

# Using MOVES2014 in Project-Level Carbon Monoxide Analyses

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## Table of Contents

<b>SECTION 1: INTRODUCTION</b> .....	<b>1</b>
1.1 PURPOSE OF THIS GUIDANCE .....	1
1.2 TYPES OF PROJECT-LEVEL CO ANALYSES .....	3
1.3 CONTACTS .....	4
1.4 GUIDANCE AND EXISTING REQUIREMENTS .....	4
<b>SECTION 2: ESTIMATING PROJECT-LEVEL CO EMISSIONS USING MOVES</b> .....	<b>5</b>
2.1 CHARACTERIZING A PROJECT IN TERMS OF LINKS .....	6
2.2 DETERMINING THE NUMBER OF MOVES RUNS.....	11
2.3 DETERMINING BASIC RUN SPECIFICATION INPUTS .....	13
2.4 ENTERING PROJECT DETAILS USING THE PROJECT DATA MANAGER .....	18
2.5 GENERATING EMISSION RATES FOR USE IN AIR QUALITY MODELING .....	27
<b>SECTION 3: EXAMPLE: USING MOVES FOR A CO SCREENING ANALYSIS OF AN INTERSECTION</b> .....	<b>29</b>
3.1 CHARACTERIZING THE PROJECT IN TERMS OF LINKS (SECTION 2.1).....	29
3.2 DETERMINING THE NUMBER OF MOVES RUNS (SECTION 2.2).....	30
3.3 DETERMINE BASIC RUN SPECIFICATION INPUTS (SECTION 2.3) .....	30
3.4 ENTERING PROJECT DETAILS USING PROJECT DATA MANAGER (SECTION 2.4) .....	31
3.5 GENERATING EMISSION RATES FOR USE IN AIR QUALITY MODELING (SECTION 2.5) .....	36
<b>SECTION 4: EXAMPLE: USING MOVES TO CALCULATE START AND IDLE EMISSION FACTORS FOR A TRANSIT FACILITY</b> .....	<b>37</b>
4.1 CHARACTERIZING THE PROJECT IN TERMS OF LINKS (SECTION 2.1).....	37
4.2 DETERMINING THE NUMBER OF MOVES RUNS (SECTION 2.2).....	38
4.3 DETERMINE BASIC RUN SPECIFICATION INPUTS (SECTION 2.3) .....	38
4.4 ENTERING PROJECT DETAILS USING PROJECT DATA MANAGER (SECTION 2.4) .....	39
4.5 GENERATING EMISSION RATES FOR USE IN AIR QUALITY MODELING (SECTION 2.5) .....	44
<b>APPENDIX A: CHARACTERIZING INTERSECTION PROJECTS FOR CO REFINED ANALYSES USING MOVES</b> .....	<b>45</b>
A.1 INTRODUCTION .....	45
A.2 OPTION 1: USING AVERAGE SPEEDS.....	46
A.3 OPTION 2: USING LINK DRIVE SCHEDULES .....	47
A.4 OPTION 3: USING OP-MODE DISTRIBUTIONS.....	49

## List of Figures

FIGURE 1. STEPS FOR USING MOVES IN PROJECT-LEVEL CO ANALYSES .....	5
FIGURE 2. DIAGRAM OF SUGGESTED LINKS FOR A SIMPLE INTERSECTION .....	7
FIGURE 3. LINKS CHARACTERIZING THE PROPOSED INTERSECTION .....	30
FIGURE 4. METEOROLOGY INPUT (AVERAGE JANUARY CONDITIONS) – INTERSECTION .....	31
FIGURE 5. FLEET AGE DISTRIBUTION (PARTIAL) – INTERSECTION .....	32
FIGURE 6. FUEL SUPPLY TABLE – INTERSECTION .....	33
FIGURE 7. FUEL FORMULATION TABLE – INTERSECTION .....	33
FIGURE 8. FUEL USAGE FRACTION -- INTERSECTION .....	33
FIGURE 9. ALTERNATIVE VEHICLE AND FUEL TECHNOLOGY (PARTIAL) -- INTERSECTION .....	34
FIGURE 10. LINK SOURCE TYPE INPUT TABLE (PARTIAL) -- INTERSECTION .....	35
FIGURE 11. LINKS TABLE – INTERSECTION .....	36
FIGURE 12. EMISSION RATE CALCULATIONS FOR EACH LINK – INTERSECTION .....	36
FIGURE 13. METEOROLOGY INPUT (AVERAGE JANUARY CONDITIONS) – TERMINAL .....	39
FIGURE 14. FLEET AGE DISTRIBUTION (PARTIAL) – TERMINAL .....	40
FIGURE 15. FUEL SUPPLY TABLE -- INTERSECTION .....	41
FIGURE 16. FUEL FORMULATION TABLE -- INTERSECTION .....	41
FIGURE 17. FUEL USAGE FRACTION -- INTERSECTION .....	41
FIGURE 18. ALTERNATIVE VEHICLE AND FUEL TECHNOLOGY (PARTIAL) -- INTERSECTION .....	42
FIGURE 19. LINK SOURCE TYPE INPUT TABLE -- TERMINAL .....	43
FIGURE 20. LINKS TABLE – TERMINAL .....	43
FIGURE 21. OFF-NETWORK TABLE .....	43
FIGURE 22. OP-MODE DISTRIBUTION TABLE – TERMINAL .....	44
FIGURE 23. EMISSION RATES FOR EACH LINK – TERMINAL .....	44
FIGURE 24. EXAMPLE OF APPROACH AND DEPARTURE LINKS FOR A SIMPLE INTERSECTION .....	45
FIGURE 25. EXAMPLE SINGLE VEHICLE SPEED TRAJECTORY THROUGH A SIGNALIZED INTERSECTION .....	47
FIGURE 26. EXAMPLE SEGMENTS OF VEHICLE ACTIVITY NEAR A SIGNALIZED INTERSECTION .....	48

# Section 1: Introduction

## 1.1 PURPOSE OF THIS GUIDANCE

### 1.1.1 General

The purpose of this guidance is to describe how to use the MOVES2014 emissions model to estimate carbon monoxide (CO) emissions from transportation projects, including roadway intersections, highways, transit projects, parking lots and intermodal terminals. This guidance can be applied when using MOVES2014 to complete project-level quantitative CO analysis, including hot-spot analyses for transportation conformity determinations, modeling project-level emissions for state implementation plan (SIP) development, and completing analyses pursuant to the National Environmental Policy Act (NEPA). This guidance applies in all states other than California, where the most recently approved version of the EMFAC model is used. EPA has coordinated with the Federal Highway Administration (FHWA) and Federal Transit Administration (FTA) in developing this guidance.

MOVES is a computer model designed by EPA to estimate emissions from cars, trucks, buses, and motorcycles.<sup>1</sup> MOVES is designed to allow users to analyze motor vehicle emissions at multiple scales, from national to county to project-level, using different levels of input data. For project-level analyses, MOVES allows users to enter specific details of vehicle activity for each link in a highway or transit project. In 2010, the MOVES model version called MOVES2010 officially replaced the previous on-road emissions model, MOBILE6.2. Subsequently, EPA made minor revisions to this version in releases of MOVES2010a and MOVES2010b.

MOVES2014 is the first major revision to the MOVES series since the original release of MOVES2010. MOVES2014 incorporates new emissions test data, the impacts of new emissions standards, new features, and other functional improvements, all of which contribute to improved estimates of criteria pollutant emissions compared to MOVES2010. This guidance covers the use of MOVES2014, and all references to “MOVES” in this guidance apply to MOVES2014 and future versions of the MOVES model, unless otherwise noted at the time those versions are announced.

Note that this guidance covers only how to use MOVES in estimating CO project-level emissions; there are other existing resources that support CO project-level analyses. For example, EPA’s regulatory recommendations for CO air quality modeling can be found in Appendix W to 40 CFR Part 51. Users should continue to consult the “1992 Guideline for Modeling Carbon Monoxide from Roadway Intersections” (1992 Guideline) for

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<sup>1</sup> The latest MOVES model, User Guide, and supporting documentation are available online at: [www.epa.gov/otaq/models/moves/index.htm](http://www.epa.gov/otaq/models/moves/index.htm). The latest policy guidance on using MOVES for transportation conformity and other purposes are also available at: [www.epa.gov/otaq/stateresources/transconf/policy.htm](http://www.epa.gov/otaq/stateresources/transconf/policy.htm).

screening analyses of intersection projects for all issues not related to the calculation of vehicle emission rates (including intersection scope and selection, receptor site selection, and air quality modeling procedures).<sup>2</sup> However, today's MOVES guidance supersedes the emission factor sections from the 1992 Guideline to reflect the use of MOVES for project-level CO analyses. See Section 1.2.1 for further background on the 1992 Guideline. Finally, users should consult EPA's "Transportation Conformity Guidance for Quantitative Hot-spot Analyses in PM<sub>2.5</sub> and PM<sub>10</sub> Nonattainment and Maintenance Areas" for how to use MOVES to conduct quantitative PM hot-spot analyses.<sup>3</sup>

### *1.1.2 Using this guidance for transportation conformity hot-spot analyses*

When using this guidance to complete quantitative CO hot-spot analyses for transportation conformity purposes, certain specific requirements apply; these are summarized here.

Transportation conformity is required under Clean Air Act section 176(c) (42 U.S.C. 7506(c)) to ensure that federally supported highway and transit project activities are consistent with ("conform to") the purpose of a SIP. EPA's transportation conformity rule (40 CFR 51.390 and Part 93) establishes the criteria and procedures for determining whether transportation activities conform to the SIP in CO nonattainment and maintenance areas. The list of areas currently designated nonattainment and maintenance for CO can be found on EPA's "Green Book" website at [www.epa.gov/oar/oaqps/greenbk/cindex.html](http://www.epa.gov/oar/oaqps/greenbk/cindex.html). This guidance applies for transportation conformity purposes in areas designated under the current CO NAAQS.<sup>4</sup>

Table 1 in 40 CFR 93.109(b) of the conformity rule outlines the requirements for project-level conformity determinations. For example, CO hot-spot analyses must be based on the latest planning assumptions available at the time the analysis begins (40 CFR 93.110) and the design concept and scope of the project must be consistent with that included in the conforming transportation plan and transportation improvement program (TIP) or regional emissions analysis (40 CFR 93.115). In addition, interagency consultation must be used to develop a process to evaluate and choose models and associated methods and assumptions to be used in CO hot-spot analyses (40 CFR 93.105(c)(1)(i)). The agencies that may be involved in the interagency consultation process include the project sponsor, state and local transportation and air quality agencies, EPA, and DOT. The roles and responsibilities of various agencies for meeting the transportation conformity requirements are addressed in 40 CFR 93.105 or in a state's approved conformity SIP. Refer to the conformity rule for a complete listing of all project-level conformity requirements.

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<sup>2</sup> "1992 Guideline for Modeling Carbon Monoxide from Roadway Intersections," (EPA-454/R-92-005, November 1992); available online at: [www.epa.gov/scram001/guidance/guide/coguide.pdf](http://www.epa.gov/scram001/guidance/guide/coguide.pdf).

<sup>3</sup> The latest version of this guidance is available online at:

<http://www.epa.gov/otaq/stateresources/transconf/projectlevel-hotspot.htm#pm-hotspot>.

<sup>4</sup> This guidance is applicable to current and future CO NAAQS revisions, unless EPA notes otherwise.

EPA has approved MOVES2014 for use in CO hot-spot analyses for project-level conformity determinations, with a two-year grace period. Refer to the Federal Register notice for more information on EPA's approval of MOVES2014 for CO hot-spot analyses.<sup>5</sup> EPA has also issued additional policy guidance on when MOVES2014 will be required for hot-spot analyses and other purposes.<sup>6</sup>

## 1.2 TYPES OF PROJECT-LEVEL CO ANALYSES

It is important to understand the context for this MOVES guidance in the overall process of completing project-level CO analyses. Project-level CO analyses consist of both emissions and air quality modeling and can be completed using either a screening or a refined analysis. Screening analyses estimate the maximum likely impacts of emissions from a given source, generally at the receptor with the highest concentrations, based on worst-case traffic and meteorological data. Such analyses can save effort in cases where requirements are met. In contrast, refined analyses use detailed local information and simulate detailed atmospheric processes to provide more specialized and accurate estimates of how nearby sources affect air quality at downwind locations.

Unless otherwise noted, the guidance in this document can be used to estimate highway and transit project emissions for all project-level CO analyses, both screening and refined. The following sections further describe the relationship of this MOVES guidance to particular types of screening and refined CO analyses.

### 1.2.1 Screening analyses of roadway intersections

The 1992 Guideline provides guidance on completing CO screening analyses of roadway intersections. As noted about, this document only supplants the 1992 Guideline insofar as to update the emission rate calculation procedures to reflect the use of MOVES; the 1992 Guideline otherwise remains in effect, and users should continue to consult that guidance for all issues not related to the calculation of vehicle emission rates (including intersection scope and selection, receptor site selection, and air quality modeling procedures).

### 1.2.2 All other screening analyses

This guidance also covers how to use MOVES for CO screening analyses of projects that are not explicitly covered by the 1992 Guideline. This would include projects such as:

- A mainline highway segment not containing an intersection;

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<sup>5</sup> See “[Federal Register Notice of Availability: Official Release of MOVES2014 Motor Vehicle Emissions Model for Emissions Inventories in SIPs and Transportation Conformity \(PDF\)](http://www.epa.gov/otaq/stateresources/transconf/policy.htm#models)”; available online at: <http://www.epa.gov/otaq/stateresources/transconf/policy.htm#models>

<sup>6</sup> “Policy Guidance on the Use of MOVES2014 for State Implementation Plan Development, Transportation Conformity, and Other Purposes,” EPA-420-B-14-008 (July 2014); available online at: <http://www.epa.gov/otaq/models/moves/documents/420b14008.pdf>.

- An intersection project that includes off-network activity (that is, any activity not occurring on a roadway, such as a truck stop, parking lot, or terminal facility);
- Any other project that includes off-network activity;
- Transit and other terminal projects.

