# CAL-CET2018 Technical Support Document

Technical Memorandum
November 16, 2018



## 1. Introduction

This technical support document for Caltrans Construction Emissions Tool (CAL-CET2018) includes technical terminology that may be unfamiliar to the user. The terminology is related to construction project emissions assessments. A glossary of terms is provided at the end of this document, and it is recommended that the tool user review the glossary before reading the rest of the document to understand technical details of CAL-CET2018.

Construction equipment usage at transportation projects is a source of both fine ($PM_{2.5}$) and coarse ($PM_{10}$) particulate matters. It is also a source of oxides of nitrogen ($NO_x$), which contributes to the formation of $PM_{2.5}$ and ozone in the atmosphere, and other pollutants such as carbon dioxide ($CO_2$). Air districts and other regulatory agencies have shown growing interest in evaluating transportation-related construction emissions to support transportation and air quality planning. The Caltrans construction emissions tool (CAL-CET) was developed to help Caltrans analysts improve the calculation of construction-related emissions. In summary, CAL-CET requires user input on project characteristics (e.g., project length, working days, type, and construction cost[1]), and the user can override default values in any of the optional input fields. From this starting point, the tool performs the following functions.

- Calculates equipment-related costs for the project based on construction cost allocation assumptions for each of seven project types;
- Calculates total equipment activity (i.e., hours of operation) by applying a usage rate in units of hours per $100,000 of equipment costs;
- Allocates total equipment hours for the project to operational phases and equipment types; and
- Estimates emissions for each phase by applying emission rates (e.g., grams of $NO_x$ per horsepower-hour of operation) to equipment activity estimates.

CAL-CET estimates exhaust emissions of total organic gases (TOG), reactive organic gases (ROG), carbon monoxide (CO), $NO_x$, $PM_{10}$, $PM_{2.5}$, $CO_2$, methane ($CH_4$), nitrous oxide ($N_2O$), and black carbon (BC) from off-road equipment and on-road vehicles. It also estimates hydrofluorocarbon (HFC) AC

[1] This construction cost estimate should include only roadway and structural construction costs. Mobilization, contingency, and right-of-way acquisition costs should not be included.

system leakage emissions from on-road vehicles, PM emissions from area-wide fugitive dust, and evaporative emissions from painting and asphalt concrete paving.

This document provides detailed information on the underlying methods and data that CAL-CET2018 Version 1.0 relies upon to (1) estimate project-level equipment activity; and (2) calculate emissions resulting from that activity. Note that instructions for applying CAL-CET to project-level assessments are included in a user's guide that is embedded in the tool itself.

# 2. Equipment Activity Estimates

## Background

In 2002, a UC Davis-Caltrans Air Quality Project research team began work on a construction emission estimation tool specifically designed for Caltrans highway projects. This work, which eventually laid the foundation for the development of CAL-CET, initially derived equipment activity estimates from unit rates that associated equipment hours with material quantities (e.g., cubic yards of material moved) for eight primary operational phases of a construction project. Equipment activity hours used to develop the unit rates for each operational phase were derived from actual field inspectors' diaries for 30 projects selected as representative of the types of Caltrans projects under construction between 2000 and 2005 (Kable, 2006). Corresponding material quantities for each phase were assembled from a larger data set of 7,768 Caltrans project bids that Caltrans Headquarters, Division of Engineering Services, had compiled for their materials testing workload estimation models (Niemeier et al., 2012). Preliminary testing and consultation with Caltrans Headquarters, Division of Construction (Construction), indicated that this approach underestimated total equipment hours for small projects compared to estimates developed by Construction from projected daily production rates[2].

After further consultation with Construction, CAL-CET was updated using Construction's engineering economic analysis rather than material quantities to estimate equipment activity, incorporating statewide data on equipment rental costs and usage rates. This approach is consistent with Caltrans' construction payment methods, which treat costs for equipment rental as a component of construction costs. The cost-based method would account for all work activities, including minor work items, allowing CAL-CET to estimate the expected population of equipment and the number of hours that the equipment will be present on the job site.

Another key enhancement to CAL-CET was the application of established construction field operation practices to estimate the proportion of time that specific types of equipment are not in operation and producing no emissions for various operational phases. Equipment may be on the job site and rented to the project, yet not in continuous use and, therefore, not emitting pollutants at all times. Typical construction field operation practices involve a combination of human labor and equipment

[2] Amount of work and construction materials expended per day (e.g., linear feet of drainage pipe installed per working day).

usage, whereby equipment would be off or idle during periods when the labor force is completing preparation steps or other aspects of the operation that do not require equipment usage.

Figure 1 summarizes the step-by-step process used by CAL-CET to estimate and allocate equipment activity, as well as the input parameters required to complete each step in the process.

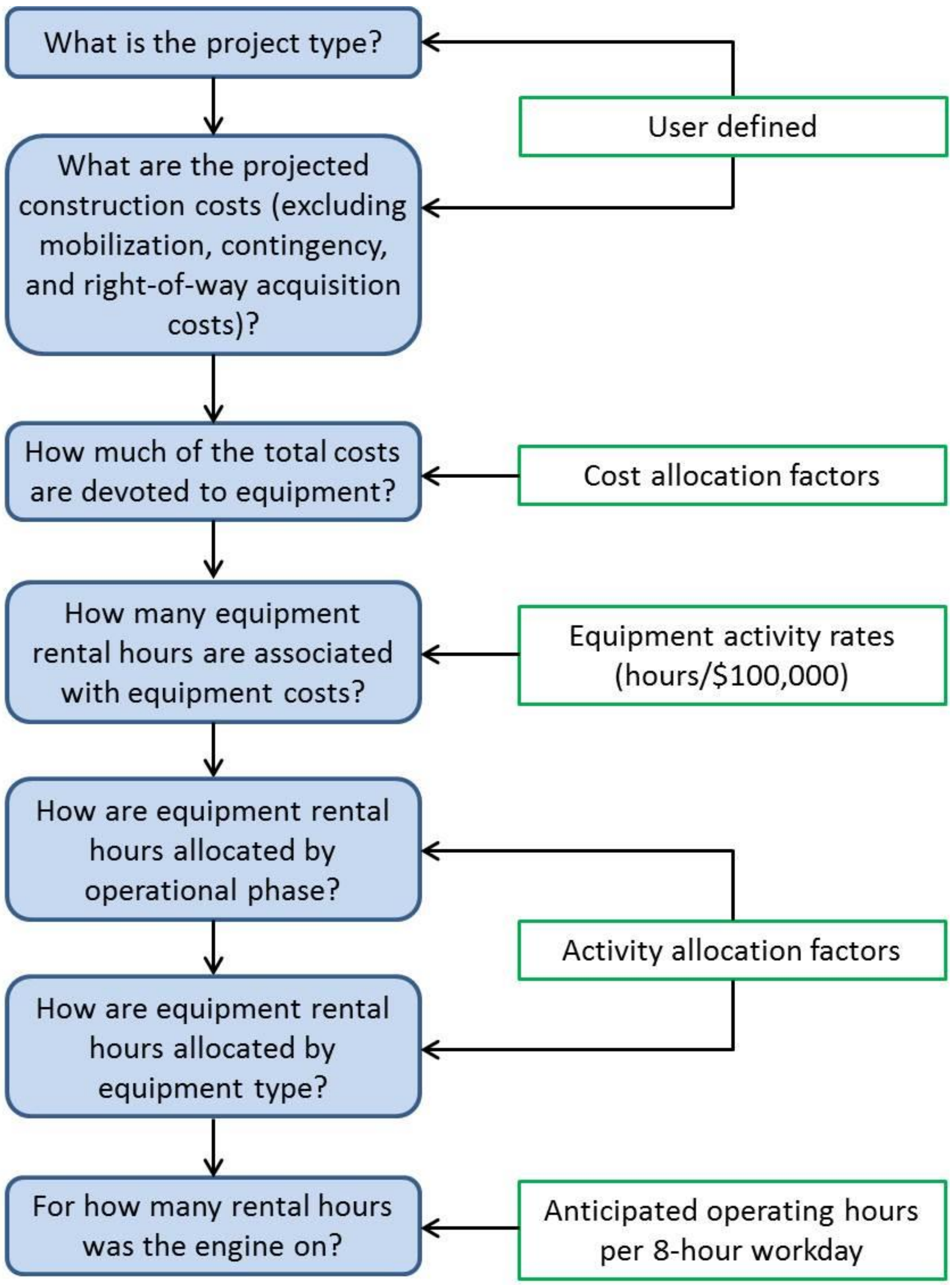


Figure 1. Flow chart summarizing the CAL-CET equipment activity estimation process.

