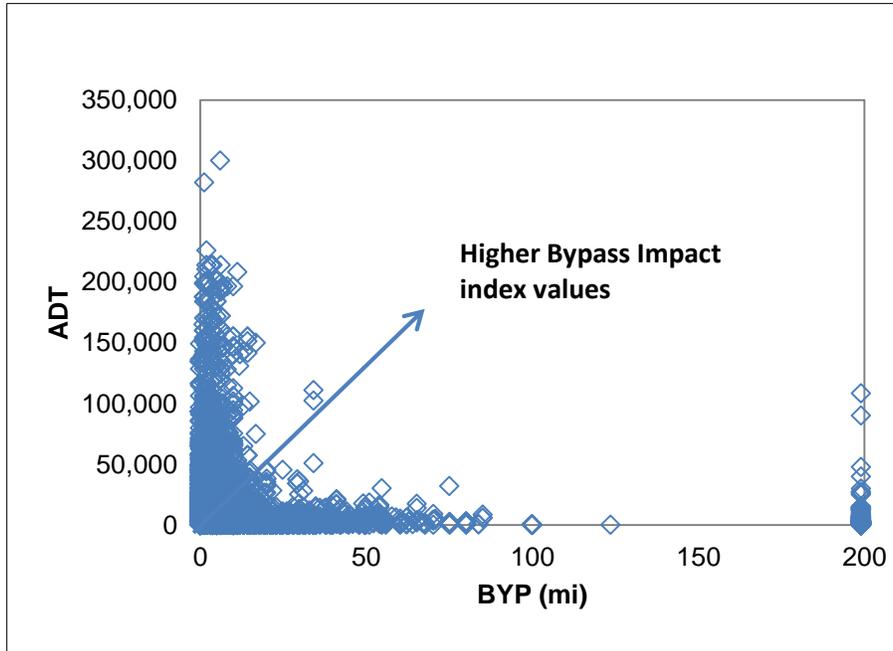
**Figure 3. Index Value Function for Variable C: AGR(ADT) (Annualized Growth Rate of Annual Daily Traffic)**

*Variable D (Bypass Impact) and  $V_D$*

Variable D conveys the combined effect of a structure’s ADT and its inventory BYP in the potential event of closure of the structure to traffic. This concept addresses a perceived weakness in the SR scoring methodology in which the impact of BYP is represented by the product of BYP and ADT, resulting in a single numerical value that masks the individual magnitudes of ADT and BYP. The variable developed here separates rather than conflates these two structure characteristics because their separate magnitudes are consequential to real traffic flows. High ADT diverted from a structure taken out of service will delay a larger number of drivers and consequently impact the surrounding roads (and communities) more adversely, even with a relatively short inventory BYP, than would the diversion of a low level of ADT on a structure with a high inventory BYP. Analysis of structure inventory data also suggests that Virginia structures with high ADT and low BYP tend to be in urban regions with denser road networks, implying potentially more congested routes tasked to serve as detours for additional traffic in the event of a structure closure.

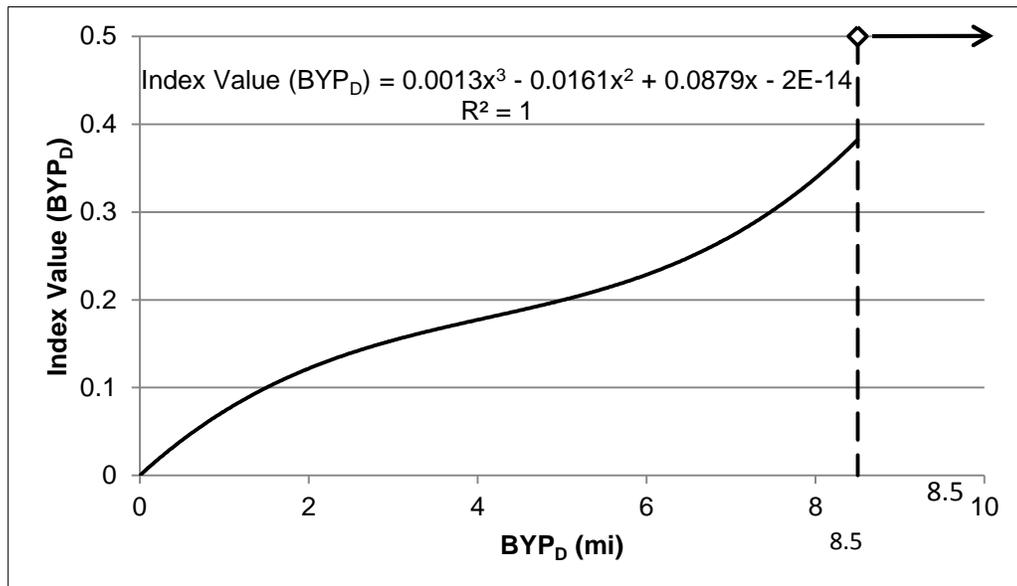
Figure 4 illustrates the overall concept of Variable D in the IF tool. Structures with both high BYP and high ADT (tending toward the northeast quadrant) are assigned a higher index value,  $V_D$ , than structures with a lower value for either BYP or ADT. (A BYP of 99 or 199 miles indicate an inventory route that has no outlet.)

Because high ADT / low BYP and low ADT / high BYP combinations are recognized in this study to have different implications for the relative importance of structures (even if their products are equivalent), BYP and ADT make separate contributions to a structure’s  $V_D$  index value by means of separate index value functions that are added together. Figures 5 and 6 show the index functions for  $BYP_D$  and  $ADT_D$ , and each contributes up to one-half (i.e., 0.5) of the final index value,  $V_D$ , for Variable D.



**Figure 4. Concept of Bypass Impact (Variable D). Blue markers represent structures featuring the given BYP (Bypass Detour Length) and ADT (Average Daily Traffic).**

As shown in Figures 5 and 6, index values of 0 are assigned for  $BYP_D$  and  $ADT_D$  of 0, and maximum index values (0.5) are assigned for  $BYP_D$  of more than 8.5 miles and for  $ADT_D$  of more than 25,000 (which marks the 90th percentile in the ADT data used here). Thus a structure will be assigned a higher total index value,  $V_D$ , if it has high inventory values for both ADT and BYP and correspondingly lower  $V_D$  values at lower levels of either BYP or ADT.



**Figure 5. Index Value Function for BYP (Bypass Detour Length) Factor in Variable D**

Although not fully visible in the scale of Figure 6, the  $ADT_D$  function gives an index value of 0 for  $ADT_D$  less than 37. The maximum index value (0.5) occurs for all  $ADT$  in the top 10th percentile of  $ADT$ , i.e.,  $ADT$  above 25,000 and extending up to 300,000. The continuous portion of the  $ADT_D$  function is the result of intentional mapping of index value increments to  $ADT$  percentiles in order to provide a logical rationale for index values insofar as the data permit (the same approach as taken in Variable A).

For example, the 90th percentile occurs in this dataset at  $ADT_D$  of 25,000, so the “point” index value on the  $ADT_D$  function at 25,000 is computed as  $(0.90)*0.5$  or 0.45, where 0.5 is the maximum index value possible for the influence of  $ADT_D$  on Variable D. After point index values are computed according to this rule for the 10th through the 90th percentiles, a trend line is fit satisfactorily with the formula shown in Figure 6. As noted previously, the top 10th percentile of  $ADT$  in the March 2016 structure inventory has an enormous range (>23,000 to 300,000) and low frequencies. The  $ADT$  in that percentile is therefore grouped into a flat index value bracket of 0.50 and joined to the continuous portion by a step. Both the minimum of 37 and the 90th percentile at 25,000 result from current data and may change with revisions of those data.

As noted, the sum of the separate index values of  $BYP_D$  and  $ADT_D$  for a given structure comprises the index value,  $V_D$ , for Variable D (with a maximum possible value of 1.0, as for all variables). Figure 7 shows the range of values that a structure’s  $V_D$  may take as the sum of its  $BYP_D$  index value (calculated from the formula in Figure 5) and its  $ADT_D$  index value (calculated from the formula in Figure 6). Figure 7 conveys the intent of the expert panel that for a given  $ADT$  (rows), the value of  $V_D$  increases as  $BYP$  (columns) increases, and for a given  $BYP$ , the value of  $V_D$  increases as  $ADT$  increases.

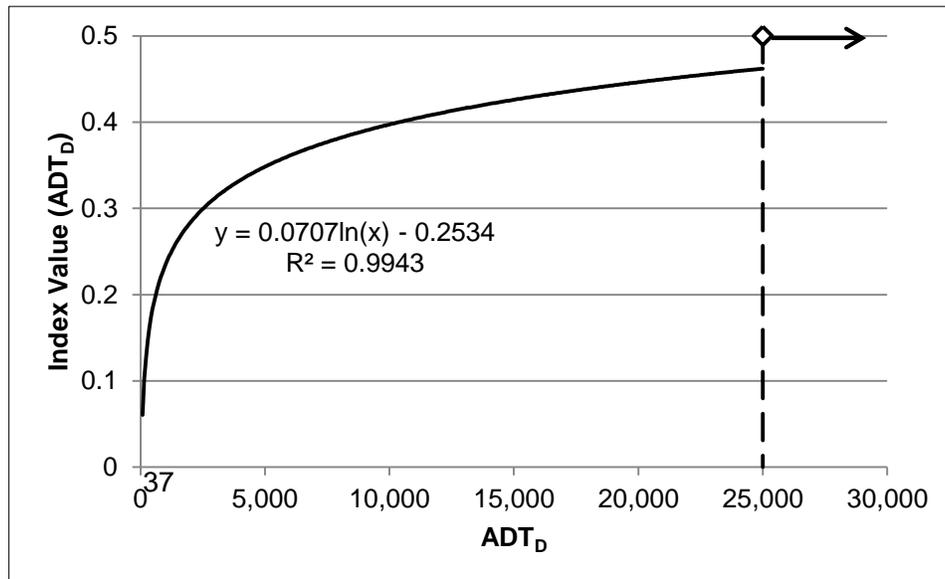


Figure 6. Index Value Function for ADT (Average Daily Traffic) Factor in Variable D

An example from Figure 7 highlights a further intention of the expert panel: a structure with an ADT of 85 (relatively low) and a BYP of 8.5 miles (relatively high) would generate a  $V_D$  of 0.44, but a structure with a BYP of 2 miles (relatively low) carrying an ADT of 25,000 (relatively high) would generate a  $V_D$  of 0.58. The latter structure scores higher on Variable D on the reasoning that the detour of 25,000 vehicles for even 2 miles would be a more severe hardship overall than a far longer detour for only 85 vehicles (on average in a 24-hour period). The functions employed here ensure a higher index value,  $V_D$ , for the structure with a relatively high ADT and a relatively low BYP than for the reverse case.

