Project K759 Final Report
CA4PRS Software and Training Upgrade

Executive Summary

The current CA4PRS training program was designed around an application using old technologies including Visual Basic 6.0 and while still supported through the Windows XP platform, it is not widely supported nor functional in Windows 7+. Microsoft no longer supports XP as an operating system meaning that if CA4PRS is not updated the it will be obsolete and non-operational. To ensure CA4PRS' usefulness today and into the future this project was focused on updating and converting the CA4PRS software and training suite to a responsive web-based application capable of being accessed from any device without need for installation support.

Objectives and Benefits

To ensure long term usefulness of the software by today's evolving computing platforms this project will convert the existing CA4PRS training and software into a web-application. Some key benefits of the conversion include:

- Expanding user base by making it accessible to all users despite operating system and device
  Simplifying workflow and interfaces to streamline input and reporting
- Eliminating installation issues that are preventing wider adoption by making it responsive and available on laptops, desktops, tablets, and mobile devices.
- Reducing maintenance and support costs by centralizing the training and application with updates available instantly for all users.
- Streamlined deployment and training process by incorporating in blended learning with in-class and online methods

Results

The project completed all key objectives and launched at the end of 2016. The completed web application suite, Rapid Road Rehabilitation, or R3, contains three applications that allow users to perform functions similar to those contained within the original CA4PRS. These include:

- **Road Scheduler:** Road Scheduler is a web-based tool the allows you to rapidly produce conceptual construction estimates based on limited information describing the physical materials, resources, and time allocated for the project. Road Scheduler can perform 3

types of analyses (construction productivity, traffic impacts, and costs) for 7 types of paving jobs.
- **Work Zone Traffic:** The Traffic Impacts model is the second model in the R3 application suite that allows you to estimate the work-zone traffic impacts resulting from a paving strategy. With this model, you can compare the performance of different closure scenarios by identifying the most severe hours and extent of traffic congestion, as well as the implied value of time lost by roadway users.
- **Cost Estimator:** Cost Estimator is a third model in the R3 application suite that allows you to estimate the total agency cost of a paving job. Cost Estimator is designed to work in tandem with Road Scheduler and the Work Zone Traffic module, the results from which can be used as inputs in Cost Estimator. Nevertheless, Cost Estimator works independently of the other two models and can be used as a standalone application.

The web application along with all training materials are available at: http://rapidroadrehab.headlight.paviasystems.com. This report contains the final users guide for the application.

R3: An Overview

Rapid Road Rehabilitation -- R3 for short -- is an application suite of construction scoping tools aimed to help you estimate construction productivity, traffic impacts from work zones, and total project costs for pavement projects. R3's underlying methods are based on over 40 years of research based on research from University of California in conjunction with Caltrans, the University of Washington, and methods outlined by the Federal Highway Administration, the National Cooperative Highway Research Program, and American Association of State Highway and Transportation Officials.

R3 brings it source methods and research to a web-based platform for the first time, providing a unified medium for collaborative engineering work for developing paving strategies. No installation is necessary, and there are no files to transfer -- all of your work is saved online and accessible anywhere with an internet connection and by all of your team members. R3 also highly encourages collaboration, allowing you and your team members contribute your individual expertises to relevant parts of the model. You can update, expand upon, review, compare your work at any time.

R3 focuses on optimizing the user experience. It's rich but simple interface is accompanied by a wealth of instructive tooltips and learning materials available through the Pavia Academy so that even new users can quickly gain proficiency at using the application. Advanced users can explore the underlying methods and browse recommended values from research and validated case studies developed over the last 15 years.

R3 also focuses on giving you meaningful results that can be easily communicated. The design of R3's reporting system is guided by a principal of clarity - results are reproducible from the information contained in a report. The application's reporting system relies heavily on figures (often interactive) to convey results in a meaningful, but concise manner.

Road Scheduler

Road Scheduler aims to help you figure out how fast you can build your project. Using a basic set of construction specifications and project constraints, the model determines how quickly your pavement can be constructed and helps you identify weaknesses in your paving strategy with a robust, interactive reporting system.