The guidance will note when different procedures are appropriate when using MOVES to complete a CO screening analysis for such projects. In some cases, the procedures for using MOVES for these types of screening analyses will be the same as using MOVES for a CO refined analysis (see Section 1.2.3). When this is the case, this guidance covers these situations in a single section for brevity.

### *1.2.3 Refined analyses of any project*

In certain situations, project sponsors may want or need to complete a CO refined analysis. Although a refined analysis requires significantly more data and effort, this option may be convenient for transportation projects that require both a PM and CO quantitative hot-spot analysis. This guidance gives additional guidance on using MOVES for refined analyses to explain how the full capabilities of the model can be employed in these situations.

## **1.3 CONTACTS**

For specific transportation conformity questions concerning a particular nonattainment or maintenance area, please contact the transportation conformity staff person responsible for your state at the appropriate EPA Regional Office. Contact information for EPA Regional Offices can be found at:

[www.epa.gov/otaq/stateresources/transconf/contacts.htm](http://www.epa.gov/otaq/stateresources/transconf/contacts.htm).

General questions on using MOVES for CO project-level analysis can be directed to the MOVES in-box at [mobile@epa.gov](mailto:mobile@epa.gov).

Technical questions about this guidance can be directed to [conformity-hotspot@epa.gov](mailto:conformity-hotspot@epa.gov).

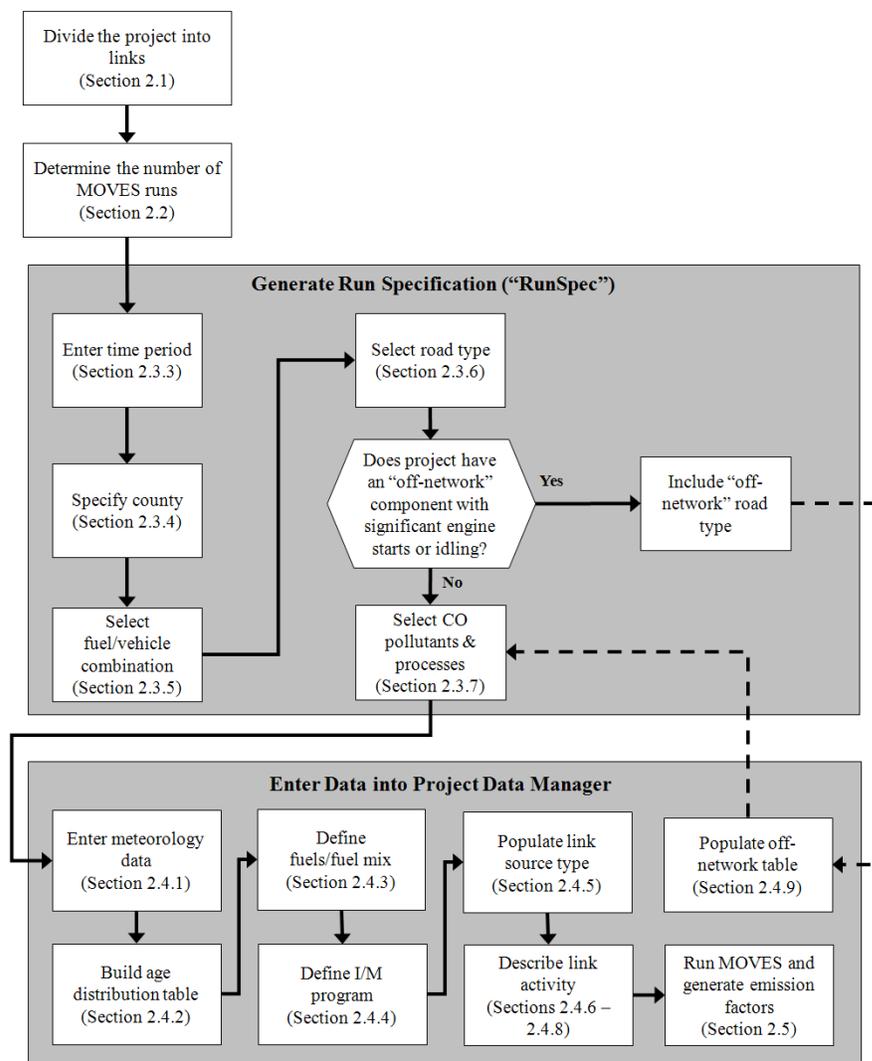
## **1.4 GUIDANCE AND EXISTING REQUIREMENTS**

This guidance does not create any new requirements. The Clean Air Act and the regulations described in this document contain legally binding requirements. This guidance is not a substitute for those provisions or regulations, nor is it a regulation in itself. Thus, it does not impose legally binding requirements on EPA, DOT, states, or the regulated community, and may not apply to a particular situation based upon the circumstances. EPA retains the discretion to adopt approaches on a case-by-case basis that may differ from this guidance but still comply with the statute and applicable regulations. This guidance may be revised periodically without public notice.

## Section 2: Estimating Project-Level CO Emissions Using MOVES

This guidance addresses the necessary steps to run MOVES to estimate a project's emissions for a project-level CO analysis. The guidance describes how to provide the appropriate inputs to MOVES to generate the emission factors necessary to complete the air quality analysis. This section presumes users already have a basic understanding of how to run MOVES, either by attending MOVES training or reviewing the MOVES User Guide.<sup>7</sup> Figure 1 describes the general process for estimating the CO emissions at the project level using MOVES.

**Figure 1. Steps for Using MOVES in Project-Level CO Analyses**



<sup>7</sup> Available via the MOVES website at: [www.epa.gov/otaaq/models/moves/](http://www.epa.gov/otaaq/models/moves/)

MOVES includes a default database of meteorology, fleet, activity, fuel, and control program data for the entire United States. The data included in this database come from a variety of sources and are not necessarily the most accurate or up-to-date information available at the local level for a particular project. This guidance will describe when the use of that default database is appropriate for a project-level CO analysis.

## 2.1 CHARACTERIZING A PROJECT IN TERMS OF LINKS

The first step in completing a project-level CO analysis using MOVES is to define a project's links in order to accurately capture emissions where they occur. Within MOVES, a link represents a segment of road (or an "off-network" location as described below) where a certain type of vehicle activity occurs. Generally, the links specified for a project should include segments with similar traffic/activity conditions and characteristics. For example, a free-flow highway segment with a relatively stable average speed might be modeled as a single link, whereas an intersection will involve several types of links, as described further below. From the link-specific activity and other inputs, MOVES calculates emissions from every link of a project for a given time period (or run). In MOVES, running emissions, including periods of idling at traffic signals, are defined in the Links Importer (see Section 2.4.6).

This section gives different guidance on how to characterize links in MOVES, depending on the type of project and CO analysis involved, as follows:

- For a screening analysis of a roadway intersection being completed in accordance with the 1992 Guideline, see Section 2.1.1;
- For all other screening analyses, including intersection projects that include off-network activity, see Section 2.1.2;
- For a refined analysis of any project, see Section 2.1.2.

### 2.1.1 *Screening analyses of roadway intersections*

According to EPA's regulatory recommendations for air quality modeling (Section 5.2.3 of Appendix W to 40 CFR Part 51), CO screening analyses of intersection projects should use the CAL3QHC dispersion model. Performing such an analysis for an intersection using the CAL3QHC dispersion model requires emission rates for both free-flow traffic (determined by defining "free flow" links) and idling traffic (determined from "queue links").<sup>8</sup> Free-flow links can be used to represent traffic approaching and departing an intersection. See Section 3 of this guidance for an example of how to use MOVES for a CO screening analysis of an intersection.

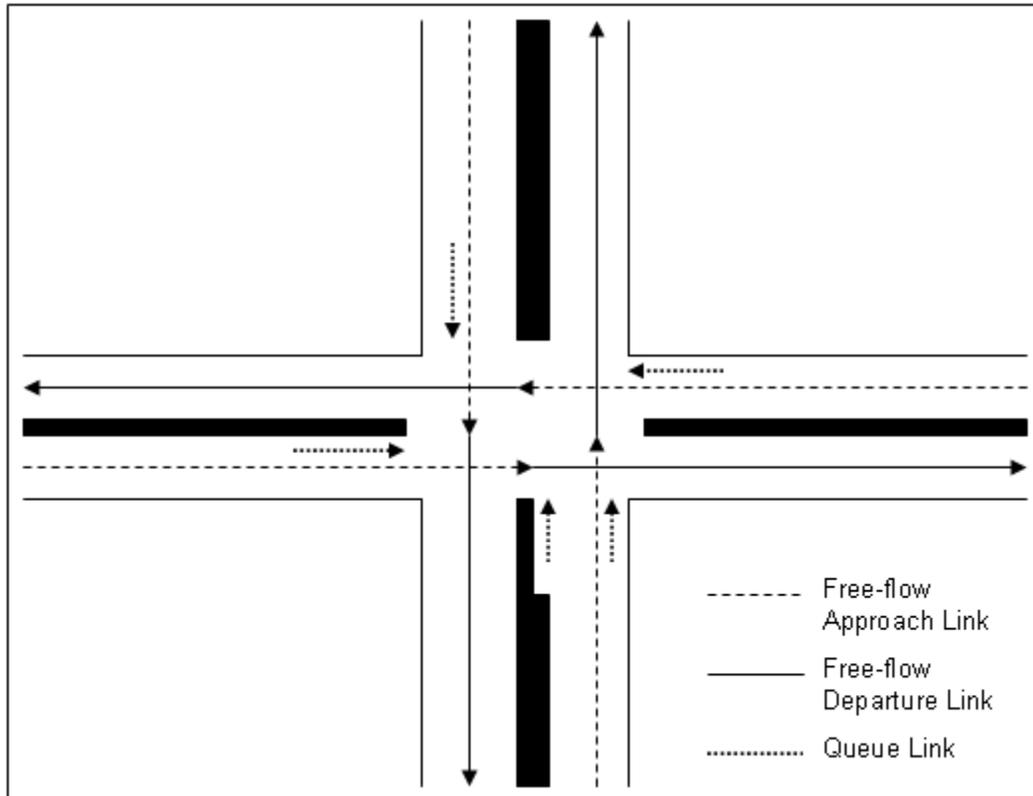
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<sup>8</sup> The 1992 Guideline describes how to use CAL3QHC when performing dispersion modeling for intersections (see 1992 Guideline, page 1-5). To be consistent with the 1992 Guideline, this guidance recommends use of the CAL3QHC queuing algorithm for intersection idle queues when completing a CO screening analysis of an intersection. This differs from the recommendation for refined analyses, where idling should be explicitly included in the link activity entered into MOVES, rather than determined by the CAL3QHC queuing algorithm. Since the purpose of a screening analysis is inherently different from that of a refined analysis, the separate methods still serve the respective goals of each approach.

Note that the 1992 Guideline does not cover screening analyses of intersections that include off-network activity. For those situations, refer to Section 2.1.2.

Figure 2 is an example of a simple intersection showing free-flow approach, free-flow departure, and queue links. The following sections provide more information on how to define these links in MOVES.

**Figure 2. Diagram of Suggested Links for a Simple Intersection**



### Free-flow Approach and Departure Links

Free-flow links are used to represent vehicle activity on intersection approach and departure links. The intersection in Figure 2, for example, shows four free-flow approach and four free-flow departure links. Free-flow links are described by the average speeds experienced by drivers travelling along the link in the absence of the delay caused by an intersection traffic signal. Users should define a free-flow link as the center-to-center distance from the intersection of interest to the next intersection. As described in Section 4.7.4 of the 1992 Guideline, a maximum of 300 meters for this distance is sufficient, but users may specify a longer distance for completeness.<sup>9</sup>

<sup>9</sup> Since the goal of the MOVES run is to produce a grams/vehicle-mile emission rate, the exact length or volume of each link is not important for running MOVES, although it is important for subsequent CAL3QHC dispersion modeling.

## Queue Links

A queue link is used to represent vehicles idling at an intersection. The intersection in Figure 2, for example, shows five queue links. Since MOVES is calculating a gram per vehicle-hour emission factor in this case, the exact length of the queue is not important. As opposed to free-flow and departure links, which use grams/veh-mile, queue links require a gram/veh-hour emission rate.

### *2.1.2 All other screening analyses and refined analyses of any project*

When completing screening analyses of projects not covered by the 1992 Guideline, or any refined analysis, there are several options for characterizing link activity for project-level CO emissions. The following text describes how different types of links can be characterized in MOVES.

## General

In MOVES, activity on free-flow highway links can be defined by an average speed, link drive schedule, or operating mode (“Op-Mode”) distribution (discussed in Section 2.4.8). For analyses with MOVES, average speed and traffic volume is required, at a minimum, for each link. If no other information is available, MOVES uses default assumptions of vehicle activity patterns (called drive cycles) for average speed and type of roadway to estimate emissions. Default drive cycles use different combinations of vehicle activity (acceleration, deceleration, cruise, and/or idle) depending on the speed and road type. For example, if the link average speed is 30 mph and it is an urban arterial (urban unrestricted road type), MOVES uses a default drive cycle that includes a high proportion of acceleration, deceleration, and idle activity as would be expected on an urban arterial with frequent stops. If the average speed is 60 mph and it is a rural freeway (rural restricted road type), MOVES uses a default drive cycle that assumes a higher proportion of cruise activity, smaller proportions of acceleration and deceleration activity, and little or no idle activity.

Project sponsors should determine average congested speeds by using appropriate methods based on best practices used for highway analysis.<sup>10</sup> Some resources are available through FHWA’s Travel Model Improvement Program (TMIP).<sup>11</sup> Methodologies for computing intersection control delay are provided in the “Highway Capacity Manual 2010.”<sup>12</sup>

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<sup>10</sup> When completing screening analyses of projects not covered by the 1992 Guideline, or any refined analysis, idling vehicles should be represented in combination with decelerating, accelerating, and free-flow traffic on an approach segment of an intersection. Note that this is in contrast to the guidance given when completing a CO screening analysis of an intersection, when the CAL3QHC queuing algorithm is recommended in order to be consistent with the 1992 Guideline (see Section 2.1.1).