ADT <sub>D</sub>	BYP <sub>D</sub> (mi)					
	0	2	4	6	8.5	>8.5
85	0.06	0.18	0.24	0.29	0.44	0.56
175	0.11	0.23	0.29	0.34	0.49	0.61
300	0.15	0.27	0.33	0.38	0.53	0.65
525	0.19	0.31	0.37	0.42	0.57	0.69
1000	0.23	0.36	0.41	0.46	0.62	0.73
2200	0.29	0.41	0.47	0.52	0.67	0.79
5000	0.35	0.47	0.53	0.58	0.73	0.85
11000	0.40	0.53	0.58	0.63	0.79	0.90
25000	0.46	0.58	0.64	0.69	0.84	0.96
>25000	0.50	0.62	0.68	0.73	0.88	1.00

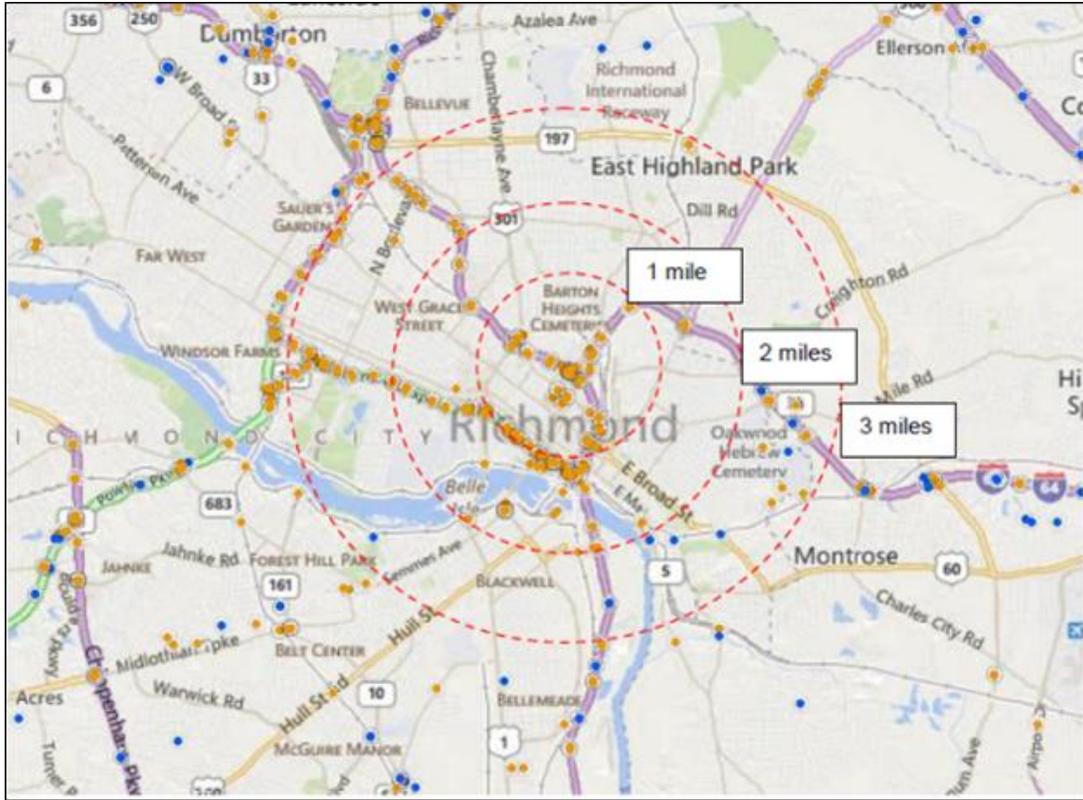
Figure 7.  $V_D$  Ranges for a Structure

*Variable E (Access Impact) and  $V_E$*

Variable E reflects the “essentiality” of a structure in providing access to key or potentially critical facilities and the magnitude of the role the structure might play during an emergency mobilization. The index value  $V_E$  for a particular structure is intended to quantify the impact of structure closure on critical facilities (points of interest [POIs]) that are located within 3 miles of the structure.

The concept of Variable E is inclusive rather than restrictive. Whereas it may be self-evident when closure of a structure will impede a significant access route to one or more POIs, it may not be as readily apparent that a closed structure could close off potentially valuable detour routes needed in an emergency mobilization or evacuation. To guard against inadvertent unawareness of a structure’s potential role, Variable E assumes that if a POI is located within a straight-line 3-mile radius of a structure (i.e., by aerial distance), the structure may be needed for access to or from the POI under emergency circumstances. It should be noted that the variable does not rank the relative degree of criticality of any structure to nearby facilities. POIs in the IF score consist of hospitals, schools, and fire and rescue stations.

The reference database for Variable E is developed by joining structure BYP data with data from the VDOT GIS, resulting in a set of POIs lying within a maximum aerial radius of 3 miles of inventory structures. Not all inventory structures qualify for the Variable E reference database since they do not all have POIs (as defined here) within 3 aerial miles. Figure 8 illustrates the concept of Variable E in evaluating a structure’s relative importance to nearby POIs. The structure is at the center, whereas POIs exist within the radial belts.



**Figure 8. Concept of Access Impact (Variable E). Variable E Values are higher with a shorter radial distance (up to 3 miles) between a structure and points of interest coupled with a higher bypass detour length.**

By drawing on two databases, an index value,  $V_E$ , for Variable E requires two steps for complete calculation. In the first step, a preliminary  $V_E$  value is computed based on the proximity of POIs to the structure and the structure's inventory BYP. Since some structures in the reference database have the (imposed) maximum of 50 POIs within 3 aerial miles, each potentially requiring a detailed calculation based on its exact proximity to a structure, a computational simplification for the first step was adopted as follows: all POIs located in any direction in 0.5-mile radial belts around a structure are computed as a group lying at the minimum radial distance corresponding to the belt.

In other words, the computational simplification allows each radial belt to be characterized by a single distance set at the minimum limit of the belt (i.e., 0.0 for the first half-mile belt, 1.0 for the 1.0–1.5 mile belt, and so on through 2.5 for the 2.5–3.0 mile belt). With a limit of 3 miles, there are six half-mile radial belts around each structure, thus six grouped sets of POIs potentially to consider, although each POI within a given belt contributes separately and equally to the preliminary  $V_E$  value. The expert panel thought that sufficient accuracy was achieved by grouping POIs into half-mile radii in any direction to justify avoidance of a separate calculation for each POI that qualifies relative to a structure.

The proximity index value function ( $PROX_E$ ) in Figure 9 applies to each POI within 3 miles of a given structure. The shape of the function implies the opinion of the expert panel that a structure within 1 mile of a POI is more likely to play a critical role for that POI than for a more distant POI, and although there is gradual reduction in proximity impact (i.e.,  $PROX_E$ ) with

increasing distance (decreasing proximity), it is initially and intentionally a more gradual reduction than in the mid-distances of 1 to 2.5 miles, in which range a small difference in proximity may be important in an emergency mobilization. Distances over 2.5 miles are not easily distinguishable from 3 miles, so the index value declines gradually above distances of 2.5 miles. It should be recalled, however, that the actual computation employs the simplification of using discrete points on the function corresponding to minimum belt boundaries, i.e., 0, 0.5, 1.0, and so on.

In Figure 10, which applies to a given structure, the shape of the index value function  $BYP_E$  shows that the impact of the structure  $BYP$  is assumed to increase as  $BYP$  increases. The shape of Figure 10 implies that the expert panel saw little practical distinction in structure impact on a POI for  $BYP$  between 0.5 mile and 1.5 mile, as reflected in the slow increase in the  $BYP_E$  function. However, harmful impacts of increasing  $BYP$  on POI access are assumed to increase always until the maximum index value is reached at 5 miles and sustained for higher distances, under the reasoning that a longer detour gives more opportunity for simultaneous occurrence of impedances.

The preliminary calculation of  $V_E$  scores, assessed for each POI according to Figures 9 and 10 and summed for all POI relevant to a given structure, results in a scale of raw scores that is much larger than the scale of the IF score (0 to 1.0). Consequently, in the second and final step before importation of a structure's  $V_E$  score into an IF score calculation, raw  $V_E$  scores are normalized by the maximum raw  $V_E$  value generated by any structure in the current reference database. In the current reference database, the maximum raw Variable E score is about 23.9. Therefore all raw  $V_E$  values are normalized to a scale of 0 to 1.0 on the basis of the maximum raw value to produce final  $V_E$  for use in the IF calculation.

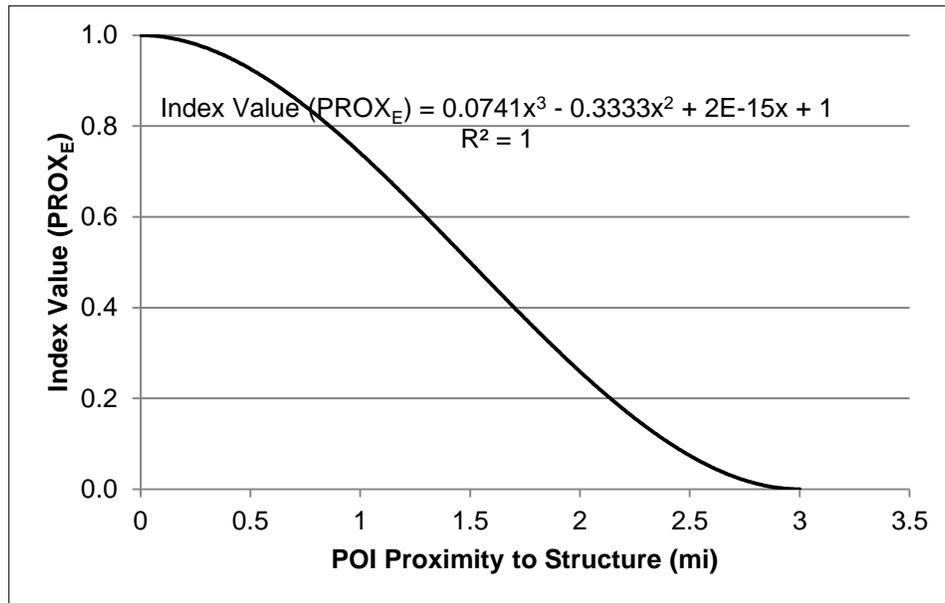


Figure 9. Index Value Function for Proximity Factor in Variable E. POI = point of interest.

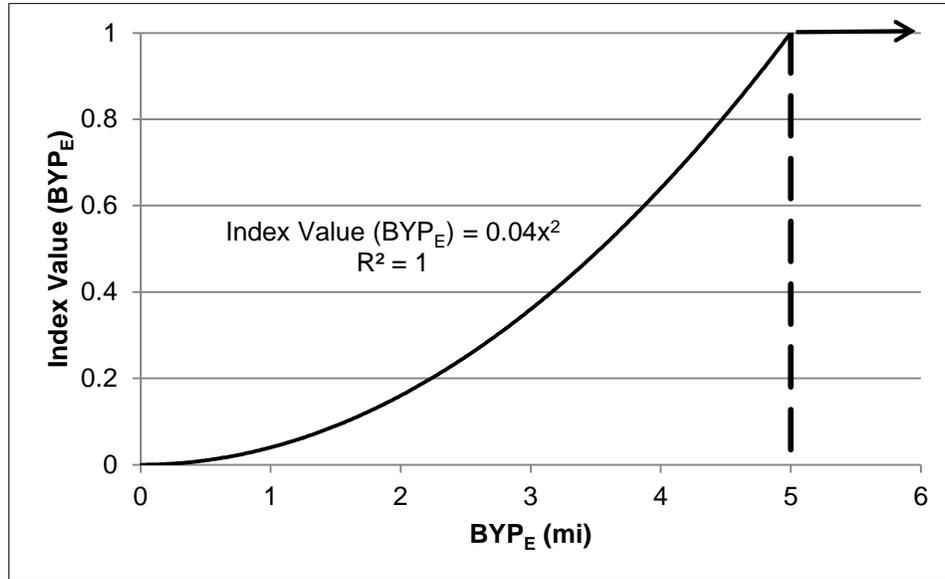


Figure 10. Index Value Function for BYP (Bypass Detour Length) Factor in Variable E

To recap, the product of the index values  $BYP_E$  and  $PROX_E$  comprises the contribution of a single POI to the structure's raw  $V_E$  value. As illustrated in Figure 7, however, numerous POIs may be within range of a given structure and their scores are summed for the total preliminary  $V_E$  value for a structure.

Figure 11 shows a range of preliminary  $V_E$  values potentially generated by a single POI. Figure 11 illustrates the intent of the expert panel that for a given  $BYP_E$ , the score generated by a POI decreases with higher distance between the POI and the structure but for a given distance (radial belt), the score increases as  $BYP_E$  increases. A POI very close to a structure ( $PROX_E$  value below 0.5 mile) that has a  $BYP_E$  of 5 miles or more contributes the maximum possible for a single POI (i.e., 1.000); a POI located relatively far away from a structure ( $PROX_E$  value of 3 miles) with a very low  $BYP_E$  contributes the minimum impact shown in Figure 11 at 0.003.

