Traffic Generating Development and Roadway Life Consumption

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16. Abstract (Limit: 250 words)

This report describes the development of a tool to estimate the impacts to pavements associated with heavy vehicle traffic related to the construction of large wind turbine developments. In a growing number of areas, large wind farms are constructed in a very short time, often resulting in extreme impacts to the pavements on which the construction traffic must travel. This report attempts to assist the local agency in estimating the damage expected due to the sudden influx of construction traffic and in predicting the associated maintenance and rehabilitation costs to the road network used by the traffic.

The Traffic Generators calculation tool for estimating pavement impacts, developed as part of this project, is a spreadsheet based tool that takes user input from the agency as well as the developer, and combines this information into an estimate of pavement damage. This is done in three ways – difference in granular equivalent pavement design, MnDOT overlay design, and percent of pavement life consumed. With guidance in this report, the agency can select which of the three methods is most appropriate for their particular situation. The tool then provides an estimate of cost required to repair the roadway network to its condition prior to the heavy influx of construction traffic.

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EXECUTIVE SUMMARY

This report describes the development of a tool to estimate the impacts to pavements associated with heavy vehicle traffic related to the construction of large wind turbine developments. In a growing number of areas, large wind farms are constructed over one or two seasons, often resulting in extreme impacts to the pavements on which the construction traffic must travel. The tool developed under this project attempts to assist the local agency in estimating the damage expected due to the sudden influx of construction traffic and in predicting the associated maintenance and rehabilitation costs to the road network used by the traffic. The network of roads on which the construction traffic travels to arrive at the site location most often progresses from interstate and state highway pavements (typically with very high pavement design in terms of allowable loads) to smaller county roads on pavements with lower allowable loads in their original design.

A literature review was conducted to evaluate existing methods and current thinking in the determination and calculation of pavement damage caused by large a influx of heavy vehicles in one concentrated time period. Useful information was found in the work of several researchers and agencies across the Unites States and in other parts of the world.

The Traffic Generators calculation tool for estimating pavement impacts, developed as part of this project, is a spreadsheet based tool that takes user input from the agency as well as the developer and combines this information into an estimate of pavement damage. This is done in three ways, and the agency can select which of the three methods is most appropriate for its particular situation. Guidelines are provided for the selection of the appropriate method. The three methods used in the tool are the GE Difference, MnDOT Overlay, and Percent of Life Consumed methods. The tool then provides an estimate of cost required to repair the roadway network to its condition prior to the heavy influx of construction traffic.

Chapter 1. Introduction

This report describes the development of a tool to estimate the impacts to pavements associated with heavy vehicle traffic related to the construction of large wind turbine developments – often called wind farms. In a growing number of areas, large wind farms are constructed over one or two seasons, often resulting in extreme impacts to the pavements on which the construction traffic must travel. The tool developed under this project attempts to assist the local agency in estimating the damage expected due to the sudden influx of construction traffic and in predicting the associated maintenance and rehabilitation costs to the road network used by the traffic.

The network of roads on which the construction traffic travels to arrive at the site location most often progresses from interstate and state highway pavements (typically with very high pavement design in terms of allowable loads) to smaller county roads on pavements with lower allowable loads in their original design. As can be seen in Figure 1, assuming slightly variable annual traffic load (in terms of Equivalent Single Axle Loads – or ESALs) and a large, single-season amount of traffic related to construction of a wind farm, the additional traffic is seen as a small addition in a single year compared to the same amount of traffic traveling on a local road with less pavement structure. In this example, it is assumed that the same development traffic leaves the interstate and traverses the county road, thus applying a similar amount of ESALs to each roadway.

Figure 1. Pavement Loads (ESALs) over Time.

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It is important to notice the scale of the vertical axes for the interstate and the county road in this example (that of the county road is 1/10 that of the interstate highway. It is evident, however, that the large amount of ESALs at year 12 is only slightly noticeable among the interstate traffic, and that it is approximately five times that of the annual traffic on the county road. While this is simply an example, it is typical of the amounts of traffic loading applied to some county roadways when these developments are constructed. While the heavily constructed interstate pavement is easily able to accommodate the additional traffic in one season, the smaller county road pavements are not.

The Heavy Traffic Generators tool described in this report allows the user (usually the county road authority) to estimate the damage that may be inflicted on the pavements in a localized area during a single season or two of heavy construction traffic. The results of the analysis conducted by the tool include an estimate of the cost to repair and/or reconstruct the impacted pavements to restore them to their original condition. The analysis methods incorporated into the tool are commonly accepted models that are recognized nationally (or at least statewide) and by the general pavement engineering community. The tool is an implementation of those models with a specific purpose to evaluate the impacts of these heavy loads on local pavements.

Chapter 2. REVIEW OF LITERATURE

This chapter provides a detailed literature review that was conducted as part of the Traffic Generating Developments and Roadway Life Consumption project. It includes results of literature searches conducted by the MnDOT Library staff, a Transportation Research Synthesis conducted by CTC & Associates, and reviews conducted by the MSU project staff.

The literature search conducted by the MnDOT library was augmented by the review conducted by MSU, and these are presented in a single section. The transportation research synthesis was submitted to MSU as a standalone report, and was published as TRS1001 [1].

Literature Review

Typically, local roads are not designed to handle large, unanticipated loads. When a new facility is built that generates large amounts of heavy vehicles, whether temporarily or permanently, the road network and other items associated with it (corner turning radii, geometric design, speeds, policies, etc.) is often inadequate, and pavement or other failures may occur long before originally anticipated. The costs associated with these early pavement failures and the maintenance and rehabilitation that they necessitate are almost always borne by the local highway agency. In most cases, the local agency is not equipped financially to accommodate these additional costs. Some examples of this type of development include:

- Hog farms,
- Ethanol plants,
- Shipping and distribution centers,
- Container shipping yards,
- Logging stations,
- Wind farms, and
- Beet plant dumping stations.

This literature review focuses on the impacts of new traffic generating sites, including pavement deterioration and other associated costs. There are three major categories of focus in this topic: pavement deterioration, other impacts and "who pays for what" scenarios, and local policies that should be addressed in order to ameliorate the situation of the local agency and assign costs to the source of the impact.

Political environments can range from an "agency pays" approach to a "developer pays" approach and anywhere in between. Problems are more easily addressed in the early stages of site development, and a consistent set of policies should be developed that can be adopted by cities, counties, and the state so that all agencies treat site developers equally and fairly.

Pavement Deterioration

Pavement deterioration is perhaps the most critical of the issues related to new, large site developments. Pavement deterioration in general has been to focus of many reports and research studies. Some specific studies related to large traffic generators include the following.

Rutherford, M.S., K.G. Buss, and D.C. Overbay, *Analysis of the Impact upon State and Local Roads of Transporting Garbage to Centralized Solid Waste Disposal Sites*, **South Dakota Department of Transportation, 1994.[2]**

Describes methods to evaluate incremental damage on roads due to solid waste vehicles. This report uses load equivalencies to estimate damage to flexible pavements due to these vehicles. Incremental damage is estimated by evaluating the amount of traffic prior to the installation of a solid waste station and the estimated additional loads to be experienced by the roadways after the station is constructed. The incremental costs are based on data obtained from counties in South Dakota. A model is described which can be used to estimate incremental pavement damage and costs. The model is written in Microsoft Visual Basic.

Dodoo, N.A., and N. Thorpe, *A New Approach for Allocating Pavement Damage Between Heavy Goods Vehicles for Road-User Charging*, **Transport Policy, Vol. 12, No. 5, Elsevier, 2005.[3]**

This report discusses the alignment of pavement damage and other costs with the vehicles responsible for the damage. It presents a framework for a system of aligning the costs (damage) with the charges (fees and taxes). It presents several implementation issues that need to be overcome before widespread implementation is practical. It is primarily based on European models and issues.

Bhatti, M.A., et al., *PAVESIM: Simulation of Pavement Damage Due to Heavy Vehicles*, **Iowa Department of Transportation and University of Iowa, Iowa City, 1997.[4]**

The computer program PAVESIM is a dynamic simulation environment which was created to help develop performance-based operations policy and assignment of pavement damage costs. A secondary model, called TruckSim, was developed at the University of Michigan to model heavy vehicles in the traffic stream and on the pavement. It is primarily used for concrete pavements.

Huntington, G., and K. Ksaibati, *Methodology for Assessing Heavy Traffic Impacts on Gravel Roads*, **Transportation Research Board 88th Annual Meeting, January 2009.[5]**

This report focused on the effect of oil and natural gas drilling activities in Wyoming. One objective was to assess the impacts to the counties' roads from these activities. Recommendations were made for improving the individual roads in the three counties, and the costs for the improvements were estimated. The impacts were evaluated based on the rate of maintenance and rehabilitation activities on the roads where drilling activities were taking place, versus roads in areas where no drilling was being conducted. The greatest impact of these activities were observed on collectors, rather than local roads. "It is clearly demonstrated that heavy traffic associated with drilling activities has done significant damage to these three counties' roads, above and beyond what would be anticipated from typical traffic loads." The methodology developed in this report could

be adapted to other road systems experiencing "a significant influx of heavy truck traffic" to assess the additional traffic's impact.