<sup>11</sup> See FHWA’s Travel Model Improvement Program website: <http://tmip.fhwa.dot.gov/>.

<sup>12</sup> Users should consult the most recent version of the Highway Capacity Manual. As of the release of this guidance, the latest version is the “Highway Capacity Manual 2010,” which can be obtained from the Transportation Research Board (see <http://hcm.trb.org/?qr=1> for details).

As described further in Section 2.4.8, for refined analyses, users are encouraged to take advantage of the full capabilities of MOVES for estimating emissions on different highway and intersection project links when completing CO refined analyses. Although average speeds and travel volumes are typically available for most transportation projects and may need to be relied upon during the transition to using MOVES, users can develop and use more precise data through the MOVES Operating Mode Distribution Importer or Link Drive Schedule Importer, as described further below. When more detailed data are available to describe the pattern of changes in vehicle activity (proportion of time in acceleration, deceleration, cruise, or idle activity) over a length of road, MOVES is capable of calculating these specific emission impacts. EPA encourages users to consider these options for CO refined analyses of highway and intersection projects, especially as MOVES is implemented further into the future, or for more advanced MOVES applications.

### Free-flow Highway Links

The links defined in MOVES should capture the expected physical layout of a project and representative variations in vehicle activity. A simple example would be a single, one directional, four-lane highway that could be characterized as just one link. More sophisticated analyses may break up traffic flow on that single link into multiple links of varying operating modes or drive cycles that may have different emission factors depending on the relative acceleration, cruise, or deceleration activity on each segment of that link. In general, the definition of a link will depend on how much the type of vehicle activity (acceleration, deceleration, cruise or idle) changes over a length of roadway, the level of detail of available data, and the modeling approach used with MOVES. For a highway lane where vehicle behavior is fairly constant, the length of the link could be longer and the use of detailed activity data will have a smaller impact on results.

### Intersection Links

If the project analysis is a CO refined analysis involving intersections, the intersections need to be treated separately from the free-flow links that connect to those intersections. Although road segments between intersections may experience free-flow traffic operations, the approaches and departures from the intersections will likely involve acceleration, deceleration, and idling activity not present on the free-flow link. For intersection modeling, the definition of link length will depend on the geometry of the intersection, how that geometry affects vehicle activity, and the level of detail of available activity information. Guidance for defining intersection links for a CO refined analysis is given in the appendix, but the definition of links used for a particular project will depend of the specific details of that project and the amount of available activity information.

*Note: For both free-flow highway and intersection links, users may directly enter output from traffic simulation models in the form of second-by-second individual vehicle trajectories. These vehicle trajectories for each road segment can be*

*input into MOVES using the Link Drive Schedule Importer and defined as unique LinkIDs. There are no limits in MOVES as to how many links can be defined; however, model run times increase as the user defines more links. More information on using vehicle trajectories from traffic microsimulation models for CO refined analyses can be found in the appendix.*

### Off-Network Links

In any project-level CO analysis, the project being analyzed may include “off-network” activity. Off-network in the context of MOVES refers to any activity not occurring on a roadway. Examples of off-network activity include truck stops, parking lots, and transit and other terminals. This section describes how to characterize off-network activity into links; entering off-network links into MOVES using the Off-Network Importer will be covered in Section 2.4.8. While an off-network link could have a combination of start, hotelling, idling, and running activity, note that MOVES can only model one link with start and hotelling activity per run. If a project contains multiple links with start and hotelling activity, separate MOVES runs may be needed.

**Start activity:** For off-network sources such as a parking lot or transit terminal, the user should have information on starts per hour (or peak hour starts). Additionally, if there are vehicles starting, it is necessary to provide an estimate of the duration that vehicles are parked before starting (soak-time distribution). It is recommended that the user divide such a project into separate links to appropriately characterize variability in emission density within the project area. In this case, each “link” describes an area with a certain number of vehicle starts per hour.

**Idling activity:**

- **Hotelling:** In MOVES, hotelling applies only to long haul combination trucks, source type ID 62. Hotelling activity includes long duration idling (classified in MOVES as OpModeID 200), and use of auxiliary power units (APUs, classified in MOVES as OpModeID 201). Additionally, hotelling operation using electric power (no emissions) can be modeled using OpMode 203. Only one link per run can have hotelling activity.
- **Other Idling:** Idling for other vehicles and shorter periods of idling for long-haul combination trucks should be modeled as a project link with an operating mode distribution that consists only of idle operation (OpModeID 1). This can be specified in the Links table by inputting the vehicle population, i.e., the number of vehicles idling during the hour (or idling during peak hour) and specifying an average speed of “0” mph. There is no limit to the number of links that can have this type of idling activity. Multiple links can be defined for the same off-network area to capture idling activity of various vehicle types.

**Running activity:** Some transit and other terminal projects may have significant running emissions similar to free-flow highway projects (such as buses and trucks coming to and from an intermodal terminal). These emissions can be calculated by defining one or more unique running links as described in Section 2.1.2 and the appendix (that is, in

addition to any other roadway links associated with the project). These running link emissions can then be aggregated with the emissions from the other activities happening on the off-network link (e.g., starts and idling from non-running activity on the transit or other terminal link) outside of the MOVES model to generate the necessary air quality model inputs.

*Note: The user may choose to exclude sources such as a separate service drive, separate small employee parking lot, or other minor sources that are determined to be insignificant to project emissions.*

## **2.2 DETERMINING THE NUMBER OF MOVES RUNS**

The following section describes the number of MOVES runs that may be needed for project-level CO analyses.<sup>13</sup>

### *2.2.1 Screening analyses of roadway intersections*

For a CO screening analysis of an intersection project, only one MOVES scenario (run) is necessary for each analysis year. To remain consistent with the 1992 Guideline for such analyses, this guidance describes how to use “worst-case” conditions.<sup>14</sup> To capture anticipated worst-case conditions, users should define the MOVES run specification (“RunSpec”) using the peak hourly traffic volume expected for the intersection project. As stated in the 1992 Guideline, the peak hour traffic conditions are defined as the average or typical values during the hour of the day which usually records the peak hour traffic, rather than the worst case traffic conditions for the entire year.<sup>15</sup> Average speeds, vehicle mix, and idle times should reflect conditions at the peak period. Project sponsors should use the appropriate methods based on best practices used for highway analysis in the area for determining peak period traffic conditions. Some resources for determining traffic characteristics are available through FHWA’s Travel Model Improvement Program (TMIP).<sup>16</sup> Guidance on how to enter these individual inputs into MOVES is discussed in Section 2.4.

### *2.2.2 All other screening analyses*

The 1992 Guideline does not expressly address what conditions should be captured for a CO screening analysis of a project that is not solely a roadway intersection. Project sponsors are encouraged to employ best professional practices and appropriate methods and use the interagency consultation process or procedures to determine the appropriate number of MOVES runs for these screening analysis situations.

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<sup>13</sup> If completing a CO quantitative hot-spot analysis for transportation conformity purposes, users should refer to the conformity rule requirements when selecting travel activity data. See Section 1.1.2 for a summary of these conformity requirements.

<sup>14</sup> See 1992 Guideline, Section 4.

<sup>15</sup> See 1992 Guideline, Section 1.3.

<sup>16</sup> FHWA Travel Model Improvement Program website: <http://tmip.fhwa.dot.gov/>.

### 2.2.3 Refined analyses of any project

If MOVES is being used to complete a CO refined analysis, more than one MOVES run may be needed to capture any emission rate variation due to changes in temperature, volume, speeds, and fleet mix over the course of the day, season, or year being analyzed. However, the specific number of MOVES runs needed will depend on the situation. For example, where potential CO NAAQS violations are expected to occur in only one quarter of the calendar year (e.g., only a wintertime violation), the user might choose to model only a single day to represent all days within that quarter. However, if CO NAAQS violations are expected in multiple quarters, or if variations in travel activity and/or temperature within a single quarter need to be accounted for, then additional MOVES runs may be necessary.

Project sponsors may have activity data collected at a range of possible temporal resolutions. Depending on the sophistication of the activity data analysis for a given project, these data may range from a daily average-hour and peak-hour value to hourly estimates for all days of the year. The remainder of this section describes how project sponsors can use MOVES for CO refined analyses in cases where they have (1) typical travel activity data, and (2) more detailed travel activity data.

#### Projects with Typical Travel Activity Data

Traffic forecasts for highway and intersection projects are often completed for annual average daily traffic volumes, with an allocation factor for a daily peak-hour volume. This data can be used to conduct an analysis with MOVES that is representative for all hours of the day, or year being considered. The most reasonable methods in accordance with good practice should be used to obtain the peak-hour allocation factors and diurnal distribution of traffic and the methods must be determined in accordance with interagency consultation procedures (40 CFR 93.105(c)(1)(i)). It is important to capture variation in emission rates as activity and ambient temperature change over the period being analyzed.

One option is to represent traffic over four time periods: morning peak (AM), midday (MD), evening peak (PM), and overnight (ON). For example, the peak-hour volume can be used to represent activity conditions over a three-hour morning (AM) and three-hour evening (PM) period. The remaining 18 hours of the day can be represented by the average-hour volume (AADT minus the total volume assigned to the peak period, divided by the number of off-peak hours). These 18 hours would be divided into a midday (MD) and overnight (ON) period.

The following is one suggested approach for an analysis employing the average-hour/peak-hour traffic scenario:

- Morning peak (AM) emissions based on traffic data and meteorology occurring between 6 a.m. and 9 a.m.;
- Midday (MD) emissions based on data from 9 a.m. to 4 p.m.;
- Evening peak (PM) emissions based on data from 4 p.m. to 7 p.m.; and

- Overnight (ON) emissions based on data from 7 p.m. to 6 a.m.

Also, if there are local or project-specific data to suggest that the AM or PM peak traffic periods will occur in different hours than the default values suggested here, or over a longer or shorter period of time, the hours representing each time period may adjusted accordingly.

### Projects with Additional Travel Activity Data

Some project sponsors may have developed traffic or other activity data to show variations in volume and speed across hours, days, or months. Additionally, if users are modeling a transit or other terminal project, traffic volumes, starts, and idling estimates are likely to be readily available for each hour of the day. Under either of these circumstances, users may choose to apply the methodology described above (using average-hour and peak-hour as representative for all hours of the time period being calculated). Alternatively, additional MOVES runs could be generated to produce unique emission factors using these additional activity data and emission factors for each period of time for which specific activity data are available.

## **2.3 DETERMINING BASIC RUN SPECIFICATION INPUTS**

Once the user has defined the project conceptually in terms of links and determined the number of MOVES runs, the next step in using MOVES for project-level analyses is to develop a run specification (“RunSpec”). The RunSpec is a computer file in XML format that can be edited and executed directly or with the MOVES Graphical User Interface (GUI). MOVES requires the user to set up a RunSpec to define the place and time of the analysis as well as the vehicle types, road types, fuel types, and the emission-producing processes and pollutants that will be included in the analysis. The headings in this subsection describe each set of input options needed to create the RunSpec as defined in the Navigation panel of the MOVES GUI. In order to create a project-level RunSpec, the user must go down the Navigation panel filling in the appropriate data for each of the items listed. Those panels are:

- Description
- Scale
- Time Spans
- Geographic Bounds
- Vehicles/Equipment
- Road Type
- Pollutants and Processes
- Manage Input Data Sets
- Strategies
- Output
- Advanced Performance Features

Additional information on each panel can be found in the MOVES User Guide available on EPA's website ([www.epa.gov/otaq/models/moves/index.htm](http://www.epa.gov/otaq/models/moves/index.htm)). The appropriate sections of the user guide are referenced when describing the RunSpec creation process below.

### 2.3.1 Description

This panel allows the user to enter a description of the RunSpec using up to 5,000 characters of text. Entering a complete description of the RunSpec is important for users to keep track of their MOVES runs as well as to provide supporting documentation for the regulatory submission. Users may want to identify the project, the time period being analyzed, and the purpose of the analysis in this field.

### 2.3.2 Scale

The Scale panel in MOVES allows the user to select different scales or domains for the MOVES analysis. All MOVES runs for project-level analyses must be done using the "Project" domain in the "Scale" panel. The Project domain is necessary to allow MOVES to accept detailed activity input at the link level.<sup>17</sup>

The Scale panel also requires users to select either "Inventory" or "Emission Rates" which produces output as either grams/hour or grams/vehicle-mile emission rates, respectively.<sup>18</sup>

For screening analyses of intersections, since CAL3QHC requires emission rates in terms of both grams/vehicle-mile for free-flow links and grams/veh-hour for queue links, users performing an analysis for a project which includes vehicle queuing (such as is the case with an intersection) should select Inventory as output. From the Inventory output, appropriate emission rates can be calculated through several post-processing steps described in Section 2.5.

When completing screening analyses of projects not covered by the 1992 Guideline, or any refined analysis, users may benefit from choosing either Rates or Inventory depending on the specifics of the project (including the air quality model being used to complete the analysis):

- When a grams/hour emission factor is needed for air quality modeling, users should select "Inventory," which produces results for total emissions on each link; this is equivalent to a grams/hour/link emission factor.
- When a gram/vehicle-mile emission factor is needed, the "Emission Rates" option should be selected to produce link specific grams/vehicle-mile emission factors.

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<sup>17</sup> Running MOVES using the "County" or "National" domains would not allow for detailed link level input or output that is needed for project-level CO analyses.

<sup>18</sup> The Scale panel also includes options for Onroad or Nonroad models. This guidance applies only to the Onroad model in MOVES.

This guidance explains the steps of post-processing both “Inventory” and “Emission Rates” results to produce the desired emission factors in Section 2.5.

### *2.3.3 Time Spans*

The Time Spans panel is used to define the specific time period covered in the MOVES run. The Time Spans panel is divided into five sections, which allow the user to select time aggregation level, year, month, day, and hour included in the run.

The MOVES model processes one hour, of one day, of one month, of one year for each run; that is, each MOVES run represents one specific hour. The user should enter the desired time period in the MOVES Time Spans panel. Time aggregation should be set to “hour,” which indicates no pre-aggregation. The “day” selection should be set to “weekday” or “weekend,” but not both.