$PROX_E$ (mi)	$BYP_E$ (mi)					
	1	2	3	4	5	>5
0.0						
0.5	0.040	0.160	0.360	0.640	1.000	1.000
1.0	0.037	0.148	0.333	0.593	0.926	0.926
1.5	0.030	0.119	0.267	0.474	0.741	0.741
2.0	0.020	0.080	0.180	0.320	0.500	0.500
2.5	0.010	0.041	0.093	0.166	0.259	0.259
3.0	0.003	0.012	0.027	0.047	0.074	0.074

Figure 11. Range of Scores Contributed to Raw Variable E by Single POIs

To summarize, in the first step a preliminary  $V_E$  for each structure is computed by taking the product of the  $PROX_E$  function value for a POI in a given radial belt (Figure 9) the number of POIs in the belt' and the  $BYP_E$  function value corresponding to the structure's  $BYP$  (Figure 10), summed across all radial belts around the structure that contain POIs. This procedure for any structure  $k$  can be simplified algebraically to Equation 3.

$$\text{Variable } E_k = \text{Index value for } BYP_{E,k} \times \sum_j n_j \times \text{Proximity index value for } j \text{ [Eq. 3]}$$

where

$k$  = federal structure number

$n_j$  = number of POI in proximity range  $j$

$j = \{0 \text{ to } < 0.5, 0.5 \text{ to } < 1, 1 \text{ to } < 1.5, 1.5 \text{ to } < 2, 2 \text{ to } < 2.5, 2.5 \text{ to } < 3\}$

and

1. the  $BYP_E$  index value for structure  $k$  is calculated according to the formula given in Figure 10
2. the proximity index value ( $PROX_E$ ) for radial belt  $j$  is calculated according to the formula given in Figure 9 using minimum limits for each range  $j$  as the proximity value for the range.

The second and final step to generate the final  $V_E$  for use in the structure's IF score calculation is normalization of the structure's raw  $V_E$  score value by means of the maximum raw  $V_E$  score for any structure in the current reference database.

The procedure to be followed in the event of an update in the geospatial shapefile of POI relative to VDOT-maintained structures is documented in Appendix G.

### *Designated Networks*

The variables discussed earlier are designed to quantify aspects of structure use that differentiate them: the type and intensity of use; the connectivity provided to and from key locations of services or aggregations of vulnerable populations; and the burden placed on road users and detour routes if a structure is taken out of service.

The "designated networks" variables (see Table 1) allow the structure's IF score to reflect the value of the structure to each of four designated roadway systems. Each of the four networks included in this model depends on its infrastructure to be in service both for simple connectivity and for the satisfactory achievement of the intended purpose of the network. Consequently, the IF component employs a separate variable for each designated network although the networks overlap to some extent in actual road miles. The National Highway System (NHS) is a common layer to three of the four designated networks that were included in the IF component, but the NHS was omitted from this analysis because it lacks a specific purpose that is not captured more precisely in one of the four designated networks that were included.

Four designated network fields are available in the structure inventory database as shown in Table 1: Base Highways (BHN) (Federal Inventory Item 12); Strategic Highways (STRAHNET) (Federal Inventory Item 100); Designated National Network Highways (STAA) (Federal Inventory Item 110); and the Virginia Highway System (VSYS) (State Item 185).

The IF score incorporates the first three networks (BHN, STRAHNET, and STAA) based on the logic that a network “designation” implies that (1) the routes have unique objectives that must be supported with maintenance and replacement expenditures as needed to keep structures in service, and (2) were the structures on the networks to be closed, intended users would be diverted to off-network routes with resultant travel delays and potentially failed network objectives. Although “user costs” are not quantified in this tool, it is a premise of the current analysis that travel delays for vehicles with high-value or time-critical cargo (e.g., commercial freight and/or military convoys, and potentially passenger vehicles) imposed by structure closure on a designated network are significant factors in differentiating the relative importance of structures.

The VSYS is explicitly included as a designated network in this analysis. VSYS designation implies a standard of VDOT maintenance (unlike with the other three networks) and does not imply a specific network objective or user. In fact, a facility is occasionally reclassified in VSYS following a travel demand shift toward or away from the facility. The VSYS employs highway classes established by the administrative classification system used in Virginia since the Byrd Act of 1932, and VSYS categories of primary, secondary, and urban highways comprise the “State Highway System” referenced in the *Code of Virginia*. The expert panel is cognizant of VDOT’s effort under the Acts of Assembly Chapter 896 (2007) to conform Virginia’s administrative classification system to the functional classification of the FHWA (VDOT, 2009b). Yet given that the structure inventory continues to record VSYS classification for the facilities carrying structures, the IF scoring tool employs the administrative classification system in the VSYS variable.

Finally, during the period of this study some inventory route classifications in Virginia changed pursuant to requirements of the “enhanced NHS” implemented in the federal transportation authorization of 2012 (i.e., MAP-21). Therefore, there may be some shifts in structure importance rankings as the inventory route reclassifications are fully incorporated into the structure inventory databases.

#### *Variable F (BHN) and $V_F$*

The definition of the BHN is taken directly from the *Federal and State Structure Inventory Coding Guide* as (1) the mainline (i.e., through lane) segments of the NHS, (2) the rural and urban principal arterial system, and (3) the rural minor arterial system (VDOT, 2009a). Appendix A contains a map of the BHN in Virginia at the time of this writing.

The size of the BHN is a function of the size of the NHS. The NHS was first defined in the National Highway System Designation Act of 1995. Formerly statutorily limited to 155,000 miles ( $\pm 15\%$ ), the NHS was expanded to 220,000 under MAP-21 (FHWA, 2012). Within

Virginia, 99% of the 1,903 rural miles and 73% of the 1,527 urban miles of the NHS are owned by VDOT (FHWA, 2013b).

Thus the BHN includes through-lane portions (i.e., lanes designated for through traffic) of the NHS and additional portions of the highway system defined according to the FHWA functional classification system, itself based on how travel through a network of roads can be “channelized within the network in a logical and efficient manner. Functional classification defines the nature of this channelization process by defining the part that any particular road or street should play in serving the flow of trips through a highway network” (FHWA, 2013a).

The FHWA describes the three functionally classified subsystems in the BHN:

The [urban] principal arterial system should carry the major portion of trips entering and leaving the urban area, as well as the majority of through movements desiring to bypass the central city. In addition, significant intra-area travel, such as between central business districts and outlying residential areas between major inner city communities, or between major suburban centers, should be served by this system. . . . Finally, this system in small urban and urbanized areas should provide continuity for all rural arterials which intercept the urban boundary.

The rural principal arterial system consists of a connected rural network of continuous routes having the following characteristics: [s]erve corridor movements having trip length and travel density characteristics indicative of substantial statewide or interstate travel; serve all, or virtually all, urban areas of 50,000 and over population and a large majority of those with population of 25,000 and over; and provide an integrated network without stub connections except where unusual geographic or traffic flow conditions dictate otherwise (e.g., international boundary connections and connections to coastal cities).

The rural minor arterial road system should, in conjunction with the principal arterial system, form a rural network having the following characteristics: link cities and larger towns (and other traffic generators, such as major resort areas, that are capable of attracting travel over similarly long distances) and form an integrated network providing interstate and intercounty service; be spaced at such intervals, consistent with population density, so that all developed areas of the State are within a reasonable distance of an arterial highway; and provide (because of the two characteristics defined immediately above) service to corridors with trip lengths and travel density greater than those predominantly served by rural collector or local systems. Minor arterials therefore constitute routes whose design should be expected to provide for relatively high overall travel speeds, with minimum interference to through-movement.

The index value  $V_F$  for any structure has a value of 1 (on the BHN) or 0 (off the BHN).

*Variable G (STRAHNET) and  $V_G$*

STRAHNET represents the “total minimum public highway network necessary to support defense deployment needs” as determined by the U.S. Department of Defense and the U.S. Department of Transportation (Military Surface Deployment and Distribution Command, 2013). Nationally a 62,791-mile system with 75% on the interstate system, in Virginia the STRAHNET system contained 1,040 rural miles and 623 urban miles, with 67% of the miles on the interstate system, as of May 2013 (FHWA, 2013c). This study comported with FHWA practice by including non-interstate routes that connect interstate STRAHNET routes with military installations and ports as part of the total minimum defense public highway network within

Virginia needed to support a defense emergency (FHWA, 2014). Appendix B shows the current STRAHNET in Virginia.

The index value  $V_G$  for any structure has a value of 1 (on STRAHNET) or 0 (off STRAHNET).

#### *Variable H (STAA) and $V_H$*

The STAA network, a name derived from its origins in the Surface Transportation Assistance Act (STAA) of 1982, was established nearly a decade before the NHS and bears no purposeful relation to it. When it was authorized by federal transportation legislation in 1982, the nearly 200,000 miles of the STAA network were established to provide a nationwide road system for the use of “conventional combination” trucks to facilitate interstate commerce. The network includes “the Interstate System and those portions of the Federal-aid Primary System . . . serving to link principal cities and densely developed portions of the States . . . [on] high volume route[s] utilized extensively by large vehicles for interstate commerce [which do] not have any unusual characteristics causing current or anticipated safety problems.” Appendix C shows the current STAA network in Virginia.

For all participating states, routes lying on the STAA network are specified in Title 23, Section 658, of the *Code of Federal Regulations* (CFR). The STAA network in all states consists generally of interstate highways (with some interstate exclusions) and additional routes. The criteria that originally qualified routes for the STAA network specified in part that in addition to being a high-volume route, “[t]he route has adequate geometrics to support safe operations, considering . . . bridge clearances and load limits.” The STAA network has remained largely unchanged for decades, although provision is made for modifications of routes.

“Conventional” combination trucks were defined in the STAA as a tractor with one semi-trailer no more than 48 feet in length (at the time the maximum length of a single trailer, but the maximum trailer length has since been extended) or a tractor with a 28-foot semitrailer with a 28-foot trailer, neither combination more than 102 inches wide.

The index value  $V_H$  for any structure is 1 (on STAA) or 0 (off STAA).

#### *Variable I (VSYS) and $V_I$*

Virginia has used administrative classifications to organize its highway system since passage of the Byrd Act in 1932. With that legislation, what had been the state highway system became the primary and the secondary systems, both formed from county roads for which the legislation transferred responsibility to the Commonwealth Department of Highways. According to VDOT (2012), current lengths by class are as follows:

- *Interstate*: 1,118 miles of 4-to-10-lane highways that connect states and major cities
- *Primary*: 8,111 miles of 2-to-6-lane roads that connect cities and towns with each other and with interstates

- *Secondary*: 48,305 miles of local connector or county roads.

Because of extensive requirements in the *Code of Virginia* for maintenance and construction funding that are based on administrative road classification until recent new legislation is fully implemented, inclusion in the IF component of the VSYS designation of the structure's inventory route is viewed by the expert panel as mandatory. Going forward, the tool can be adapted to incorporate the classification system observed in the structure inventory.

The index value  $V_I$  corresponds to the classification of the facility carrying the structure: 1.0 for interstate, 0.5 for primary or urban (grouped together), and 0 for secondary or other (grouped together).

## **Excel Spreadsheet Tool and Macro Module for Batch Calculations**

### **Excel Spreadsheet Tool**

An Excel spreadsheet tool was created to perform the algebra to transform the selected inventory items into the explanatory variables and index values that determine a structure's IF score. All the raw data from the applicable structure inventory database are manually imported into the tool spreadsheet directly below the scoring tool itself. The inventory items used in the IF score calculation can be revised manually, if necessary, in order to update an importance ranking instantly or to examine the effect of a change in the raw values of relevant inventory data. All necessary calculations except those for Access Impact are performed in the spreadsheet that contains the tool and the current inventory data.

The index value for Access Impact,  $V_E$ , for a given structure is imported from a static database/calculator that is adjacent to the IF scoring tool in the Excel workbook. Similar to the IF tool, the  $V_E$  calculator lies in a worksheet above its database, which contains qualifying hospitals, schools, and fire/rescue stations (i.e., POIs) by name and proximity to the structure. Excel formulas in the  $V_E$  calculator pull data relevant to a given structure from the geospatial database and calculate a preliminary  $V_E$  and a final  $V_E$ , based on a preliminary maximum score that is identified in advance (and should be confirmed with every structure inventory refresh). The calculator automatically provides a count of POIs by type and by half-mile radius around the structure. After import to the main tool, the  $V_E$  value contributes to the IF score by means of the scoring tool algorithms.