Since we seldom get things right the first time, Road Scheduler includes a comparison feature that allows you compare the performance of alternative paving strategies that may include different closure methods, paving methods, working methods, and alternative closures. Featuring a probabilistic model and a wealth of closure options, Road Scheduler also allows you to incorporate known risks into your model and generates reports that allow you to understand how uncertainty impacts constructability.

Work Zone Traffic

The Work Zone Traffic model allows you to measure the traffic impacts associated with closures due to your paving project. The model is intended for use in tandem with Road Scheduler, but can be used independently. Once you determine your paving strategy, you may use the application determine whether your project will yield acceptable levels of traffic.

With this model, you can estimate and compare the performance of different closure scenarios by identifying the most severe hours and extent of traffic congestion, as well as the implied value of time lost by roadway users. You will need to provide some information about how the roadway operations before and during construction, and the daily traffic patterns through your work zone.

The underlying calculation algorithms are based on methods modified from the 2000 Highway Capacity Manual by AASHTO, the 1996 FHWA Technical Bulletin on Life Cycle Cost Analysis.

Cost Estimator

When you're satisfied with the predicted traffic performance of your project, you can use the Agency Cost Estimator to rapidly scope the affordability of your pavement project even in the face of cost uncertainties. This application facilitates the estimate of key project costs including construction, roadway, total project costs, and escalation and discount adjustments.

Combined with Road Scheduler and the Work Zone Traffic models, the results of Cost Estimator are intended to help you develop a cost-effective construction strategy for your pavement project. Along with construction productivity and traffic impacts, Cost Estimator enables you to incorporate economic considerations into the design of your construction strategy.

How User Guides are Structured for R3 Applications

Overview of Features and Functionality

This chapter of a model's user guide provides a basic overview of the application's features and capabilities and highlights key analysis options currently available. The chapter intends to address the following questions:

- What is the intent of / motivation behind the model?
- How does the model fit into the overarching R3 application suite?
- What does the model calculate?
- What key analysis options are available?

Definitions and Background Knowledge

In this chapter, background knowledge is provided to explain the underlying logic and concepts that are incorporated into the model's algorithms, including model limitations. Although primarily intended for new users unfamiliar with the relevant construction practices, advanced users may benefit from reviewing the concepts presented in this section to ensure clarity. The chapter generally addresses the following guiding questions:

- What knowledge is pre-requisite to use this application?
- What are the limitations or boundaries of the model?
- What are important terms or concepts used in this application?
- What are the underlying methods used in this model (references)?

Simulation Model and Data Requirements

This chapter explains the data required to run each model and improve understanding of how inputs are translated into results. The sections contained in this chapter explain relevant considerations when specifying inputs and how different analysis options will affect the simulation, calculation, or results. The guiding questions addressed in this chapter include:

- What are the data requirements and how do model inputs interact with each other?
- What considerations are important when specifying inputs?
- What are recommended input values based on case studies?

Best Practice Examples

This chapter provides users with a full demonstration on how to successfully run a model. Each section in this chapter contains a walkthrough of each input included in the model using a case study from literature. Generally, the chapter aims to answer the following questions:

- How do I specify input values for this model in the user interface?
- What best practices should I consider when specifying inputs?
- How should considerations and constraints affect how I enter values?
- How do I avoid errors in logic or consistency when filling in this model?

Interpreting Reports

This chapter explains how to interpret the results generated in each report. The chapter is intended to help you answer the following questions:

- How do I interpret the results of this model?
- How can I interact with certain results in the report?
- How might the results in the report be leveraged for other analyses?

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1.0.0. Overview of Features and Functionality

The section in this user guide define key features offered by Road Scheduler and provide conceptual knowledge on how the simulation is structured.

Road Scheduler is a web-based tool the allows you to rapidly produce conceptual construction estimates based on limited information describing the physical materials, resources, and time allocated for the project. Road Scheduler can perform 3 types of analyses (construction productivity, traffic impacts, and costs) for 7 types of paving jobs. Additionally, the analysis for construction productivity features a probabilistic model (as opposed to the default deterministic) to provide more descriptive results and is discussed in more detail in Section 1.0.3.

