

MOVES Operating Mode Distribution Generator

Documentation Report

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1. BACKGROUND AND PROJECT OVERVIEW

This report presents the approach that TranSystems | E.H. Pechan used to develop the MOVES operating mode distribution generator. After describing the overall methodology, this document discusses issues related to allowable pollutants, processes, and operating modes. Finally, the generator spreadsheet structure is outlined and the user input worksheet is presented in details, along with instructions on how to use the tool. Along with this documentation report, a PowerPoint “training” presentation and an Excel spreadsheet were developed to illustrate how to use the operating mode distribution generator for a concrete example.

There are 3 different methods for describing travel activity in MOVES. Those include the average speed approach, the driving cycle approach (speed by second), and the operating mode distribution approach (fraction of activity by operating mode—includes bins by VSP and speed ranges, idling, braking, etc.) The latter is the most accurate and give users the ability to take full advantage of MOVES capabilities to model the emissions impact of variations in vehicle speed, acceleration, as well as road characteristics.

The main issue with the operating mode distribution approach is the difficulty for users to generate the required MOVES input. The objective of this project is to design an operating mode distribution “generator”. This tool will help users take advantage of the MOVES VSP bins structure, without having to create their own operating mode distributions. The spreadsheet-based tool is currently designed for users running the model at the project-level scale, especially for PM or CO hot-spot analyses in highway and/or intersection projects.

2. TOOL DEVELOPMENT METHODOLOGY

i. GENERAL APPROACH

The basic concept behind this generator is to utilize a number of user-provided parameters to automatically generate an appropriate operating mode distribution. These parameters are much easier for users to collect than those required for an operating mode distribution. User inputs include average speed and road grade, which are the factors with the strongest impact on operating modes.

Based on these two basic inputs, the generator selects a “default” MOVES operating mode distribution. This default distribution is then adjusted and re-normalized to account for other project-specific parameters. The other inputs that users are required to provide for their project include link information, hour of the day, day of the week, and idle fraction. The latter is directly used to replace the MOVES default fraction

allocated to OpModelID 1, which represents idling (the same idling fraction is used for all source types). In order to cover all possible situations, the “default” MOVES operating mode distributions were generated for all source types.

ii. DEFAULT MOVES OPERATING MODE DISTRIBUTIONS

TranSystems | E.H. Pechan developed a database of default MOVES operating mode distributions by running the MOVES model at the project-level for a number of average speed and road grade combinations. The version of the model used for this project was MOVES2010a (version 2010/08/26), and the corresponding default MOVES database was ‘movesdb20100830’ (dated August 30, 2010).

Each combination of speed and grade led to a default MOVES operating mode distribution, which was extracted from the MOVES execution database (after deleting all records with negative PolProcessIDs and OpModelIDs). As agreed with EPA, the average speed increments were 1 mph within the 0mph to 45 mph range and the road grade increments were 0.5% between -5% and +5%. It is important to note that each MOVES vehicle category has a limited range of allowable average speeds. This was not an issue for high speeds (since the maximum allowable speed is higher than 45mph for all vehicle types) but it did have an impact at lower speeds. For instance, short-haul combination trucks have a minimum allowable average speed of 5.8 mph. Whenever a MOVES run is performed with an average speed below 5.8mph, no default operating mode is generated for this vehicle type. However, for the purpose of this tool, it is essential that an operating mode distribution is “generated” for all vehicle types and all average speeds within the 0mph to 45 mph range. To resolve this issue, if the user selects a link average speed below the allowable limit, the default operating mode distribution generated with the lowest allowable speed (i.e. the 6mph MOVES run in the short-haul combination trucks example) was selected. A similar approach was used for all vehicle categories. The minimum allowable average speed and corresponding “default speed” runs are listed in Table 1 below. For more details, refer to table 2.3.3.4.12 of the MOVES user guide¹.