The tool calculates IF scores manually upon entry of the FSN of interest in a designated cell. The tool automatically draws in the Access Impact index value from the linked tool containing the geospatial POI database. In this "open" form, each variable can be inspected for the individual impact it has on a structure's relative importance in comparison with another structure. Finally, the tool provides transparency in the factors that lead to a structure's importance ranking relative to other VDOT-maintained structures.

## **Macro Module for Batch Calculations**

More than 19,000 VDOT-maintained structures are typically eligible to be evaluated for IF scores from a structure inventory database, excluding those that are not in service that may be ineligible for ranking. For this reason, a macro module was added to run and record all variable index values and IF scores for each eligible structure. A database of more than 19,000 eligible structures can be completed by means of the macro in less than 2 hours, thereby generating 10 scores per structure including the IF ranking. This record allows detailed examination of the IF scores and variable sub-scores pertaining to the many structures eligible for ranking at any one time.

The macro module made possible a statistical analysis of the tool's overall performance and in particular allowed (1) examination of relationships among raw inventory data items used in IF scores and (2) evaluation of whether the coefficients (weights) that the expert panel originally selected for the variables were performing as intended.

The tool developed in this study is completely reliant on available structure inventory data, so it is susceptible to the same data deficiencies that affect other scoring formulas in current use. Specifically, these data are occasionally incomplete or inaccurate for a structure. It was therefore decided that if any of the required structure inventory items were not provided or were 0, the IF scores are not computable either manually or by the macro. No default values are supplied in the IF scoring tool, in the expectation that the absence of a score would draw attention to a data problem. Once the problem is noted, it may be remedied by manual input of the FSN in the tool and revision of the problem item in the column below the FSN. A revised IF score is automatically generated by the tool if the input dataset is complete.

The macro module code, programmed in Visual Basic for Applications, is provided in Appendix E.

## **Statistical Evaluation of Preliminary Results**

The tool generates more than 19,000 structure importance rankings for any given inventory database, and IF scores depend wholly on the interaction of inventory data within the specification of the model (i.e., Equation 1). ADT data are particularly important to IF scores since they contribute to the values of four of the nine explanatory variables. For this reason it was considered necessary to explore statistically the particular role of ADT in the structure rankings and interdependencies among all the variables. To do this, three tasks were identified: (1) analysis of relationships between raw structure inventory items used in importance ranking calculations; (2) analysis of relationships between explanatory variables used in importance ranking calculations; and (3) adjustments to coefficients (i.e., weights) in the model to correct for findings in Tasks 1 and 2.

## Analysis of Relationships Between Raw Structure Inventory Items Used in IF Scores

The primary question with respect to the raw structure inventory items selected to be used in the importance rankings was whether IF scores were highly correlated with any of them, in particular with raw ADT data. If so, the model could be deemed overcomplicated and could probably be improved through simplification. The second important question was the degree of collinearity that actually exists between the raw structure inventory items employed in the model, with similar implications for model simplification if collinearity was determined to be high.

To examine whether raw ADT data or any other raw inventory items underlying the explanatory variables dominate the IF score, bivariate correlation analysis was performed as a first task. The results are given in Figure 12 for the inventory structure database of March 2016. For every raw inventory item, statistical correlation is significant at the 0.05 level (two-tailed test) and there were 19,311 structures evaluated.

The question of excessive correlation between ADT and IF scores was resolved. Bivariate correlation between ADT and IF scores ranked in mid-range (0.590) in this simple test and is therefore of no concern.

The bivariate correlation of greatest positive magnitude between raw structure characteristics and IF scores occurred for BHN (0.712). This outcome is explained by deliberate model design since structures that lie on routes included in the BHN were intentionally identified as relatively more important to the VDOT-maintained network than structures that do not. There was a similar magnitude but negative correlation (-0.797) between secondary highway system designation and IF scores. This is also an intended result of the “importance” model developed in this study: secondary routes are not rated as important to the VDOT-maintained network as are primary and interstate routes. In both cases, however, the correlation rates are not of concern, given the large number of observations at 19,311.

	IF SCORE	ADT	ADTT	BHN	STRAHNET	STAA	INT	SEC	BYPASS	LANES
IF SCORE	1.000									
ADT	0.590	1.000								
ADTT	-0.008	-0.036	1.000							
BHN	0.712	0.425	0.018	1.000						
STRAHNET	0.621	0.535	-0.045	0.473	1.000					
STAA	0.698	0.532	-0.043	0.526	0.683	1.000				
INT	0.608	0.585	-0.047	0.508	0.756	0.692	1.000			
SEC	-0.797	-0.425	-0.026	-0.741	-0.458	-0.546	-0.459	1.000		
BYPASS	-0.100	-0.124	-0.017	-0.135	-0.130	-0.148	-0.122	0.151	1.000	
LANES	0.416	0.681	-0.011	0.324	0.289	0.331	0.291	-0.329	-0.123	1.000

Figure 12. Bivariate Correlations Between IF Scores and Raw Structure Inventory Items, March 2016 Structure Inventory File

As a second task, regression analysis between IF scores and (raw) structure inventory items was performed. It should be kept in mind that the inventory items are not expected to explain the final IF score to a high degree since IF scores are determined (i.e., fully determined) by the explanatory variables rather than simple inventory items. The regression results with nonstandardized coefficients are presented in Equation 4a, and regression results with standardized coefficients are presented in Equation 4b.

$$IF\ score = (0.3702) + (1.3234E-06) \times ADT - (3.634E-07) \times ADTT + (0.0530) \times BHN + (0.0526) \times STRAHNET + (0.0985) \times STAA + (0.0003) \times INT - (0.1621) \times SEC + (0.0002) \times BYPASS + (0.0023) \times LANES \quad [Eq. 4a]$$

$$IF\ score = (0.1536)^* \times ADT^* - (0.0011)^* \times ADTT^* + (0.1371)^* \times BHN^* + (0.1186)^* \times STRAHNET^* + (0.2128)^* \times STAA^* + (0.0015)^* \times INT^* - (0.4623)^* \times SEC^* + (0.0561)^* \times BYPASS^* + (0.0162)^* \times LANES^* \quad [Eq. 4b]$$

where 19,311 structures are evaluated,  $R^2 = 0.781$ , all coefficients are significant at the 0.05 level, and asterisks (\*) indicate standardized variables and coefficients.

Face values of nonstandardized coefficients do not accurately represent the relative importance of explanatory variables in a regression equation if different units and scales of measurement are present among the variables, as in this case. For this reason, Equation 4b shows the corresponding standardized coefficients that compensate for scale differences between variables and provide unit-free comparisons of inventory item impact on the dependent variable. The standardized coefficient of 0.1536 on ADT\* in Equation 4b indicates that for every increase of 1 standard deviation in ADT\*, the IF score will increase by 0.1536 of a standard deviation. Stated differently, ADT\* alone explains 15.36% of the variation in IF scores. Four raw inventory items have similar or larger effects than ADT, and four have smaller effects. In summary, the standardized coefficients for inventory items in Equation 4b do not suggest a singularly large influence of any simple inventory item on the IF score.

### **Analysis of Relationships Between Explanatory Variables Used in IF Scores**

In the formula for the IF score (Equation 1), selected structure inventory items were combined into explanatory variables that determine the relative importance of structures. Since several explanatory variables of the IF score have inventory items in common (e.g., ADT and BYP), the index values for the explanatory variables were examined for collinearity and for their relative impact on IF scores. Similar to the simple inventory items, this was accomplished by means of bivariate correlation analysis and regression analysis. Marked collinearity between explanatory variables would suggest that the model could be simplified and still provide equivalent information about the relative importance of VDOT-maintained structures. Determining relative impacts of the explanatory variables through regression analysis would show whether the model was working as intended.

Bivariate correlation results for the variable index values are given in Figure 13. The number of structures evaluated is 19,311, all correlations are significant at the 0.05 level, and variables are defined as in Equation 1.

	IF SCORE	V <sub>A</sub>	V <sub>B</sub>	V <sub>C</sub>	V <sub>D</sub>	V <sub>E</sub>	V <sub>F</sub>	V <sub>G</sub>	V <sub>H</sub>	V <sub>I</sub>
IF SCORE	1.000									
V <sub>A</sub>	0.910	1.000								
V <sub>B</sub>	0.873	0.797	1.000							
V <sub>C</sub>	0.179	0.048	0.038	1.000						
V <sub>D</sub>	0.626	0.493	0.369	-0.073	1.000					
V <sub>E</sub>	0.296	0.276	0.107	-0.049	0.330	1.000				
V <sub>F</sub>	0.712	0.618	0.691	-0.121	0.330	0.091	1.000			
V <sub>G</sub>	0.659	0.553	0.657	-0.055	0.172	0.124	0.515	1.000		
V <sub>H</sub>	0.698	0.582	0.761	0.023	0.165	0.067	0.526	0.735	1.000	
V <sub>I</sub>	0.839	0.750	0.822	-0.010	0.337	0.149	0.753	0.725	0.702	1.000

**Figure 13. Bivariate Correlations Between IF Scores and Explanatory Variables, March 2016 Structure Inventory File**

The large number of structures in the analysis (19,311) and the deterministic type of model cause even the highest correlation (IF-V<sub>A</sub> at 0.910) to be of no concern, since a correlation does not signify causation. All correlation signs are expected or very small if not readily explained, such as the negative correlation between V<sub>D</sub> (Bypass Impact) and V<sub>C</sub> ((AGR)ADT). Other correlations have self-evident explanations of only secondary interest here.

A structure's relative importance ranking is determined by (1) the explanatory variables selected by the expert panel, and (2) the weight assigned to each explanatory variable by the expert panel. The intended weights are given in Equation 1, but regression analysis can reveal the actual impacts exerted by the explanatory variables in determining IF scores.

Linear regression analysis was performed on IF scores generated by Equation 1 using the March 2016 structure inventory database. Since the explanatory variables are nonstandardized, the regression coefficients on the explanatory variables are also nonstandardized and therefore cannot be taken as the actual relative impacts of the explanatory variables. Actual relative impacts would be shown by the standardized coefficients on the variables in the regression. The results are given in Equations 5a and 5b, where the original coefficients from Equation 1 are in Equation 5a and corresponding standardized coefficients are in Equation 5b. Ideally, actual relative impacts of explanatory variables would be identical to intended impacts, but this is clearly not the case.

$$IF\ score = (0.200) \times V_A + (0.100) \times V_B + (0.150) \times V_C + (0.250) \times V_D + (0.100) \times V_E + (0.05) \times V_F + (0.05) \times V_G + (0.05) \times V_H + (0.05) \times V_I \quad [\text{Eq. 5a}]$$

$$IF\ score = (0.345)^* \times V_A^* + (0.161)^* \times V_B^* + (0.199)^* \times V_C^* + (0.281)^* \times V_D^* + (0.054)^* \times V_E^* + (0.129)^* \times V_F^* + (0.099)^* \times V_G^* + (0.108)^* \times V_H^* + (0.102)^* \times V_I^* \quad [\text{Eq. 5b}]$$

All 19,311 structures are included, R<sup>2</sup> = 1 as expected, all coefficients are significant at the 0.05 level, and standardized variables and coefficients are indicated by an asterisk (\*). The

“goodness of fit” value of 1 confirms that the fully determined model and the Excel macro module are working properly and IF scores have no chance influences.

The regression analysis also revealed that the actual impacts of the explanatory variables in Equation 5b differ from the intended impacts of the nonstandardized coefficients in Equation 5a. For example, whereas  $V_D$  (Bypass Impact) was intended to be the most influential variable for an IF score, in fact  $V_A$  (ADT/LN) was most influential, as shown by the respective standardized coefficients, 0.2811 and 0.3445. To be accurate, Equation 5b states that a change of one standard deviation in  $V_A$  will increase the IF score by 34.5% of a standard deviation, whereas the same magnitude of change in Variable D will cause an increase of only 28.1% of a standard deviation in the IF score.