## Overview of Data Sources

The CAL-CET input parameters shown in Figure 1 above were developed from a variety of data sources, including data published by the Caltrans Division of Construction and information from the 30 project dataset assembled from field inspector diaries. Table 1 summarizes the data sources used to develop the CAL-CET input parameters. A more detailed description of each parameter and its development is provided in the sub-sections that follow.

**Table 1.** Parameters used by CAL-CET2018 to estimate and allocate equipment activity.

| Parameter | Data Source(s) | Notes |
|---|---|---|
| Project type | Selected by the user from a drop-down menu | Seven project types are available:<br>1. Mainline improvements<br>2. Roadside improvements<br>3. Pavement preservation<br>4. Bridge construction and preservation<br>5. Traffic safety and operations<br>6. Storm water and drainage<br>7. Landscaping |
| Construction cost | Provided by the user | The cost should include only roadway and structure construction. Consult with the project engineer to compile the necessary project cost information. |
| Cost allocation factors | Developed by Caltrans construction engineers based on four years (2012-2015) of Force Account billables | These factors assign a percentage of overall project cost to equipment costs based on project type. |
| Equipment activity rates | Developed using:<br>• Caltrans equipment rental rates in effect from April 1, 2016 through March 21, 2017 (Caltrans, 2016)<br>• Caltrans equipment usage reports from January 1, 2013 to December 2017.<br>• Diary-based equipment activity data from the 30 project dataset (Kable, 2006) | Units are hours/$100,000 (hours of equipment usage per $100,000 of equipment costs, in year 2017 dollars). These rental hours include time periods for which the equipment is inactive (i.e., the engine is off). |
| Activity allocation factors by operational phase | Derived from diary-based equipment activity data from the 30 representative projects (Kable, 2006) | These factors vary by project type. |
| Activity allocation factors by equipment type | Derived from diary-based equipment activity data from the 30 representative projects (Kable, 2006) | These factors vary by operational phase. |

| Parameter | Data Source(s) | Notes |
|---|---|---|
| Operating hours per workday | Provided by Caltrans construction engineers based on project experience and engineering judgement | These factors are used to adjust usage hours for each type of equipment to account for periods when the engine is off and no emissions are produced. |

## Project Type

CAL-CET allows users to classify a project into one of seven different project types. These types are similar to the project categories in the quarterly and annual Project Delivery Reports that Caltrans prepares for the California Transportation Commission and the California State Legislature.[3] The seven project types and their associated work activities are:

1. Mainline improvements – new roadway construction; roadway widening, reconstruction, or realignment; addition of connectors, ramps, or lanes (e.g., truck, passing, or high-occupancy vehicle [HOV] lanes).
2. Roadside improvements – shoulders, sidewalks, curbs, sound walls, bike lanes, vista points, park-and-ride lots, rest stops.[4]
3. Pavement preservation – overlay installation, resurfacing, rehabilitation.
4. Bridge construction and preservation – replacement, widening, retrofit, repair, railing addition.
5. Traffic safety and operations – medians, barriers, signage and striping, lighting, signalization, ramp meters, vehicle detectors.
6. Storm water and drainage – water quality, filtration, culverts, drains, dikes, ditches, basins.
7. Landscaping – planting, irrigation, preservation.

The construction items for each operational phase in CAL-CET are summarized in **Appendix A**.

## Construction Cost

The input cost value should include only roadway and structure construction costs. Mobilization, contingency, and right-of-way acquisition costs should not be included. Because equipment activity rates (hours/$100,000) are based on 2017 dollars, users have the option of rolling the cost estimate back to 2017 by using the Caltrans Construction Price Index value.[5] The user must provide the last 12 months index value for the most recent 4$^{th}$ Quarter, and CAL-CET will use this value in conjunction with the last 12 months index value for the 4$^{th}$ Quarter of 2017 to adjust the construction cost.

## Cost Allocation Factors

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[3] See for example: http://www.dot.ca.gov/projmgmt/ctc/PDReport_Legislature_FY1415.pdf.
[4] Rest stops include the construction of restroom buildings.
[5] This information can be found at: http://www.dot.ca.gov/hq/esc/oe/hist_price_index.html.

For Caltrans construction projects, one method of payment for Contract Change Orders (CCOs) is the Extra Work at Force Account method, as outlined under Title 23, Code of Federal Regulations (CFR), Part 635, Subpart B. For federal-aid highway projects, federal policy requires that actual costs be used to determine extra work payments to compensate the contractor for the cost of equipment (at established rental rates), labor, and materials. Caltrans analyzed four years (2012-2015) of Force Account data from the Caltrans Extra Work Billing System (see Figure 2), selecting CCO invoices that had billable items under all three categories (equipment, labor, and materials). The total costs for each billing category were summed across all invoices. These values were then divided by the sum of total costs across all invoices to calculate cost allocation factors by billing category.

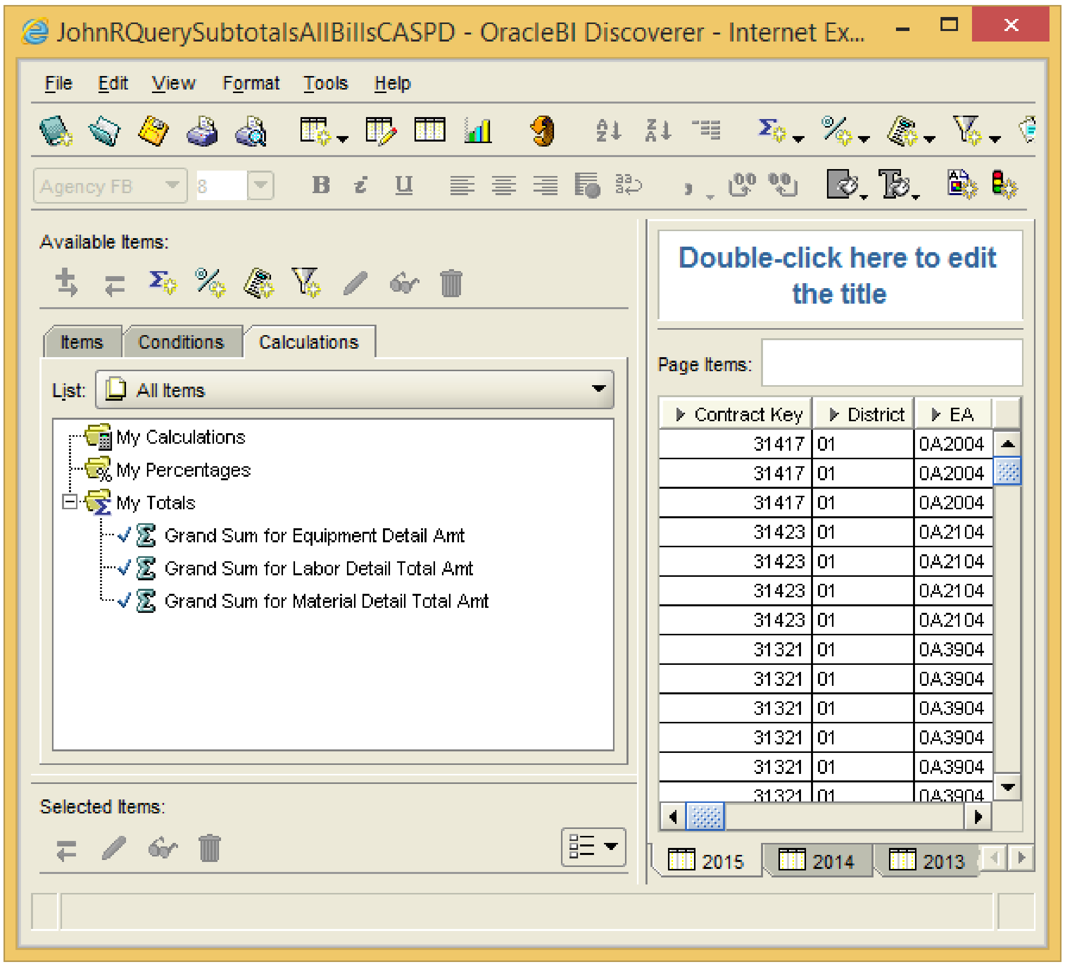


Figure 2. Screenshot of the Caltrans Extra Work Billing System used to query Force Account data.

Additional assessments and refinements were applied to the cost allocation factors to account for variations among project types. For example, through discussion with Caltrans Headquarters, Division of Engineering Services – Structure Construction, it was determined that structure projects such as bridge construction typically have a lower proportion of overall cost associated with equipment than non-structure project types. This is primarily because structural work, especially concrete operations, usually involves more manual labor than equipment activity.