Other Infrastructure Impacts

Impacts other than to the pavement structure are also often prevalent when a new large-vehicle traffic generator is placed within the local road network. These can include the following.

- Geometrics of the local roadway system (speed, vehicles, sight distance, pavement width, slopes, turning radii, etc.)
- Dust
- Noise
- Localized pavement failures
- Damage to bridges
- Moving utilities for large vehicles
- Moving signs and other traffic control devices for large vehicles
- Developing and implementing detours and road closures

Some of the research relating to these issues include:

Bropst, W.A., et al., *Panel Discussion: Community Impacts and Local Autonomy*, Transportation Research Board, Transportation Research Circular No. 216, 1980.[6]

This report is mainly of a "panel discussion" about possible impacts to local rural roads due to increased coal production. "Townships in these areas lack the fiscal means to keep these roads in proper repair, and local residents have to contend with badly damaged pavements, as well as the other safety and environmental hazards associated with coal mining."

Boile, M, et al., *Infrastructure Costs Attributable to Commercial Vehicles*, Report No. FHWA-NJ-2001-030, Federal Highway Administration, Washington, DC, 2001.[7]

This report describes a "comprehensive study on infrastructure costs attributable to heavy vehicles." The two objectives of the study are to 1) review the availability of methods for allocating roadway maintenance costs to different types of vehicle classes, and 2) to determine the existence and availability of methodologies to estimate the impact of different types of buses on highway infrastructure. The report recommends a cost allocation study for the state of New Jersey, to develop a clearer picture of the cost responsibility of each vehicle class.

Local Agency Policy

The policies adopted (or those not adopted) by local agencies can have a dramatic effect on large traffic generators and site development. Some of the issues that were addressed include:

- Permitting (overweight, large vehicles, etc.)
- Working with local agency and law enforcement with scheduling and temporary traffic control, and contact with the local 911 system to inform of road closures and detours for emergency vehicles.

Small, K.A., et al., ***Road Work: A New Highway Pricing and Investment Policy*****, Brookings Institution, 1989.[8]**

This book proposes a "comprehensive highway policy to meet the goals of efficiency, equity, and financial soundness" based on efficient pricing to regulate demand for highway services and efficient investment to minimize the total public and private cost of providing them. Some of the policy recommendations include pavement-wear taxes for heavy trucks, congestion taxes for all vehicles, and optimal investments in road durability.

Poole, R.W., ***Getting to Yes on Bigger Trucks*****, Public Works Financing, Vol. 161, 2002.[9]**

While this report discusses the issues of bigger (larger, heavier) trucks on the existing highway networks, it also addresses the problem of discrepancies between federal and state standards for truck weight limits. This article takes a closer look at this debate over whether or not to increase federally imposed commercial trucking weight limits.

Recommendations

Based on the literature review and the End-User Product document, the following recommendations were made for developing the tool which was the primary deliverable of this project.

1. Investigate the South Dakota report further to determine the applicability of its conclusions as well as the level of detail in the computer model. There may be some benefit to utilizing that model as a starting point.
2. Evaluate the PAVESIM model to determine is suitability for estimating the damage and related costs to roadways due to large traffic generators.
3. Conduct additional literature review and develop further recommendations on the policy side of this issue.
4. Develop a work plan for a combined project with objectives for two research products. The first should be a set of "best practices" for local government agencies. This should address not only the pavement deterioration issues, but also recommended policies for dealing with developers wishing to build within a county. Items that should be addressed include the "other infrastructure impacts" mentioned above, the "who pays for what" questions, and the overall liability, accountability, and responsibility questions related to these impacts. The second product should be either a standalone computer program or a spreadsheet "calculator" based on currently-used pavement design methods which are common to local agencies within Minnesota. The calculator would estimate the incremental damage and related costs of additional maintenance, rehabilitation, and/or reconstruction necessary due to the presence of the traffic generator facility.

5. The project team should work closely with the "Real World Pavement Preservation Solutions" team to gather data from counties in Minnesota and determine common pavement construction, maintenance, and rehabilitation schemes for inclusion into the calculator.

The recommendations above were addressed, to the extent possible, and are summarized below.

- The South Dakota report [2] was reviewed and several components were incorporated into the tool development in this project.
- The PAVESIM software [4] is applicable only to concrete pavements, and primarily on higher vehicular volume roads. This model was not pursued further as an option for this project.
- The additional literature review was conducted by CTC & Associates, and was published by MnDOT as TRS-1001 [1]
- The project team developed the impacts assessment tool in conjunction with another project funded by the LRRB which focused on the policies and other guidelines relating to heavy vehicle impacts.

Chapter 3. IMPACTS TOOL DEVELOPMENT AND REVIEW

The impact calculator was developed over a period of about one year, in conjunction with the policy guidelines tool, and with the guidance of the TAP and additional assistance from specific TAP members. Others individuals outside of the TAP membership were asked to provide reviews of the tool at various stages in its development. These additional reviewers provided essential comments on the tool's usability and applicability to real world situations.

The impacts calculator tool is based on the following principles.

1. Additional loads on pavements cause incremental damage to the pavement structure and the ride quality provided by the road.
2. Unanticipated loads for which the pavement structure was not designed cause the roadway to fail prematurely and the highway agency to expend additional funds unexpectedly.
3. Additional pavement damage can be estimated by the number of ESALs applied to the pavement, and by the resulting material and pavement structure needed to accommodate that damage.
4. The computation of damage and the resulting recommended corrective activities are based on established pavement design, deterioration, and rehabilitation models developed and/or adopted by MnDOT [10], the American Association of State Highway and Transportation Officials (AASHTO) [11], and other agencies.

The tool is developed within the Microsoft Excel 2010 environment, and is arranged to accept inputs in three categories:

- Basic information about vehicles, loads, and costs,
- Information provided by the developer regarding routes and number of anticipated loads, and
- Information provided by the agency regarding pavements, materials, and other design parameters.

The tool also computes the damage and estimates the cost to recover the pavement structure in three ways, as described below. These three methods are provided in order to provide the user with more information and options from which to choose. The most appropriate choice will depend on several conditions, which are described later in this report. Print versions of each tab in the impact tool spreadsheet are provided at the end of this report.

- **GE Difference**

    This method predicts the overall GE that would have been required if the new development had been considered in the original pavement design. It makes a comparison of pavement designs (using the MnDOT GE method [10]). Both designs utilize the same soil subgrade but compute different ESAL values. The first design is based on the ESALs computed by the agency at the time of original design, using the anticipated ESALs at that time. The second design begins with the original design ESALs and then adds the estimated ESALs due to the traffic generated by the

development. Each pavement design is computed in terms of the Granular Equivalent, and the difference between the two design is assumed to be the required pavement structure needed due to the additional ESALs. The tool assumes the additional GE to be designed as bituminous material, but this could be constructed in other layers as well. The cost is then computed based on the cost per inch of bituminous material.

- **MnDOT Overlay Design**

  This method considers the current condition of the affected pavement, in terms of estimated ESALs since construction, and then determines an appropriate bituminous overlay thickness to restore the pavement to the same condition. The cost is then computed based on the cost per inch of bituminous material.

- **Percent of Life Consumed**

  The percent life consumed method simply takes the original design ESALs and the estimated ESALs from the development, and computes a percentage of the original expected pavement life. The predicted cost is then computed based on the reconstruction cost of the pavement.

Tool Structure

The inputs to the impacts tool are placed on several different tabs within the Microsoft Excel 2010 environment. These tabs are labeled, in order from left to right, as follows. A description of the contents and usage of each of these tabs is then presented.

- Summary
- Instructions
- Report
- Load and Cost Info
- Developer Info
- Agency Info

Summary

The summary tab (shown in Figure 2) is simply for basic information about the project, who prepared the analysis, and the date. Basic information about the tool and the version number are also included in this tab. From this tab all other tabs can be accessed.

Instructions

This sheet (shown in Figure 3) contains the basic instructions for the tool's use, and provides basic guidance regarding the various inputs required by the tool.

Report

On this tab, shown in Figures 10 and 11, a summary of all the information entered by the users (agency and developer) is presented, as well as a compilation of the pavement life values

calculated by the tool. This sheet is set up so that when the user clicks the "Print Report" button at the top of the sheet, a useful printout is generated.

Load and Cost Information

The Load and Cost Information tab (Figures 4, 5, and 6) is where the user enters the basic data regarding costs, vehicles and loads, and other information necessary for the pavement design and remaining life computations. Each of these inputs is described in the next section.

Developer Information

The Developer Information tab (shown in Figure 7) allows information from the developer to be entered for the life consumption calculations. This information may be entered either by the agency, or by the developer directly. In the latter case, the agency would provide a copy of the spreadsheet tool for the particular project to the developer, who would in turn enter the appropriate data and return the electronic file to the agency. The tool is set up to allow this information to be entered either by average loads per turbine (of each type of load) by total, cumulative loads per road segment, if more detail is known about the nature of the hauling routes.

Agency Information

The Agency Information tab (shown in Figure 8) provides a place for the agency representative to enter specific information regarding the pavement structures and original design information, if available. This information is then used in the pavement life consumption calculations as well as the overall cost computations.