The relative impacts of the explanatory variables on IF scores are indicated by the ratio between the coefficients corresponding to the variables. Figure 14 gives the intended ratios of the impacts of the explanatory variables as shown in Equation 1. Figure 15 gives the actual ratios between the impacts on IF scores of the explanatory variables, as revealed by ratios between the standardized coefficients in Equation 5b.

Goal Coefficients	A/B	A								
	B	$V_A$	$V_B$	$V_C$	$V_D$	$V_E$	$V_F$	$V_G$	$V_H$	$V_I$
0.20	$V_A$	1.000								
0.10	$V_B$	2.000	1.000							
0.15	$V_C$	1.333	0.667	1.000						
0.25	$V_D$	0.800	0.400	0.600	1.000					
0.10	$V_E$	2.000	1.000	1.500	2.500	1.000				
0.05	$V_F$	4.000	2.000	3.000	5.000	2.000	1.000			
0.05	$V_G$	4.000	2.000	3.000	5.000	2.000	1.000	1.000		
0.05	$V_H$	4.000	2.000	3.000	5.000	2.000	1.000	1.000	1.000	
0.05	$V_I$	4.000	2.000	3.000	5.000	2.000	1.000	1.000	1.000	1.000

Figure 14. Intended Relative Impacts on IF Scores of Explanatory Variables, Goal Coefficients

Standardized Coefficients	A/B	A								
	B	$V_A^*$	$V_B^*$	$V_C^*$	$V_D^*$	$V_E^*$	$V_F^*$	$V_G^*$	$V_H^*$	$V_I^*$
0.345	$V_A^*$	1.000								
0.161	$V_B^*$	2.138	1.000							
0.199	$V_C^*$	1.729	0.809	1.000						
0.281	$V_D^*$	1.226	0.573	0.709	1.000					
0.054	$V_E^*$	6.335	2.963	3.664	5.169	1.000				
0.129	$V_F^*$	2.665	1.247	1.542	2.175	0.421	1.000			
0.099	$V_G^*$	3.494	1.634	2.021	2.851	0.552	1.311	1.000		
0.108	$V_H^*$	3.189	1.492	1.844	2.602	0.503	1.196	0.913	1.000	
0.102	$V_I^*$	3.371	1.577	1.950	2.751	0.532	1.265	0.965	1.057	1.000

Figure 15. Actual Relative Impacts on IF Scores of Explanatory Variables, Standardized Coefficients (\*)

The overall magnitude of the discrepancies between the intended and actual coefficient ratios is implied by the sum of the absolute differences between each intended and actual ratio for a given pair of variables. Between Figures 14 and 15, this discrepancy measurement was calculated to be 12.37 and therefore raised a potentially serious shortcoming of the present model specification in that IF scores were being at least partly determined by uncontrolled factors.

### Adjustments of the Model Specification

The results of the variable ratios resulting from the goal coefficients suggested that adjustment of the model specification in Equation 5a would better align the model's performance with the intent of the expert panel. In fact, it was considered essential to the quality of the model that the nonstandardized coefficients on the explanatory variables in the IF formula be adjusted to result in "actual" relative impacts that were closer to those intended (as shown in Figure 14). As important, this adjustment would support the transparency of the model and protect IF scores from uncontrolled influences.

By the use of the known relationship between nonstandardized and standardized coefficients given in Equation 6, new nonstandardized coefficients were back-calculated from the *desired standardized coefficients*, as shown by example for Variable A.

$$\beta_i^* = \beta_i \cdot (S_{X_i} \div S_Y) \quad [\text{Eq. 6}]$$

where

$\beta_i^*$  is the standardized coefficient for standardized index values of variable  $i$   
 $\beta_i$  is the nonstandardized coefficient for nonstandardized index values of variable  $i$   
 $X_i$  is the set of nonstandardized index values for variable  $i$  (for all structures)  
 $Y$  is the IF score  
 $S$  is the standard deviation statistic.

The method for developing back-calculated, nonstandardized, normalized (BNN) coefficients is demonstrated for Variable A:

$$\begin{aligned} \beta_i^* &= \beta_i \cdot (S_{X_i} \div S_Y) \text{ by Equation 6} \\ \beta_A^* &= 0.20, \text{ the "goal" coefficient for Variable A in Equation 1} \\ 0.20 &= \beta_A \cdot (S_{V_A} \div S_{IF}) \\ 0.20 \cdot (S_{IF} \div S_{V_A}) &= \beta_A. \end{aligned}$$

After calculation of  $\beta_A$  through  $\beta_I$  by the same method, using standard deviations provided by Excel's Data Analysis Toolpack descriptive statistics, the coefficients were normalized (summing to 1.0) as the last step of their transformation into BNN coefficients. By replacing each coefficient in Equation 5a with BNN coefficients, Equation 5a becomes Equation 7:

$$IF\ score = (0.147)V_A + (0.079)V_B + (0.143)V_C + (0.282)V_D + (0.233)V_E + (0.024)V_F + (0.032)V_G + (0.029)V_H + (0.031)V_I \quad [Eq. 7]$$

IF score and explanatory variable statistics are altered by Equation 7 compared to Equation 5a, and regression of IF scores on the explanatory variables now reveals standardized coefficients (i.e., unit-free coefficients) with relative impacts very close to those intended, as shown in Figure 16.

The absolute magnitude of difference between the relative impacts in Figure 14 (intended) and the relative impacts in Figure 16 (actual) is reduced to 0.0014. In other words, the new standardized coefficients that are generated by the regression program using the BNN coefficients shown in Equation 7 reveal that the variables now have the intended relative impacts on IF scores. This result supports replacing the original coefficients in the IF formula of Equation 5a with the BNN coefficients of Equation 7.

Figure 17 shows the Excel tool calculation of the IF score for FSN 388, with the BNN coefficients in place.

BNN Coeff.	Standardized Coefficients	A/B	A									
		B	V <sub>A</sub> *	V <sub>B</sub> *	V <sub>C</sub> *	V <sub>D</sub> *	V <sub>E</sub> *	V <sub>F</sub> *	V <sub>G</sub> *	V <sub>H</sub> *	V <sub>I</sub> *	
0.147	0.313	V <sub>A</sub> *	1.000									
0.079	0.157	V <sub>B</sub> *	2.000	1.000								
0.143	0.235	V <sub>C</sub> *	1.333	0.667	1.000							
0.282	0.392	V <sub>D</sub> *	0.800	0.400	0.600	1.000						
0.233	0.157	V <sub>E</sub> *	2.000	1.000	1.500	2.500	1.000					
0.024	0.078	V <sub>F</sub> *	4.000	2.000	3.000	5.000	2.000	1.000				
0.032	0.078	V <sub>G</sub> *	4.000	2.000	3.000	5.000	2.000	1.000	1.000			
0.029	0.078	V <sub>H</sub> *	4.000	2.000	3.000	5.000	2.000	1.000	1.000	1.000		
0.031	0.078	V <sub>I</sub> *	4.000	2.000	3.000	5.000	2.000	1.000	1.000	1.000	1.000	

Figure 16. Actual Relative Impacts on IF Scores of Explanatory Variables, BNN Coefficients

MARCH 2016 CSV1 FILE	FED STR NO.	388	VARIABLES				IF SCORE
			VARIABLE VALUE	VARIABLE INDEX VALUE	BNN COEFFS		
ADT	42		ADT/LN V <sub>A</sub>	21	0.000	0.1470	0.000
Lanes	2		ADTT/LN V <sub>B</sub>	0	0.0000	0.0786	0.000
TR %	0		AGR (ADT) V <sub>C</sub>	1.23%	0.189	0.1430	0.027
ADTYR	2,014		Bypass Impact V <sub>D</sub>	1.242			
ADT FUT	55			42	0.098	0.2816	0.028
ADTFUTYR	2,035		Access Impact V <sub>E</sub>	3	0.001	0.2329	0.000
BYPASS	1.24		BHN V <sub>F</sub>	0	0.000	0.0245	0.000
POI (add-in)	3		STRAHNET V <sub>G</sub>	0	0.000	0.0321	0.000
BHN (add-in)	0		STAA V <sub>H</sub>	0	0.000	0.0293	0.000
STRAHNET	0		VA SYSTEM V <sub>I</sub>	5	0.000	0.0310	0.000
STAA(Truckne	0						
VA SYSTEM	5						
District	0						
Hist Sig	0						
							<b>0.0548</b>

Figure 17. Example of IF Scoring Tool With Back-calculated Nonstandardized Normalized Coefficients, Federal Structure Number 388

FSN 388 is on a secondary inventory route; has low ADT, few critical facilities (POIs) nearby, a low BYP, and a low estimated traffic growth; and is not part of any designated system included in the model, all of which are reflected in a relatively low IF score of 0.0548. By contrast, Figure 18 shows the example of FSN 18073 that is located on a primary inventory route. Inventory data for this structure show higher AGR(ADT), a longer inventory BYP, higher ADT, and more critical facilities nearby (16 versus 3) than inventory data show for FSN 388. The IF score for FSN 18073 is 0.5102.

Figure 19 shows the Access Impact supplementary tool as it appears when the main tool is computing IF scores for FSN 18073 as shown in Figure 18. The critical facilities are enumerated by distance from the structure, and each facility can be identified in detail in a database lying below the tool in the same worksheet.

Descriptive statistics of IF scores calculated under each set of coefficients show that under the BNN coefficients, the IF score mean is slightly lower with a slightly lower standard error of the mean. The standard deviation of IF scores falls with BNN coefficients, as do kurtosis and skewness measures, implying that the estimate of the mean is more robust. The median value falls slightly and the mode value rises slightly with BNN coefficients. Overall, the BNN-generated IF score data are clustered more closely around the mean and are therefore more reliable.

MARCH 2016 CSV1 FILE	FED STR NO.	18073				
	ADT	17,565				
	Lanes	4				
	TR %	1				
	ADTYR	2,014				
	ADT FUT	29,139				
	ADTFUTYR	2,021				
	BYPASS	3.00				
	POI (add-in)	16				
	BHN (add-in)	0				
	STRAHNET	0				
	STAA(Truckne	0				
	VA SYSTEM	P				
	District	0				
	Hist Sig	0				

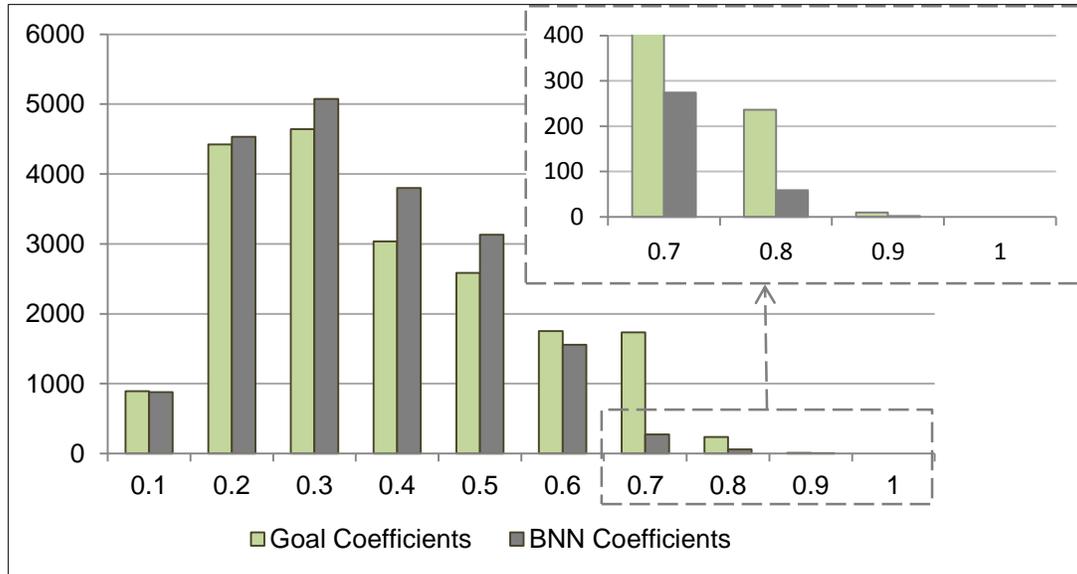
VARIABLES	VARIABLE VALUE	VARIABLE INDEX VALUE	BNN COEFFS	IF SCORE
ADT/LN: $V_A$	4,391	0.818	0.1470	0.120
ADTT/LN: $V_B$	44	0.3460	0.0786	0.027
AGR (ADT): $V_C$	6.53%	1.000	0.1430	0.143
Bypass Impact: $V_D$	2,998 17,565	0.591	0.2816	0.167
Access Impact: $V_E$	16	0.162	0.2329	0.038
BHN: $V_F$	0	0.000	0.0245	0.000
STRAHNET: $V_G$	0	0.000	0.0321	0.000
STAA: $V_H$	0	0.000	0.0293	0.000
VA SYSTEM: $V_I$	P	0.500	0.0310	0.015
				<b>0.5102</b>