Table 2 summarizes the resulting cost allocation factors, which are used within CAL-CET to estimate the fraction of total project costs that are associated with construction equipment. Across all project types, the percentage of total costs associated with equipment rentals range from 15% to 22%. While the distribution factors associated with labor and material costs fluctuate each year, analysis of the Caltrans Extra Work Billing System indicated that the factor associated with equipment costs remains consistent across the four analysis years.

**Table 2.** Cost allocation percentages by project type.

| Project Type | Percentage of Construction Costs | | |
|---|---|---|---|
| | Labor | Materials | Equipment |
| Mainline improvements | 33% | 47% | 20% |
| Roadside improvements | 36% | 46% | 18% |
| Pavement preservation | 31% | 47% | 22% |
| Bridge construction and preservation | 35% | 50% | 15% |
| Traffic safety and operations | 33% | 45% | 22% |
| Storm water and drainage | 33% | 45% | 22% |
| Landscaping | 38% | 42% | 20% |

## Equipment Activity Rates

To estimate overall equipment hours associated with a given project, the tool development team estimated equipment activity rates in units of hours per $100,000[6] of equipment costs. The first step in developing these activity rates was calculating an average hourly rental rate for each type of construction equipment covered by CAL-CET. These average rental rates were calculated using two data sets:

1. Caltrans Division of Construction Annual Equipment Rental Rates – the Division of Construction compiles an equipment rental rate book each year that provides hourly rental rates for various makes and models of equipment. The rental rates adhere to the principles and guidelines of the Federal Acquisition Regulation codified under Title 48, CFR Part 31.105. The rental rate information corresponded to the publication period of April 1, 2016 through March 21, 2017 (Caltrans, 2016).
2. Caltrans Division of Construction Annual Equipment Usage Report – as part of their financial database, the Division of Construction records the rental hours for various equipment makes and models each year. Five most recent usage reports (2013, 2014, 2015, 2016, and 2017) were used to evaluate the equipment models most commonly used on Caltrans projects throughout the state.

[6] For project analysis purposes, the dollar amounts referenced in this document should be treated as 2017 dollars, unless otherwise specified.

For a given equipment type, fractions of total equipment hours by model for the years 2013-2017 from the Caltrans usage reports were used as weighting factors to calculate a weighted average rental rate for each type of equipment provided in CAL-CET. All equipment models were included in this calculation, which was performed using the equation below:

$$ARR = \sum_{i=1}^{n} WF_i \times RR_i$$

Where:

ARR = The average rental rate for a given equipment type

$WF_i$ = The weighting factor for equipment model $i$, which is the fraction of annual equipment hours from the Caltrans usage reports associated with that model

$RR_i$ = The rental rate for equipment model $i$

This process ensured that, for each equipment type, rental rates for the most commonly used equipment models had the greatest influence on the final result. Once the average rental rate for each equipment type was determined, the rates were applied to diary-based equipment activity data from the 30 representative projects to calculate total equipment costs for each project in 2017 dollars.

To get a single representative activity rate for each project type, the hours of equipment usage and equipment costs were summed across all individual projects of a given type. The total hours of equipment usage were then divided by total equipment costs to generate the final equipment activity rate. More specifically, for all individual projects within each project type (e.g., mainline improvement, traffic safety, and bridge construction), the hours of equipment usage were divided by the total equipment cost, and this value was then multiplied by 100,000 to develop an activity rate in units of hours per $100,000 of equipment costs. Sample data for the "Mainline Improvements" project type are shown in **Table 3**, both for individual projects and the overall project type. This process was repeated across all project types to generate the final equipment activity rates shown in shown in **Table 4**.[7]

[7] For non-Caltrans projects, consideration should be given to accounting for differences between Caltrans equipment rental rates and construction fleets and the lead agency's construction practices.

**Table 3.** Equipment hours and costs for projects of the "Mainline Improvements" type.

| Project Type | Project ID | Equipment Hours | Equipment Cost | Hrs/$100,000 |
|---|---|---|---|---|
| Mainline Improvements | 03-0C5304 | 706 | $30,457 | 2,549 |
| | 03-366404 | 33,547 | $1,694,625 | 2,167 |
| | 03-367714 | 38,851 | $1,740,842 | 2,302 |
| | 03-374214 | 4,666 | $237,153 | 2,017 |
| | 06-336604 | 10,535 | $461,317 | 2,437 |
| | 06-342154 | 11,853 | $881,824 | 1,444 |
| | **All Projects** | **100,157** | **$5,046,218** | 2,112 |

**Table 4.** Equipment activity rates by project type.

| Project Type | Equipment Activity Rate (Hours/$100,000) |
|---|---|
| Mainline improvements | 2,112 |
| Roadside improvements | 2,624 |
| Pavement preservation | 1,830 |
| Bridge construction and preservation | 2,279 |
| Traffic safety and operations | 2,674 |
| Storm water and drainage | 3,379 |
| Landscaping | 3,379 |

Note that the average equipment activity rates for each project type provide a reasonable representation of the range of activity rates across individual projects within that overall project type, as shown in Figure 3.

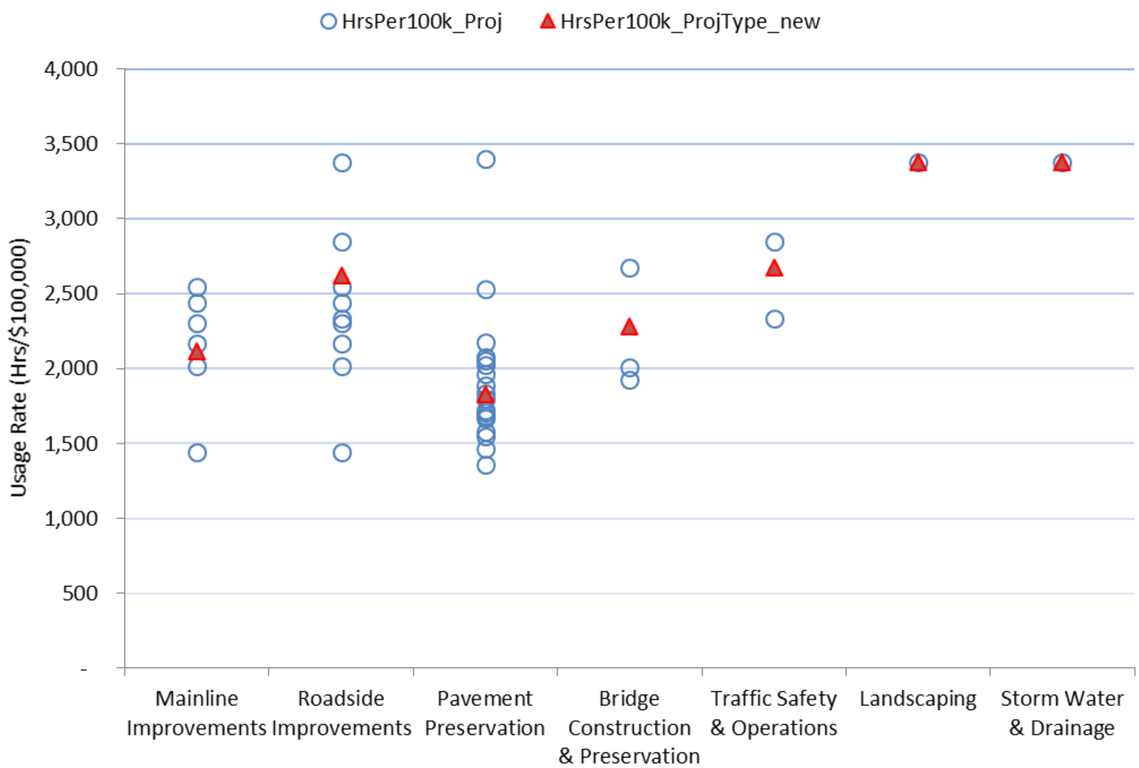


**Figure 3.** Individual and average equipment activity rates for projects within a given project type.

## Equipment Hours Allocations

Once total equipment activity (in hours) is estimated using project equipment costs and the equipment activity rates, these total hours must be allocated to operational phases and equipment types. In CAL-CET, these allocations are done using diary data derived from the 30 representative Caltrans projects. Originally, these 30 projects were categorized into six project types to correlate with the overall distribution of projects under construction by Caltrans between 2000 and 2005. These six previous project types were:

- Resurface existing highway
- Pavement rehabilitation/widening
- Construct freeway/extra lane
- Construct, reconstruct bridge
- Construct median, thrie beam barrier
- Landscaping

Since these six previous project types used for the original categorization differ somewhat from the current seven project types defined in CAL-CET, a cross-walk was developed to establish a relationship between the two categorization schemes, as shown in **Table 5**. Note that a one-to-one match does not exist for all project types between the two categorization schemes. For example, the "Pavement Rehabilitation/widening" project type from the original 30 project dataset may involve work that falls into both the "Pavement Preservation" and "Mainline Improvements" project types in the new categorization scheme. However, these projects appeared to mainly involve rehabilitation work, making it more appropriate to classify them as "Pavement Preservation." Once this mapping between categorization schemes was complete, the reallocated equipment activity percentages for CAL-CET were calculated, as shown in Table 6.