To be consistent with the 1992 Guideline, for a CO screening analysis of an intersection, the year, month, and hour should be set to specifically describe the peak traffic scenario. For example, the run describing a peak traffic scenario might be: 2015, January, 8:00 to 8:59 a.m. (both the start and end hours set to “8:00 a.m. to 8:59 a.m.”).

### *2.3.4 Geographic Bounds*

The Geographic Bounds panel allows the user to define the specific county that will be modeled. The MOVES database includes county codes and descriptive information for all 3,222 counties in the United States. Specifying a county in MOVES determines certain default information for the analysis. Users should select the specific county where the project is located. Only a single county (or single custom domain) can be included in a MOVES run at the project level. If a project spans multiple counties, users have three options:

1. If the county-specific local data is the same for all the counties in the project, select the county in which the majority of the project is located;
2. If not, separate the project into multiple parts, each of which is in a separate county, and do a separate MOVES run for each part; or
3. Use the custom domain option to model one unique area that represents all the project counties.

### *2.3.5 Vehicles/Equipment*

The Vehicles/Equipment panel is used to specify the vehicle types that are included in the MOVES run. MOVES allows the user to select from among 13 “source use types” (the terminology that MOVES uses to describe vehicle types), and several different fuels. Some fuel/source type combinations do not exist (e.g., diesel motorcycles) and therefore are not included in the MOVES database. Users should always select Gasoline, CNG, Diesel, and Ethanol (E-85) and all valid vehicle type combinations in the Vehicle/Equipment panel to reflect the full range of vehicles that will operate in the project area.

### 2.3.6 Road Type

The Road Type panel is used to define the types of roads that are included in the project. MOVES defines five different Road Types:

- Rural Restricted Access – a rural highway that can be accessed only by an on-ramp;
- Rural Unrestricted Access – all other rural roads (arterials, connectors, and local streets);
- Urban Restricted Access – an urban highway that can be accessed only by an on-ramp;
- Urban Unrestricted Access – all other urban roads (arterials, connectors, and local streets); and
- Off-Network – any location where the predominant activity is vehicle starts and hotelling (parking lots, truck stops, rest areas, freight or bus terminals).

MOVES uses these road types to determine the default drive cycle on a particular link. For example, MOVES uses drive cycles for unrestricted access road types that assume stop-and-go driving, including multiple accelerations, decelerations, and short periods of idling. For restricted access road types, MOVES uses drive cycles that include a higher fraction of cruise activity with much less time spent accelerating and idling.

Road Type is a necessary input into the RunSpec and users should select one or more of the five road types that correspond to the road types of the project. The determination of rural or urban road types should be based on the Highway Performance Monitoring System (HPMS) functional classification of the road type.

### 2.3.7 Pollutants and Processes

The Pollutant and Processes panel is used to select both the types of pollutants and the emission processes that produce them. When completing a CO screening analysis of an intersection project using CAL3QHC, both free-flow and queue links will be characterized. For CO emissions from these links, MOVES calculates emissions for two separate processes:

- Running Exhaust
- Crankcase Running Exhaust

If modeling an intersection, users should select Carbon Monoxide (CO): “Running Exhaust” and “Crankcase Running Exhaust.” Emission rates will be post-processed from the MOVES output to calculate an aggregate of both processes.

MOVES does not automatically sum the appropriate processes to create an aggregate emission factor, although EPA has created MOVES scripts that automate the summing of aggregate emissions when completing project-level analyses. These scripts are available through the post-processing menu of the MOVES GUI and are discussed in Section 2.5

When completing screening analyses of projects not covered by the 1992 Guideline, or any refined analysis, users can similarly sum the processes described above using the MOVES post-processing scripts to calculate aggregate emissions from the MOVES output.

If the project contains an off-network link, users should select Carbon Monoxide (CO): “Starting Exhaust”, “Crankcase Starting Exhaust”, “Extended Idling Exhaust”, “Crankcase Extended Idling Exhaust”, and/or “Auxiliary Power Exhaust” depending on the vehicle activity occurring on the off-network link. Emission rates will need to be post-processed from the MOVES output using the MOVES post-processing scripts discussed in Section 2.5.

### *2.3.8 Manage Input Databases* (MOVES User Guide Section 2.2.8)

Most project-level CO analyses will not use the Manage Input Data Sets panel. One possible application is to specify user-supplied databases to be read by the model during execution of a run. However, for project-level analyses in MOVES, the Project Data Manager, described in Section 2.4, serves this same function while providing for the creation of data table templates and for the review of default data. EPA specifically developed the Project Data Manager for project analyses and recommends using it to create and specify user supplied database tables instead of the Manage Input Databases panel.

### *2.3.9 Strategies*

In MOVES, the Strategies panel does not contain any relevant options or inputs for project-level analysis, and should be skipped.

### *2.3.10 Output*

Selecting Output in the Navigation panel provides access to two additional panels: General Output and Output Emissions Detail. Each of these allows the user to specify aspects of the output data.

Under General Output, users should make sure to choose “grams” and “miles” for the output units in order to provide results for air quality modeling. Also, “Distance Traveled” and “Population” should be selected under the “Activity” heading to obtain vehicle volume information for each link in the output.

Output Emissions Detail is used to specify the level of detail desired in the output data. Emissions by hour and link are the default selections and cannot be changed. EPA recommends that users select the box labeled “Emission Process.” No other boxes should be selected in order to produce fleet aggregate emission rates for each link. Emission

rates for each process can be appropriately summed to calculate aggregate CO emission rates for each link (as described previously in Section 2.3.7).

### 2.3.11 Advanced Performance Features

Most project-level CO analyses will not use the Advanced Performance Features panel. This panel can be skipped.

## 2.4 ENTERING PROJECT DETAILS USING THE PROJECT DATA MANAGER

After completion of all the necessary panels to create the RunSpec, the user must then create the necessary input database tables that describe the project in detail. For a typical project-level analysis, only one set of input database tables will need to be created. This is done using the Project Data Manager, which can be accessed from the Pre-Processing menu item at the top of the MOVES GUI or by selecting Enter/Edit Data in the Domain Input Database section of the Geographic Bounds panel.

The Project Data Manager includes multiple tabs that open importers, which are used to enter project-specific data. These tabs and importers are:

- Meteorology Data
- Age Distribution
- Fuel
- Inspection and Maintenance
- Link Source Type
- Links
- Link Drive Schedule
- Operating Mode Distribution
- Off-Network
- Hotelling
- Retrofit Data

Each of the importers allows the user to create a template file with required data field names and with some key fields populated. The user then edits this template to add project specific local data with a spreadsheet application or other tool and imports the data files into MOVES. In some importers, there is also the option to export default data from the MOVES database in order to review it. Once the user determines that the default data are accurate and applicable to the particular project, or determines that the default data need to be changed and makes those changes, the user then imports that data into MOVES. Details of the mechanics of using the data importers are provided in the MOVES User Guide. Guidance for the use of these importers when completing project-level CO analyses is described below.

*Note: Most analyses will not use all of the importers, and it is not necessary to see all “green checks” to run MOVES. For instance, a project with no off-network*

*links will not use the Off-Network, Operating Mode Distribution, or Hotelling importers when activity is defined through the average speed function of the Links importer. These tabs will remain “red X’s” but do not indicate a problem with a run.*

For all project-level CO analyses, if the project contains an off-network link, both the Off-Network table and Operating Mode Distribution table should be populated and imported (as well as the Hotelling table if hotelling activity is occurring in the project.) See Sections 2.1.2 and 2.4.8 for information on modeling off-network links in MOVES.

#### *2.4.1 Meteorology*

The Meteorology Data Importer is used to import temperature and humidity data for the month and hour that are defined in the MOVES run specification. Default temperature and humidity values are available in MOVES, but are not recommended for use in a project-level CO analysis.

#### Screening Analyses of Roadway Intersections

The 1992 Guideline recommends the following two options for defining temperature and humidity for screening analyses of intersections:

1. The temperature and humidity corresponding to each of the ten highest non-overlapping 8-hour CO monitoring values for the last three years should be obtained. The average 8-hour temperature and humidity for each event should be calculated and then all ten values should be averaged for use with MOVES.
2. Alternatively, the average temperature and humidity in January may be used.<sup>19</sup>

Meteorological data may be obtained either from the National Weather Service (NWS) or as part of a site-specific measurement program. Local universities, the Federal Aviation Administration (FAA), military stations, and state and local air agencies may also be sources of such data. The National Oceanic and Atmospheric Administration’s National Climatic Data Center (NCDC; online at [www.ncdc.noaa.gov](http://www.ncdc.noaa.gov)) is the world’s largest active archive of weather data through which years of archived data can be obtained. A data source should be selected that is representative of local meteorological conditions.

#### All Other Screening Analyses

The 1992 Guideline does not expressly address what conditions should be captured for a CO screening analysis of a project that is not solely a roadway intersection. However, the guidance given in the 1992 Guideline may also be appropriate for any CO screening analysis.

#### Refined Analyses of Any Project

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<sup>19</sup> See 1992 Guideline, Section 4.7.1.

For refined analyses, users should enter data specific to the project's location and time period modeled, as CO emissions are found to vary significantly depending on temperature. As discussed in Section 2.2.3, MOVES will typically be run for multiple time periods and specific meteorology data that accurately represents these runs is needed. Within each period of the day, in each quarter selected, temperatures should be used that represent the average temperature within that time period. For example, for January AM peak periods corresponding to 6 a.m. to 9 a.m., the average January temperature based on the meteorological record for those hours should be used in estimating the average January AM peak period temperature for MOVES runs. The user may choose to run additional hours and temperatures beyond the number of traffic periods for which data exist. For example, within an 11-hour overnight (ON) modeling period, temperature data could be used to differentiate hours with significantly different temperatures, despite having assumed identical traffic estimates. Humidity estimates should be based on the same hours and data source as the temperature estimates.

#### *2.4.2 Age Distribution*

The Age Distribution Importer is used to enter data that provides the distribution of vehicle fractions by age for each calendar year (yearID) and vehicle type (sourceTypeID). These data are required for running MOVES at the project level. The distribution of ageID (the variable for age) fractions must sum to one for each vehicle type and year.

To build a MOVES-compatible age distribution table for project-level CO analyses, there are three possible options.

1. If available, users should use the latest available state or local age distribution assumptions from their SIP or transportation conformity regional emissions analysis.
2. If the project is designed to serve a fleet that operates only locally, such as a drayage yard or bus terminal, the user should provide project-specific fleet age distribution data. For most captive fleets, an exact age distribution should be readily available or obtainable. The data should be in a format compatible with MOVES.
3. If no state or local age distribution is available, the MOVES default age distribution should be used. This can be obtained from the tables available on the EPA website: [www.epa.gov/otaq/models/moves/tools.htm](http://www.epa.gov/otaq/models/moves/tools.htm). The user can select the analysis year(s) and find the corresponding age distribution. These fractions are national defaults and could be significantly different than the local project age distribution. Age distribution can have a considerable impact on emission estimates, so the default data should be used only if an alternative state or local dataset cannot be obtained.

### 2.4.3 Fuel

The Fuel Importer contains four required tables: Fuel Supply, Fuel Formulation, Fuel Usage, and AVFT (Alternative Vehicle and Fuel Technology). The Fuel Supply table defines the fuels present in the project area. The Fuel Formulation table defines the properties of those fuels. The Fuel Usage table defines the fraction of Ethanol (E-85) capable vehicles that are using E-85 vs. conventional gasoline. Finally, the AVFT table defines the prevalence of each vehicle/fuel type combination for the project area.

Users should review the default fuel data in MOVES by exporting it through the Fuel tab, and make changes only if local volumetric fuel property information is available. Otherwise, EPA strongly recommends that the MOVES default fuel information be used for project-level CO analyses unless a full local fuel property study exists. The exception to this is in the case of Reid Vapor Pressure (RVP), where a user should change the value to reflect the differences between ethanol and non-ethanol blended gasoline. This should be done using the “Fuel Wizard” accessible in the Fuel tab. See the MOVES user guide for additional information about using the Fuel Wizard.

For additional guidance on defining fuel information, consult the MOVES Technical Guidance, available online at:

[www.epa.gov/otaq/stateresources/transconf/policy.htm#models](http://www.epa.gov/otaq/stateresources/transconf/policy.htm#models).

### 2.4.4 Inspection and Maintenance (I/M)

Projects within areas covered by an I/M program should define the program in the MOVES Inspection and Maintenance Importer. Users should first examine the default I/M program description included in MOVES for the particular county in question. The default I/M data can be reviewed by selecting the Export Default Data button in the I/M tab of the Project Data Manager. Users should review the details of the default I/M program and make any necessary changes to match the actual local program that is planned to be in place in the year being analyzed.

For additional guidance on defining an I/M program in MOVES, consult the MOVES Technical Guidance, available online at:

[www.epa.gov/otaq/stateresources/transconf/policy.htm#models](http://www.epa.gov/otaq/stateresources/transconf/policy.htm#models).

### 2.4.5 Link Source Type

The Link Source Type Importer allows users to enter the fraction of the link traffic volume which is represented by each vehicle type (source type). It is not required if the project contains only an off-network link. For each LinkID, the “SourceTypeHourFractions” must sum to one across all source types.

Additionally, the user must ensure that the source types selected in the MOVES Vehicles/Equipment panel match the source types defined through the Link Source Type Importer.

There are no defaults that can be exported from the Link Source Type Importer. For any analysis at the project level, the user must provide source type fractions for all vehicles being modeled. There are two options available to populate the Link Source Type input:

1. For projects that will have an entirely different source type distribution than that of the regional fleet, the preferred option is for the user to collect project-specific data. This data could be based on analysis of similar existing projects.
2. If the project traffic data suggests that the source type distribution for the project can be represented by the distribution of the regional fleet for a given road type, the user can provide a source type distribution consistent with the road type used in the latest regional emissions analysis.