Figure 18. Example of IF Scoring Tool With Back-calculated Nonstandardized Normalized Coefficients, Federal Structure Number 18073

FED STR NO.	TOTAL POIs	HOSPITAL	SCHOOLS	FIRE/RESCUE	RANGE	INDEX VALUES	
18073	16	4	8	4			
0-0.5 mi	2	0	0	2	0.0	0.7191	
0.5-1 mi	4	2	2	0	0.5	1.3317	
1-1.5 mi	4	2	1	1	1.0	1.0654	
1.5-2 mi	2	0	1	1	1.5	0.3596	
2-2.5 mi	3	0	3	0	2.0	0.2797	
2.5-3 mi	1	0	1	0	2.5	0.0266	
RAW SCORE						3.7821	
BYPASS = 3.00						NORMALIZED INDEX VALUE	<b>0.16171</b>

Figure 19. Access Impact Tool, Federal Structure Number 18073

Finally, the overall effect on IF scores of using BNN coefficients in place of goal coefficients in the final model specification is shown in Figure 20 for the March 2016 structure inventory. BNN coefficients visibly shift IF scores toward the range of 0.3 through 0.5 by means of calibrating the model specification to the intent of the expert panel.



**Figure 20. Frequencies of IF Scores With Goal Coefficients and With Back-calculated Nonstandardized Normalized Coefficients, March 2016 Structure Inventory**

## DISCUSSION

The IF score adds a unique tool to scoring tools already used routinely by VDOT’s Structure and Bridge Division. The methodology developed to generate IF scores intentionally uses the same source data that the DBF and SR formulas have used, but the IF methodology ranks the demand for and connectivity role of a structure rather than its physical condition or age. BNN coefficients in the final IF formulation of Equation 7 ensure that the explanatory variables have relative impacts on IF scores in agreement with the model originally specified by the expert panel and shown in Equation 1.

To conclude the description of the development of this new scoring tool, four questions have been identified for additional clarification:

1. Is the absence of total ADT as an explicit explanatory variable in Equation 7 equivalent to omitting total ADT altogether from the score calculation?
2. Why are IF scores themselves not “normalized” (i.e., why is the maximum raw score for a given database not converted from face value to a value of 1.0)?
3. Could refreshing of the structure inventory database using original distributions for index values cause IF scores to change for a given structure in spite of no specific changes in its characteristics?

4. Are IF scores stable over time (i.e., is the calculator tool vulnerable to wide swings in calculated values)?

First, the IF scoring tool is distinct from current structure scoring tools in employing ADT per lane and truck ADT per lane as explicit variables in Equations 1 and 7 that contribute to a structure's importance relative to other structures. Per lane specifications were employed because it was strongly suspected that other variables would implicitly introduce the influence of simple ADT, leaving room in the model for other combination variables related to travel demand for a structure, such as ADT/LN. This question was explored by means of several statistical tools, the results of which are summarized here:

- Figure 12 shows that IF scores are positively correlated with total ADT (0.590), as expected.
- Figure 12 shows that total ADT is positively correlated with the interstate highway system (0.585) and negatively correlated with the secondary system (-0.425). Analysis of current inventory data showed that 99.2% of secondary system roads carry ADT of 25,000 or less whereas only 51.2% of interstate highways carry that lower level of ADT.
- Figure 12 shows that the three other designated networks have similarly positive correlations with total ADT and positive correlations with IF scores that are comparable to that of the interstate system.
- Equation 4b shows that simple ADT explains 15.36% of variation in IF scores in the current structure inventory.

Taken together, this evidence suggests that simple ADT volumes are implicitly influential on IF scores, mainly by means of the four designated highway variables. This outcome supports the decision of the expert panel to employ ADT/LN and ADTT/LN to incorporate "intensity" of travel demand relative to structure capacity as an additional perspective of traffic volumes carried by a given structure, perspectives that would not have been captured in the ADT or ADTT variables alone.

Second, although IF scores range potentially from 0 to 1.0, the maximum score in a given structure inventory database is not "normalized" to 1.0 because to do so could have falsely suggested that the structure(s) with a ("normalized") IF score of 1.0 represented a "standard" of maximum possible structure importance, leading to false certainties about score comparisons within given databases and across inventory database updates. In addition, the normalization of IF scores could have introduced a second mistaken assumption about IF scores: that the highest IF score generated from a given inventory database represents the structure with the highest scores in every explanatory variable when it actually identifies the highest total score in a given structure inventory. In other words, structures will vary in the characteristics used in the IF score, and no single structure is realistically likely to obtain the maximum observed variable value in every characteristic. The expert panel elected to preserve this information by means of

non-normalized IF scores. Although subtle, the ranking of non-normalized IF scores could support some complex decisions with useful information.

As a case in point, FSN 27447 on an interstate inventory route was computed to have the highest IF score in the March 2016 structure inventory, yet it did not have the highest estimated annualized traffic growth rate ( $V_C$ ) of all VDOT-maintained structures in the March 2016 inventory or the single highest index values for Bypass Impact or Access Impact. To be specific, on interstate routes, 108 other structures had higher annualized traffic growth rate forecasts; 12 structures had the same (maximum) index values for Bypass Impact; and 45 structures had higher index values for Access Impact. Yet summation of the effects of all of the explanatory variables generated the highest IF score for FSN 27447 because of the model specification. This depth of information is readily accessible in the non-normalized score calculations but would be lost in a normalized IF score.

Third, refreshing of the structure database may cause relative importance rankings to shift if the new database is sufficiently altered from the previous one for any number of causes. This possibility can be handled easily by recalibration of the three explanatory variables with percentile-based index value functions (ADT/LN and ADTT/LN) or percentile-based components (Bypass Impact) in order to align the new data within accurately representative percentiles. In other words, although a structure might be in the 50th percentile in one of these variables in the current database, it may or may not be in that position in a refreshed inventory and for valid reasons. To summarize, the distributions of explanatory variables with percentile-based index value functions should be examined periodically to ensure that they continue to “fit” the index value formulas assigned to the variable.

Fourth, although the importance of accurate and timely data for use in calculating accurate relative IF rankings of structures cannot be overstated, a significant change in a correctly calculated score might still occur over time for reasons outside the calculation itself. Accurate current ADT, ADTT and ADT forecasts are of the highest importance to accurate relative IF scores, as are periodically updated GIS files on POIs within 3 miles of each structure, but controlling for the quality of these data items will not account for all possible sources of IF score variability.

## CONCLUSIONS

- *The logic of the IF scoring concept links relative structure importance with structure use and location rather than physical attributes such as condition, age, geometric configuration, and capacity.*
- *The IF concept is expressed numerically by a formula that combines a set of explanatory variables compiled from familiar and readily available structure inventory data.*
- *The IF score provides an easily understood measurement of a structure’s importance as compared to other structures in the inventory. Because the scales of the IF score and its*

*component variables are all normalized on a scale of 0 to 1.0, the scoring is readily understood by technical experts and other users.*

- *If structure data are missing or coded as not available, an error score is generated by the IF score calculator. However, the scoring tool allows “manual” correction of problematic data and instantaneous generation of a structure score.*
- *The IF score can be employed in conjunction with other tool scores based on physical condition data and cost-effectiveness to inform decision-makers about which structures most justify priority funding and which structures are relatively less competitive for those funds.*
- *To attain accuracy in relative importance rankings, it is necessary to have accurate data.*
- *Timely data on ADT, ADTT, and ADT forecasts require assistance from VDOT’s Traffic Engineering Division. In addition, continuing assistance from VDOT’s Information Technology Division is required for refreshing of the geopotential database supporting the Access Impact variable.*

## **RECOMMENDATIONS**

1. *VDOT’s Structure and Bridge Division should include consideration of IF scores in making closure decisions and in the process of allocating funds since only these scores, among current practices, rank VDOT-maintained structures by their importance to Virginia’s road system.*
2. *VDOT’s Structure and Bridge Division should consider the new IF rankings, alongside condition and budget data, in decisions relating to bridge maintenance such as ranking structures for rehabilitation or replacement, restorative maintenance, and preventative maintenance actions when preparing the annual needs assessment.*
3. *VDOT’s Traffic Engineering Division and Information Technology Division should provide support to VDOT’s Structure and Bridge Division to automate the export of relevant data that are incorporated into the IF tool from data sources outside the Structure and Bridge Division.*

## **BENEFITS AND IMPLEMENTATION**

### **Benefits**

The IF score provides the first objective measurement of the relative importance of VDOT-maintained structures, and it replaces structure scoring tools whose methodologies had become obsolete. By ranking structure importance by data-determined criteria, the IF score

supports transparent decision-making about the investment of federal and state funds for management of the multi-billion dollar inventory of VDOT's Structure and Bridge Division.

In addition, IF scoring critically supports the multi-objective "State of Good Repair Prioritization Process Methodology" developed by VDOT's Structure and Bridge Division in direct response to the requirements of the second enactment clause of HB 1887, Chapter 684, of the 2015 Acts of Assembly (§ 33.2-369 of the *Code of Virginia*).

Further, VDOT's new asset management plan answers the requirement of Section 1106 of MAP-21 for the development of asset management plans for the NHS in all states, and the VDOT multi-objective plan including the IF component comports with rules proposed in 2015 by the FHWA with respect to the development of such plans (23 CFR Part 515).

With establishment of a transparent, data-driven, structure importance ranking framework of timely value to VDOT's Structure and Bridge Division, refinements and improvements to the tool can readily continue as data and methods are improved.

### **Implementation**

To implement the study recommendations, the following actions have been or will be taken:

1. VDOT's proposed "state of good repair" methodology, in which IF scores are weighted more heavily at present than the other four components, was approved by Virginia's Commonwealth Transportation Board in June 2016.
2. The State Structure and Bridge Engineer has issued the IF methodology, numerical rankings, and tool with associated equations for project level reference by district and central office personnel.
3. VDOT's Asset Management Division and Structure and Bridge Division have used the IF score as a critical component for selection of projects that will receive "state of good repair" funding in accordance with Section 33.2-369 of the *Code of Virginia*.
4. IF scores will be employed in 2016 for VDOT recommendations of prioritization of locality-owned bridges, pursuant to VDOT's State of Good Repair Prioritization Process Methodology.
5. The State Structure and Bridge Engineer will establish an objective structure *closure* policy that incorporates the IF concept for bridges by March 2017.

To summarize, the staff of VDOT's Structure and Bridge Division has already incorporated the IF methodology as a key part of the multi-objective prioritization formula for Virginia structures, which answers recent federal and state requirements regarding achievement of a "state of good repair" of state-maintained bridges.