Once total equipment hours for a project have been allocated to operational phases, the next step is to allocate hours to each individual equipment type. This step also relies on diary data from the 30 representative projects and is largely consistent with the initial CAL-CET methodology.[8] The diary data were used to identify key equipment types used during each phase of construction and to develop a distribution of the percentage of equipment hours associated with each equipment type. For example, within the base/subbase/imported borrow operational phase, 18 equipment types used to complete the work were identified. Among those equipment types, excavators accounted for 4.5% of the total equipment hours associated with that phase. A complete list of allocation percentages by operational phase and equipment type is shown in Table 7.

**Table 5.** Cross-walk for allocating equipment hours by operational phase.

| Project Type | Data Source for Allocating Equipment Hours by Operational Phase |
|---|---|
| Mainline improvements | Percentages taken directly from the "Construct freeway/extra lane" project type |
| Roadside improvements | Percentages represent the average of data from the following project types (no pavement or bridge work):<br>• Construct freeway/extra lane<br>• Construct median, thrie beam barrier<br>• Landscaping |
| Pavement preservation | Percentages represent the average of data from the "Resurface existing highway" and "Pavement rehabilitation/widening" project types |
| Bridge construction and preservation | Percentages taken directly from the "Construct, reconstruct bridge" project type |
| Traffic safety and operations | Percentages taken directly from the "Construct median, thrie beam barrier" project type |
| Storm water and drainage | Percentages taken directly from the "Landscaping" project type |
| Landscaping | Percentages taken directly from the "Landscaping" project type |

[8] Note that the initial version of CAL-CET included the striping/painting activities as a part of the Paving operational phase. In the current version of CAL-CET striping/painting activities are moved into the Traffic Signalization Signage phase.

**Table 6.** Equipment activity allocation percentages by project type and operational phase.

| Phase | Project Type | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mainline Improvements | Roadside Improvements | Pavement Preservation | Bridge Construction, Reconstruction | Traffic Safety & Operations | Storm Water & Drainage | Land scaping |
| Land Clearing and Grubbing | 2.3% | 1.3% | 0.1% | 0.7% | 0.0% | 1.7% | 1.7% |
| Roadway Excavation & Removal | 15.5% | 8.7% | 19.0% | 4.1% | 10.9% | 0.1% | 0.1% |
| Structural Excavation & Removal | 2.2% | 0.7% | 0.3% | 11.4% | 0.0% | 0.0% | 0.0% |
| Base and Subbase | 13.2% | 5.8% | 7.8% | 9.0% | 4.0% | 0.8% | 0.8% |
| Structural Concrete | 11.3% | 5.1% | 2.1% | 46.6% | 0.0% | 4.5% | 4.5% |
| Paving | 12.6% | 6.7% | 27.1% | 2.4% | 7.7% | 0.0% | 0.0% |
| Drainage / Environmental / Landscaping | 11.8% | 35.1% | 6.0% | 4.2% | 0.2% | 92.6% | 92.6% |
| Traffic Signalization / Striping / Painting | 31.2% | 36.6% | 37.6% | 21.6% | 77.1% | 0.4% | 0.4% |
| Total | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

**Table 7.** Distribution of hours by equipment type, across eight construction operational phases used to characterize Caltrans projects. (Page 1 of 2)

| Equipment Type (some equipment types are not used in all operational phases) | % Average Hours of Equipment Use by Operational Phase | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Base/Subbase /Imp. Borrow | Drainage/Env/ Landscaping | Land Clearing/ Grubbing | Paving | Roadway Excavation & Removal | Structural Concrete | Structural Excavation & Removal | Traffic Signalization/ Striping/ Painting |
| Heavy-Duty Trucks | 14.57 | 12.47 | 18.45 | 16.24 | 13.77 | 8.56 | 9.44 | 17.89 |
| Light-Duty Truck | 10.88 | 19.61 | 6.84 | 14.43 | 12.13 | 23.66 | 14.57 | 16.66 |
| Aerial Lifts | | 0.29 | | | | 3.84 | 9.10 | 1.12 |
| Bore/Drill Rigs | | 1.73 | | | 0.72 | 1.45 | 0.94 | 2.79 |
| Cement & Mortar Mixers | | | | | | 4.47 | 0.52 | 4.71 |
| Commercial Turf Equipment | | 1.28 | | | | | | 0.06 |
| Concrete/Industrial Saws | 0.21 | 0.42 | 0.95 | 5.25 | 1.74 | 1.58 | 0.46 | 0.26 |
| Cranes | | 0.51 | | 0.08 | | 1.77 | 1.68 | 0.65 |
| Crawler Tractors/Dozers | 6.63 | 1.16 | 3.05 | 0.16 | 5.73 | 0.25 | 0.68 | 0.41 |
| Crushing/Processing Equipment | | | | | | | | |
| Excavators | 4.52 | 1.96 | 23.29 | 1.78 | 4.83 | 0.85 | 5.99 | 1.06 |
| Graders | 10.13 | 0.43 | 2.49 | 1.20 | 7.10 | 0.24 | | 0.28 |
| Lt. Commercial Air Compressors | 0.60 | 2.77 | 18.77 | 1.02 | 0.63 | 6.86 | 11.34 | 1.57 |
| Lt. Commercial Generator Sets | | 9.42 | | 0.93 | 0.55 | 12.67 | 6.91 | 0.63 |
| Lt. Commercial Pressure Washers | | | | | | | | |
| Lt. Commercial Pumps | | | | | | | | |
| Lt. Commercial Welders | | 8.42 | | | 1.18 | 1.48 | 0.07 | 0.03 |
| Off-Highway Tractors | | | | | | | | |
| Off-Highway Trucks | | | | | | | | |

**Table 7.** Distribution of hours by equipment type, across eight construction operational phases used to characterize Caltrans projects. (Page 2 of 2)

| Equipment Type (some equipment types are not used in all operational phases) | % Average Hours of Equipment Use by Operational Phase | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Base/Sub base/Imp. Borrow | Drainage/Env/ Landscaping | Land Clearing/ Grubbing | Paving | Roadway Excavation & Removal | Structural Concrete | Structural Excavation & Removal | Traffic Signalization/ Striping/ Painting |
| Other Construction Equipment | | | | | | | | |
| Other General Industrial Equipment | | 0.96 | | 0.68 | 0.93 | 2.92 | 0.13 | 1.69 |
| Pavers/Shoulder Backing/AC Dikes | 1.83 | 1.58 | | 7.90 | 0.31 | 2.80 | | 1.31 |
| Paving Equipment | 1.47 | 1.63 | | 7.52 | 0.86 | 0.82 | | 0.29 |
| Plate Compactors | 1.81 | 0.83 | | 0.84 | 0.74 | 0.42 | 1.03 | 0.05 |
| Rollers | 8.22 | 1.37 | 0.94 | 17.20 | 5.85 | 1.12 | 1.02 | 0.56 |
| Rough Terrain Forklifts | 0.55 | 0.41 | | 0.39 | 0.38 | 9.75 | 2.96 | 1.49 |
| Rubber Tire Dozers | | | | | | | | |
| Rubber Tire Loaders | 4.84 | 2.60 | 2.71 | 3.87 | 4.90 | 3.02 | 2.24 | 0.57 |
| Scrapers | 12.30 | 0.37 | 5.61 | 0.36 | 8.19 | 0.81 | 0.15 | |
| Signal Boards | 3.19 | 1.88 | 3.96 | 2.67 | 5.14 | 3.51 | 5.48 | 40.02 |
| Skid Steer Loaders | 0.46 | 5.68 | 2.34 | 1.90 | 1.16 | 1.72 | 1.59 | 1.09 |
| Surfacing Equipment | 1.85 | 0.11 | | 1.89 | 3.13 | 1.21 | 6.36 | 0.91 |
| Sweepers/Scrubbers | 4.10 | 1.36 | 0.82 | 4.97 | 3.78 | 0.12 | 0.06 | 0.76 |
| Tampers/Rammers | 0.68 | 0.26 | 1.69 | 0.49 | 0.52 | 0.23 | | 0.13 |
| Tractors/Loaders/Backhoes | 4.02 | 6.07 | 1.91 | 5.65 | 8.51 | 2.28 | 2.95 | 1.72 |
| Trenchers | 0.35 | 13.43 | 1.32 | | | 1.04 | | 0.85 |
| Water Trucks | 6.80 | 1.00 | 4.87 | 2.58 | 7.23 | 0.57 | 14.33 | 0.44 |
| **Total** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** |

This table presents summary findings from the 30 project diaries concerning the equipment types used for each construction operational phase and the percent of hours within an operation assigned to a given equipment type. Numbers may not sum to 100% because of rounding.