Tool Inputs

The tool requires the following inputs, depending on the analysis method chosen. This section is divided into subsections relating to the general information requested. In most cases, all of the related inputs are found on the same tab, and this is indicated in its heading.

Load and Cost Info Tab

The ESAL calculation is one of the primary factors in pavement design for all methods derived from the method in the AASHTO Guide for Design of Pavement Structures [11] commonly known as the *AASHTO Guide* or the *AASHTO method*. The equivalent single axle load for any vehicle is a way of relating its load and axle configuration to a standard "equivalent single axle load" of 18,000 lbs. For the purposes of the impacts assessment tool, the following inputs are required.

Terminal Serviceability

The serviceability of a pavement is defined by AASHTO as the "ability to serve the type of traffic (automobiles and trucks) which use the facility [11]. The primary measure of serviceability is the Present Serviceability Index (PSI), which ranges from 0 (impossible road) to 5 (perfect road)." The terminal serviceability is defined as the lowest allowable PSI, and is

"based on the lowest index that will be tolerated before rehabilitation, resurfacing, or reconstruction becomes necessary" [11].

The AASHTO Guide suggests a terminal serviceability of 2.5 for major highways, and 2.0 for "highways with lesser traffic volumes" [11]. The agency user of this tool will need to make the appropriate determination for the state aid highways and county roads in his or her county.

Estimate of Pavement Structural Number

The concept of pavement structural number is similar to the granular equivalent, but on a different scale. Whereas individual materials are given "granular equivalents" from 0.5 to 2.25 inches, individual layers are given "layer coefficients" from 0.09 to 0.44 or so, in the AASHTO method. For example, whereas an asphalt concrete pavement "wear course" might be assigned a granular equivalent of 2.25 inches in the GE method, the same material and layer may be assigned a layer coefficient of 0.44 in the AASHTO method. A base layer may be assigned a granular equivalent of 0.75 or 1.00 inches in the GE method, and a 0.09 or 0.11 in the AASHTO method. The structural number for a particular pavement is then the sum of the products of layer thicknesses and layer coefficients for each structural layer in the pavement, similar to the manner in which GE is computed.

An estimate of the structural number is normally based on the actual layer thicknesses and default layer coefficients. In the absence of additional information, layer coefficients of 0.44, 0.14, and 0.09 can be used as default values for the surface, base, and subbase layers, respectively. For example, a pavement structure with 5 inches of asphalt concrete, 6 inches of base, and 12 inches of subbase materials would have an estimated structural number of 4.12, computed as follows.

$$SN = \sum_i a_i D_i$$

$$SN = 0.44 \cdot 5 + 0.14 \cdot 6 + 0.09 \cdot 12 = 4.12$$

Where,

$SN =$ structural number,

$a_i =$ layer coefficient, and

$D_i =$ layer thickness, in.

GE per Inch of Bituminous

This value is typically the standard 2.25 inches of granular equivalent specified in the MnDOT Pavement Manual [10] but can be changed by the agency as desired.

Cost of Total Pavement Surface Replacement

This value is the total cost of replacing a pavement on a road including excavation to the subgrade and rebuilding the pavement, on a per-mile basis. This cost would include the demolition and excavation of the roadway to the subgrade, and the reconstruction of the

pavement structure and any other items such as ditches, curb and gutter, driveways, etc. that are found on a typical roadway in the area of the development.

Cost of Overlay

This is the cost of constructing an overlay on a roadway that already has a paved bituminous surface, in units of dollars per mile, per inch of overlay. The tool also assumes that this is for a 2-lane roadway, so that the cost entered in this cell should be approximately doubled for a 4-lane roadway. This cost should include only the design, surface preparation, localized repairs, and other items relating to the overlay.

Increments for Bituminous Rounding

Since the tool could compute needed overlays to a high level of precision (to the nearest hundredth of an inch, for example) it is necessary to specify the smallest increment to which an overlay would be designed. Typically this is one-half inch, but could be a different value depending on the agency's preferences. Later, in the description of the tool's computation, the impacts calculations only include the portion of the overlay that is estimated to be attributed to the development, and not the entire thickness rounded to the next increment.

Minimum Bituminous Overlay Thickness

The minimum bituminous overlay thickness is necessary when estimating the cost of an overlay construction in order to make a reasonable representation of the cost. As stated in the previous item, this does not mean that the total cost of the minimum overlay will be assigned to the development's impacts, but that is will be pro-rated if the estimate impact is less than the minimum overlay thickness.

Axle Type and Load

In order to compute the estimated ESALs per vehicle, as mentioned at the beginning of this section, basic information must be known about the individual axles and the loads that they impart to the pavement. Each axle type (single, tandem, tridem) and wheel configuration (single wheel, dual wheel) has a different impact on the pavement, in terms of the stresses due to wheel loads. On this tab in the tool, there are different vehicle definitions, with standard axle and wheel configurations so that specific vehicles may be assigned an ESAL value.

To perform this calculation, the following information is needed for each vehicle.

- Load on steering axle (this axle is assumed to be a single wheel, single axle)
- Load and type of additional axles (drive axles, trailer axles, etc.)

The tool includes standard vehicle types that are typically found on wind turbine construction sites, such as aggregate and concrete trucks, as well as the larger, multi-axle trucks carrying the turbine components themselves. These are generally standard tractor-trailer combinations with additional axles. For example, one type of truck that could carry the nacelle might have the following axle types and loads.

1. Steer Axle   18,000 lbs   Single Axle
2. First Axle Set   40,000 lbs   Tridem Axle
3. Second Axle Set   60,000 lbs   Tridem Axle
4. Third Axle Set   60,000 lbs   Tridem Axle
5. Fourth Axle Set   40,000 lbs   Tridem Axle

This vehicle has a gross weight of 218,000 lbs on 13 axles, combined into five axle sets (the steer axle and four tridem axles).

The computation of ESALs for each of these vehicles is discussed in a later section.

In addition to the standard vehicle types, the tool contains the option to define two custom vehicles that may have different axle configurations than the aggregate, concrete, or turbine component trucks. For each of these, up to six axle sets may be defined, each with their gross axle load and the type of axle.

Agency Information Tab

As described earlier in this section, the information in this tab is related to the roadway and pavement properties, and other preferences of the agency regarding the design and construction of roadways impacted by heavy vehicles. Each road segment is given a unique row in the tool, and the following information is requested.

Existing Road Segment

This is the name of the road segment described on this row. It should have a unique identifying name that is descriptive enough to avoid confusion.

Pavement Type

The pavement type is indicated by "P" for paved, and "G" for gravel. Currently only paved roads are analyzed in the tool.

Subgrade R-Value

The R-value of the subgrade, based on soil type, physical testing, or other means. The pavement manual provides information regarding the estimate of R-value when other data or testing is not available.

Cumulative ESALs since Last Reconstruction

This is an estimate of the cumulative ESALs since the last time the roadway was reconstructed. It can be estimated by the historical AADT counts and presumed vehicle classification since that time. It can also be estimated by taking the original design ESALs (discussed in the next section) and the number of years since its last reconstruction.

Design ESALs from Previous Design

This number should be taken from the original plans at the time the roadway was last designed and reconstructed. Often this information is not readily available, but historical practices within a county may lead to an accurate estimate. Other means may also be used, such as historical estimates of AADT and vehicle classification.

20-Year Project ESALs without Development

If the proposed development were not to occur, and the associated heavy loads therefore were not to impact the roadways, this value is the estimate of the ESALs that would be expected on the roadways over the next 20 years. It is thus the anticipated ESALs without the development traffic.

Existing Pavement GE

This is computed in a similar way as the structural number, described in the previous section. The existing layer thicknesses and the associated granular equivalents are combined to determine the overall pavement GE.

Effective GE

Since the materials comprising the pavement layers deteriorate over time, due to traffic loads and the environment, the effective GE is a factor, in terms of a percentage of the original GE of the pavement, to account for the anticipated overall deterioration of the pavement structure. For the design of overlays, the Pavement Manual [10] suggests a value "between two-thirds and three-quarters of the G.E. computed for the existing pavement in order to add a degree of conservatism to the design."

Appropriate Design Method

The appropriate design method to use for a particular roadway can be chosen either the same for all roadways in the analysis or based on individual conditions. The three design methods were described in a previous section. General guidelines for the selection of an appropriate method are given below.

GE Difference. The GE difference method may be selected when an agency is not anticipating large impacts, in terms of consumed roadway life, and does not expect to reconstruct or to overlay the roadway after the conclusion of the heavy development traffic. The agency may plan on some future construction, and it is important to know the estimated accumulated traffic impact due to a particular development.

MnDOT Overlay Design. The overlay design method is used for roadways where the expected consumed life is larger than in the GE Difference method, but not greater than about 50% of the original life expectancy of the roadway, in terms of ESALs. Using this method, it is assumed that the underlying pavement structure is not compromised, and that an overlay can be expected to restore the pavement nearly to its original functional and structural condition.