## ACKNOWLEDGMENTS

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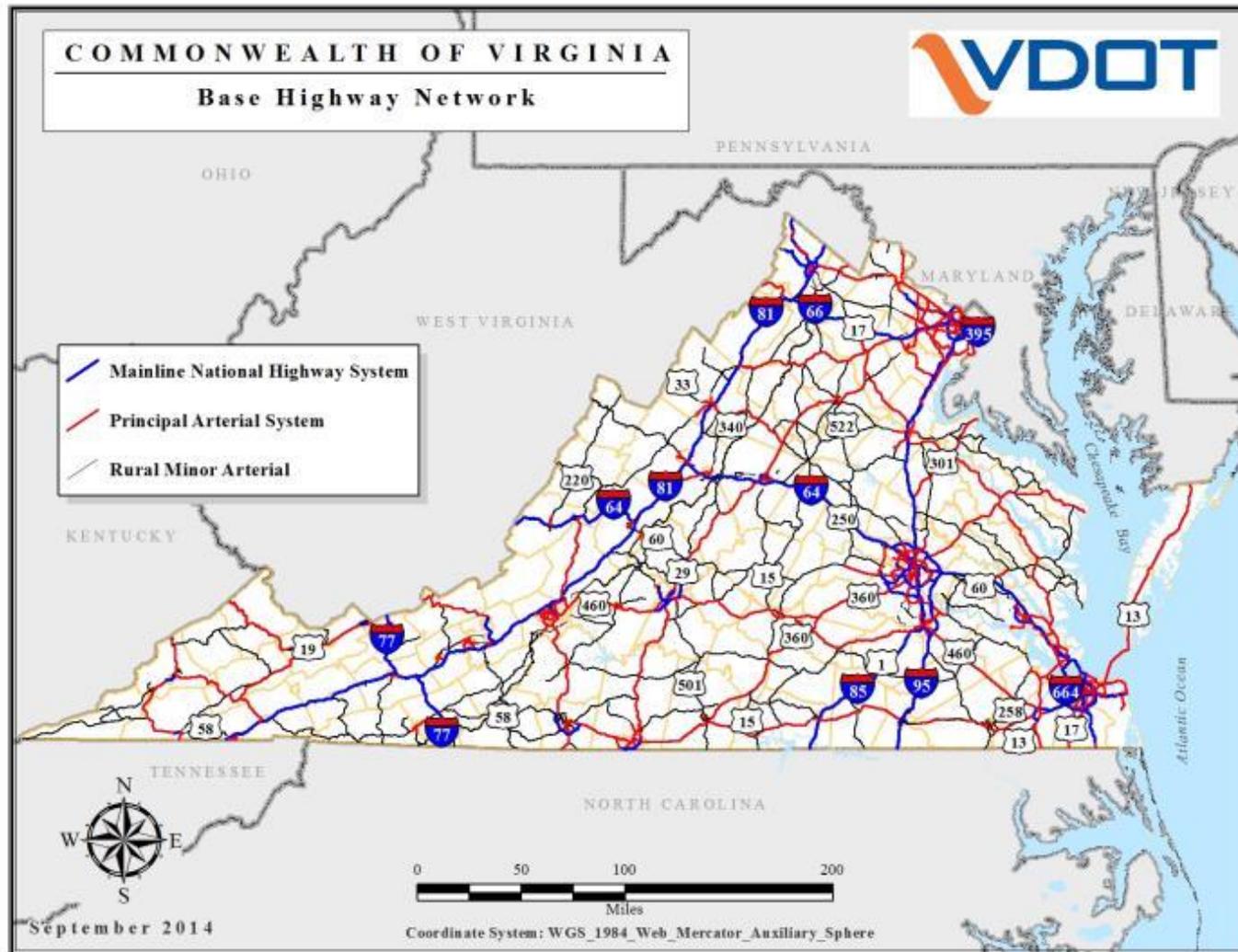
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## APPENDIX A

### BASE HIGHWAY NETWORK (BHN) IN VIRGINIA

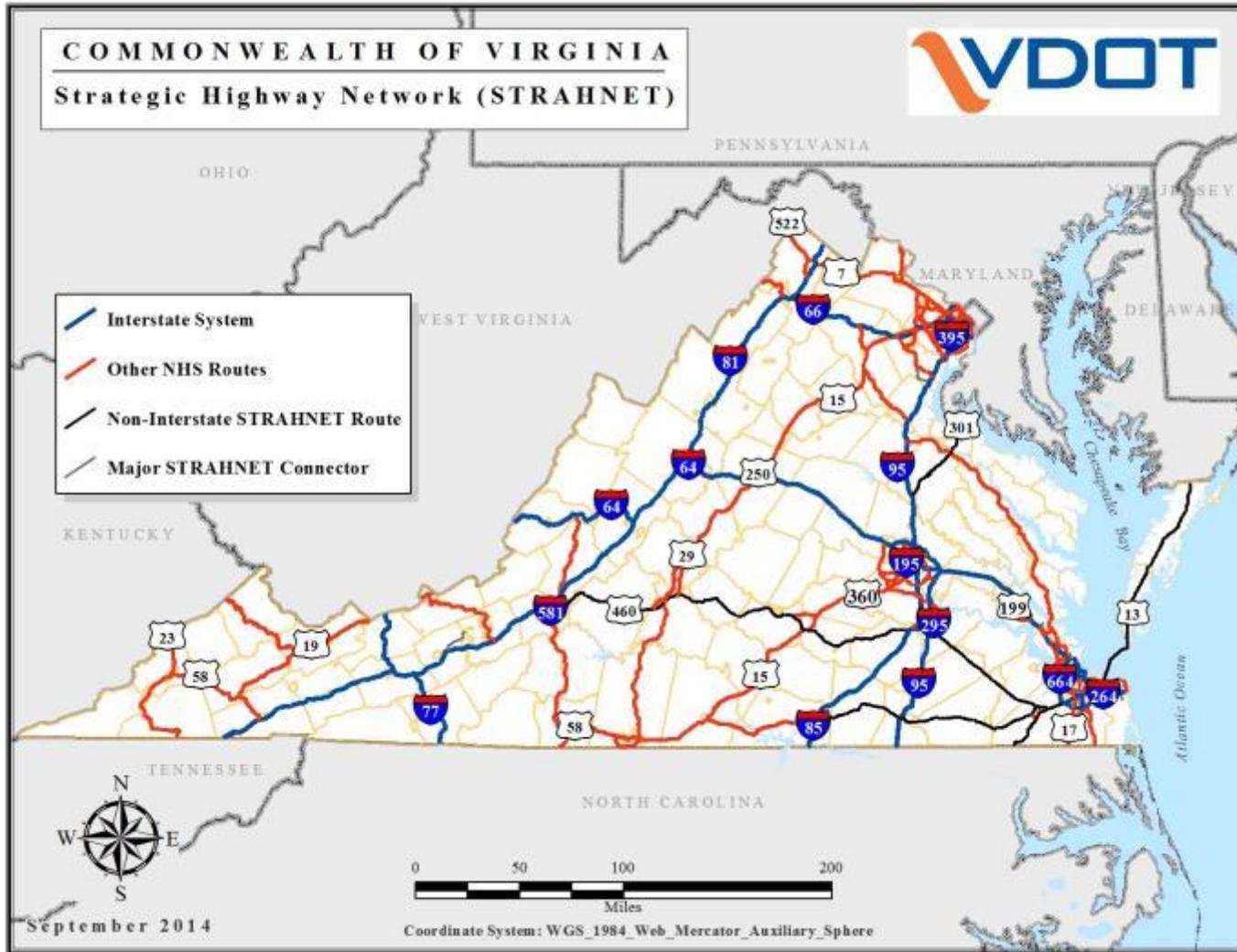


Source: John P. Cooke, VDOT IT Division.



## APPENDIX B

### STRATEGIC HIGHWAY NETWORK (STRAHNET) IN VIRGINIA

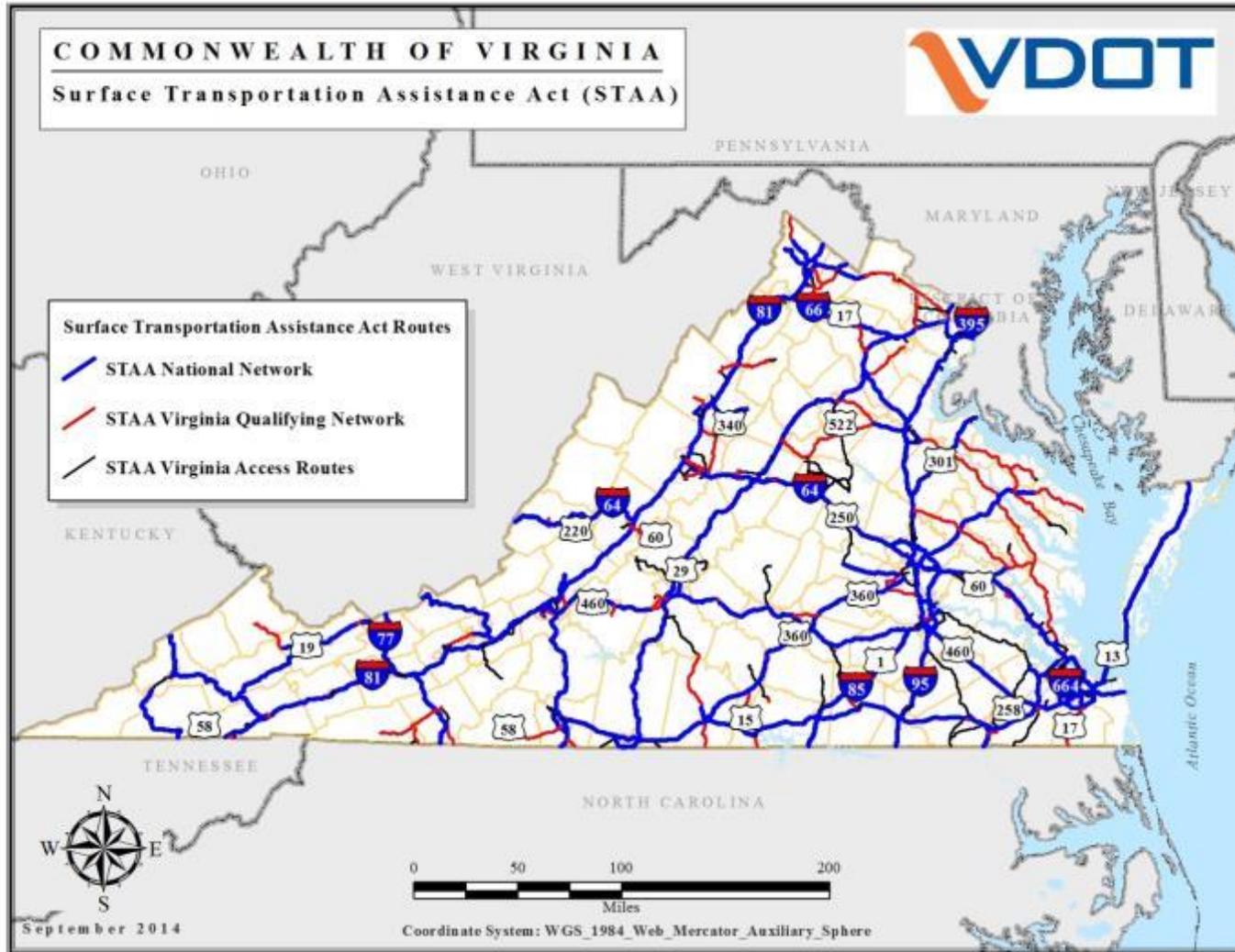


Source: John P. Cooke, VDOT IT Division.



## APPENDIX C

### SURFACE TRANSPORTATION ASSISTANCE ACT (STAA) NETWORK IN VIRGINIA



Source: John P. Cooke, VDOT IT Division.



## APPENDIX D

### PREPARING RAW CSV1 FILE DATA FOR USE IN THE SCORING TOOL

1. Start with PONTIS CSV1[month-day-year] file:

1. Column AV: “oppostcl”  
FILTER 1: Remove “!”, “\_”, “G”, “K” (structures are currently in service)
2. Column J: “on\_under”  
FILTER 2: Select “1” only (lanes are on the structure)  
 This filter prepares the “lanes” column for use in the Tool.
3. Column U: “type\_constr”  
FILTER 3: Remove “D”, “F”, “L”, “P”, “S” (excludes irrelevant structures)
4. Column AL: “custodian”  
FILTER 4: Select “1” only (VDOT maintains structure)
5. Column AK: “maint\_resp\_state”  
FILTER 5: Remove “DCL”, “DOD”, “MDL”, “NPS”, “USG” (also “DMV”, “MWA”, “NPA”, “WMA” if present).

After application of these filters, the database should consist of VDOT-maintained, open structures with the designated number of lanes *on* the structure.