Table 1 – Minimum allowable average speed and corresponding default runs

| <i>SourceTypeID</i> | <i>Description</i> | <i>Minimum Speed (mph)</i> | <i>Default run speed (mph) used if user selects a speed < allowed range</i> |
|---------------------|------------------------|----------------------------|--------------------------------------------------------------------------------|
| 11 | Motorcycle | 2.5 | 3.0 |
| 21 | Passenger Car | 2.5 | 3.0 |
| 31 | Passenger Truck | 2.5 | 3.0 |
| 32 | Light Commercial Truck | 2.5 | 3.0 |

¹ Motor Vehicle Emission Simulator (MOVES), User Guide for MOVES2010a, EPA-420-B-10-036, August 2010.

| <i>SourceTypeID</i> | <i>Description</i> | <i>Minimum Speed (mph)</i> | <i>Default run speed (mph) used if user selects a speed < allowed range</i> |
|---------------------|-------------------------------------|----------------------------|--------------------------------------------------------------------------------|
| 41 | <i>Intercity Bus</i> | 4.6 | 5.0 |
| 42 | <i>Transit Bus</i> | 15.0 | 15.0 ² |
| 43 | <i>School Bus</i> | 15.0 | 15.0 ³ |
| 51 | <i>Refuse Truck</i> | 2.2 | 3.0 |
| 52 | <i>Single Unit Short-haul Truck</i> | 4.6 | 5.0 |
| 53 | <i>Single Unit Long-haul Truck</i> | 4.6 | 5.0 |
| 54 | <i>Motor Home</i> | 4.6 | 5.0 |
| 61 | <i>Combination Short-haul Truck</i> | 5.8 | 6.0 |
| 52 | <i>Combination Long-haul Truck</i> | 5.8 | 6.0 |

iii. POLLUTANTS, PROCESSES, AND OPERATING MODES

Since this OpMode distribution generator is aimed at generating operating mode distributions for PM or CO hot-spot analyses in highway and/or intersection projects, no off-network operating mode distribution is generated by this tool. Therefore, extended idling and start emissions are not included. The following emission processes are the only ones that were modeled in the default MOVES runs: Running Exhaust, Crankcase Running Exhaust, Brakewear, and Tirewear (evaporative processes were not included since hydrocarbons or hazardous air pollutants are modeled).

Based on the criteria listed above, the full list of pollutants, processes, and PolProcessIDs relevant to the tool is presented on Table 2 (Total Energy Consumption was selected because it is required to calculate PM emissions). Table 3 presents the corresponding operating modes. The last column of Table 2 indicates which PolProcessIDs were actually in the MOVES “template” developed by creating a MOVES RunSpec and exporting a template of the OpMode Distribution. This list shows that PolProcessIDs for Sulfate Particulate PM10/PM2.5, Total PM10/PM2.5, PM10 Brakewear/Tirewear, and Crankcase Running Exhaust (all pollutants) are not present. This is due to the fact that some pollutants and processes are “chained” in the MOVES calculations and do not need to appear in the operating mode to be calculated. For instance, the Sulfate PM Emissions Calculator is ‘chained to’ the Total Energy Consumption Calculator: this indicates that the calculator computes sulfate emissions as the product of a sulfate emission factor and total energy consumption of the corresponding MOVES emission process⁴.

² Note: the minimum average speeds reported in the MOVES2010a User Guide for source types 42 and 43 are incorrect. The actual minimums should be 15.0 mph, per personal communication with EPA OTAQ’s Chris Dresser (email, 12/21/2011).

³ Ibid.

⁴ Draft Motor Vehicle Emission Simulator (MOVES) 2009, Software Design and Reference Manual, EPA-420-B-09-007, March 2009.