Percent of Life Consumed. This method is intended when a large portion (approximately greater than 50%) of the pavement's original expected life is predicted to be consumed during the development traffic. In such cases it may be reasonable to expect that the roadway is close to the end of its anticipated life, or that it has already exceeded it. This is a much more expensive option in general, and before a final decision is made to utilize this method, the agency and developer should conduct some visual observations after the development traffic has been completed. An alternative design rather than complete pavement reconstruction may be a viable alternative.

Add / Delete Row

The "Add 1 Row" and "Delete Last Row" user buttons are for ease in managing multiple road segments and for copying the relevant cell formulas needed for determining the estimated total impact. Pressing these buttons on either tab (Agency or Developer Information) creates or deletes one row in each tab.

<u>*Developer Information Tab*</u>

This section of the tool contains information to be supplied by the developer, if possible, which will identify the specific roadway segments that will be utilized by the various heavy trucks during the construction of the wind turbine development. There are two options for entering this information – by an average number of truck loads on each road segment per turbine constructed, or by specifying the number of each type of load on each road segment. The following sections will define the required input for both methods, and then each method will be described in more detail.

Existing Road Segment

This is the same information as requested in the Agency Information Tab, and it should match with the roadway segment name defined by the agency. Either party may define the roadway segments first, but the second should use the segment names already identified. Alternatively, the agency and developer may agree on segments and their identifying names prior to entering the other information.

Segment Length

This is the length of the particular roadway segment. The roads should be segmented finely enough so that the same number of loads are anticipated on an entire segment. If there are other side routes that some trucks may use to arrive at specific turbine locations, the roadway should be divided into two or more segments.

Road Authority

This is the agency that has authority and responsibility for the construction and maintenance of the particular roadway. Possible entries in these fields could be "County", "City", or "State".

Number of Turbines

The number of turbines for which heavy vehicles will be traversing the roadway segment. This is used with the "Average Loads Per Turbine" method.

Vehicle Loads

The number of loads of each vehicle type that is anticipated on the particular roadway segment. These are divided into several categories of vehicles, as indicated in the list below.

- Aggregate trucks
- Concrete trucks
- Trucks carrying turbine components
- Crane Assemblies
- Rough Terrain (RT) Cranes
- Two user-defined trucks

Vehicle Load Input Methods

As mentioned, there are two methods for entering the information on the number of heavy vehicles estimated on a particular roadway segment - the "cumulative loads per road segment" and "average loads per turbine" methods. By selecting the desired method in the grey box in the upper right corner of the tool window, the appropriate cells are changed to yellow, indicating an expected data entry.

In the cumulative loads per road segment method, the anticipated loads of each type are entered for each road segment. This requires more initial planning by the developer but can result in a more precise computation of the pavement impact.

The average loads per turbine method requires the number of turbines (and associated aggregate, concrete, and other loads) that are expected to be transported on the specific roadway. Then the overall average loads per turbine for the entire development are entered in the appropriate cells. The tool then performs the calculation, distributing the number of loads per truck type to each road segment.

Add / Delete Row

The "Add 1 Row" and "Delete Last Row" user buttons are for ease in managing multiple road segments and for copying the relevant cell formulas needed for determining the estimated total impact. Pressing these buttons on either tab (Agency or Developer Information) creates or deletes one row in each tab.

Tool Input Pages

The following pages include page capture images of the individual sheets in the Microsoft Excel spreadsheet, including the following.

- Summary
- Instructions
- Load and Cost Information
- Developer Information
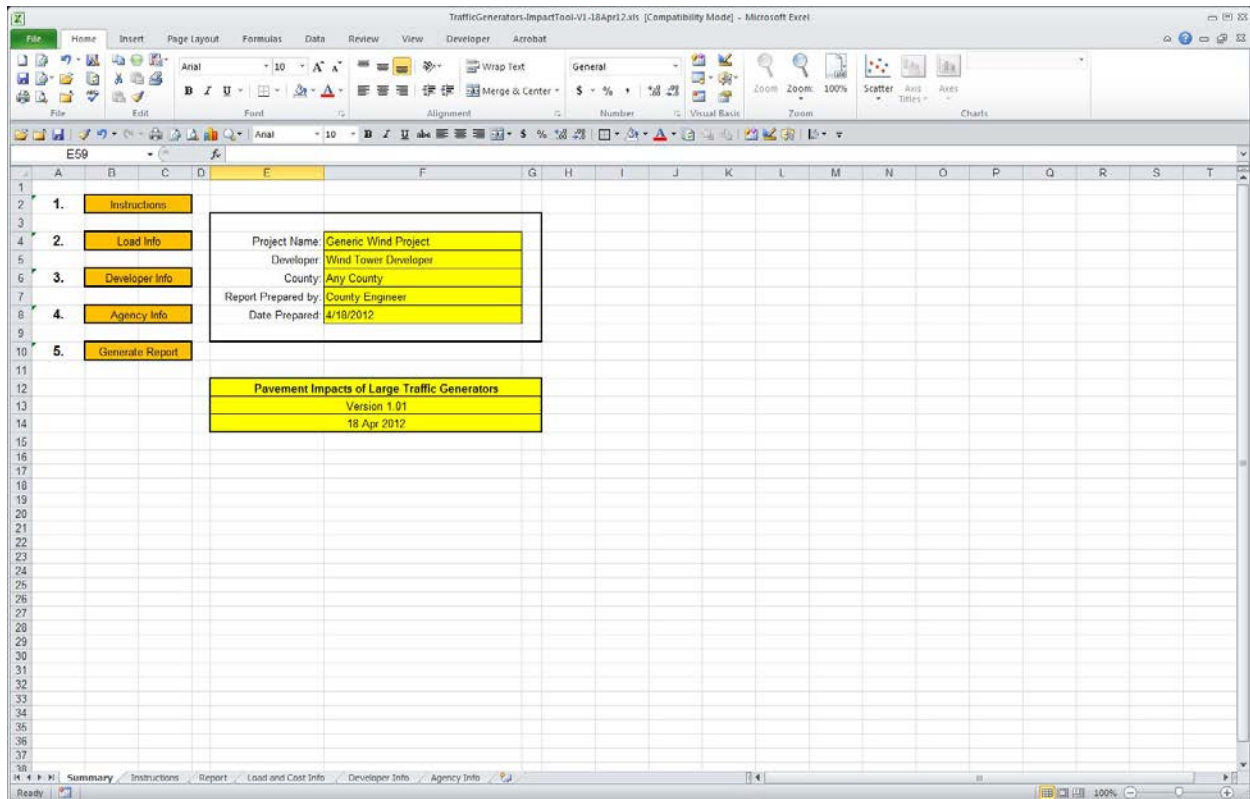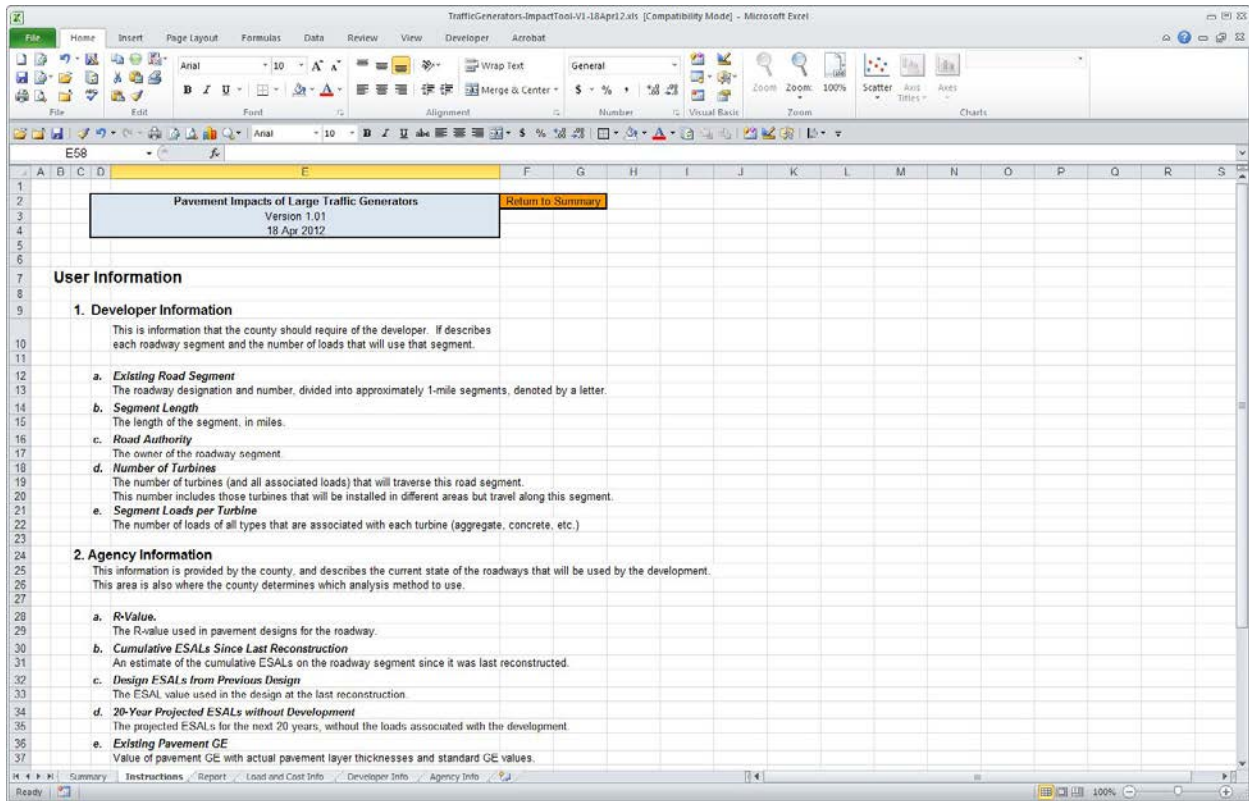- Agency Information

Figure 2. Sample of Summary Tab.