2. A structure’s binary score (on-1/off-0) for the Base Highway Network is currently generated by means of a look-up table. VDOT’s Structure and Bridge Division has provided these data for the tool to date. In the future, BHN data may be incorporated into the CSV1 file.
3. CSV1 file data shown in the current IF scoring tool spreadsheet are of two types:  
 Type 1: elective informational data  
 Type 2: data required for score calculation.

The table shows both data types. Type 1 data are italicized, and Type 2 data are not. All columns in the CSV1 file except those shown in the table may be disregarded in the IF scoring tool.

BRKEY (FSN)	F8/S3
ADTTOTAL	F29
LANES	F28A
TRPCT	F109
ADTYEAR	F30
ADT FUTURE	F114
ADTFUTYEAR	F115
EBYPASSLEN	F19
POI	(add-in)
BHN	(add-in)
STRAHNET	F100

STAA	F110
VA SYSTEM	S185
<i>District</i>	<i>F2</i>
<i>Hist Sig</i>	<i>F37</i>

4. To run the calculator on refreshed inventory data, the data in the table are compiled in a new table *in the order shown* and imported to the calculator *starting in cell A25* as with the current data.
5. Delete the contents of cells Y25 through AJXXXXX (i.e., the row representing the last structure of the previous dataset) before running the macro for new scores on a refreshed dataset.

## APPENDIX E

### MACRO MODULE FOR BATCH CALCULATIONS OF IF SCORES

```
Option Explicit
Sub FillColumns()
Dim I, J, K As Integer
Dim ProxSheetName As String

Dim ws
Application.ScreenUpdating = False
For Each ws In Worksheets
    If Left (LTrim(ws.Name), 2 ) = "AC" Then ProxSheetName = ws.Name
Next ws

I=25
While Not IsEmpty (Cells(I,1)
    Cells (2, 3) = Cells (I,1)
    Cells (I, 25) = Cells (13,10)
    Cells (I, 26) = Worksheets (ProxSheetName).Cells(12,8)
    For K = 3 To 12
        Cells (I, 24 + K) = Cells (K, 8)
    Next
    I = I+1
Wend
Application.ScreenUpdating = True
End Sub
```



## APPENDIX F

### ADJUSTMENTS OF COEFFICIENTS ON VARIABLES IN THE IMPORTANCE FACTOR FORMULA (EXCEL METHOD)

The model specification in this report is the result of extensive discussion by the expert panel on the characteristics of structures that rank them with respect to their relative importance to the VDOT network. The weights (coefficients in Equation 1) assigned to the explanatory variables may be altered by the method documented here. The method emphasizes calibration of the coefficients to the intent of the modelers, such that a coefficient of 0.2 on one variable means that it has twice the unit-free impact on the IF score compared to a variable with a coefficient of 0.1. All explanatory variables are nonstandardized.

1. MACRO-RUN1: Run the macro module using *goal* coefficients (i.e., weight the model according to *preference*) to produce IF scores and variable index values (IVs) for all in-service, VDOT-maintained structures in the inventory database.
2. Delete or set aside structures with no (or negative) numerical IF score.
3. Obtain standard deviations of the RUN1 IF scores and variable IVs for use in Step 4:
  - a. Using the Excel Data Analysis add-in tool pack, run Descriptive Statistics on RUN1 IF scores to obtain the standard deviation of the IF score sample (n= # scored structures in current inventory database).
  - b. Run Descriptive Statistics on RUN1 IVs corresponding to each variable to obtain standard deviations for each variable (n= # scored structures in current inventory database).
4. Calculate standardized (i.e., unit-free) coefficients for each variable according to the formula:

$$\beta_i^* = \beta_i * \frac{S_{X_i}}{S_Y}$$

where

$\beta_i^*$  = standardized coefficient for variable  $i$

$\beta_i$  = nonstandardized coefficient for variable  $i$  (i.e., goal coefficients in RUN1 formula)

$S_{X_i}$  = standard deviation of index values for variable  $i$

$S_Y$  = standard deviation of IF scores.

5. Compare ratios between the calculated standardized coefficients (Step 4) with ratios between goal (nonstandardized) coefficients in the IF formula (Step 1) to evaluate internal discrepancies between the two sets of coefficients. For example, if RUN1 goal (nonstandardized) coefficients are  $a$ ,  $b$ ,  $c$ ,  $d$ , and  $e$ , and corresponding RUN1 standardized coefficients are  $a^*$ ,  $b^*$ ,  $c^*$ ,  $d^*$ , and  $e^*$ , then the difference between  $a/b$  and  $a^*/b^*$ ,  $a/c$  and  $a^*/c^*$ , and so on may be used to summarily evaluate overall discrepancies.

6. Using the formula in Step 4 and the standard deviations of Step 3, set standardized coefficients equal to RUN1 goal coefficients and back-calculate nonstandardized coefficients to use in the IF formula in RUN2. Normalize these coefficients on the basis of their sum so that they add to 1.0. These are now the BNN (back-calculated, nonstandardized, normalized) coefficients to use in the tool.

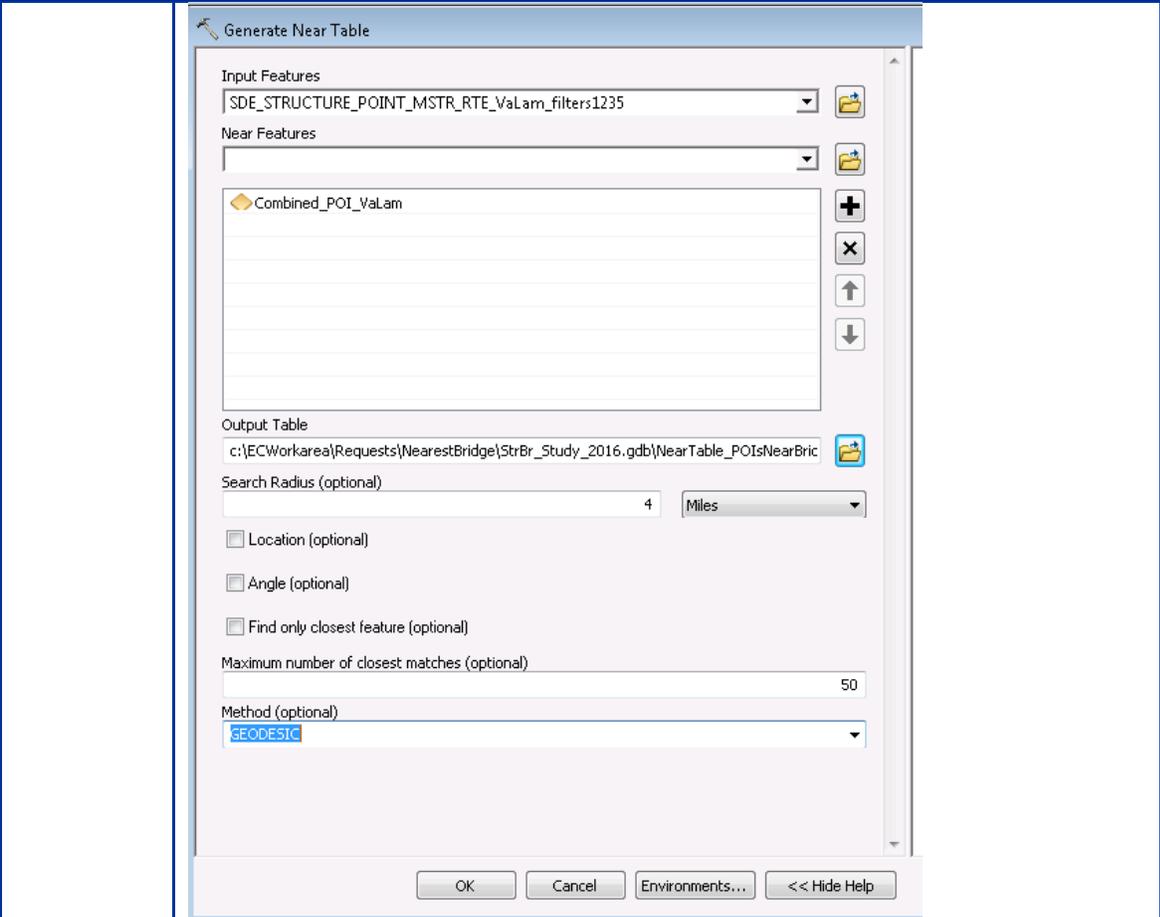
*Steps 7 through 9 provide a check on the success of the coefficient adjustment process.*

7. MACRO-RUN2: Repeat Step 1 using the BNN coefficients developed in Step 6.
8. Repeat Steps 3 and 4 using results from RUN2.
9. Compare the ratios between the RUN2 *standardized* coefficients and the ratios between the RUN1 *goal* coefficients to evaluate discrepancies between the two sets. The BNN coefficients used in the formula should result in RUN2 standardized (i.e., unit-free) coefficients whose interrelationships closely resemble those of the goal coefficients.
10. If results are superior to those of the goal coefficients, replace goal coefficients in the IF tool with the BNN coefficients resulting from Step 6. Otherwise, look for a mathematical error.

## APPENDIX G

### VDOT GIS SERVICE INFORMATION

<b>NOTES</b>	
Purpose	This effort is meant to determine which public schools, hospitals, and fire/rescue stations (POIs) fall within a determined proximity (straight-line distance) to state-maintained structures. This information will be used to help determine detour routes, maintenance scheduling, etc.
Data	<p><b>Hospitals</b>            Source: Virginia Economic Development Partnership            Currency: 11.2013            Count: 160</p> <p><b>Fire/Rescue Stations</b>            Source: Virginia Department of Emergency Management            Currency: 05.2015            Count: 1025</p> <p><b>Public Schools</b>            Source: Virginia Economic Development Partnership            Currency: 12.2014            Count: 2117</p> <p><b>Structures</b>            Source: Virginia Department of Transportation            Currency: as located 03.2016            Count: 28160</p>
Method	<p>The following summarizes the approach used with ArcGIS Desktop (v10):</p> <ul style="list-style-type: none"> <li>• All data were exported from ArcSDE into a file geodatabase so that this analysis could be replicated with a snapshot of point in time data.</li> <li>• All input data (hospitals, schools, fire stations) were merged (delete and append) to create a single point of interest (POI) feature class.</li> <li>• The POI feature class was reprojected to Virginia Lambert (NAD_1983_Virginia_Lambert wkid: 3968 EPSG).</li> <li>• The Structure feature class was reprojected to Virginia Lambert (NAD_1983_Virginia_Lambert wkid: 3968 EPSG).</li> <li>• Structure_VaLam feature was filtered using the following filters               <ul style="list-style-type: none"> <li>— OPPOSTCL NOT IN ('G,' 'K')</li> <li>— STRUCTURE_ON_OVER_CODE = '1'</li> <li>— STRUCTURE_CONSTR_TYPE_CODE NOT IN ('D,' 'F,' 'L,' 'P,' 'S')</li> <li>— VA_MAINT_RESP NOT IN ('DCL,' 'DOD,' 'MDL,' 'NPS,' 'USGS,' 'DMV,' 'MWA,' 'WMA')</li> </ul> </li> <li>• A "Near Table" was generated with the "<i>StructuresFiltered</i>" feature class as the <i>IN</i> feature and the <i>POI</i> feature class as the <i>NEAR</i> feature; "Maximum number of closest features" = 50; Method = 'Geodesic.'</li> </ul>



- An attribute (NEAR\_DIST\_MILES) was added to the resultant table to store the distance between each POI and the closest bridges (max. 50). The mileage was calculated using the NEAR\_DIST attribute that had the distance in meters using the following equation:  

$$\text{NEAR\_DIST\_MILES} = \text{NEAR\_DIST} * 0.00062137.$$
- The output table was then joined back to the POI and StructuresFiltered feature classes using the NEAR\_FID and the IN\_FID and exported to the dbf file and then imported into Excel to create the xlsx file.
  - Create join for NearTable : JOIN DATA join on NEAR\_FID to CombinedPOI on OBJECTID.
  - Create second join for NearTable : JOIN DATA join on IN\_FID to StructuresFiltered on OBJECTID.

Output      The results of this effort include the following:

- Data File – 1 xlsx file