Table 2 – List of pollutants, processes, and PolProcessIDs

| <i>PolProcessID</i> | <i>processID</i> | <i>processName</i> | <i>pollutantID</i> | <i>pollutantName</i> | <i>In Template?</i> |
|---------------------|------------------|------------------------|--------------------|---------------------------------------|---------------------|
| 201 | 1 | Running Exhaust | 2 | Carbon Monoxide (CO) | Yes |
| 215 | 15 | Crank. Running Exhaust | 2 | Carbon Monoxide (CO) | No |
| 9101 | 1 | Running Exhaust | 91 | Total Energy Consumption | Yes |
| 10001 | 1 | Running Exhaust | 100 | Primary Exhaust PM10 - Total | No |
| 10015 | 15 | Crank. Running Exhaust | 100 | Primary Exhaust PM10 - Total | No |
| 10101 | 1 | Running Exhaust | 101 | Primary PM10 - Organic Carbon | Yes |
| 10115 | 15 | Crank. Running Exhaust | 101 | Primary PM10 - Organic Carbon | No |
| 10201 | 1 | Running Exhaust | 102 | Primary PM10 - Elemental Carbon | Yes |
| 10215 | 15 | Crank. Running Exhaust | 102 | Primary PM10 - Elemental Carbon | No |
| 10501 | 1 | Running Exhaust | 105 | Primary PM10 - Sulfate Particulate | No |
| 10515 | 15 | Crank. Running Exhaust | 105 | Primary PM10 - Sulfate Particulate | No |
| 10609 | 9 | Brakewear | 106 | Primary PM10 - Brakewear Particulate | No |
| 10710 | 10 | Tirewear | 107 | Primary PM10 - Tirewear Particulate | No |
| 11001 | 1 | Running Exhaust | 110 | Primary Exhaust PM2.5 - Total | No |
| 11015 | 15 | Crank. Running Exhaust | 110 | Primary Exhaust PM2.5 - Total | No |
| 11101 | 1 | Running Exhaust | 111 | Primary PM2.5 - Organic Carbon | Yes |
| 11115 | 15 | Crank. Running Exhaust | 111 | Primary PM2.5 - Organic Carbon | No |
| 11201 | 1 | Running Exhaust | 112 | Primary PM2.5 - Elemental Carbon | Yes |
| 11215 | 15 | Crank. Running Exhaust | 112 | Primary PM2.5 - Elemental Carbon | No |
| 11501 | 1 | Running Exhaust | 115 | Primary PM2.5 - Sulfate Particulate | No |
| 11515 | 15 | Crank. Running Exhaust | 115 | Primary PM2.5 - Sulfate Particulate | No |
| 11609 | 9 | Brakewear | 116 | Primary PM2.5 - Brakewear Particulate | Yes |
| 11710 | 10 | Tirewear | 117 | Primary PM2.5 - Tirewear Particulate | Yes |

As agreed with EPA and in order to reduce the complexity of the spreadsheet, the tool does not offer the option to select only some of those pollutants and processes. Instead, the tool generates an operating mode distribution that includes the 3 pollutants (PM10, PM2.5, and CO) and all 4 processes. This is not an issue since importing an operating mode distribution table in MOVES with more pollutants and processes than those selected in the RunSpec does not cause any errors (a warning message will appear indicating that some polprocessIDs are imported but not used). For the same reason, the tool does not ask users to select vehicle categories (the operating mode distribution is generated for all 13 MOVES source types). Also, to simplify the user interface and decrease calculation time, the tool only allows the user to model one link at a time. Users who wish to create operating mode distributions for several links can use the spreadsheet multiple times.