## Engine Operating Hours

Individual pieces of construction equipment may be present on a job site but not in continuous use throughout a typical 8-hour workday (with the exception of equipment like signal boards used for traffic control). As a result, a given piece of equipment may be onsite and "rented" to the project, but not actively working (i.e., the engine is off and no emissions are produced). Since the purpose of CAL-CET is to estimate emissions, total equipment hours derived from rental rates must be adjusted to account for engine-off periods.

To support this adjustment, Caltrans engineers provided a table of estimated engine operating (i.e., engine on) hours per 8-hour workday for equipment types to which CAL-CET assigns hours for each operational phase, as previously shown in Table 7. These estimates culminated from Caltrans Construction engineers' field experience and engineering judgement and are shown in **Table 8**. Factors that limit equipment daily operation include preparation work that must be undertaken at the beginning of a work shift before any equipment can be used and cleanup work that must be done at the end of the shift before the job site is shut down for the day.

In addition, any required lane closures at a construction site limit the amount of time available to conduct actual work activities. To provide for the safety of the public and construction workers, no work may be performed on a highway until a lane closure is properly set up, and all work operations must be cleared from the highway by the end of the lane closure time period. Other factors considered by Caltrans Construction engineers in developing the data in Table 8 include the type of equipment and the typical work activities it performs during each operational phase. For example, during operations that involve earthwork or excavation, a water truck would be used heavily to control fugitive dust and maintain soil saturation. However, for other operations, the water truck is primarily onsite to provide support and would typically be stationary. In addition, engines on equipment such as aerial lifts are only used to move the equipment into position. The lift is then locked in place while work is being conducted. Therefore, a lift may be used for an entire work shift, though the engine is running for only a limited time.

Finally, note that in Table 8, some fields for operating hours are blank, which represent equipment types to which CAL-CET does not assign hours for a given operational phase. However, users have the option of manually altering the default equipment populations (number of pieces of equipment) produced by the tool based on the requirements of their project. Given the atypical nature of such equipment assignments, a 50% utilization rate will be assumed (i.e., 4 hours of engine operation during an 8-hour workday). This value is within the range of average equipment usage across individual operational phases, which varies from 3.0 to 4.7 hours.

**Table 8.** Typical engine operating hours by equipment type, across eight construction operational phases used to characterize Caltrans projects. (Page 1 of 2)

| Equipment Type | Typical Operating (Engine on) Hours Per 8 hour Workday | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Base/Subbase /Imp. Borrow | Drainage/Env/ Landscaping | Land Clearing/ Grubbing | Paving | Roadway Excavation & Removal | Structural Concrete | Structural Excavation & Removal | Traffic Signalization/ Striping/ Painting |
| Heavy-Duty Trucks | 7.00 | 5.00 | 6.00 | 6.00 | 7.00 | 6.00 | 5.00 | 4.00 |
| Light-Duty Truck | 4.00 | 2.00 | 2.00 | 3.00 | 2.00 | 2.00 | 2.00 | 4.00 |
| Aerial Lifts | | 1.00 | | 1.00 | | 3.00 | 2.00 | 3.00 |
| Bore/Drill Rigs | | 2.00 | | 2.00 | 3.00 | 2.00 | 6.00 | 4.00 |
| Cement & Mortar Mixers | | 3.00 | | | | 5.00 | | 3.00 |
| Commercial Turf Equipment | | 7.00 | | | | | 4.00 | 1.00 |
| Concrete/Industrial Saws | 2.00 | 2.00 | 2.00 | 4.00 | 6.00 | 1.00 | 4.00 | 5.00 |
| Cranes | | 2.00 | | 2.00 | | 5.00 | 3.00 | 4.00 |
| Crawler Tractors/Dozers | 7.00 | 3.00 | 6.00 | 3.00 | 6.00 | 1.00 | 4.00 | 1.00 |
| Crushing/Processing Equipment | | | | | | | | |
| Excavators | 5.00 | 3.00 | 6.00 | 3.00 | 7.00 | 1.00 | 7.00 | 2.00 |
| Graders | 7.00 | 2.00 | 6.00 | 3.00 | 7.00 | 1.00 | 2.00 | 1.00 |
| Lt. Commercial Air Compressors | 2.00 | 3.00 | 5.00 | 1.00 | 3.00 | 6.00 | 6.00 | 5.00 |
| Lt. Commercial Generator Sets | 5.00 | 4.00 | | 6.00 | 5.00 | 7.00 | 5.00 | 3.00 |
| Lt. Commercial Pressure Washers | | | | | | | | |
| Lt. Commercial Pumps | | | | | | | | |
| Lt. Commercial Welders | | 1.00 | | | | 3.00 | 4.00 | 1.00 |
| Off-Highway Tractors | | | | | | | | |
| Off-Highway Trucks | | | | | | | | |

**Table 8.** Typical engine operating hours by equipment type, across eight construction operational phases used to characterize Caltrans projects. (Page 2 of 2)

| Equipment Type | Typical Operating (Engine on) Hours Per 8 hour Workday | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Base/Sub base/Imp. Borrow | Drainage/Env/ Landscaping | Land Clearing/ Grubbing | Paving | Roadway Excavation & Removal | Structural Concrete | Structural Excavation & Removal | Traffic Signalization/ Striping/ Painting |
| Other Construction Equipment | | | | | | | | |
| Other General Industrial Equipment | | | | | | 4.00 | 2.00 | 5.00 |
| Pavers/Shoulder Backing/AC Dikes | 7.00 | 7.00 | | 7.00 | 7.00 | 7.00 | | 7.00 |
| Paving Equipment | 7.00 | 7.00 | | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| Plate Compactors | 2.00 | 3.00 | | 4.00 | 2.00 | 1.00 | 4.00 | 1.00 |
| Rollers | 7.00 | 3.00 | 3.00 | 7.00 | 7.00 | 1.00 | 4.00 | 2.00 |
| Rough Terrain Forklifts | 2.00 | 2.00 | | 2.00 | 2.00 | 5.00 | 2.00 | 2.00 |
| Rubber Tire Dozers | | | | | | | | |
| Rubber Tire Loaders | 5.00 | 5.00 | 6.00 | 2.00 | 7.00 | 4.00 | 6.00 | 2.00 |
| Scrapers | 6.00 | 1.00 | 7.00 | 2.00 | 7.00 | 1.00 | 2.00 | |
| Signal Boards | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Skid Steer Loaders | 2.00 | 6.00 | 6.00 | 4.00 | 2.00 | 3.00 | 3.00 | 3.00 |
| Surfacing Equipment | 2.00 | 1.00 | | 6.00 | 6.00 | 3.00 | 2.00 | 4.00 |
| Sweepers/Scrubbers | 4.00 | 4.00 | 3.00 | 6.00 | 3.00 | 2.00 | 2.00 | 2.00 |
| Tampers/Rammers | 2.00 | 3.00 | 2.00 | 2.00 | 4.00 | 1.00 | 2.00 | |
| Tractors/Loaders/Backhoes | 5.00 | 6.00 | 4.00 | 2.00 | 4.00 | 4.00 | 6.00 | 3.00 |
| Trenchers | 2.00 | 6.00 | 1.00 | | | | | 4.00 |
| Water Trucks | 6.00 | 3.00 | 7.00 | 2.00 | 7.00 | 3.00 | 4.00 | 3.00 |

This table presents engine operating hours per 8-hour workday for the equipment types assigned to each construction operation phase by CAL-CET. For example, a value of 2.00 indicates that the given equipment engine is typically on and generating emissions for 2.00 hours during each 8-hour workday, or 25% of the time. Where fields for operating hours are blank, CAL-CET does not assign hours to that equipment type for the specified operational phase. However, users have the option of manually assigning equipment to operational phases. Given the atypical nature of these assignments, a 50% utilization rate will be assumed (i.e., 4 hours of engine operation during an 8-hour workday).