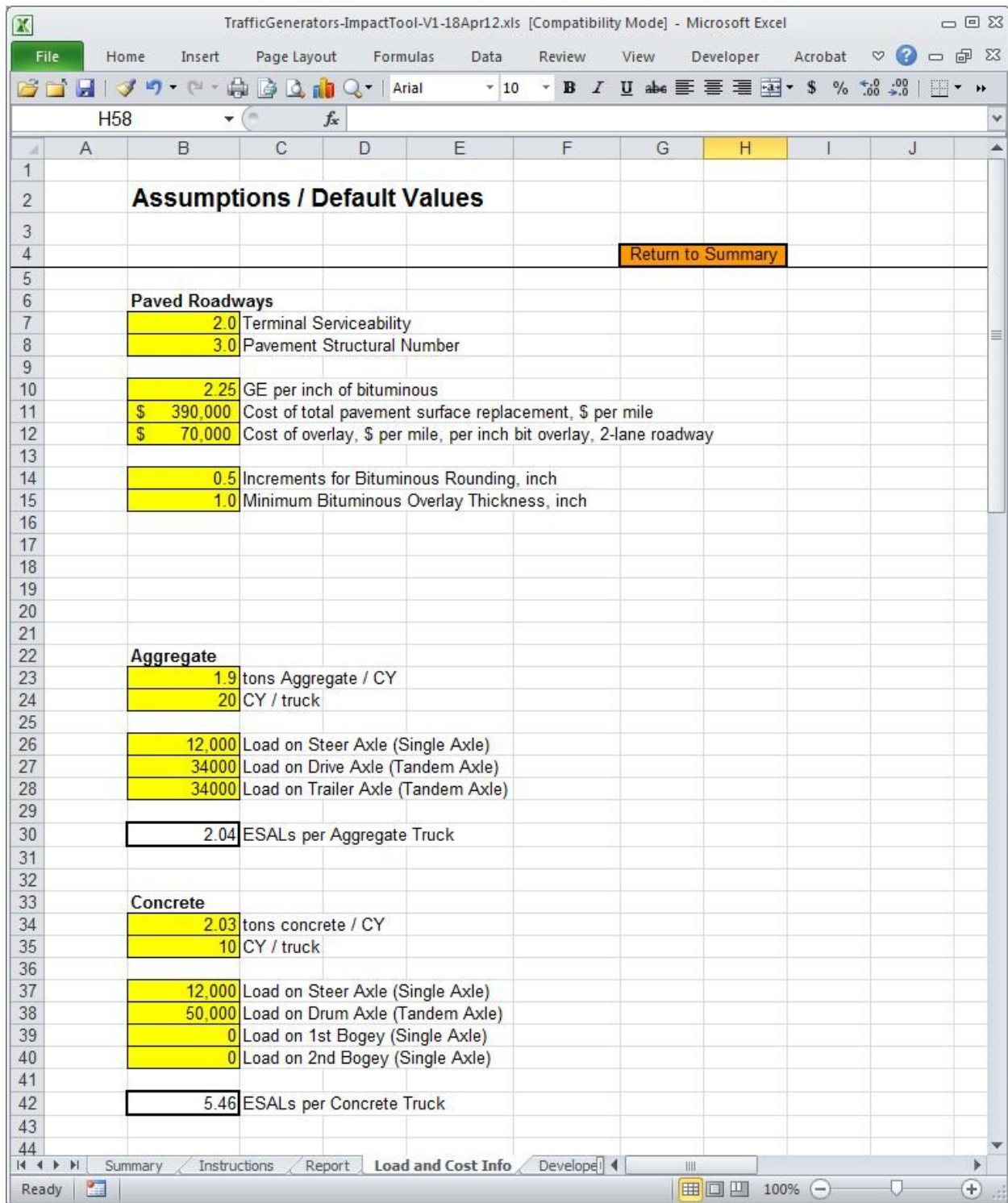**Figure 3. Sample of Instructions Tab.**

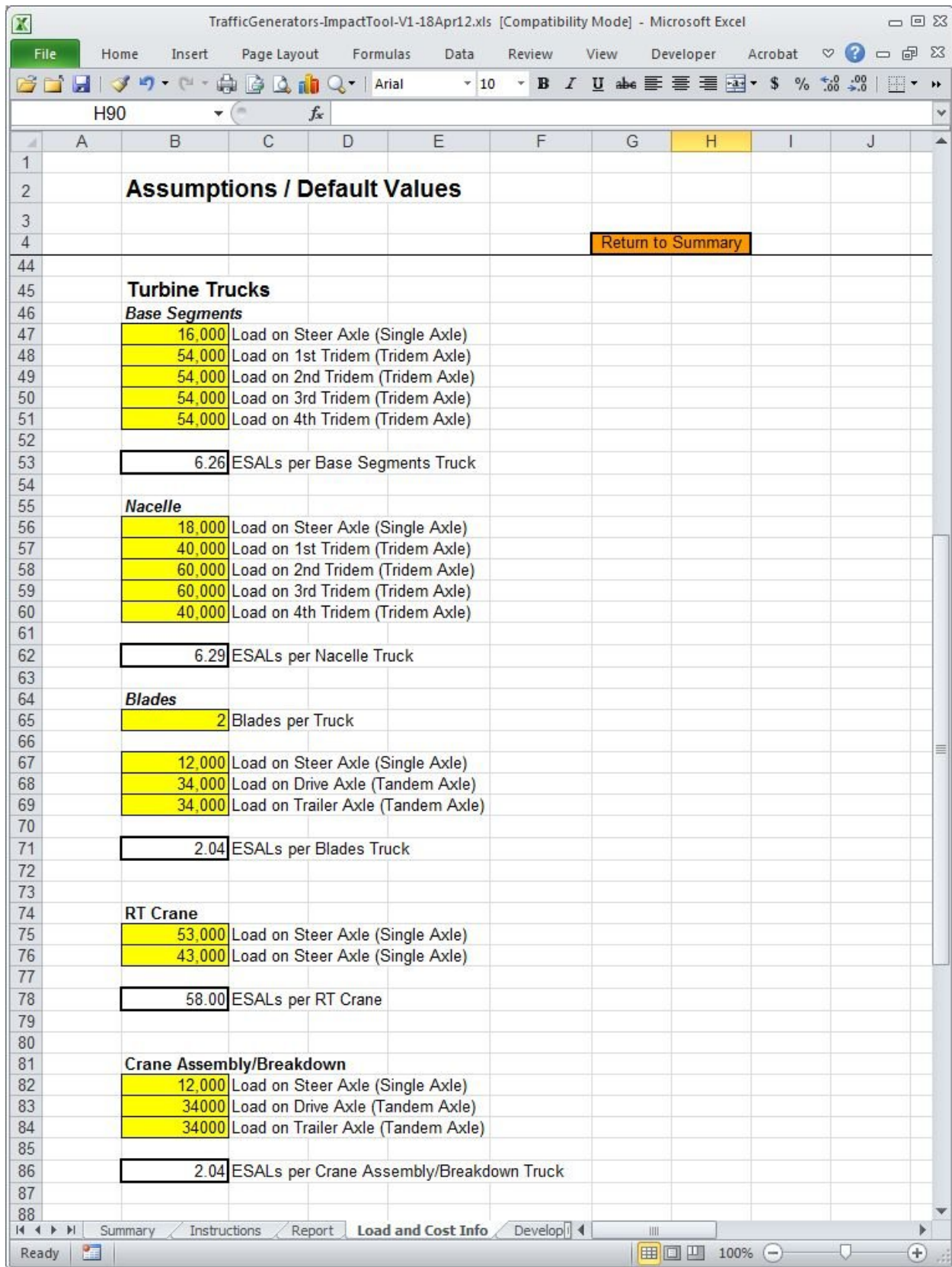**Figure 4. Sample of Load and Cost Information Tab – Part 1.**