Table 3 – List of operating modes

| <i>OpModeIDs and Operating Mode Description</i> | |
|---------------------------------------------------------------------|-------------------------------------------------------------|
| <i>All PolProcessIDs except Tirewear/Brakewear</i> | <i>Tirewear/Brakewear PolProcessIDs (10710 & 11710)</i> |
| 0 <i>Braking</i> | 400 <i>tirewear ;idle</i> |
| 1 <i>Idling</i> | 401 <i>tirewear ;speed < 2.5mph</i> |
| 11 <i>Low Speed Coasting; VSP< 0; 1<=Speed<25</i> | 402 <i>tirewear;2.5mph <= speed < 7.5mph</i> |
| 12 <i>Cruise/Acceleration; 0<=VSP< 3; 1<= Speed<25</i> | 403 <i>tirewear;7.5mph <= speed < 12.5mph</i> |
| 13 <i>Cruise/Acceleration; 3<=VSP< 6; 1<=Speed<25</i> | 404 <i>tirewear;12.5mph <= speed < 17.5mph</i> |
| 14 <i>Cruise/Acceleration; 6<=VSP< 9; 1<=Speed<25</i> | 405 <i>tirewear;17.5mph <= speed <22.5mph</i> |
| 15 <i>Cruise/Acceleration; 9<=VSP<12; 1<=Speed<25</i> | 406 <i>tirewear;22.5mph <= speed < 27.5mph</i> |
| 16 <i>Cruise/Acceleration; 12<=VSP; 1<=Speed<25</i> | 407 <i>tirewear;27.5mph <= speed < 32.5mph</i> |
| 21 <i>Moderate Speed Coasting; VSP< 0; 25<=Speed<50</i> | 408 <i>tirewear;32.5mph <= speed < 37.5mph</i> |
| 22 <i>Cruise/Acceleration; 0<=VSP< 3; 25<=Speed<50</i> | 409 <i>tirewear;37.5mph <= speed < 42.5mph</i> |
| 23 <i>Cruise/Acceleration; 3<=VSP< 6; 25<=Speed<50</i> | 410 <i>tirewear;42.5mph <= speed < 47.5mph</i> |
| 24 <i>Cruise/Acceleration; 6<=VSP< 9; 25<=Speed<50</i> | 411 <i>tirewear;47.5mph <= speed < 52.5mph</i> |
| 25 <i>Cruise/Acceleration; 9<=VSP<12; 25<=Speed<50</i> | 412 <i>tirewear;52.5mph <= speed < 57.5mph</i> |
| 27 <i>Cruise/Acceleration; 12<=VSP<18; 25<=Speed<50</i> | 413 <i>tirewear;57.5mph <= speed < 62.5mph</i> |
| 28 <i>Cruise/Acceleration; 18<=VSP<24; 25<=Speed<50</i> | 414 <i>tirewear;62.5mph <= speed < 67.5mph</i> |
| 29 <i>Cruise/Acceleration; 24<=VSP<30; 25<=Speed<50</i> | 415 <i>tirewear;67.5mph <= speed < 72.5mph</i> |
| 30 <i>Cruise/Acceleration; 30<=VSP; 25<=Speed<50</i> | 416 <i>tirewear;72.5mph <= speed</i> |
| 33 <i>Cruise/Acceleration; VSP< 6; 50<=Speed</i> | 501 <i>brakewear; stopped</i> |
| 35 <i>Cruise/Acceleration; 6<=VSP<12; 50<=Speed</i> | |
| 37 <i>Cruise/Acceleration; 12<=VSP<18; 50<=Speed</i> | |
| 38 <i>Cruise/Acceleration; 18<=VSP<24; 50<=Speed</i> | |
| 39 <i>Cruise/Acceleration; 24<=VSP<30; 50<=Speed</i> | |
| 40 <i>Cruise/Acceleration; 30<=VSP; 50<=Speed</i> | |

3. MOVES OPERATING MODE DISTRIBUTION GENERATOR

i. OVERALL SPREADSHEET STRUCTURE

The operating mode distribution generator structure can be broken-down into the following sections:

- “Instructions” worksheet
- “User Inputs” worksheet

- “*Paste Default OpMode Here*” worksheet
- “*Default OpMode Files*” worksheet
- “*MOVES OpMode Distribution*” worksheet (generator output)
- Calculation and Mapping worksheets (hidden)
 - OpModelIntermediate1
 - OpModelIntermediate2
 - OpModelIDs
 - HourIDMapping
 - MiniSpeedMapping
 - PolProcessIDs

The “*Instructions*” worksheet serves two main purposes: first, it describes the inputs that the user is required to supply in order to generate an operating mode distribution. Then, it provides detailed steps that the user needs to take (“How to Use This Tool” guide). The instructions worksheet also lists all the pages included in the tool (inputs, calculation pages, mapping pages, and output) and provides a brief description of their format, role, and operation. The inputs worksheet allows users to define the project parameters; this page is described in detail in the next section.