# 3. Emissions Estimates

Once the equipment activity by operational phase and equipment type has been adjusted to account for engine-off hours, CAL-CET estimates exhaust emissions by applying appropriate emission factors (g/hp-hr) to the estimated activity data (hours) and rated horse power for each type of equipment. In addition, the tool estimates PM emissions from area-wide fugitive dust and evaporative emissions from painting and asphalt concrete paving. CAL-CET outputs both emissions and fuel consumption estimates by operational phase, source type, and calendar year for the total project (tons) and for an average day (lb). The current version of the tool also provides an estimate of maximum daily average emissions over the course of the project. This section provides information on how emissions estimates are prepared and reported in CAL-CET.

## Exhaust Emissions

### *Off-Road Mobile Sources*

The off-road mobile source category includes emissions from construction equipment and off-road trucks. CAL-CET estimates exhaust emissions from off-road mobile sources using the following formula:

$$E_{OFF} = \sum_{i=1}^{n} N_i \times EF_i \times P_i \times L_i \times H_i$$

Where:

$E_{OFF}$ = Total off-road exhaust emissions for the project

$N_i$ = Number of pieces of equipment for equipment type $i$

$EF_i$ = Emission factor for equipment type $i$ (g/brake-hp-hr)

$P_i$ = Rated power of equipment type $i$ (hp)

$L_i$ = Load factor for equipment type $i$ (ratio of actual power used to available power)

$H_i$ = Hours of use per day for equipment type $i$

The exhaust emission factors used in CAL-CET were derived from the California Air Resources Board's (CARB) OFFROAD2017 model, which estimates emissions for a variety of off-road mobile sources (https://www.arb.ca.gov/msei/ordiesel/ordas_ef_fcf_2017.pdf). Data from the OFFROAD2017 - ORION Web Database were processed to obtain the following statewide parameters: zero-hour emission factors (steady-state emission factors for new equipment), equipment model years based on horsepower and tier categories (and, subsequently accumulated use hours), and fuel correction factors. Where applicable, parameters were calculated as averages weighted by calendar year- and model year-specific activity (hours/year). CAL-CET uses default zero-hour emission factors that are an activity-weighted average across all model years and horsepower categories. Users can select an emission standard tier category (e.g., Tier 4) that will be applied to all off-road construction equipment, and can also select different tiers for individual types of equipment. Note that changing the tier standard from the default value to the latest Tier 4 will substantially reduce equipment emissions for various pollutants (e.g., $NO_x$ and PM), but not for fuel consumption and $CO_2$ because fuel consumption rates and $CO_2$ emission rates are not specifically regulated under the engine tier standards. Deterioration rates were calculated as averages across model years in each horsepower and tier category using data in the OFFROAD2017 spreadsheet tool (https://www.arb.ca.gov/msei/ordiesel/ordas_ef_fcf_2017_v7.xlsx). For CO, TOG, ROG, $NO_x$, $PM_{10}$, $PM_{2.5}$, and $CO_2$, emission factors for any equipment type are computed using the following formula:

$$EF = (EF0 + DR \times CHrs) \times FCF$$

Where:

EF0 = zero-hour emission factor (g/hp-hr)

DR = deterioration rate (g/hp-hr$^2$)

CHrs = cumulative engine hours

FCF = fuel correction factor (unitless)

Note that emission factors for any equipment type are computed by adjusting the zero-hour emission factors to account for the transient demands of equipment operation and emission changes with the age of the engine (deterioration). The FCF is applied to adjust for differences in sulfur and aromatic content between federal and California fuel.

Emission factors for $CH_4$, $N_2O$, and BC for off-road equipment were obtained from California's Greenhouse Gas Inventory for 2015 (https://www.arb.ca.gov/cc/inventory/doc/doc_index.php).

Default load factors are directly from OFFROAD2017 for various types of equipment and default horsepower values are calculated as OFFROAD2017 population-weighted averages across engine model years and horsepower categories. These factors represent the fraction of available power that is typically used during operations. For example, for diesel excavators, the load factor of 0.38 means that 38% of available power is typically used while an excavator is in operation.

## *On-road Mobile Sources*

The on-road mobile source category includes emissions from light-duty trucks and heavy-duty trucks (including water trucks) used to transport materials or employees to and from the construction site (excluding commute trips). The basic formula used to calculate on-road exhaust emissions is:

$$E_{ON} = \sum_{i=1}^{n} N_i \times A_i \times EF_i$$

Where:

$E_{ON}$ = Total on-road emissions for the project

$N_i$ = Number of vehicle round trips for vehicle type *i*

$A_i$ = Average round trip distance for vehicle type *i* (mi/round trip)

$EF_i$ = Emission factor for vehicle type $i$ (g/mi)

The daily vehicle activity (i.e., vehicle miles) for trucks in the on-road mobile source emissions calculation is estimated based on the user's input of number of round trips per day and an average round trip distance (CAL-CET includes a default of 20 miles per vehicle round trip for heavy-duty trucks and a default of two times the length of the project per vehicle round trip for light-duty trucks). Emission and fuel consumption factors for light-duty trucks and heavy-duty trucks were obtained from EMFAC2017 for an average speed of 30 miles per hour. In CAL-CET, light-duty truck corresponds to light-duty truck 1 and 2 in EMFAC2017; heavy-duty truck corresponds to light heavy-duty, medium heavy-duty, and heavy heavy-duty trucks in EMFAC2017. Water trucks are specified as medium heavy-duty trucks and their emission factors were obtained from EMFAC2017 for an average speed of 10 miles per hour. For on-road trucks, emission factors for $CH_4$ and $N_2O$ are from EMFAC2017; HFC emission factors for on-road trucks were estimated by CARB by combining data from SAE International's Test Procedure for Determining Refrigerant Emissions from Mobile Air Conditioning Systems (SAE J2763) (SAE International, 2015) and CARB's annual average HFC leakage data (Gallagher et al., 2016; Schwarz, 2001; Wimberger and Stover, 2009; Vincent et al., 2004); BC emission factors are from CARB speciation profiles (https://www.arb.ca.gov/ei/speciate/speciate.htm).

## Fugitive Dust Emissions

Disturbed areas on the construction site emit fugitive dust, which is mostly in the form of $PM_{10}$ (i.e., coarse particles). CARB's area-wide emissions methodology for road construction dust (California Air Resources Board, 1997) recommends a constant $PM_{10}$ emission factor of 220 lb/acre-month. This factor was developed by Midwest Research Institute (1996) and is applied in CAL-CET as follows:

$$FD_{PM10} = \theta \times A_i \times EF \,/\, 22$$

Where:

$FD_{PM10}$ = Daily $PM_{10}$ emissions from fugitive dust

$\theta$ = Dust control effect (default is assumed to be 50%)

$A_i$ = Acres disturbed during operation $i$

EF = Emission factor for $PM_{10}$ (220 lb/acre-month)

22 = Assumed number of working days per month

Note that in this method, the total disturbed area for an operation is distributed evenly across all working days for that operation. The total disturbed area is computed based on the projected roadway length using parameters suggested by CARB for road construction (California Air Resources Board, 1997), as shown in Table 9.

**Table 9.** Disturbed acreage parameters by road type.

| Road Type | Disturbed Acres Per Mile |
|---|---|
| Freeway | 12.1 |
| Highway | 9.2 |
| City and County | 7.8 |

## Evaporative Emissions

The main pollutant from painting and asphalt application is volatile organic compound (VOC) emissions, which are reported as TOG and ROG in CAL-CET. Painting primarily refers to surface coatings, which can be water-based or solvent-based. Evaporative emissions from painting operations are calculated in CAL-CET as follows:

$$EV_{VOC} = EF_{wb} \times V_{wb} + EF_{sb} \times V_{sb}$$

Where:

$EV_{VOC}$ = Total evaporative VOC emissions from painting

$EF_{wb}$ = Emission factor for water-based paints (0.74 lb/gal)

$V_{wb}$ = Volume of water-based paints (gal)

$EF_{sb}$ = Emission factor for solvent-based paints (3.87 lb/gal)

$V_{sb}$ = Volume of solvent-based paints (gal)

Note that the VOC emission rate for water-based coatings is much lower than the emission rate for solvent-based coatings, which is due to the lower VOC content in water-based paints.

Estimation of asphalt emissions follows EPA's AP-42 compendium (U.S. Environmental Protection Agency, 1995), which bases VOC emissions on the amount of volatile petroleum distillates, or diluents, used to liquefy (or "cutback") the asphalt cement. This method assumes naphtha is used as a diluent, with a density of 0.7 kg/l, and that the density of asphalt cement is 1.1 kg/l. It is also assumed that 95% of the diluent evaporates. CAL-CET requires the user to input the total mass of the asphalt being applied and the diluent content (% by volume); a default value of 35% diluent content is included in the tool.