#### *2.4.6 Links*

The Links Importer is used to define the individual roadway links. All links being modeled should have unique IDs. The Links Importer requires information on each link's length (in miles), traffic volume (units of vehicles per hour), average speed (miles per hour), and road grade (percent). Users should follow guidance given in Section 2.1 when determining the number of links and the length of each link.

#### *2.4.7 Retrofit Data*

The Retrofit Importer is used to apply a retrofit program to the fleet. For example, a bus terminal project might include plans to mitigate emissions by retrofitting the bus fleet that will operate at that terminal with control equipment that reduces CO emissions. In that case, the user would specify the details of the retrofit project using the Retrofit Data Importer. The latest guidance on retrofit programs can be located at the EPA's conformity website: [www.epa.gov/otaq/stateresources/transconf/policy.htm](http://www.epa.gov/otaq/stateresources/transconf/policy.htm). Strategies that affect vehicle activity, such as implementing a truck idle reduction plan, should be handled in the Off-Network Importer and Links Importer.

#### *2.4.8 Describing vehicle activity for screening analyses of roadway intersections*

The Links Importer is also where users may describe vehicle activity for intersection links, including the approach/departure free-flow links and queue links.

Consistent with the 1992 Guideline, to produce emission rates for a CO screening analysis of an intersection, users performing such an analysis should calculate emissions

based on average speeds. The average speed defined for each link is internally matched with a MOVES default drive cycle based on that average speed, road grade, and road type and used to calculate emissions. The intersection free-flow links and queue links should be defined as follows:

#### Free-Flow Approach and Departure Links

An average free-flow speed and traffic volume should be defined for each free-flow link that reflects conditions at peak traffic conditions. A variety of methods are available to estimate average free-flow speed. Project sponsors should use the appropriate method based on best practices used for highway analysis in the area for determining congested average speeds.

#### Queue Links

Queue links should be assigned an average speed of zero, indicating entirely idle operation.

#### *2.4.9 Describing vehicle activity for all other screening analyses and refined analyses of any project*

When completing screening analyses of projects not covered by the 1992 Guideline, or any refined analysis, users may use the average speed input or choose to use alternative MOVES activity inputs such as a Link Drive Schedule or Operating Mode Distribution. This section describes these options in more detail, as well as describing how to enter off-network activity into MOVES.

#### Entering Link Activity into MOVES

MOVES determines vehicle emissions based on operating modes, which represent different types of vehicle activity such as acceleration (at different rates), deceleration, idle, and cruise that have distinct emission rates. MOVES handles these data in the form of a distribution of the time vehicles spend in different operating modes. This capability is central to the use of MOVES for CO refined analyses, in particular, because it allows for the analysis of fine distinctions between vehicle behavior and emissions. For example, the full emission benefits of a project designed to smooth traffic flow can best be realized by taking into account the changes in acceleration, deceleration, and idle activity that result from the project.

There are several methods that users may employ to calculate an Op-Mode distribution based on the project design and available traffic information. MOVES currently offers three options that the user can employ to add link activity data, depending on data availability. These are:

1. Provide average speed and road type through the Links input:

Using this approach, MOVES will calculate emissions based on a default drive cycle for a given speed, grade, and road type. Input of link drive schedules or operating mode distributions is not needed. For users modeling a free-flow link with only basic information on average speed and volume on a link, this option may be appropriate. This approach accounts for some differences in emissions due to changes in operating modes associated with different average speeds on a specific road type. However, this approach provides the least resolution when analyzing the emission impact of a project because the default drive cycles used by the model may not accurately reflect the specific project. For instance, due to the range of operating modes associated with intersection projects, a single average speed would not spatially capture localized idling and acceleration emissions.

2. Provide a link drive schedule using the Link Drive Schedule Importer:

The Link Drive Schedule Importer allows the user to define the precise speed and grade as a function of time (seconds) on a particular roadway link. The time domain is entered in units of seconds, the speed variable is miles-per-hour and the grade variable in percent grade (vertical distance/lateral distance, 100% grade equals a 45-degree slope). MOVES builds an Operating Mode Distribution from the Link Drive Schedule and uses it to calculate link running emissions.

Individual Link Drive Schedules cannot be entered for separate source types. The Link Drive Schedule therefore represents the “tracer” path of an average vehicle on each link. Link drive schedules could be based on observations using methods such as chase (floating) cars on similar types of links, or on expected vehicle activity based an analysis of link geometry. Link drive schedules will only represent average vehicle activity, not the full range of activity that will occur on the link. As described in the appendix, users can overcome this limitation by defining multiple links for the same portion of the project (links that “overlap”) with separate source distributions and drive schedules to model individual vehicles.

3. Provide a detailed operating mode distribution for the link:

The Operating Mode Distribution Importer allows the user to directly import operating mode fraction data for source types, hour/day combinations, roadway links, and pollutant/process combinations that are included in the run specification. Operating mode distributions may be obtained from:

- Op-Mode distribution data from other locations with similar geometric and operational (traffic) characteristics;<sup>20</sup> or

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<sup>20</sup> For example, chase (or floating) cars, traffic cameras, and radar guns have been used previously to collect some traffic data for use in intelligent transportation systems and other applications. EPA encourages the development of validated methods for collecting verifiable vehicle operating mode distribution data at specific locations representative of different projects covered by this guidance.

- Output from traffic micro-simulation models.<sup>21</sup>

Users should consider the discussion in this section when deciding on the appropriate activity input, as the MOVES model is capable of using complex and highly resolved activity datasets to calculate link level emissions. EPA encourages the development of validated methods for collecting verifiable vehicle Op-Mode distribution data at locations and in traffic conditions representative of different projects covered by this guidance. However, the user should determine the most robust activity dataset that can be reasonably collected while still achieving the goal of determining an accurate assessment of the CO air quality impacts from a given project. The decision to populate the Links table, Link Drive Schedule, or Op-Mode Distribution should be based on the data available to the user and should reflect the vehicle activity and behavior on each link.

*Note: If either the average speed or link-drive schedule approach is used, it is not necessary to input an Op-Mode distribution for on-road link activity.*

### Entering Off-Network Links

Using the Off-Network Importer is only necessary for project-level CO analyses if the project includes an area where vehicles are parked, starting their engines, or in hotelling mode (such as a truck stop, parking lot, or passenger or freight intermodal terminal). In these cases, the off-network table should be populated and imported.<sup>22</sup>

There are no default values available for any of the off-network inputs, so users will need to populate the Off-Network table with information describing vehicle activity in the off-network area being modeled. The required fields are vehicle population, start fraction, and extended idle fraction:

- The vehicle population reflects the total number of vehicles parked, starting, or hotelling on the off-network area over the course of the hour covered by the MOVES run.
- The start fraction is the fraction of the total vehicle population that starts during the hour.
- The extended idle fraction specifies the fraction of time that the vehicle population spends in hotelling operation in the hour.<sup>23</sup>

Hotelling operation applies only to long-haul combination trucks and is defined as the operation of the truck in “hotelling” mode, typically at overnight rest areas. In order to heat and cool the cab, as well as to run appliances, an added energy load is necessary. This energy is provided either by the engine (extended idle mode), auxiliary power unit

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<sup>21</sup> A traffic micro-simulation model can be used to construct link drive schedules or operating mode distributions if prior validation of the model’s predictions of speed and acceleration patterns for roadway links similar to those in the project was conducted. If a user has a micro-simulation model that has been previously demonstrated to adequately predict speed/acceleration patterns for relevant vehicle classes (e.g., heavy-duty), and has a procedure for importing data into MOVES, it may be appropriate to use the micro-simulation model.

<sup>22</sup> See the MOVES User Guide for more information about using the Off-Network Importer.

<sup>23</sup> Parked fraction is not required as an input and can be left blank.

(APU mode), or truck-stop electrification (essentially modeled as engine-off). Shorter periods of idling for long-haul combination trucks and all idling for other vehicles should be modeled as a project link with an Op-Mode distribution that consists only of idle operation (Op-Mode 1). This can be specified in the Links table by inputting the vehicle population and specifying an average speed of “0” mph.

For vehicle population inputs, the user should be able to rely on existing project documentation. The user will also need to estimate the number of starts and hotelling operation of the facility during the peak hour. For example, in a bus terminal project, the user could estimate the number of starts for the peak hour based on expected passenger ridership and proposed operating schedules for the buses using the terminal.

Information on start and hotelling activity should be specific to the project being modeled. However, data from similar projects could be adapted for use in a CO hot-spot analysis, when appropriate. For instance, the ratio of starts to vehicles for a project being analyzed could be determined by studying a similar parking lot.

If an off-network link is defined, users must also define an Op-Mode distribution that describes the soak-time distribution of vehicles on the link; this will affect the start emissions. Any hotelling operation on an off-network link must be described by the Op-Mode distribution with a fraction of 1.0 for Opmode ID 200 (Extended Idle Mode), 1.0 for Opmode ID 201 (APU use), and/or 1.0 Opmode ID 203 (engine-off/truck stop electrification).

There are no default soak-time distributions available. Soak times and soak-time distributions should be specific to the type of project being modeled. The soak time is the time a vehicle is stationary with the engine turned off, following the last time it was operated. This information could either be directly collected or obtained from information collected for a similar project. For instance, a park-and-ride lot may have vehicles parked for eight or nine hours prior to starting, while an intermodal freight terminal may have vehicles parked for only one hour before starting. This information should be defined through the appropriate distribution of soak-time Op-Modes (OpModeIDs 101-108) in the Op-Mode distribution table.

Additionally, users modeling hotelling activity must also import a hotellingactivitydistribution table through the Hotelling Importer of the Project Data Manager. This input describes, by model year, the amount of hotelling activity in each of four modes: extended idle mode, auxiliary power mode, battery power (electrification), and engine-off. Note that battery power and engine-off both yield zero emissions. Default information is available, but should not be used. Local hotelling activity for a given project will likely be different than the national defaults.

The methods and assumptions used to derive off-network inputs (including starts, hotelling activity, and soak-time distributions) should be documented as part of the analysis, including any adjustments based on data from similar projects.

## 2.5 GENERATING EMISSION RATES FOR USE IN AIR QUALITY MODELING

When run to calculate “Inventory” output (as described in Section 2.3.2), the MOVES model does not explicitly produce the required emission rates. The emission results are calculated by MOVES in terms of absolute grams for each link defined in the “Links” input file. Therefore, the user will need run a MOVES post-processing script to generate the grams/vehicle-mile, grams/vehicle-hour, or other appropriate emission rate. The following sections describe these procedures in more detail for CO screening analyses of intersections as well as other situations.

### 2.5.1 *Screening analyses of roadway intersections*

As noted earlier, according to EPA’s regulatory recommendations for air quality modeling (Section 5.2.3 of Appendix W to 40 CFR Part 51), the CAL3QHC model would be used for CO screening analyses of intersection projects. CAL3QHC calculates air quality estimates based on the defined emission rate, volume of traffic on, and length of a given link in combination with information on signal timing, queue length, and Level-of-Service (LOS). For these analyses, the required information from MOVES is a grams/vehicle-mile emission rate for each free-flow link and a grams/vehicle-hour emission rate for each queue link. After running MOVES, the CO\_CAL3QHC\_EF script can be run on the output database. The script can be accessed through the MOVES post-processing menu. After running the script, a new table will be created in the MOVES output database called “CO\_EmissionFactors” (note: you may need to refresh the MySQL workbench screen to display). The table will contain summary gram/veh-mile rates for running/free-flow links and gram/veh-hour idle rates for queue links. These rates may be used directly in CAL3QHC.

### 2.5.2 *All other screening analyses and refined analyses of any project*

When completing screening analyses of projects not covered by the 1992 Guideline, or any refined analysis, MOVES provides results as either an emission total (if “Inventory” output is selected when developing the RunSpec) or an emission factor (if “Emission Rates” output is selected). The emission results are produced for each pollutant and process and are calculated in terms of grams per link or grams/vehicle-mile per link.

Depending on the application, either grams/veh-hour/link or grams/veh-mile/link emission rates may be necessary. To generate a grams/link/hour emission rate, users may run the CO\_Grams\_Per\_Hour script on a completed output database. The script can be accessed in the post-processing menu of MOVES. After successfully running the script, a new table will be created in the output database called “CO\_Grams\_Per\_Hour.” The emission rates from this table can be used in a refined model such as AERMOD.

To generate a grams/mile/link emission rate, users may run the CO\_Grams\_Per\_Veh\_Mile script on a completed output database. The script can be accessed in the post-processing menu of MOVES. After successfully running the script,

a new table will be created in the output database called “CO\_Grams\_Per\_Veh\_Mile.” The emission rates from this table can be used in a refined model such as CALQHCR.

This concludes the discussion on how to generate project-level CO emission rates using MOVES. Please refer to the 1992 Guideline and Appendix W to 40 CFR Part 51 for further information on how to incorporate MOVES emission rates into air quality modeling.

## **Section 3: Example: Using MOVES for a CO Screening Analysis of an Intersection**

The following is an abbreviated example of using MOVES to calculate CO emission rates for a portion of an intersection project. The example shown is of a single, one-way arterial road through a signalized intersection; while real-world projects would be more complex, this simplified example makes it easier to demonstrate the steps necessary to calculate emission rates using MOVES.

This example does not include the subsequent air quality modeling; project sponsors should refer to the 1992 Guideline for an example of running CAL3QHC for an intersection project using CO emission rates.

Note also that this example includes only an intersection of the type covered by the 1992 Guideline. This example is not relevant for CO refined analyses and may not be relevant for other types of projects. Additionally, all activity will be defined through the average speed function of the Links Importer. It is therefore not necessary to import a Link Drive Schedule, Op-Mode Distribution, or Off-Network table.

The following is some pertinent data about the example project being analyzed:

- The analysis is of a single intersection (see next section for details) located in a county in a state other than California.
- The analysis month and year is January 2015.
- Meteorological data for January at this location is 16.1 degrees Fahrenheit and 80.3% relative humidity.
- All vehicle types are present in the intersection being analyzed; however, no local age distribution is available.
- There is no I/M program for the county where the project is located. This input will not be used.