Because the data requirements to run the simulation can be complex, the overarching goal of the user guides is to provide you with a structured explanation of:

1) What the application can do (User Guide 1.0, the current document)
2) What conceptual knowledge is required to use the application (User Guide 1.1)
3) What information must be specifically collected and considered (User Guide 1.2)
4) How to run a simulation with an illustrated demonstration (User Guides 1.3-4)
5) How to interpret the results in the detailed report (User Guide 1.5)
6) How to generate and interpret a comparison report (User Guide 1.6)

In particular, the user guides in this section will answer the following questions:

1.0.1: What kinds of analyses can the application perform?
1.0.2: What paving methods does the application support?
1.0.3: How do the deterministic and probabilistic methods used by the application work?
1.0.4: What assumptions does the model make, and what is included in the simulation?
1.0.5: What is included in reports and how a comparison report differ from a detailed report?

1.0.1. Analysis Methods

Road Scheduler enables users to rapidly estimate the scope of their paving job in terms of construction time, traffic impacts, and cost efficiency, even if only basic knowledge is available for the project itself. The app also allows users to compare alternatives such as paving methods, closure windows, detour impacts, and life-cycle costs. Scoper enables users with little background in pavement construction to quickly provide reasonable decision-making estimates for paving jobs.

R3 is capable of measuring three performance characteristics of a paving job:

(1) Productivity Analysis, which addresses construction productivity and paving;
(2) Work-zone Analysis, which addresses traffic impacts and user costs; and
(3) Agency Costs, which addresses the life-cycle cost performance of the pavement

We will focus solely on Schedule Analysis in this series.

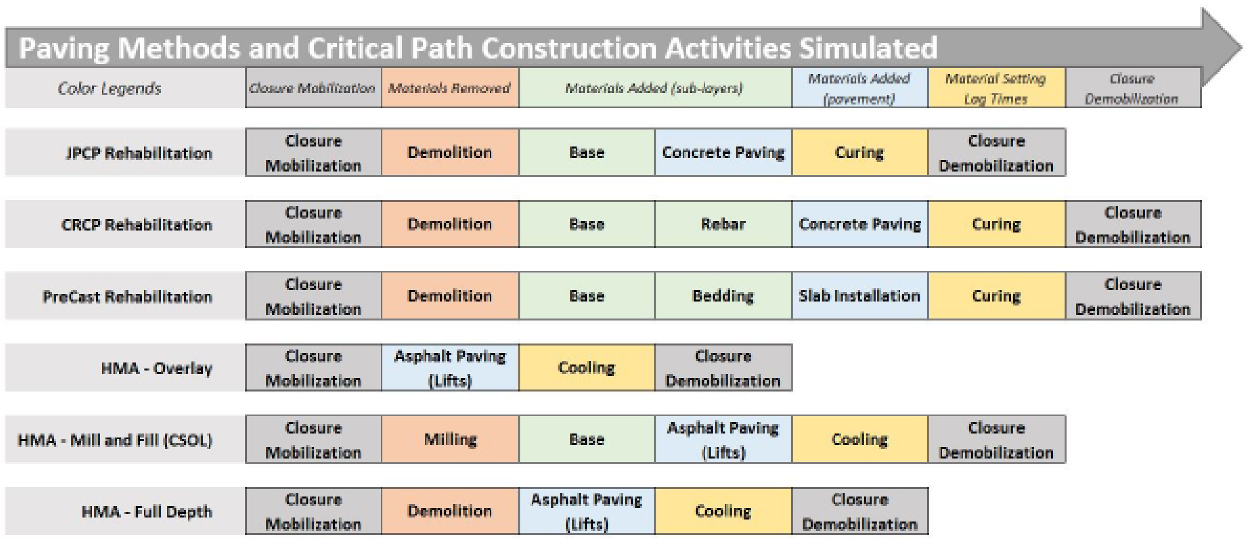
The above analyses are available for all paving methods (discussed in 1.0.2), but only the Production Analysis offers a probabilistic analysis option (discussed in 1.0.3).