## Daily Emissions

### *Length of Operations*

CAL-CET calculates the duration of each operational phase, or "Length of Operations" for each phase, using the user-defined estimated working days for the project and default values for the percentage of working days for each phase by project type. The phase duration is calculated as the number of working days. These working days are a preliminary estimate. It is the analyst's responsibility to ensure that the estimated working days are reflective of the anticipated work schedule for the project. The analyst should consult with the the number of contract working days. Experience and judgment should be used in the final determination of contract working days for each project.

The default working day percentages shown in **Figure 4** and **Table 10** are derived from the diary data of off-road equipment usage in the 30 Caltrans representative projects. On-road vehicles and signal boards were not considered in developing the default length of operations since they can be used for various purposes in addition to the primary operational activities. This minimizes the potential for over-estimating the length of operation and ensures that the number of working days are properly accounted for when major construction equipment are in use and emissions would be highest. The following steps outline the analysis methodology:

1. Identify dates that are working days in the diary data for the 30 projects; working days are dates on which there is at least one piece of off-road equipment with non-zero work shifts.
2. Sum the working days by phase for each of the 30 projects from the diary data.
3. For each project type in the 30 projects, sum the working days by phase across the corresponding projects; these are project type-specific working days by phase.
4. For each project type in the 30 projects, sum the working days across phases; these are the total working days for each project type.
5. For each project type in the 30 projects, calculate the length of operation percentages by phase ($LOO_{phase,\ project\ type}$ (%)) by dividing the project type-specific working days by phase (Step 2) by the total working days for each project type (Step 3).
6. Map the length of operation percentages by phase for the project types in the 30 projects to the project types used in CAL-CET using simple averaging.
7. Normalize the length of operation percentages (Step 5) to ensure the sum across phases for each project type equals 100%.

The Length of Operations (LOO) in working days by phase and project type is then calculated as the number of work days (Monday through Friday) using the default percentage of working days between the project start date and end date determined from the estimated working days for the project. The default percentages of working days, or length of operations, for each phase and project type are shown in Table 10. LOO is rounded to the nearest day.

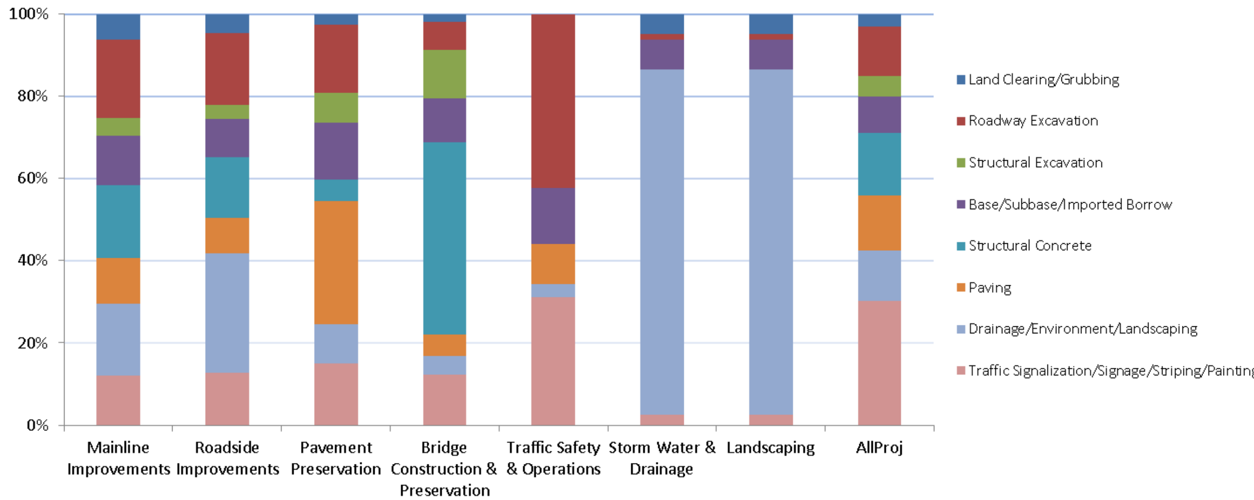


**Figure 4.** Default distribution of working days by operation phase and project type.

**Table 10.** Length of operation percentages by project type and operational phase.

| Phase | Project Type | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mainline Improvements | Roadside Improvements | Pavement Preservation | Bridge Construction, Reconstruction | Traffic Safety & Operations | Storm Water & Drainage | Land scaping |
| Land Clearing and Grubbing | 6% | 5% | 3% | 2% | 0% | 5% | 5% |
| Roadway Excavation & Removal | 19% | 17% | 17% | 7% | 42% | 1% | 1% |
| Structural Excavation & Removal | 4% | 4% | 7% | 12% | 0% | 0% | 0% |
| Base and Subbase | 12% | 9% | 14% | 11% | 14% | 7% | 7% |
| Structural Concrete | 18% | 15% | 5% | 47% | 0% | 0% | 0% |
| Paving | 11% | 9% | 30% | 5% | 10% | 0% | 0% |
| Drainage / Environmental / Landscaping | 17% | 29% | 10% | 5% | 3% | 84% | 84% |
| Traffic Signalization / Striping / Painting | 12% | 13% | 15% | 12% | 31% | 2% | 2% |
| **Total** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** |

### Average Daily Emissions

To estimate average daily emissions for each operational phase, CAL-CET divides the total emissions for a given phase by the default or user-defined duration of that phase in units of working days. Users also have the option of defining a start date for each individual phase and allowing overlap to occur between two or more phases. If start dates for individual phases are not provided, CAL-CET assumes that each operational phase occurs in sequential order with no overlap.

### Maximum Daily Average Emissions

Several air quality management districts in California have adopted air quality thresholds of significance for criteria pollutants under California Environmental Quality Act (CEQA) guidelines to assess air quality impacts from development projects. Emissions resulting from construction activities are typically assessed by daily average or annual average. For example, the Sacramento Metropolitan Air Quality Management District (SMAQMD) defined a construction-related $NO_x$ emissions threshold within their region as a maximum daily value of 85 lb.  To assist project analysts in their discussion with the local air districts, CAL-CET includes estimates of maximum daily average emissions.

The methodology is consistent with the approach established by SMAQMD for the Roadway Construction Emissions Model (RCEM), which reports the highest average daily emissions across all construction operational phases as the maximum daily value. CAL-CET, like RCEM, allows operations to overlap as needed and considers this overlap in the calculation of maximum daily emissions.

Given the default schedule of operations, and any user-changes to the default schedule, functionality was added to CAL-CET to estimate maximum daily average emissions as follows:

1. Average daily emissions are estimated for each operational phase based on the user-defined estimated working days for the project.
2. If applicable, user-defined changes to the default project schedule (i.e., phase-specific start dates and phase durations) are checked to determine whether any phases overlap in time.
3. If no overlap occurs, the highest average daily value across all phases is identified as the maximum daily average emissions for each pollutant.
4. If overlap occurs, the average daily emissions for overlapping phases are summed and compared to the average daily emissions for individual phases to identify a maximum value for each pollutant.

Note that this approach accounts for variability in equipment activity and emissions between different operational phases. However, this approach does not consider daily variations within a given phase, because such daily variations are difficult to predict for a given project at the planning stage.

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## Glossary of Terms

| | |
|---|---|
| Construction diary | A record that documents construction project activities, including work progress, site conditions, and labor and equipment usage |
| Equipment activity | Hours of equipment operation |
| Equipment hours | Hours of equipment operation (also referred to as equipment activity) |
| Operational phase | A distinct part of the construction process in which activities are grouped together (e.g., construction activities in the Land Clearing/Grubbing operational phase result in preparing the work area by removing trees, vegetation, or other material that may interfere with roadway construction) |
| Production rate | Amount of work and construction materials expended for a construction item per day (e.g., linear feet of drainage pipe installed per working day for drainage activity |
| Usage rate | Hours of equipment use per $100,000 of equipment costs |