### **3.1 CHARACTERIZING THE PROJECT IN TERMS OF LINKS (SECTION 2.1)**

A diagram of one road involved in a proposed intersection project is shown in Figure 3. A single free-flow approach link (Link 1) leads to a signalized intersection; vehicles idle at the defined queue link (Link 2), and exit the intersection on the free-flow departure link (Link 3). Vehicle volumes and average speeds are estimated to reflect typical peak hour activity:

Link 1 (Free-flow Approach Link): 1000 vehicles per hour – 45 mph average speed

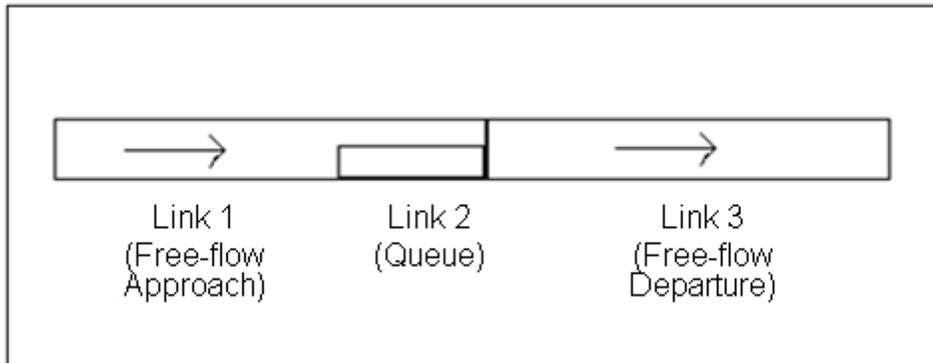
Link 2 (Queue Link): 1000 vehicles per hour – 0 mph speed (idle)

Link 3 (Free-flow Departure Link): 1000 vehicles per hour – 45 mph average speed

All links are at 0% grade. Approach and departure links each have a length of 300 meters. The queue link is assigned a link length of 50 meters.

*Note: Since the goal of the MOVES run is to produce a grams/vehicle-mile and/or grams/vehicle-hour emission rate(s), the exact length or volume of each link is not important for running MOVES, although it is important for subsequent CAL3QHC dispersion modeling.*

**Figure 3. Links Characterizing the Proposed Intersection**



### **3.2 DETERMINING THE NUMBER OF MOVES RUNS (SECTION 2.2)**

This example follows the 1992 Guideline by conservatively using typical peak-hour traffic activity in one MOVES run to generate emission rates.

### **3.3 DETERMINE BASIC RUN SPECIFICATION INPUTS (SECTION 2.3)**

When configuring MOVES for the analysis, a RunSpec is developed following the guidance in Section 2.3:

- From the Scale menu, selecting the “Project” domain; in addition, choosing output in “Inventory” so that total emissions are produced for each link (see Section 2.3.2).
- From the Time Spans Panel, the appropriate year, month, day, and hour is selected (see Section 2.3.3).
- From the Geographic Bounds Panel, the specific county is selected that contains the project (see Section 2.3.4).
- From the Vehicles/Equipment Panel, all vehicle types and fuel types (Gasoline, Diesel, and CNG) are selected (see Section 2.3.5).
- From the Road Types Panel, the Urban Unrestricted road type is selected (see Section 2.3.6).
- From the Pollutants and Processes Panel, the pollutant/processes CO Running and CO Crankcase Running are selected according to the guidance (see Section 2.3.7).

- In the Output Panel, an output database is specified with grams and miles selected as units (see Section 2.3.10). Population and Distance Traveled are selected as Activity outputs. No additional boxes are selected Output Emission Detail (some will be automatically checked).

### 3.4 ENTERING PROJECT DETAILS USING PROJECT DATA MANAGER (SECTION 2.4)

After filling out the appropriate selections in the RunSpec, the project details were entered using the Project Data Manager.

#### 3.4.1 Meteorology

The meteorology table was populated using the second option in Section 2.4.1 with the average January temperature (16.1 degrees Fahrenheit) and relative humidity (80.3%). The meteorology input table is shown in Figure 4.

**Figure 4. Meteorology Input (Average January Conditions) – Intersection**

monthID	zoneID	hourID	temperatur	relHumidity
1	261610	8	16.1	80.3

### 3.4.2 Age Distribution

The default MOVES age distribution for 2015 was used. For the purposes of this example, the latest regional emissions analysis was assumed to have used the default MOBILE6.2 age distribution, and since no local data was available, the MOVES default age distribution was used for the analysis based on Section 2.4.2 of the guidance (shown in Figure 5).

**Figure 5. Fleet Age Distribution (Partial) – Intersection**

sourceTyp	yearD	ageID	ageFraction
11	2015	0	0.071362191
11	2015	1	0.07107502
11	2015	2	0.071146886
11	2015	3	0.070357165
11	2015	4	0.06852054
11	2015	5	0.065452453
11	2015	6	0.064116688
11	2015	7	0.061838426
11	2015	8	0.058893745
11	2015	9	0.054935985
11	2015	10	0.047725317
11	2015	11	0.04225918
11	2015	12	0.037962345
11	2015	13	0.033661184
11	2015	14	0.030885008
11	2015	15	0.028873588
11	2015	16	0.024984025
11	2015	17	0.021668832
11	2015	18	0.015195363
11	2015	19	0.011894789
11	2015	20	0.009375122
11	2015	21	0.007629987
11	2015	22	0.006015678
11	2015	23	0.004322881
11	2015	24	0.00322715
11	2015	25	0.002695276

### 3.4.3 Fuels

As recommended in Section 2.4.3 of this guidance, the default MOVES fuel information was used for the analysis (Figures 6, 7, 8, and 9).

**Figure 6. Fuel Supply Table – Intersection**

fuelRegionID	fuelYearID	monthGroup	fuelFormul	marketShare	marketShareCV
270000000	2015	1	3213	0.962069	0.5
270000000	2015	1	3215	0.037931	0.5
270000000	2015	1	25005	1	0.5
270000000	2015	1	27001	1	0.5
270000000	2015	1	28001	1	0.5

**Figure 7. Fuel Formulation Table – Intersection**

fuelFormul	fuelSubtyp	RVP	sulfurLevel	ETOHVolu	MTBEVolu	ETBEVolu	TAMEVolu	aromaticC	olefinConte	benzeneC	e200	e300
10	10	6.9	30	0	0	0	0	26.1	5.6	1	41.09	83.09
20	20	0	11	0	0	0	0	0	0	0	0	0
30	30	0	7.6	0	0	0	0	0	0	0	0	0
50	51	7.7	11	85	0	0	0	0	0	0	49.9	89.5
96	10	8.7	338	0	0	0	0	26.4	11.9	1.64	50	83
97	10	6.6	150	0	11.7581	0	0	24	11	0.8	52	84
98	10	6.9	30	0	0	0	0	26.1	5.6	1	41.09	83.09
99	10	6.9	90	0	0	0	0	26.1	5.6	1	41.09	83.09
3213	12	12.9	30	10	0	0	0	20.3	6.17	0.63	57.36	85.11
3215	15	11.9	30	15	0	0	0	18.26	4.97	0.63	63.59	85.58
25005	21	0	15	0	0	0	0	0	0	0	0	0
27001	51	10.5	8	74	0	0	0	0	0	0	49.9	89.5
28001	30	0	7.6	0	0	0	0	0	0	0	0	0

**Figure 8. Fuel Usage Fraction -- Intersection**

countyID	fuelYearID	modelYear	sourceBin	fuelSupply	usageFraction
26161	2015	0	1	1	1
26161	2015	0	2	2	1
26161	2015	0	3	3	1
26161	2015	0	5	1	0.986574
26161	2015	0	5	5	0.013426

**Figure 9. Alternative Vehicle and Fuel Technology (Partial) -- Intersection**

sourceTyp	modelYear	fuelTypeID	engTechID	fuelEngFraction
11	1960	1	1	1
11	1961	1	1	1
11	1962	1	1	1
11	1963	1	1	1
11	1964	1	1	1
11	1965	1	1	1
11	1966	1	1	1
11	1967	1	1	1
11	1968	1	1	1
11	1969	1	1	1
11	1970	1	1	1
11	1971	1	1	1
11	1972	1	1	1
11	1973	1	1	1
11	1974	1	1	1
11	1975	1	1	1
11	1976	1	1	1
11	1977	1	1	1
11	1978	1	1	1
11	1979	1	1	1
11	1980	1	1	1
11	1981	1	1	1
11	1982	1	1	1
11	1983	1	1	1
11	1984	1	1	1
11	1985	1	1	1

### 3.4.4 Inspection and Maintenance (I/M)

The county being modeled does not have an I/M program. The MOVES Inspection and Maintenance Importer will not be used in this example.

### 3.4.5 Link Source Type

The distribution of source types was defined based on the distribution of vehicles on arterial roads used in the latest regional emissions analysis (see Figure 10). The distribution used was identical for all links.

**Figure 10. Link Source Type Input Table (Partial) -- Intersection**

linkID	sourceTyp	sourceTypeHourFraction
1	11	0.007765201
1	21	0.705029711
1	31	0.229256275
1	32	0.027446469
1	41	0.000386647
1	42	0.00022614
1	43	0.002651314
1	51	0.000322048
1	52	0.016833872
1	53	0.001936932
1	54	0.003817565
1	61	0.004327825
1	62	0.004904574
2	11	0.007765201
2	21	0.705029711
2	31	0.229256275
2	32	0.027446469
2	41	0.000386647
2	42	0.00022614
2	43	0.002651314
2	51	0.000322048
2	52	0.016833872
2	53	0.001936932
2	54	0.003817565
2	61	0.004327825
2	62	0.004904574

### 3.4.6 Links

The Links table was populated with the parameters of each link (shown in Figure 11). Links 1 and 3 (free-flow approach and departure links) were assigned a link length of 300 meters (0.1875 miles), a link volume of 1000, and an average speed of 45 mph. Link 2 was assigned a link length of 50 meters (0.016 miles), a link volume of 1000, and an average speed of 0 mph. Since no Op-Mode distribution or Link-Drive Schedule is defined for any of the links, MOVES will calculate emission based on average speed, road type, and grade.

**Figure 11. Links Table – Intersection**

linkID	countyID	zoneID	roadTypeID	linkLength	linkVolume	linkAvgSpe	linkDescription	linkAvgGrade
1	26161	261610	5	0.25	1000	45	Approach Link	0
2	26161	261610	5	1.200	1000	25	Queue Link	0
3	26161	261610	5	0.25	1000	45	Departure Link	0

## 3.5 GENERATING EMISSION RATES FOR USE IN AIR QUALITY MODELING (SECTION 2.5)

After running MOVES, the MOVES CO\_CAL3QHC\_EF post-processing script is run. The resulting emission rates (shown in bold in Figure 12) are 2.935 grams/vehicle-mile for the free-flow approach and departure links (Links 1 and 3) and 18.752 grams/vehicle-hour for vehicles idling on the queue link (Link 2). These rates can be now be used in CAL3QHC to complete this CO screening analysis.

**Figure 12. Emission Rate Calculations for Each Link – Intersection**

movesRur	yearId	monthId	dayId	hourId	linkId	pollutant	GramsPer	GramsPerVehHour
1	2015	1	5	8	1	CO	<b>2.934844</b>	
1	2015	1	5	8	2	CO		<b>18.75164577</b>
1	2015	1	5	8	3	CO	<b>2.934844</b>	

## **Section 4: Example: Using MOVES to Calculate Start and Idle Emission Factors for a Transit Facility**

The following is an abbreviated example of using MOVES to calculate CO emission rates for the start and idle activity (gram/vehicle-start and gram/vehicle-hour, respectively) for passenger vehicles associated with a park-and-ride lot serving a transit bus facility. Although this example is for the peak (or worst-case) hour, the methodology described for calculating start and idle emission factors could apply to both screening and refined analyses. For illustrative purposes, the passenger vehicles are assumed to be entirely gasoline passenger cars (source type 21). Additionally, only start and idle emissions are considered in this example. A more realistic scenario would, of course, also include emissions associated with the transit buses entering and exiting the facility (in addition to the emissions from the passenger vehicles). Users should refer to Section 2 of the guidance, as well as the intersection example in Section 3, for information on how activity on free-flow and queue links would be defined for such a park-and-ride lot and transit terminal.

Although a real-world project would likely be more complex, this simplified example makes it easier to demonstrate the steps necessary to calculate emission rates using MOVES.

The following is some pertinent data about the example project being analyzed:

- The analysis is of a park-and-ride lot serving a transit bus facility (see next section for details) located in a county in a state other than California.
- The analysis month and year is January 2015.
- Meteorological data for January at this location is 25 degrees Fahrenheit and 70% relative humidity.
- An age distribution for passenger cars is available from the latest regional conformity analysis.
- Project engineers have estimated soak times for the cars that will use the lot based on an analysis of similar facilities (see next section for details).
- There is no I/M program active in the county where the project is located.

### **4.1 CHARACTERIZING THE PROJECT IN TERMS OF LINKS (SECTION 2.1)**

In order to calculate both a start emission factor and idle emission factor for passenger cars, two links are defined. A single idle link (Link 1) is defined to represent idling passenger cars. The start emission activity from the vehicles is defined through an off-network link (Link 2). The following traffic data is available for the peak hour of activity:

Link 1 (Idle Link): 50 passenger cars idling – 0 mph average speed (idle)

Link 2 (Off-network Link): 100 starts during the peak hour

The lengths of the idle link and off-network link are set to 0 (as link length does not matter). Also, both links have a 0% grade.

Passenger cars are estimated to have been “soaking” for greater than 720 minutes before starting; that is, it has been more than 720 minutes since the cars have last started.

*Note: Since the goal of the MOVES run is to produce a grams/idle-hour and grams/vehicle-start emission rate, the exact volume of each link is not important for running MOVES.*

## **4.2 DETERMINING THE NUMBER OF MOVES RUNS (SECTION 2.2)**

Since this is a screening analysis, this example uses peak-hour vehicle activity in one MOVES run to generate “worst-case” emission rates.