After selecting a paving method, all analysis options become available to you. However, analyses must be completed sequentially, e.g. Work-zone Analysis depends on the inputs and results of the schedule analysis. You start by entering information relevant to paving productivity, followed by traffic conditions, and finally cost parameters information. A more in detailed description of the data requirements for each analysis method is provided in User Guide 1.2)

1.0.2. Paving Methods

It is important to understand how Road Scheduler conceptualizes a paving job because the activities involved determine what resources are required and specifications you must provide for them. While this section provides a conceptual overview of the application functionality, User Guide 1.2 provides a more detailed discussion of the data collection requirements for each paving method.

Road Scheduler is currently capable of modelling 7 types of paving methods, including full replacement and rehabilitation jobs. For a given paving method, the Road Scheduler simulates critical path construction activities that determine overall per closure paving productivity. A conceptual map below illustrates the construction activities modelled by Road Scheduler for each paving method.



Note that closure mobilization and demobilization activities are included for all paving methods. This is discussed in more detail in User Guides 1.1.5 and 1.2.4.

Road Scheduler determines the limiting equipment or resources for each activity based on the specifications you provide and subsequently sequences and visualizes the productivity schedule in the output of the analysis.

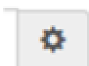
1.0.3. Analysis Type: Deterministic vs. Probabilistic

Road Scheduler offers two types of analyses for all paving methods that differ in terms of their input requirements and subsequently, the types of outputs and results possible. It is important to understand that the Deterministic method method provides single-value results while the Probabilistic method reports results with a range, qualified with a confidence interval, and statistical descriptors.

The deterministic method makes single-values parameter estimations to produce results and does not involve any statistical calculations. The method is substantially faster to simulate, has fewer input parameters to consider, but is only capable of providing single-value results.

The probabilistic method has steeper data requirements but is capable of providing more detailed results, including confidence intervals, sensitivity charts, closure productivity distributions. With this method, the user may choose which input parameters the application should consider a random variable (probabilistic).

Input values that can be specified as probabilistic will feature a ‘gear’ shaped icon on the right side of the field.



If a user designates a variable as probabilistic, the user must also specify a distribution for the variable and the distribution’s parameters, as well as simulation conditions. Chapter 1.2.7 provides more detailed discussions on selecting distributions and values. The basic differences are summarizes in the table below:

	Deterministic	**Probabilistic**
Input Requirements	Single-value estimates	Distristribution type and parameters
Outputs Possible	Single-value estimates Closure productivity charts	Standard Deviations Minimum / Maximum Adjustable Confidence Intervals Closure productivity distribution Sensitivity Charts
Underlying Method	Expected value based on single-value average estimates	Monte Carlo Simulation

There are several additional differences between deterministic and probabilistic variables worth noting:

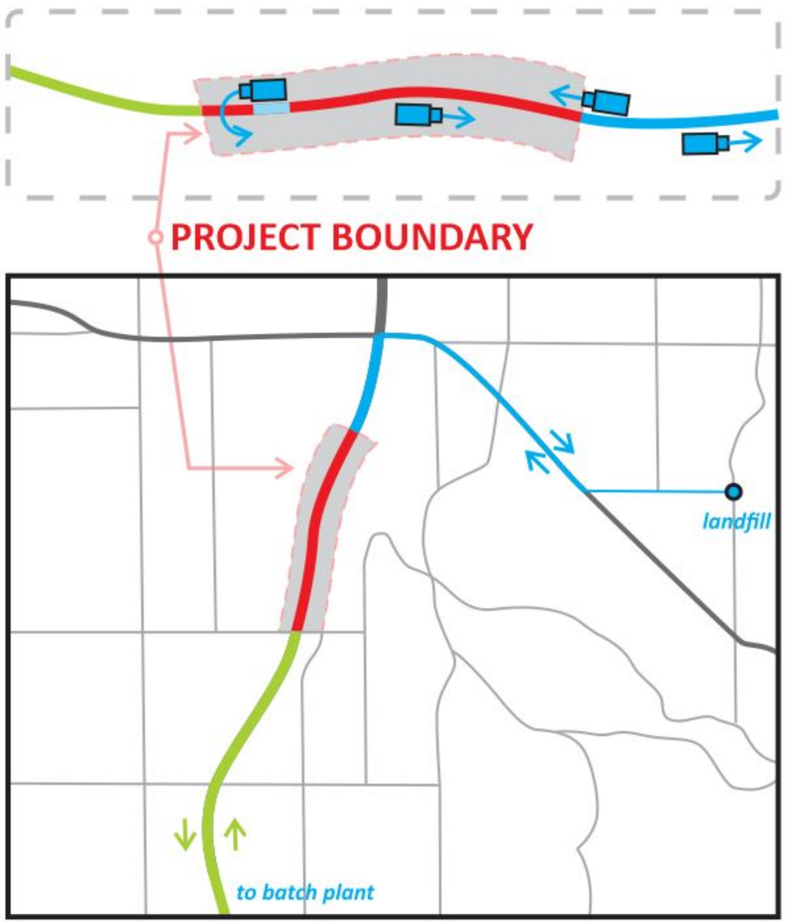
- Some deterministic variables may not be specified as probabilistic (e.g. number of teams).