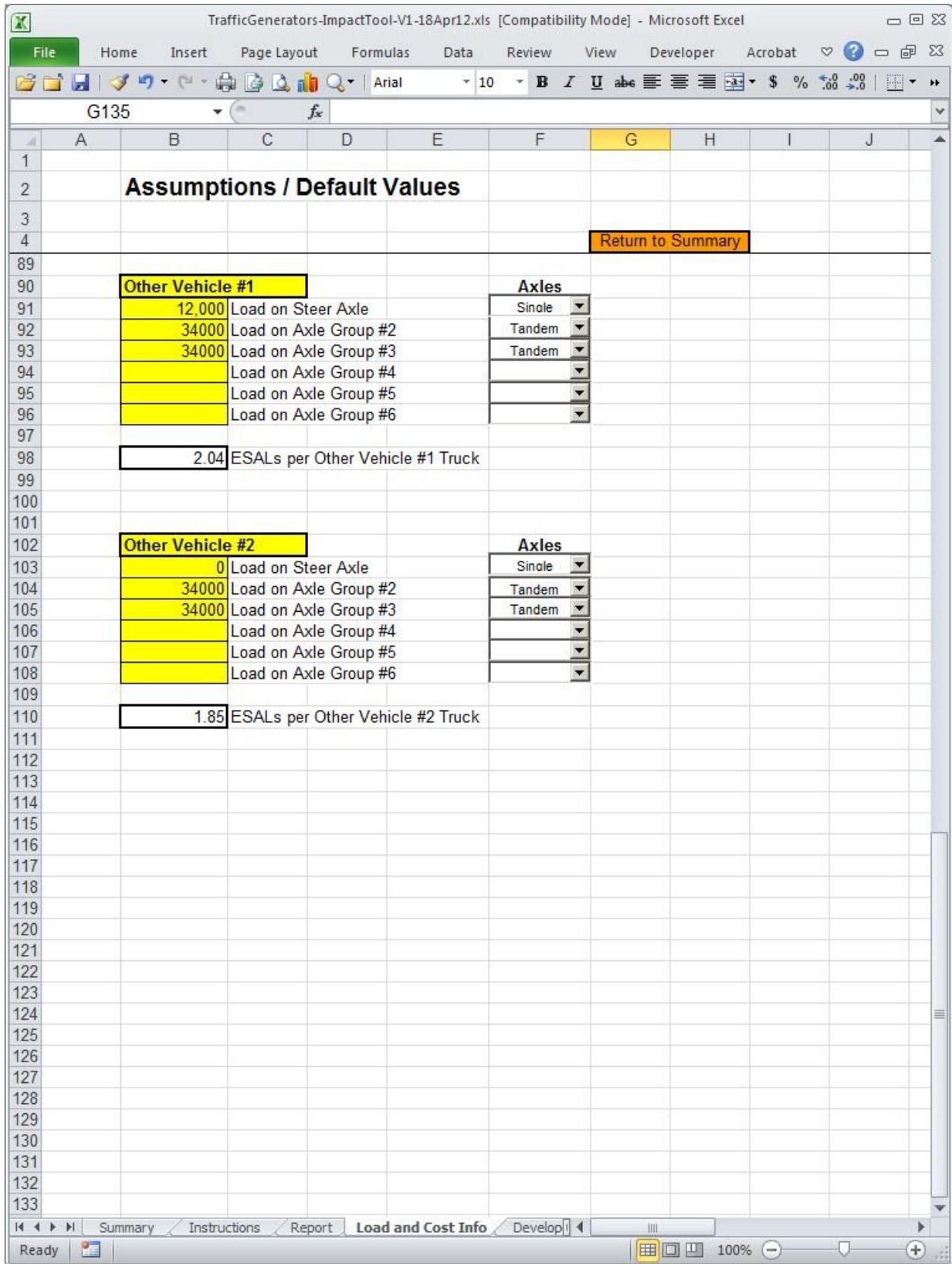**Figure 5. Sample of Load and Cost Information Tab – Part 2.**

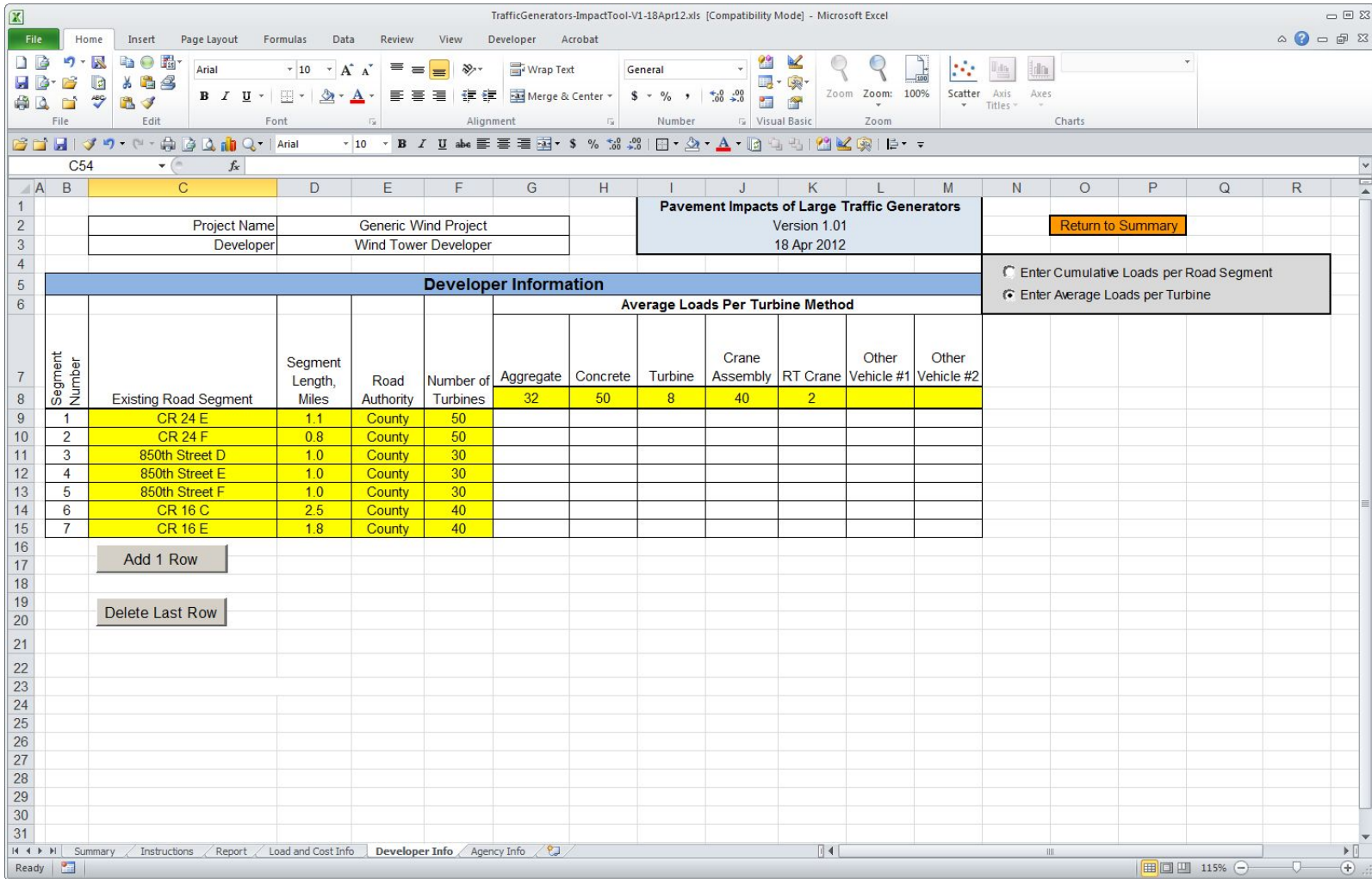**Figure 6. Sample of Load and Cost Information Tab – Part 3.**