## **4.3 DETERMINE BASIC RUN SPECIFICATION INPUTS (SECTION 2.3)**

When configuring MOVES for the analysis, a RunSpec is developed following the guidance in Section 2.3:

- From the Scale menu, selecting the “Project” domain; in addition, choosing output in “Inventory” so that total emissions are produced for each link (see Section 2.3.2).
- From the Time Spans Panel, the appropriate year, month, day, and hour are selected (see Section 2.3.3).
- From the Geographic Bounds Panel, the specific county is selected that contains the project (see Section 2.3.4).
- From the Vehicles/Equipment Panel, the Gasoline Passenger Car source type (sourceType 21) is selected (see Section 2.3.5).
- From the Road Types Panel, the Off-Network and Urban Unrestricted road types are selected (see Section 2.3.6).
- From the Pollutants and Processes Panel, the pollutant/processes CO Starts, CO Crankcase Starts, CO Running, and CO Crankcase Running are selected according to the guidance (see Section 2.3.7).
- In the Output Panel, an output database is specified with grams and miles selected as units (see Section 2.3.10). Population is selected as an Activity output. No additional boxes are selected Output Emission Detail (some will be automatically checked).

#### 4.4 ENTERING PROJECT DETAILS USING PROJECT DATA MANAGER (SECTION 2.4)

After filling out the appropriate selections in the RunSpec, the project details were entered using the Project Data Manager.

##### 4.4.1 Meteorology

The meteorology table was populated using the second option in Section 2.4.1 with the average January temperature (25 degrees Fahrenheit) and relative humidity (70%). The meteorology input table is shown in Figure 13.

**Figure 13. Meteorology Input (Average January Conditions) – Terminal**

monthID	zoneID	hourID	temperatur	relHumidity
1	261610	8	25	70

#### 4.4.2 Age Distribution

An age distribution table was used that reflects the passenger car fleet accessing the park-and-ride lot (see Figure 14). In this example, the age distribution used is based on the latest regional SIP, as discussed in Section 2.4.2 of the guidance.

**Figure 14. Fleet Age Distribution (Partial) – Terminal**

sourceTyp	yearD	ageID	ageFraction
21	2015	0	0.133990
21	2015	1	0.145950
21	2015	2	0.114040
21	2015	3	0.093500
21	2015	4	0.066700
21	2015	5	0.051590
21	2015	6	0.049480
21	2015	7	0.043290
21	2015	8	0.033510
21	2015	9	0.031090
21	2015	10	0.018740
21	2015	11	0.012660
21	2015	12	0.013140
21	2015	13	0.012240
21	2015	14	0.012450
21	2015	15	0.010690
21	2015	16	0.020260
21	2015	17	0.015660
21	2015	18	0.012790
21	2015	19	0.014070
21	2015	20	0.017810
21	2015	21	0.011510
21	2015	22	0.011170
21	2015	23	0.009270
21	2015	24	0.007693
21	2015	25	0.006385

#### 4.4.3 Fuels

As recommended in Section 2.4.3 of this guidance, the default MOVES fuel information was used for the analysis (Figures 15, 16, 17, and 18). However, the AVFT table was changed to model an entirely gasoline fleet (fractions of 1.0 for all gasoline passenger cars).

**Figure 15. Fuel Supply Table -- Intersection**

fuelRegionID	fuelYearID	monthGroup	fuelFormul	marketShare	marketShareCV
270000000	2015	1	3213	0.962069	0.5
270000000	2015	1	3215	0.037931	0.5
270000000	2015	1	25005	1	0.5
270000000	2015	1	27001	1	0.5
270000000	2015	1	28001	1	0.5

**Figure 16. Fuel Formulation Table -- Intersection**

fuelFormul	fuelSubtyp	RVP	sulfurLevel	ETOHVolu	MTBEVolu	ETBEVolu	TAMEVolu	aromaticC	olefinConte	benzeneC	e200	e300
10	10	6.9	30	0	0	0	0	26.1	5.6	1	41.09	83.09
20	20	0	11	0	0	0	0	0	0	0	0	0
30	30	0	7.6	0	0	0	0	0	0	0	0	0
50	51	7.7	11	85	0	0	0	0	0	0	49.9	89.5
96	10	8.7	338	0	0	0	0	26.4	11.9	1.64	50	83
97	10	6.6	150	0	11.7581	0	0	24	11	0.8	52	84
98	10	6.9	30	0	0	0	0	26.1	5.6	1	41.09	83.09
99	10	6.9	90	0	0	0	0	26.1	5.6	1	41.09	83.09
3213	12	12.9	30	10	0	0	0	20.3	6.17	0.63	57.36	85.11
3215	15	11.9	30	15	0	0	0	18.26	4.97	0.63	63.59	85.58
25005	21	0	15	0	0	0	0	0	0	0	0	0
27001	51	10.5	8	74	0	0	0	0	0	0	49.9	89.5
28001	30	0	7.6	0	0	0	0	0	0	0	0	0

**Figure 17. Fuel Usage Fraction -- Intersection**

countyID	fuelYearID	modelYear	sourceBin	fuelSupply	usageFraction
26161	2015	0	1	1	1
26161	2015	0	2	2	1
26161	2015	0	3	3	1
26161	2015	0	5	1	0.986574
26161	2015	0	5	5	0.013426

**Figure 18. Alternative Vehicle and Fuel Technology (Partial) -- Intersection**

sourceTyp	modelYear	fuelTypeID	engTechID	fuelEngFraction
21	1960	1	1	1
21	1961	1	1	1
21	1962	1	1	1
21	1963	1	1	1
21	1964	1	1	1
21	1965	1	1	1
21	1966	1	1	1
21	1967	1	1	1
21	1968	1	1	1
21	1969	1	1	1
21	1970	1	1	1
21	1971	1	1	1
21	1972	1	1	1
21	1973	1	1	1
21	1974	1	1	1
21	1975	1	1	1
21	1976	1	1	1
21	1977	1	1	1
21	1978	1	1	1
21	1979	1	1	1
21	1980	1	1	1
21	1981	1	1	1
21	1982	1	1	1
21	1983	1	1	1
21	1984	1	1	1
21	1985	1	1	1

#### 4.4.4 Inspection and Maintenance (I/M)

It was not necessary to input an I/M program since there was no program in the county containing the project.

#### 4.4.5 Link Source Type

A source type distribution was defined for the idle link. All activity is from passenger cars (sourceType 21 - see Figure 19). It is unnecessary to include the source type distribution for the starting vehicles on the Off-Network link (Link 2); this will be defined in the Off-Network Table (see Section 4.4.7).

**Figure 19. Link Source Type Input Table -- Terminal**

linkID	sourceTyp	sourceTypeHourFraction
1	21	1

#### 4.4.6 Links

The Links table was populated with the parameters of each link (shown in Figure 20). To reflect the previously described peak hour activity, Link 1 (idle link) was assigned a link length of 0 miles, a link volume of 50, and an average speed of 0 mph. Link 2 (off-network link) was assigned a link length of 0 miles, a link volume of 100, and an average speed of 0 mph.

**Figure 20. Links Table – Terminal**

linkID	countyID	zoneID	roadTypeID	linkLength	linkVolume	linkAvgSpeed	linkDescription	linkAvgGrade
1	26161	261610	5	0	50	0	Idle Link	0
2	26161	261610	1	0	100	0	Off-network Link (starts)	0

#### 4.4.7 Off-Network and Op-Mode Distribution

Information on start activity is defined through both the Off-Network and Op-Mode Distribution tables. First, the source type and link volume are defined in the Off-Network Table (Figure 21) with a start fraction of 1 (indicating that all 100 vehicles are starting during the hour). The extended idle fraction and parked vehicle fraction are set to 0.<sup>24</sup>

**Figure 21. Off-Network Table**

zoneID	sourceTypeID	vehiclePopulation	startFraction	extendedIdleFraction	parkedVehicleFraction
261610	21	100	1	0	0

<sup>24</sup> Note: the “Extended Idle Fraction” field is only relevant for Long-Haul Combination Diesel Trucks. See Section the MOVES User Guide for more information.

The soak distribution (the time spent parked before starting) is defined in the Op-Mode Distribution Table. As noted in Section 4.1, for this specific project, all passenger cars have been parked for greater than 720 minutes prior to starting. As shown in Figure 22, the OpModeID corresponding to this soak time is OpModeID108. Start emissions for CO come from both the start exhaust process (polProcess 202), as well as the crankcase start process (polProcess 216). A fraction of 1 for OpModeID 108 is defined for each pollutant process.

**Figure 22. Op-Mode Distribution Table – Terminal**

sourceTyp	hourDayID	linkID	polProcess	opModeID	opModeFraction
21	85	2	202	108	1
21	85	2	216	108	1

#### 4.5 GENERATING EMISSION RATES FOR USE IN AIR QUALITY MODELING (SECTION 2.5)

After running MOVES, the post-processing script “CO\_Grams\_Per\_Hour” was run on the output database. The resulting emission rates (shown in Figure 23) are used in air quality modeling.

**Figure 23. Emission Rates for Each Link – Terminal**

movesRun	yearId	monthId	hourId	linkId	pollutant	gramsPerHour
1	2015	1	8	1	Total CO	623.8187256
1	2015	1	8	2	Total CO	4709.929199

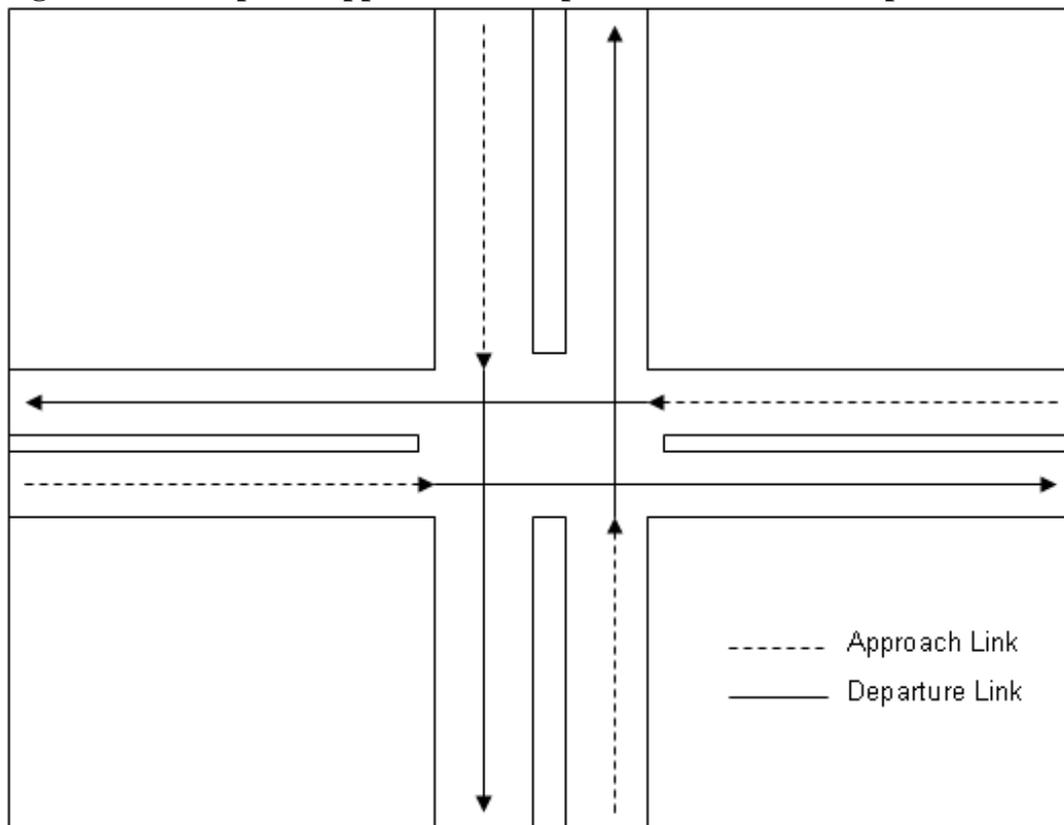
# Appendix A: Characterizing Intersection Projects for CO Refined Analyses Using MOVES

## A.1 INTRODUCTION

This appendix expands upon the discussion in Section 2.1 on how best to characterize links when modeling an intersection project using MOVES. The MOVES emissions model allows users to represent intersection traffic activity with a higher degree of sophistication compared to previous models. This appendix provides several options to describe vehicle activity to take advantage of the capabilities MOVES offers to complete modeling for CO refined analyses of intersection projects.

Figure 24 is an example of a simple signalized intersection showing the links developed by a project sponsor to represent the two general categories of vehicle activity expected to take place at this intersection (approaching the intersection and departing the intersection).

**Figure 24. Example of Approach and Departure Links for a Simple Intersection**



When modeling an intersection, each approach link or departure link can be modeled as one or more links in MOVES depending on the option chosen to enter traffic activity.

This guidance suggests three possible options for characterizing activity on each approach and departure link when CO refined analyses are completed (such as those shown in Figure 24):

- Option 1: Using average speeds
- Option 2: Using link drive schedules
- Option 3: Using Op-Mode distributions

While Option 1 may need to be relied upon more during the initial transition to using MOVES, as more detailed data are available to describe vehicle activity, users are encouraged to consider using the Options 2 and 3 to take full advantage of the capabilities of MOVES.

Once a decision has been made on how to characterize links, users should continue to develop the remaining MOVES inputs as discussed in Section 2.4 of the guidance.

## **A.2 OPTION 1: USING AVERAGE SPEEDS**

The first option is for the user to estimate the average speeds for each link in the intersection based on travel time and distance. Travel time should account for the total delay attributable to traffic signal operation, including the portion of travel when the light is green and the portion of travel when the light is red. The effect of a traffic signal cycle on travel time includes deceleration delay, move-up time in a queue, stopped delay, and acceleration delay. Using the intersection example given in Figure 24, each approach link would be modeled as one link to reflect the higher emissions associated with vehicle idling through lower speeds affected by stopped delay; each departure link would be modeled as one link to reflect the higher emissions associated with vehicle acceleration through lower speeds affected by acceleration delay.