- In a deterministic analysis, production resources with multiple units or teams specified are assumed to perform equally. This is not true for the probabilistic model: each instance of a unit is simulated with a different value based on distribution parameters specified by the user.
- The probabilistic analysis may only be applied to the productivity analysis (i.e. not cost and traffic)

1.0.4. Simulation Boundaries and Model Assumptions
The quality of results produced by Road Scheduler is influenced by the quality of data you provide. This guide is intended to describe how the application conceptualizes the construction site and provide you with considerations when selecting input values. This section lists key modelling assumptions that describe the simulation boundaries and may influence how you should interpret results. Furthermore, this section should also make you aware of current modelling limitations.

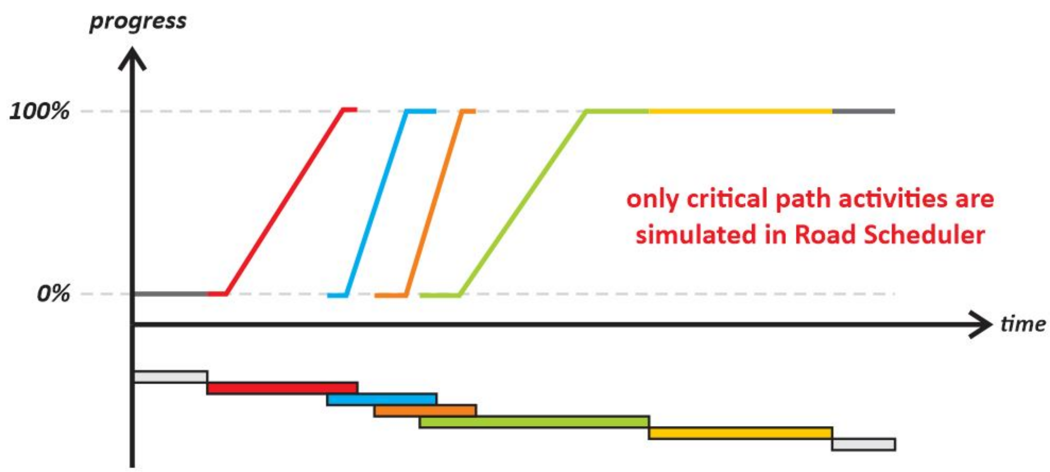
The assumptions and model limitations are generally listed in order of descending importance:

- The project boundaries includes the extent of the job site itself, plus the material production plant and hypothetical hauling/landfill site (illustrated in figure below). Consequently, analysis does not account for activities that may occur outside these boundaries, e.g. truck driving time, traffic accidents.



- The destination of demolished materials is assumed to be off-site and therefore excluded from the simulation. By doing this, Road Scheduler is assuming that the materials in question are stored in a location that does not obstruct construction. This may not necessarily be true in reality.

- The activities included in the analysis are modelled as critical-path activities in the construction schedule of a single closure. Activities such as compaction are not simulated because they are not considered a limiting resource on a critical path activity such as paving.



- The analyses (productivity, traffic, cost) are sequential: some productivity inputs are used in the traffic and cost analysis and are effectively prerequisite inputs. See User 1.2.

- The productivity analysis does not utilize traffic data. In other words, material haul / delivery times are considered constant and identical.