# Appendix A. Construction Items for the Eight Operational Phases

| Land Clearing/Grubbing |
|---|
| Clearing and grubbing |
| Remove shrub |
| Roadside clearing |

| Roadway Excavation & Removal |
|---|
| Cold plane asphalt concrete pavement |
| Crack existing concrete pavement |
| Grind existing concrete pavement |
| Obliterate surfacing |
| Remove asphalt concrete dike |
| Remove base and surfacing |
| Remove concrete barrier |
| Remove concrete (curb and gutter) |
| Remove concrete curb and sidewalk |
| Remove concrete pavement and base |
| Remove concrete (miscellaneous) |
| Remove culvert |
| Remove downdrain |
| Remove flared end section |
| Remove headwall |
| Remove inlet |
| Remove structural section |
| Roadway excavation |

| Structural Excavation & Removal |
|---|
| Bridge removal |
| Bridge removal (portion) |
| Core concrete |
| Grind bridge deck |

| Structural Excavation & Removal |
| --- |
| Remove concrete deck surface |
| Remove headwall |
| Remove unsound concrete |
| Salvage broken concrete |
| Structure excavation (bridge) |
| Structure excavation (pumping plant) |
| Structure excavation (retaining wall) |
| Structure excavation (Type A) |
| Structure excavation (Type D) |
| Structure excavation (Type DH) |

| Base/Subbase/Imported Borrow |
| --- |
| Class 2 aggregate base |
| Imported borrow |
| Imported material (shoulder backing) |
| Lean concrete base |
| Maintenance vehicle pullout |
| Sand cover |
| Shoulder backing |
| Structure backfill (bridge) |
| Structure backfill (retaining wall) |

| Structural Concrete |
| --- |
| Bar reinforcing steel |
| Bar reinforcing steel (bridge) |
| Bar reinforcing steel (epoxy coated) |
| Bar reinforcing steel (epoxy coated) (bridge) |
| Bar reinforcing steel (pumping plant) |
| Cap reinforced concrete box opening |
| Cast-in-drilled-hole concrete piling |
| Cast-in-drilled-hole concrete pile (sign foundation) |

| Structural Concrete |
| --- |
| Concrete closure wall |
| Drill and bond dowel |
| Drill and bond dowel (epoxy cartridge) |
| Drive steel piles |
| Drive steel pipe pile |
| Erect precast prestressed concrete girder |
| Furnish bridge deck treatment material (low odor) |
| Furnish polyester concrete overlay |
| Furnish precast prestressed concrete girder |
| Furnish steel pipe piling |
| Inject crack (epoxy) |
| Jeene joint systems |
| Joint seal |
| Joint seal assembly |
| Minor concrete (backfill) |
| Minor concrete (curb, sidewalk, and curb ramp) |
| Minor concrete (headwall) |
| Minor concrete (minor structure) |
| Minor concrete (miscellaneous construction) |
| Miscellaneous iron and steel |
| Miscellaneous metal (bridge) |
| Miscellaneous metal (restrainer – cable type) |
| Paving notch extension |
| Place polyester concrete overlay |
| Prepare concrete bridge deck surface |
| Prestressing cast-in-place concrete |
| Random width weathered plank texture |
| Rapid setting concrete (patch) |
| Refinish bridge deck |
| Seal joint with epoxy sealant |
| Structural concrete approach slabs |

| Structural Concrete |
| --- |
| Structural concrete bridge |
| Structural concrete bridge footing |
| Structural concrete retaining wall |
| Structure backfill (slurry cement) |
| Structure concrete (pumping plant) |
| Treat bridge deck |

| Paving |
| --- |
| Asphalt concrete (Type A; open graded) |
| Asphaltic emulsion (fog seal coat; paint binder; polymer modified) |
| Asphalt-rubber binder |
| Cold foam in-place recycling |
| Concrete pavement |
| Finishing roadway |
| Minor concrete (curb and sidewalk) |
| Minor concrete (curb ramp) |
| Minor concrete (curb) |
| Minor concrete (curb, gutter, and sidewalk) |
| Minor concrete (textured paving) |
| Pavement reinforcing fabric |
| Paving asphalt (binder-pavement reinforcing fabric) |
| Paving notch extension |
| Place asphalt concrete (miscellaneous area) |
| Replace asphalt concrete surfacing |
| Replace concrete pavement (asphalt concrete) |
| Screenings (hot-applied; medium) |
| Seal pavement joint |

| Drainage/Environment/Landscaping |
| --- |
| Abandon culvert |
| Adjust frame and cover to grade |

| Drainage/Environment/Landscaping |
| --- |
| Adjust frame and grate to grade |
| Adjust inlet |
| Adjust manhole to grade |
| Adjust slotted drain to grade |
| Alternative pipe culverts |
| Anchor assembly |
| Asphalt concrete |
| Backflow preventer assembly and enclosure |
| Base station |
| Booster pump and electrical system |
| Cap inlet |
| Channel excavation |
| Class 2 concrete (box culvert; headwall; wingwalls) |
| Clean bridge deck, drains, expansion joint |
| Commercial fertilizer (erosion control) |
| Compost (erosion control) |
| Concrete flared end sections |
| Control and neutral conductors |
| Corrugated steel pipes |
| Corrugated steel pipe downdrain |
| Develop water supply |
| Drainage pumping equipment |
| Drill seed (erosion control) |
| Duff |
| Electric remote control valves |
| Electric service (irrigation) |
| Entrance tapers |
| Fiber (erosion control) |
| Galvanized steel pipes |
| Gate valve |
| Highway planting |

| Drainage/Environment/Landscaping |
|---|
| Install manhole |
| Irrigation controller enclosure cabinet |
| Maintain existing plants |
| Manhole frame and cover |
| Modify inlet |
| Mulch (erosion control) |
| Perforated plastic pipe underdrain |
| Place asphalt concrete (miscellaneous area) |
| Place asphalt concrete dikes |
| Place weed control (rubber mat) |
| Plants |
| Plant establishment work |
| Plastic pipes |
| Plastic pipe liners |
| Prepare storm water pollution prevention plan |
| Pressure regulating valve |
| Prune existing plants |
| Pumping plant electrical equipment |
| Pure live seed (erosion control) |
| Quick coupling valve |
| Reconstruct downdrain, inlet, underdrain |
| Reinforced concrete pipes |
| Relocate valve |
| Relocate inlet |
| Rock slope protection |
| Rubberized asphalt concrete dike |
| Salvage rock slope protection |
| Soil treatment |
| Spring check valve |
| Sprinklers |
| Stabilizing emulsion (erosion control) |

| Drainage/Environment/Landscaping |
| --- |
| Station field units |
| Steel flared end sections |
| Straw (erosion control) |
| Supply line (bridge) |
| Temporary fences |
| Temporary sandbag headwall |
| Temporary silt fence |
| Temporary straw bale |
| Topsoil |
| Water pollution control |

| Traffic Signalization/Signage/Striping/Painting |
| --- |
| Barricade |
| Barrier railing |
| Buried post anchor |
| Cable anchor assembly |
| Cable railing |
| Chain link fence |
| Chain link railing |
| Concrete barriers |
| Concrete headlight glare screen |
| Construction area signs |
| Crash cushions |
| Delineator |
| Detector loop |
| Double thrie beam barrier |
| Electrical and instrumental work |
| Emergency vehicle pre-emption system |
| End section |
| Entrance taper |
| Fence |

| Traffic Signalization/Signage/Striping/Painting |
| --- |
| Flashing arrow sign |
| Furnish sign structure |
| Highway lighting |
| Highway post marker |
| Install signs and structures |
| Lighting (temporary) |
| Lighting and communication conduit (bridge) |
| Lighting and sign illumination |
| Markers |
| Message signs |
| Metal (barrier mounted sign) |
| Metal beam guard railings |
| Modify electrical equipment, flashing beacon, lighting, signal and lighting, traffic count and monitoring station |
| Portable radar trailer |
| Quadguard system |
| Quick change moveable barrier system |
| Reconstruct metal beam guard railings |
| Reconstruct thrie beam barrier |
| Relocate chain link fence |
| Relocate mailbox |
| Relocate roadside sign |
| Relocate terminal system |
| Remove beam guard railing |
| Remove chain link fence |
| Remove concrete barrier |
| Remove crash cushions |
| Remove fence |
| Remove headlight glare screen |
| Remove roadside sign |
| Remove terminal section |
| Replace loop detectors |

| Traffic Signalization/Signage/Striping/Painting |
| --- |
| Reset roadside signs |
| Rumble strip |
| Salvage count station, metal beam guard railing, single thrie beam barrier, trail marker |
| Sign illumination |
| Signal and lighting |
| Steel pipes and conduits |
| Terminal system |
| Traffic control surveillance and system |
| Traffic monitoring system |
| Traffic plastic drum |
| Tubular handrailing |

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15. Abstract

This document provides detailed information on the underlying methods and data that CAL-CET2018 Version 1.1 relies upon to (1) estimate project-level equipment activity; and (2) calculate emissions resulting from that activity. CAL-CET estimates exhaust emissions of total organic gases (TOG), reactive organic gases (ROG), carbon monoxide (CO), $NO_x$, $PM_{10}$, $PM_{2.5}$, $CO_2$, methane ($CH_4$), nitrous oxide ($N_2O$), black carbon (BC) from off-road equipment and on-road vehicles, and hydrofluorocarbons (HFC) from on-road vehicles. The tool also estimates PM emissions from area-wide fugitive dust and evaporative emissions from painting and asphalt concrete paving, as well as diesel and gasoline fuel consumption.

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