A variety of methods are available to estimate average speed. Project sponsors determine congested speeds by using appropriate methods based on best practices for highway analyses. Some resources are available through FHWA's Travel Model Improvement Program (TMIP).<sup>25</sup> Methodologies for computing intersection control delay are provided in the Highway Capacity Manual.<sup>26</sup>

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<sup>25</sup> See FHWA's TMIP website: <http://tmip.fhwa.dot.gov/>.

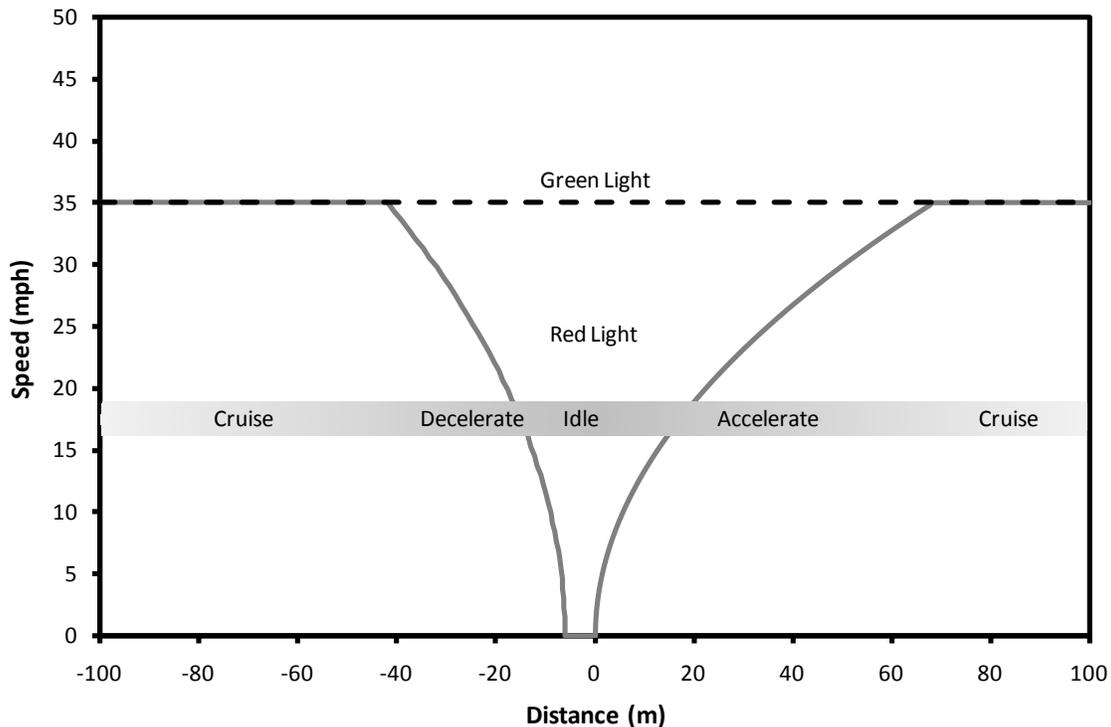
<sup>26</sup> Users should consult the most recent version of the Highway Capacity Manual. As of the release of this guidance, the latest version is the "Highway Capacity Manual 2010," which can be obtained from the Transportation Research Board (see <http://hcm.trb.org/?qr=1> for details).

### A.3 OPTION 2: USING LINK DRIVE SCHEDULES

A more refined approach is to enter vehicle activity into MOVES as a series of link drive schedules to represent individual segments of cruise, deceleration, idle, and acceleration of a congested intersection. A link drive schedule defines a speed trajectory to represent the entire vehicle fleet via second-by-second changes in speed and highway grade. Unique link drive schedules can be defined to describe types of vehicle activity that have distinct emission rates, including cruise, deceleration, idle, and acceleration.

Figure 25 illustrates why using this more refined approach can result in a more detailed emissions analysis. This figure shows the simple trajectory of a single vehicle approaching an intersection during the red signal phase of a traffic light cycle. This trajectory is characterized by several distinct phases (a steady cruise speed, decelerating to a stop for the red light, idling during the red signal phase, and accelerating when the light turns green). In contrast, the trajectory of a single vehicle approaching an intersection during the green signal phase of a traffic light cycle is characterized by a more or less steady cruise speed through the intersection.

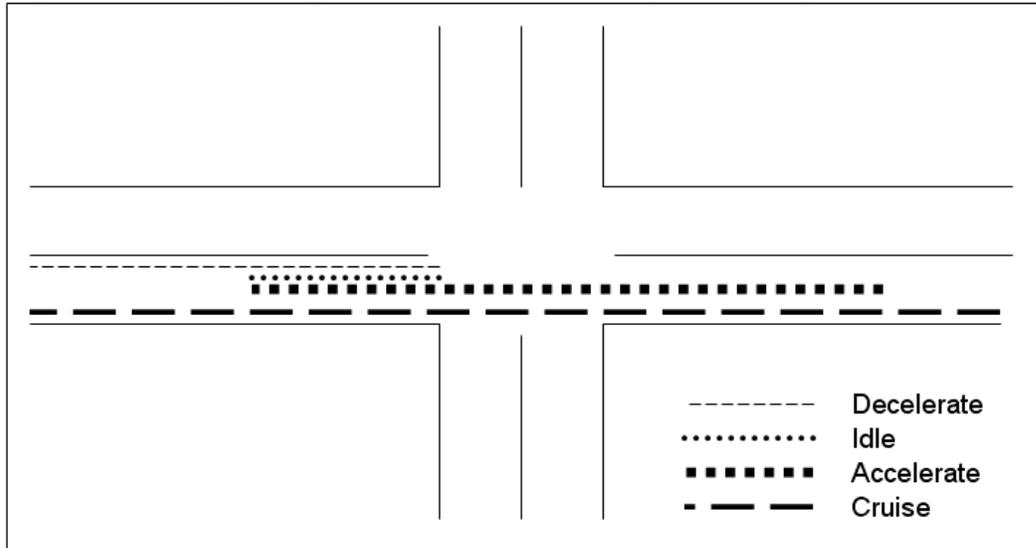
**Figure 25. Example Single Vehicle Speed Trajectory Through a Signalized Intersection**



For the example intersection in Figure 24, link drive schedules representing the different operating modes of vehicle activity on the approach and departure links can be determined. For approach links, the length of a vehicle queue is dependent on the number of vehicles subject to stopping at a red signal. Vehicles approaching a red traffic

signal decelerate over a distance extending from the intersection stop line back to the stopping distance required for the last vehicle in the queue. The average stopping distance can be calculated from the average deceleration rate and the average cruise speed. Similarly, for the departure links, vehicles departing a queue when the light turns green accelerate over a distance extending from the end of the vehicle queue to the distance required for the first vehicle to reach the cruise speed, given the rate of acceleration and cruise speed. Figure 26 provides an illustration of how the different vehicle operating modes may be apportioned spatially near this signalized intersection.

**Figure 26. Example Segments of Vehicle Activity Near a Signalized Intersection**



There are other considerations with numerous vehicles stopping and starting at an intersection over many signal cycles during an hour. For instance, heavy trucks decelerate and accelerate at slower rates than passenger cars. Drivers tend not to decelerate at a constant rate, but through a combination of coasting and light and heavy braking. And acceleration rates are initially higher when starting from a complete stop at an intersection, becoming progressively lower to make a smooth transition to cruise speed.

In the case of an uncongested intersection, the rates of vehicles approaching and departing the intersection are in equilibrium. Some vehicles may slow, and then speed up to join the dissipating queue without having to come to a full stop. Once the queue clears, approaching vehicles during the remainder of the green phase of the cycle will cruise through the intersection virtually unimpeded.

In the case of a congested intersection, the rate of vehicles approaching the intersection is greater than the rate of departure, with the result that no vehicle can travel through without stopping; vehicles approaching the traffic signal, whether it is red or green, will have to come to a full stop and idle for one or more cycles before departing the

intersection. The latest Highway Capacity Manual is a good source of information for vehicle operation through signalized intersections.

The emission factors obtained from MOVES for each segment of vehicle activity obtained via individual link drive schedules are readily transferable to air quality models.

*Note: For both free-flow highway and intersection links, users may directly enter output from traffic simulation models in the form of second-by-second individual vehicle trajectories. These vehicle trajectories for each road segment can be input into MOVES using the Link Drive Schedule Importer and defined as unique LinkIDs. There are no limits in MOVES as to how many links can be defined; however, model run times increase as the user defines more links. A representative sampling of vehicles can be used to model higher volume segments by adjusting the resulting sum of emissions to account for the higher traffic volume. For example, if a sampling of 5,000 vehicles (5,000 links) was used to represent the driving patterns of 150,000 vehicles over an hour, then the sum of emissions would be adjusted by a factor of 30 to account for the higher traffic volume (i.e., 150,000 vehicles/5,000 vehicles). Since the vehicle trajectories include idling, acceleration, deceleration, and cruise, separate roadway links do not have to be explicitly defined to show changes in driving patterns. The sum of emissions from each vehicle trajectory (LinkID) adjusted to represent the full vehicle count over an hour represents the total emission contribution of a given road segment.*

#### **A.4 OPTION 3: USING OP-MODE DISTRIBUTIONS**

A third option is for a user to generate representative Op-Mode distributions for approach and departure links by calculating the fraction of fleet travel times spent in each mode of operation. For any given signalized intersection, vehicles are cruising, decelerating, idling, and accelerating. Op-Mode distributions can be calculated from the ratios of individual mode travel times to total travel times on approach links and departure links. This type of information could be obtained from Op-Mode distribution data from (1) existing intersections with similar geometric and operational (traffic) characteristics, or (2) output from traffic simulation models for the proposed project or similar projects.

The following methodology describes a series of equations to assist in calculating vehicle travel times on approach and departure links. Note that a single approach and single departure link should be defined to characterize vehicles approaching, idling at, and departing an intersection (e.g., there is no need for an “idling link,” as vehicle idling is captured as part of the approach link).

#### A.4.1 Approach links

When modeling each approach link, the fraction of fleet travel times in seconds (s) in each mode of operation should be determined based on the fraction of time spent cruising, decelerating, accelerating, and idling:

$$\text{Total Fleet Travel Time (s)} = \text{Cruise Time} + \text{Decel Time} + \text{Accel Time} + \text{Idle Time}$$

The cruise travel time can be represented by the number of vehicles cruising multiplied by the length of approach divided by the average cruise speed.

$$\text{Cruise Time (s)} = \text{Number of Cruising Vehicles} * (\text{Length of Approach (mi)} \div \text{Average Cruise Speed (mi/hr)}) * 3600 \text{ s/hr}$$

The deceleration travel time can be represented by the number of vehicles decelerating multiplied by the average cruise speed divided by the average deceleration rate:

$$\text{Decel Time (s)} = \text{Number of Decelerating Vehicles} * (\text{Average Cruise Speed (mi/hr)} \div \text{Average Decel Rate (mi/hr/s)})$$

The acceleration travel time occurring on an approach link can be similarly represented. However, to avoid double counting acceleration activity that occurs on the departure link, users should multiply the acceleration time by the proportion of acceleration that occurs on the approach link (Accel Length Fraction on Approach):

$$\text{Accel Time (s)} = \text{Number of Accelerating Vehicles} * (\text{Average Cruise Speed (mi/hr)} \div \text{Average Accel Rate (mi/hr/s)}) * \text{Accel Length Fraction on Approach}$$

The idle travel time can be represented by the number of vehicles idling multiplied by the average stopped delay (average time spent stopped at an intersection):

$$\text{Idle Time (s)} = \text{Number of Idling Vehicles} * \text{Average Stopped Delay (s)}$$

Control delay (total delay caused by an intersection) may be used in lieu of average stopped delay, but control delay includes decelerating and accelerating travel times, which should be subtracted out (leaving only idle time).

After calculating the fraction of time spent in each mode of approach activity, users should select the appropriate MOVES Op-Mode corresponding to each particular type of activity (see Section 2.4.8 for more information). The operating modes in MOVES typifying approach links include:

- Cruise/acceleration (OpModeID 11-16, 22-25, 27-30, 33, 35, 37-40);
- Low and moderate speed coasting (OpModeID 11, 21); and
- Idling (OpModeID 1)

The relative fleet travel time fractions can be allocated to the appropriate Op-Modes in MOVES. The resulting single Op-Mode distribution accounts for relative times spent in the different driving modes (cruise, deceleration, acceleration, and idle) for the approach link.

#### A.4.2 *Departure links*

When modeling each departure link, the fraction of fleet travel times spent in each mode of operation should be determined based on the fraction of time spent cruising and accelerating:

$$\text{Total Fleet Travel Time (s)} = \text{Cruise Time} + \text{Accel Time}$$

The cruise travel time can be represented by the number of vehicles cruising multiplied by the travel distance divided by the average cruise speed:

$$\text{Cruise Time (s)} = \text{Number of Cruising Vehicles} * (\text{Length of Departure (mi)}) / (\text{Average Cruise Speed (mi/hr)} * 3600 \text{ s/hr})$$

The acceleration travel time occurring during the departure link can be represented by the number of vehicles accelerating multiplied by the average cruise speed divided by the average acceleration rate. However, to avoid double counting acceleration activity that occurs on the approach link, users should multiply the resulting acceleration time by the proportion of acceleration that occurs on the departure link (Accel Length Fraction on Departure):

$$\text{Accel Time (s)} = \text{Number of Accelerating Vehicles} * (\text{Average Cruise Speed (mi/hr)} \div \text{Average Accel Rate (mi/hr/s)}) * \text{Accel Length Fraction on Departure}$$

After calculating fraction of time spent in each mode of departure activity, users should select the appropriate MOVES Op-Mode corresponding to each particular type of activity (see Section 2.4.8 for more information). The operating modes typifying departure links include:

- Cruise/acceleration (OpModeID 11-16, 22-25, 27-30, 33, 35, 37-40)

The relative fleet travel time fractions can be allocated to the appropriate Op-Modes. The resulting single Op-Mode distribution accounts for relative times spent in the different driving modes (cruise and acceleration) for the departure link.