- The application assumes that Construction Activities have a constant productivity rate. Activities which do not progress the overall pavement progress are considered lag activities with a productivity rate of 0.

- The current version of Road Scheduler does not distinguish reused or recycled material in total material calculations.

1.0.5 Reporting Features

Road Scheduler features two ways of reporting productivity results: a detailed report for a single simulation, or a comparison report for two more more completed simulations.

Successfully completing a simulation in road scheduler will always produce a detailed report. So that results may be reproduced, the detailed report includes all input information pertaining to the project and current simulation. The key features of a detailed report include:

Detailed Reports in Road Scheduler - Summary of Content

Section	Contents
Project Details	Project information, including year of construction, project location, analysis method, paving method, and simulation identifiers
Project Scope	Geometric information about your simulated paving project, including lengths, thicknesses, areas or volumes
Overall Analysis Results	Key results such as closures, progress per closure, total project duration and effective construction time (per closure)
Linear Productivity Diagram	Visualization summarizing construction progress over time (per closure). For asphalt paving methods, the paving activity is further partitioned into lifts.
Single Closure Schedule	Includes a Gantt Chart of critical path activities modeled in the simulation, and a tabular summary of numerical details included in the chart.
Closure Productivity Histogram	Probabilistic Analysis Only. Histogram showing the distribution (relative frequency) of required number of closure windows to complete a project.
Parameter Sensitivity Analysis	Probabilistic Analysis Only. Spearman Correlation coefficients indicating input parameters that are most likely to have an impact on overall closure productivity if modified.
Resource Profiles	Summary of numerical inputs provided for each paving activity and their associated human or equipment resources. For asphalt paving methods, a summary of lift characteristics is also provided here.

In contrast, the comparison report is not automatically generated but performed manually after successfully creating and running at least two simulations in Road Scheduler for the same project. The comparison report includes a tabular summary of key outputs for selected simulations in addition to an abridged version of the detailed report for each simulation included. The intent of the comparison tool is to provide enough information to distinguish characteristics of included simulations as well as to highlight important metrics of project performance (e.g. material scopes, progress per closure, overall project duration). By comparing the results of multiple simulations, you will be able to evaluate and select better alternative construction strategies for your pavement project.

1.1.0. Definitions and Background Knowledge

The sections in this user guide provide conceptual knowledge and terminology important to understanding how pavement construction is performed and subsequently simulated by Road Scheduler.

Road Scheduler may be used by even those with a limited understanding of pavement construction. This user guide is intended to outline important construction concepts and considerations that are embedded into the logic of Road Scheduler as well as clarify or distinguish terminology used by the application.

If you possess a background in civil engineering, construction, development, or project management, you may find this particular user guide redundant. In this case, this user guide may serve as a refresher of relevant construction principles. Otherwise, you may consider skipping to the next section on simulation data requirements (User Guide 1.2).

In particular, the user guides in this section will answer the following questions:
1.1.1: What concepts require definition, clarification, or distinction to fully comprehend the terminology used in the application and user guides?
1.1.2: Why are pavement materials and geometry important to specify?
1.1.3: How does Road Scheduler sequence construction activities?
1.1.4: How does specifying a closure duration affect the productivity analysis?
1.1.5: Why is important to distinguish closure and activity mobilization/demobilization?
1.1.6: What characteristics of resources and equipment influence the rate at which construction activities are completed?

1.1.1. Key Terminology and Units

What concepts require definition, clarification, or distinction to fully comprehend the terminology used in the application and user guides?

This User Guide provides definitions to basic terminology used in Road Scheduler. Because these terms are used repeatedly, it is important to clarify how you should interpret them in the context of this application.

Analysis Options

Term	**Definition / Description**
Analysis Type: Deterministic or Probabilistic	A deterministic analysis implies that each parameter is specified as a single value. A probabilistic analysis means that one or more parameters is specified with a probability distribution and converts the analysis into a Monte Carlo simulation. In this case, additional analyses are possible and included in the reporting session, including a productivity distribution histogram and a parameter sensitivity analysis
Pavement Type	The pavement type refers to the specific methods and pre-defined construction activities required to produce the pavement. You must specify pavement type before proceeding because the activities and inputs required will change depending on your selection. Road Scheduler currently includes 3 asphalt-related methods and 3 concrete-related methods.