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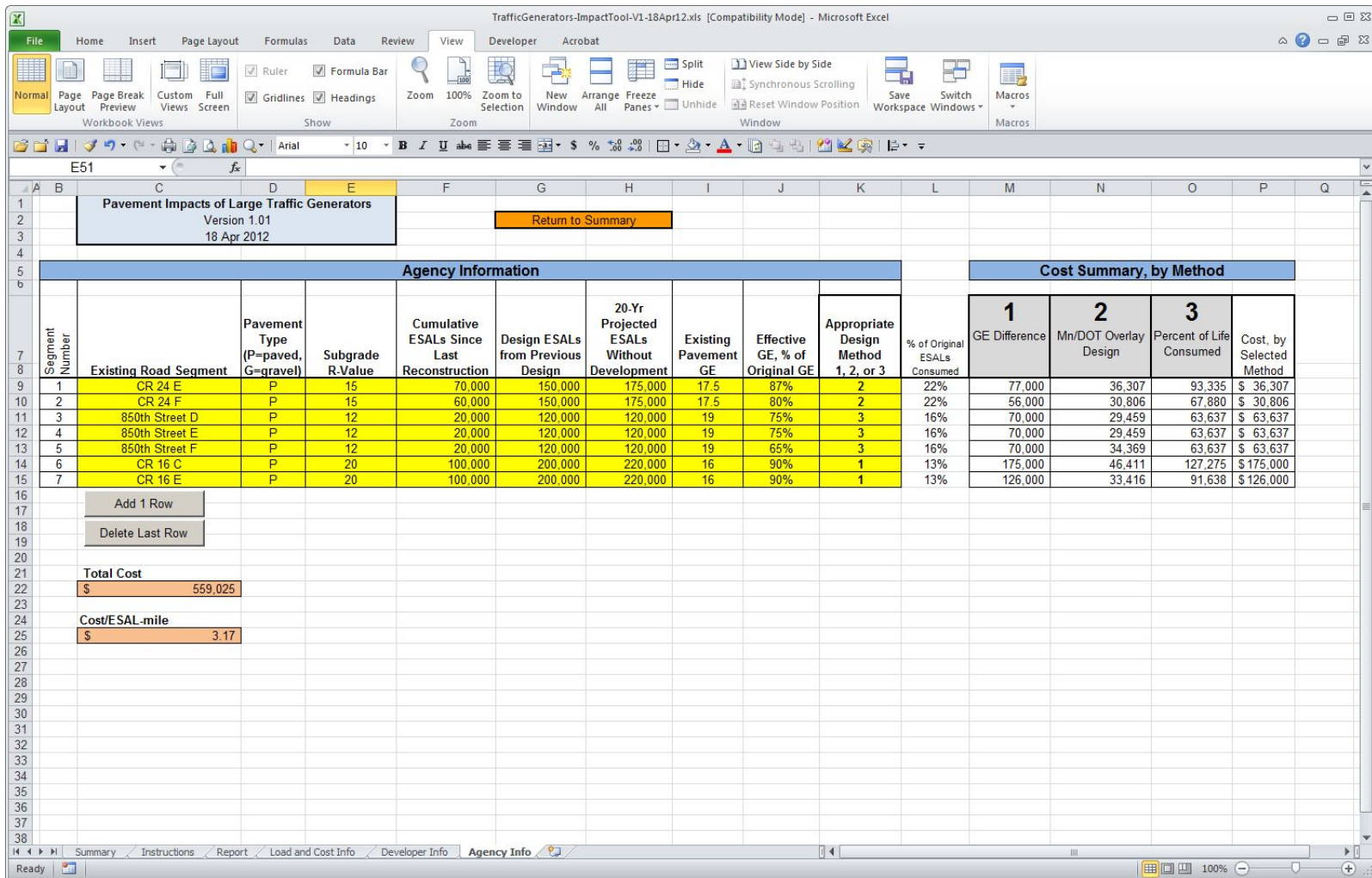**Figure 7. Sample of Developer Information Tab.**

Figure 8. Sample of Agency Information Tab.

Tool Calculations

Once all the data are entered in the three data entry tabs, a report can be generated and printed. In addition, the *Instructions* tab contains information about the types of information required for the analysis to be conducted. This tab also includes information and recommendations for selecting appropriate damage and cost calculation analysis methods.

Pavement Damage per Vehicle

The primary unit for predicting pavement damage due to vehicular traffic is the Equivalent Single Axle Load. The AASHTO Guide defines the amount of damage expected by a particular configuration of axles, tires, and loads. While the AASHTO Guide provides tables for determining the number of ESALs applied by a specific combination of load, tires, axles, and pavement structure, the tool computes these directly, using the following equations [12]. Essentially, the computation is a comparison of the damage done by the axle set in question to a standard "equivalent single axle" which is a single axle with an applied 18,000 lb load. In the following equations, the subscript *18* represents the standard 18,000 lb axle load, and the subscript *x* represents the axle load being evaluated, in kips.

$$\frac{W_x}{W_{18}} = \left[\frac{L_{18} + L_{2s}}{L_x + L_{2x}} \right]^{4.79} \left[\frac{10^{G/\beta_x}}{10^{G/\beta_{18}}} \right] [L_{2x}]^{4.33}$$

Where,

W = number of axle applications, or the inverse of the equivalency factor

L_x = axle load being evaluated, kips

L_{18} = 18, the standard axle load, kips

L_2 = code for axle configuration

      1 = single axle

      2 = tandem axle

      3 = tridem axle

      s = code for standard axle (1 for single axle)

      x = code for axle being evaluated (1, 2, or 3)

G = a function of the ratio of loss in serviceability at time t, to the potential maximum loss at the terminal serviceability, p_t.

$$G = \log\left[\frac{4.2 - p_t}{4.2 - 1.5}\right]$$

p_t = terminal serviceability, defined in a previous chapter

β = a function which determines the relationship between serviceability and axle load applications.

$$\beta = 0.4 + \left[\frac{0.081(L_x + L_{2x})^{3.23}}{(SN + 1)^{5.19} L_{2x}^{3.23}}\right]$$

SN = pavement structural number, described in a previous chapter.

Since the comparison is the number of applications of the load being evaluated to one application of the standard load, the quantity W_x/W_{18} must equal the relative number of standard loads applied by one of the evaluated loads. Thus, the equivalency factor is the reciprocal of this value.

Consumed Life Calculations

This section describes the calculations done by the tool to estimate the impacts of the heavy vehicles defined in the data input tabs. These include the GE Difference, MnDOT Overlay, and Percent of Life methods. As mentioned previously, these methods utilize established, accepted pavement design principles, and do not represent new or untested concepts or models. It is simply a combination of the various methods of pavement design and analysis.

GE Difference Method

The GE Difference Method utilizes the Bituminous Pavement Design Chart from the MnDOT Pavement Manual to obtain the pavement design that would have been designed with and without the additional traffic due to the heavy traffic generating development. The bituminous pavement design chart takes soil R-value and cumulative design lane ESALs as inputs, and provides a resulting GE value for the pavement structure. Since the R-value of the soil is the same for either scenario, the only different input is the cumulative design ESALs.

For example, the chart in Figure 9 is the design chart [10] with two different pavement designs – one with a cumulative 150,000 ESALs over its life (indicated with long dashes in the chart), and the other with an additional 50,000 ESALs due to a heavy traffic generating development (indicated with short dashes). Both designs (being in the same location) have an R-value of 15. The original design suggests a total GE of 17.5 inches while the design with an additional 50,000 ESALs suggests a total GE of 19.5 inches. The additional two inches of granular equivalent could be made up by just less than one inch of bituminous material or two inches of Class 5 base material. The additional cost for this design for the additional traffic loads is used in the GE Difference portion of the report.
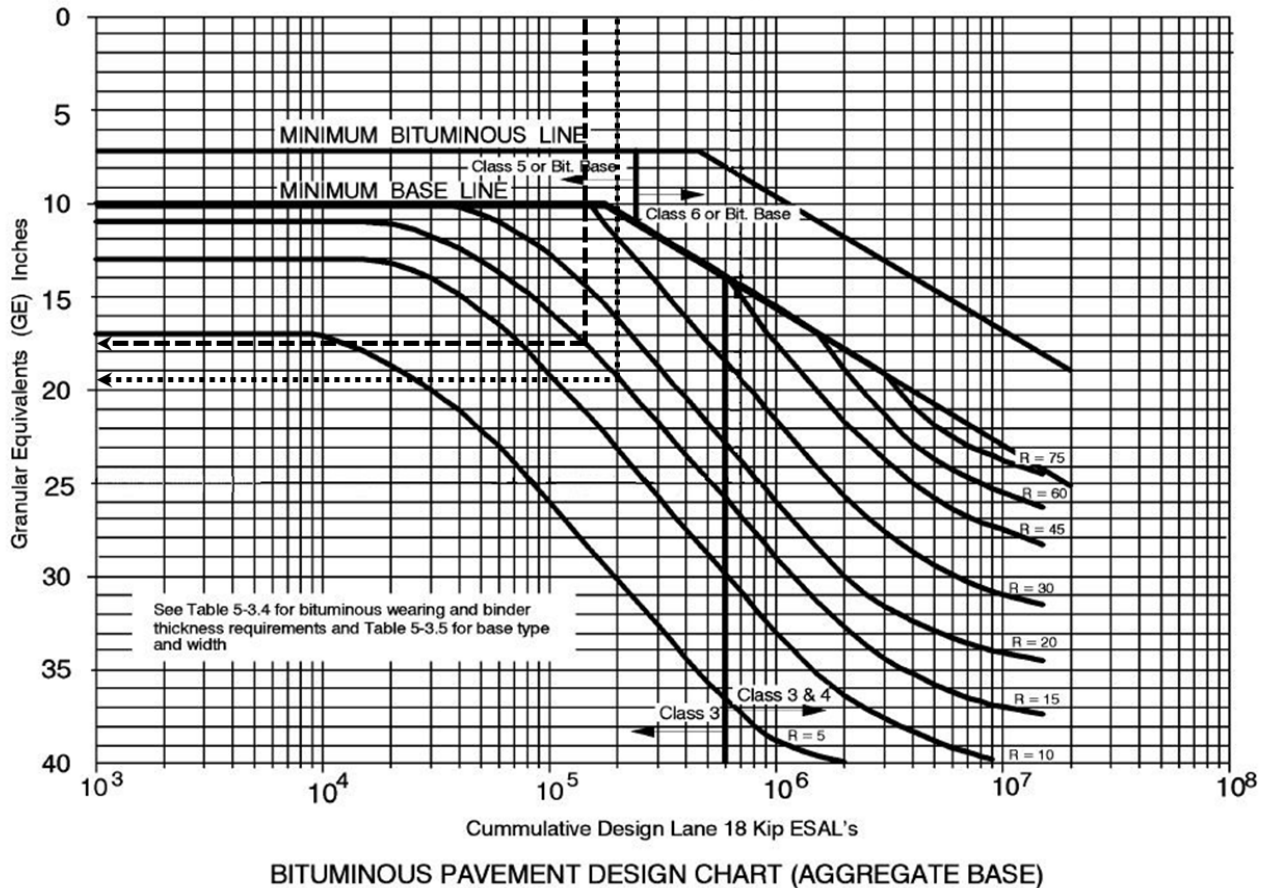
Figure 9. MnDOT Bituminous Pavement Design Chart – R-value.