The “*Default OpMode Files*” worksheet provides a list and a hyperlink to all of the existing MOVES default operating mode distributions. There are a total of 966 files (one for each speed/grade combination). Clicking on any of the links automatically opens the appropriate default operating mode distribution. Although this list is mostly provided for information purposes, one element needs to be adjusted before users can use the tool: they need to modify the path to the folder where they saved the 966 “default OpMode files” which are provided with the tool. This approach was used in order to make the size of the tool manageable. Indeed, given the large number of speed/grade combinations, it was impossible to include the default distributions in the tool itself. Tests were performed but the size of the Excel file quickly grew over 50 Mb. The consequence was endless computer calculations every time one of the user inputs was changed. The default operating mode needs to be opened (by simply clicking on the appropriate link), copied, and pasted into the “*Paste Default OpMode Here*” worksheet (see details in the “Instructions to Use the Operating Mode Distribution Generator” section).

The calculation worksheets are designed to utilize the user-provided parameters and automatically generate a suitable MOVES operating mode distribution input table. This MOVES-compatible table is populated in the output worksheet labeled “*MOVES OpMode Distribution*”. The main calculation steps are to automatically replace the default fraction allocated to OpModelID 1 (idling) with the user-provided idle

fraction and to renormalize the fractions allocated to the remaining operating modes so that the fractions sum to 1 for each PolProcessID and SourceTypeID combination.

It is important to note that when the selected average speed is high (above 35mph), the MOVES default operating mode distribution does not allocate any activity to idling for some of the source types (sourcetypeIDs 51, 61, 62 between 35mph-44mph and sourcetypeIDs 41, 51, 52, 53, 54, 61, 62 for 45mph). When that is the case, the main “structure” of the operating mode was maintained (i.e. the default fraction allocated to OpModelID 1 for idling was replaced with the user-provided idle fraction only if the default already had some idling). The mapping pages are either used in some of the calculation steps or just provide information such as a list and description of the MOVES OpModelIDs, HourIDs, or PolProcessIDs. These pages are hidden and should not be updated by users.

ii. INPUT WORKSHEET DESCRIPTION

The “*User Inputs*” worksheet allows the user to define the project parameters listed above. These parameters are listed and described below:

- Hour: This is the hour of the day to be modeled. Selections are made from a drop-down menu (24 options).
- Day: This is the day of the week to be modeled. Selections are made from a drop-down menu (2 options: weekday or weekend).
- Idle fraction: This is the fraction of time during which vehicles idle (value between 0 and 1). Selections are made from a drop-down menu (200 options, by 0.005 increments). This could have been a “free” user input (i.e. not a drop-down menu) but such an approach would have added error possibilities (for example, users inputting the fraction as a percentage).
- LinkID: This is the linkID of the link being modeled. Selections are made from direct input by users (type in a value; integer higher than 1).
- Link Description (Optional input): This optional input is a text field included for reference and has no impact on the calculations. It can be useful for operating modes with numerous links.
- Average Speed: This is the average speed of all of the vehicles on the roadway link in the given hour. Selections are made from a drop-down menu (46 options between 0 mph and 45 mph).
- Average Grade: This is the average road grade of the link. Selections are made from a drop-down menu (21 options between -5% and 5%, by 0.5% increments).
- Default Operating Mode File: This is an automatically generated cell, with a link to a MOVES default operating mode distribution for the speed/grade combination selected. This default distribution needs to be opened, copied, and pasted into the “*Paste Default OpMode Here*” worksheet (see details in the “Instructions to Use the Operating Mode Distribution Generator” section).

-
- Warnings: These warnings are automatically generated, based on users inputs. They warn users of potential issues with their inputs (for instance, when an input cell is empty).

Figures 1 through 3 illustrate the input worksheet. Figure 1 show the entire “User Inputs” worksheet, as currently designed. Red cells in the worksheet indicate required inputs. To facilitate usability and improve user experience, a description and explanation of each specific cell pops up when the user moves his/her mouse over that cell. This is illustrated in Figure 2 (left). For most required inputs, the user just needs to click on a drop-down menu and select one of the options. This is also illustrated in Figure 2 (right). When possible, cells that require inputs from the user have validation criteria. For instance, for the hour input, users only have the option of selecting an hour in the drop-down menu (which includes all 24 hours). This will avoid erroneous inputs or format differences which could lead the formulas in the spreadsheet not to work. If a user types in an incorrect number instead of selecting an hour in the drop-down menu, an error message appears as illustrated in Figure 3.



Figure 1 – “User Inputs” worksheet

| | | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|---------------|
| Hour - Select the hour of the day to be modeled | | | |
| [Redacted] | | | |
| Day - Select the day of the week to be modeled | | | |
| Weekday | | | |
| Idle fraction - Input the fraction of time during which vehicles will idle. Please note that this is a fraction (i.e. the value 0.025 represents 2.5% idling, 0.1 represents 10% idling, etc.) | | | |
| 1 <i>If you wish to use MOVES default, please select the option "Default" (in drop-down menu). If you leave blank, idle fraction will be zero.</i> | | | |
| linkID | linkDescription (optional - for your records) | Average Speed | Average Grade |
| 76 | | 15 | 2.5 |
| | | Speed 15mph - Grade 2.5% | |
| | | Default Operating Mode File → Click here to open default OpMode File | |
| WARNINGS | | | |
| Hour | Make sure to select a time for your MOVES Run. Please select an hour in the drop-down menu, cell B3. | | |
| Day | No error. You have selected to model a Weekday. | | |
| Idle Fraction | No error. You have selected to model an idle fraction of 1. | | |
| LinkID | No error. You have selected to model the LinkID 76. | | |
| Speed | No error. You have selected to model a speed of 15mph. | | |
| Grade | No error. You have selected to model a grade of 2.5%. | | |

Figure 2 – Time drop-down menu options (left: description pops up when mouse is over the cell; right: available options for time selection)

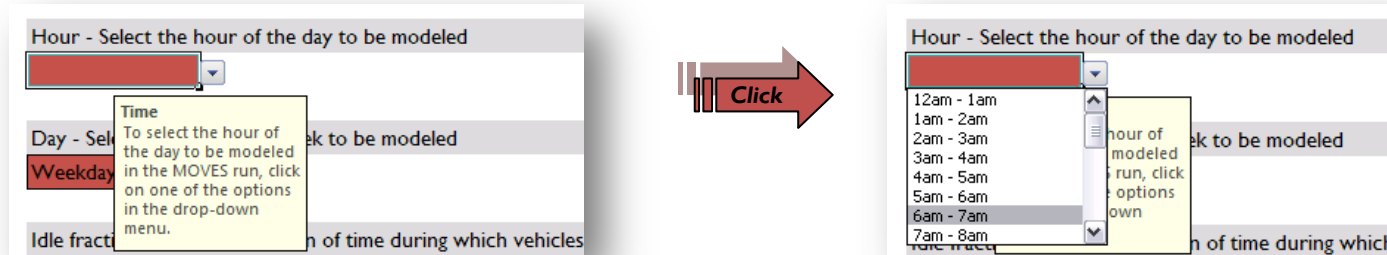
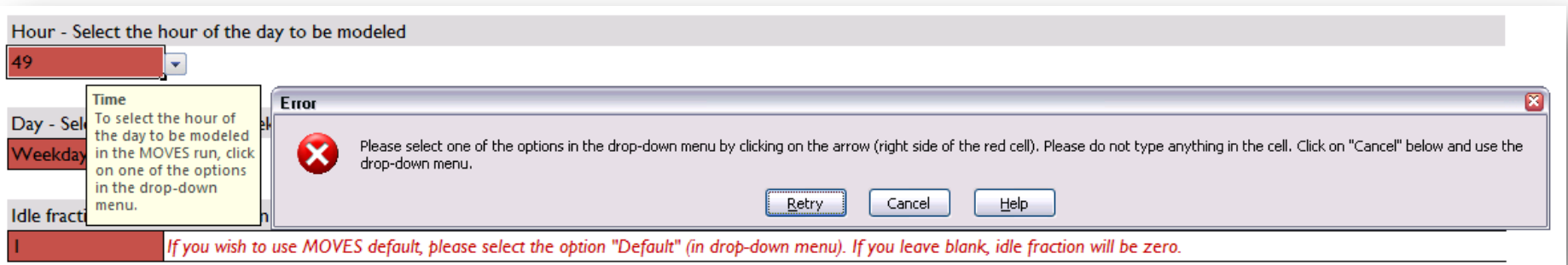