MnDOT Overlay Design

The MnDOT Overlay Design method is similar to the GE Difference method in that it uses the GE design chart. This method, however, determines the additional asphalt concrete that is required to raise an existing pavement to acceptable levels of load carrying capacity. The method determines the required GE for past and future ESALs with the development traffic, and compares that required GE to the existing, in-place GE. The past and future ESALs allows the design method to simulate the pavement structure that would have been designed at its initial construction to accommodate all of the traffic for the past and predicted in the future. Only bituminous surface material is available to be used for the additional GE required.

For example, a pavement with an R-value of 15 and an initial design of 175,000 ESALs has already carried 70,000 ESALs. Over the next 20 years it is expected to carry 100,000 ESALs of non-development traffic and 50,000 ESALs of development traffic. The MnDOT overlay design method specifies a required overlay thickness of 3 inches. The impacts of the additional traffic are pro-rated based on the development and non-development traffic. In this case,

[development ESALs] / [sum of future development and non-development ESALs], or

50,000 / (100,000 + 50,000) = 33%.

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This indicates that one third of overlay is needed due to damage attributable to the development traffic.

Percent of Life Consumed

In the percent of life consumed method, the estimated development traffic is simply divided by the initial design traffic for the pavement. Thus, in the case above, where 50,000 ESALs is expected by the development on a pavement that was designed for 170,000 ESALs, the pro-rated damage is

[development ESALs] / [original design ESALs], or

50,000 / 175,000 = 29%.

Report Generation

After all the data has been input, and the analysis conducted, the tool collects the inputs and analysis results and copies these to the Report tab. This tab is organized to show, in two printed pages, the information reported by the developer and by the agency, as well as the overall impact, in terms of cost, computed by the tool for each roadway segment, and for the entire roadway system expected to be impacted by the development. A sample of the report output can be seen in Figures 10 and 11.

The summation of all the pavement impacts due to the development traffic, based on the selected computation method for each segment, is presented to the user in the "Total Cost" and "Cost per ESAL-mile" cells in the *Agency and Impact Information* report, and can be seen in Figure 11. The *Cost per ESAL-mile* value represents the total cost of the anticipated pavement damage divided by the number of ESAL-miles applied to the pavements in the road network expected to be used by the development. The ESAL-miles value is computed by the summation of the product of the loads and their associated ESALs. For example, one truck applying 2.04 ESALs and driving a total of 3 miles from the point it enters the agency's jurisdiction to its destination at the project site would accumulate 3 * 2.04 = 6.12 ESAL-miles that are used in the report.

Project: Generic Wind Project	Date Prepared: 4/18/2012
Developer: Wind Tower Developer	County: Any County
Prepared by: County Engineer	Version 1.01

Developer Information											
					Average Loads Per Turbine Method						
Segment Number	Existing Road Segment	Segment Length, Miles	Road Authority	Number of Turbines	Aggregate	Concrete	Turbine	Crane Assembly	RT Crane	Other Vehicle #1	Other Vehicle #2
1	CR 24 E	1.1	County	50							
2	CR 24 F	0.8	County	50							
3	850th Street D	1.0	County	30							
4	850th Street E	1.0	County	30							
5	850th Street F	1.0	County	30							
6	CR 16 C	2.5	County	40							
7	CR 16 E	1.8	County	40							

Figure 10. Sample Report Output – Developer Information.

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Project: Generic Wind Project	Date Prepared: 4/18/2012
Project: Wind Tower Developer	County: Any County
Prepared by: County Engineer	Version 1.01

Total Cost:	$559,025
Cost per ESAL-mile:	$3.17

Agency Information									
Segment Number	Existing Road Segment	Pavement Type (P=paved, G=gravel)	Subgrade R-Value	Cumulative ESALs Since Last Reconstruction	Design ESALs from Previous Design	20-Yr Projected ESALs Without Development	Existing Pavement GE	Effective GE, % of Original GE	Selected Design Method	Cost, by Selected Method
1	CR 24 E	P	15	70,000	150,000	175,000	17.5	87%	Mn/DOT OL	$ 36,307
2	CR 24 F	P	15	60,000	150,000	175,000	17.5	80%	Mn/DOT OL	$ 30,806
3	850th Street D	P	12	20,000	120,000	120,000	19	75%	% Life	$ 63,637
4	850th Street E	P	12	20,000	120,000	120,000	19	75%	% Life	$ 63,637
5	850th Street F	P	12	20,000	120,000	120,000	19	65%	% Life	$ 63,637
6	CR 16 C	P	20	100,000	200,000	220,000	16	90%	GE Diff.	$ 175,000
7	CR 16 E	P	20	100,000	200,000	220,000	16	90%	GE Diff.	$ 126,000

Figure 11. Sample Report Output – Agency and Impact Information.

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Tool Review and Implementation

The traffic generators impact tool was reviewed over multiple occasions throughout its development. Several meetings were held in Mankato, MN with the entire TAP. Primarily these meetings were intended to review the policy tool reported in Tasks 2 and 3.

In addition, meetings were held with a smaller group of the TAP – Tim Stahl (Jackson County Engineer), Steve Schnieder (Nobles County Engineer), Ron Gregg (Cottonwood County Engineer) and various county technicians (primarily Wes Liepold, Jackson County). These meetings occurred on the following dates, in Windom or Jackson, MN.

- 15 January 2010
- 24 March 2010
- 30 June, 2010
- 13 August 2010

At these meetings, detailed review of the impact calculator tool was conducted, after which the project team made the appropriate changes and sent the tool to the TAP sub-group for additional comments.

At the final TAP meeting, held 16 October 2010 in Mankato, the tool was reviewed again, and approval was given for its acceptance. The final tool in spreadsheet form was delivered on 28 October 2010 to the Research Implementation Committee Chairman, Gary Danielson, and other members of the TAP.

Chapter 4. CONCLUSIONS

This report has outlined the development of a tool to estimate the impacts to pavements associated with heavy vehicle traffic related to construction of wind turbine developments. The impetus for this project was specifically very large "wind farm" projects where as many as 160 wind turbines have been constructed in a small geographic area in a single construction season. The network of roads – including interstates and state highways, County State Aid Highways, and county roads – are all utilized in the transportation of the components wind turbine construction to the site location. As described in the introduction, the major roadways are constructed to accommodate these large groups of loads all in one year. The pavements designed to carry lower levels of traffic (perhaps 100,000 design ESALs) are not intended or designed to do so.

The Heavy Traffic Generators tool allows the user (usually the county road authority) to estimate the damage that may be inflicted on the pavements in a localized area during a single season or two of heavy construction traffic. The results of the analysis conducted by the tool include an estimate of the cost to repair and/or reconstruct the affected pavements to restore them to their original condition. The analysis methods incorporated into the tool are commonly accepted models that are recognized nationally (or at least statewide) and by the general pavement engineering community. The tool is simply an implementation of those models with a specific purpose to evaluate the impacts of these heavy loads on local pavements.

Suggested Improvements

Originally, the project sponsored by the Local Road Research Board was intended to develop a tool for evaluating the impacts of heavy loads due to any type of development. A subsequent project has now incorporated that objective and will be completed soon. This new project will also have the capability to estimate heavy vehicle impacts over long periods of time, rather than the duration of construction of a single development.

Improvements that could be implemented in the new project include the following.

- Selection of specific truck types with pre-defined axle loads and configurations.
- More precise estimation of current and historical ESALs for specific road segments.
- Graphical results to indicate the predicted changes to pavement condition over time.
- A standalone software feel, although it will still be contained within a Microsoft Excel spreadsheet environment.
- More precise implementation of the Granular Equivalent model.

These potential improvements will help the next project provide a more versatile tool, in terms of the types of developments and nature of heavy traffic that it can simulate.

Implementation

The tool has been presented to many county engineers and members of the Local Road Research Board. It is also a companion to the Major Traffic Generators Impact Tool interactive document [13] available on the LRRB Web site. It was developed in conjunction with the interactive

document to assist local agencies in identifying the major components of a major traffic generator project and the necessary agreements, ordinances, permits, and maps necessary to manage a large project. The interactive document also includes policy recommendations to recapture roadway maintenance costs, such as the use of the Major Traffic Generators Impact Tool.

The tool has been developed under this project, and its use has been described in this report. The appropriate application of the tool's calculations in terms of total cost and cost per ESAL-mile are not discussed in this report. Those decisions are best left to the individual agency to determine with appropriate recommendations from local technical and legal experts.

As described above, several enhancements could be made to the tool, and some of these are planned with a new project funded through the Local Road Research Board. The new project will be more comprehensive in the types of vehicles and projects that impact the local roadways in the state of Minnesota.

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