Figure 3 – Example error message if users provide incorrect inputs



iii. INSTRUCTIONS TO USE THE OPERATING MODE DISTRIBUTION GENERATOR

The following 12 steps need to be followed to generate the operating mode distribution based on an average speed, grade, and idle fraction (steps 2-12 need to be repeated for each link to model). Please note that users may experience some waiting time during Excel calculations. Depending on the specifications of the computer, this wait may vary between a few seconds up to a few minutes. For example, TranSystems | E.H. Pechan experienced calculation times of about 5-10 seconds on a laptop running Windows XP (Intel Core i5 CPU, 2.40 GHz, 3GB RAM). This was during "normal operating conditions", i.e. while simultaneously running a number of other applications such as Outlook, Internet Explorer, Word, etc. Performance can certainly be improved by closing other applications and running Excel exclusively.

1. Modify the path to the folder where the 966 default OpMode files are saved. This is done in the "Default OpMode Files" page (cell F9): copy and paste the path to the folder (start with \\ and end with \). For instance, use the following structure: \\C:\My Folder\My Subfolder\.
2. Go to the "User Inputs" page and select the hour of the day to be modeled ("Hour" input). Select one of the options from the drop-down menu.
3. In the "User Inputs" page, select the day of the week to be modeled ("Day" input). Select one of the options from the drop-down menu.
4. In the "User Inputs" page, select the idle fraction for the vehicles modeled in your MOVES run ("Idle fraction" input). Select one of the options from the drop-down menu.
5. In the "User Inputs" page, input the linkID of the link for which you are creating an operating mode distribution. Selections are made from direct input (type in a value; integer >1).
6. In the "User Inputs" page, select the average speed of the vehicles on the link being modeled ("Average Speed" input). Select one of the options from the drop-down menu.
7. In the "User Inputs" page, select the average grade of the road for the link being modeled ("Average Grade" input). Select one of the options from the drop-down menu.
8. Steps 6 and 7 will automatically generate a link to a MOVES default operating mode distribution for the speed/grade selected. This link is in cell D14. Click on the link.
9. After clicking on the link (step 8), an Excel file will automatically open, with the relevant default operating mode distribution. Go to that new Excel file.
10. Copy the entire worksheet. Note: using "Ctrl + A" may or may not select all cells. Please make sure that the entire worksheet is selected and copied. One option to select all cells is to click on the top left corner of the worksheet (top-left of cell A1).
11. Paste the default operating mode distribution from step 9 into the page labeled "Paste Default OpMode Here". To do so, click on cell A1, then "Ctrl + V" (or right-click and "Paste"). Depending on

the specifications of your computer, you may need to wait a few seconds or a few minutes for Excel to perform the calculations required at this step.

12. Go back to the "User Inputs" page and check the warning messages. If there are none, go to the "MOVES OpMode Distribution" to get the final operating mode distribution.

Figure 4 – How to use this tool – instructions summary