Closure and Working Windows

Term	**Definition / Description**
Working Window	The working window (or closure time) refers to the continuous length of time in which a section of pavement is closed to traffic and available for construction. Road scheduler assumes that all working windows begin with a closure mobilization and end with a closure demobilization lag activity. A working window may contain multiple lag or construction activities. It may not be possible to utilize the entirety of a working window because of resource constraints, and a pavement job may require multiple working windows to complete.
Weekend Closure	This closure window implies that construction is continuously active for an entire weekend, spanning Friday evening to Monday morning. The window is at least 48 hours (Saturday and Sunday) plus any additional hours from Friday evening and Monday morning when the road is reopened to traffic. A typical weekend closure length is 55 hours, for example.
Nighttime Closure	For this type of closure, construction is active for the duration of a single evening with a typical duration of about 10 hours until the

	road is reopened to traffic.
Continuous Closure (Continuous Operation)	This type of closure refers to a working window in which construction is continuously active for the full duration and can span any number of hours. Although weekend and nighttime closures technically qualify as continuous closures, this type typically spans multiple days (more than a weekend).
Continuous Closure (Shift Operation)	In this type of closure, construction is allowed for only a certain number of hours for the day but the site otherwise remains closed to traffic for the entire duration of the closure. For example, if a shift operation is allowed for only 16 hours per day for a 72 hour closure, then a total of 48 hours will include active construction but the road is closed to traffic for entire closure duration.
Concurrent Construction	This refers to the constraint of whether two adjacent construction activities may begin simultaneously on the job site, assuming spatial and temporal constraints are satisfied. This is opposed to sequential construction in which activities may only begin after the previous activity is fully completed (i.e. including activity mobilization and demobilization times). Road Scheduler assumes sequential construction by default.
Working Method (Asphalt paving only)	Road Scheduler offers 3 options for paving asphalt lifts. [1] A full closure implies that all lanes are closed to traffic. [2] A half closure with full completion means half the lanes remain open during construction, necessitating additional time to mobilize equipment to switch paving and traffic lanes. All lifts must be paved by the end of a closure [3] A half closure with partial completion is similar, but a paving operation is stopped after a specified number of lifts are completed in each lane. However, a separate analysis must be run to complete any remaining unpaved lifts.

Types of Activities

Note: more detailed discussions are provided in subsequent chapters since activities depend on the paving method.

Term	Definition / Description
Critical Path Activity	A critical path activity refers to an activity where a change in duration would affect the overall construction productivity. In Road Scheduler, all simulated activities are considered critical path activities; activities which are not considered critical (or potentially critical) path are omitted from simulation. Unless otherwise specified, assume that Road Scheduler documents only refer to critical path activities.

Construction Activity	In Road Scheduler, this refers to an activity which physically involves the physical production, transportation, or placement of materials in a new or existing pavement. All construction activities may include 2 lag activities: a mobilization lag time prior to the activity, or a demobilization lag time after the activity.
Lag Activity	In Road Scheduler, this refers to an activity in which no actual progress is made in terms of pavement construction or demolition, but is necessary to preparing or dismantling activities. Lag activities are designated only with a lag time or duration (typically in hours). Examples of lag activities include: ■ mobilization / demobilization (for closure or activity) ■ concrete curing and asphalt cooling ■ traffic switch times
Closure Mobilization or Demobilization	Closure Mobilization is the first activity in considered in a closure for any paving method and is one of many lag activities considered in the simulation. Closure mobilization is the first critical path activity considered in the productivity analysis and it is typically followed by a demolition activity. Hours refers to the amount of time required to initially set up or stage equipment and crew for a single paving closure. Similarly, Closure Demobilization is the final activity for all closures (regardless of paving method) that influences when a road can be re-opened to traffic. This duration is compared to any post-paving activities (such as curing for concrete-based pavements) to determine which activity restricts the re-opening time. For example, if the entered time is smaller than curing time, Curing will be the activity that determines the re-opening time. Hours refers to the amount of time required to dismantle equipment, clean up the workspace, and/or prior to re-opening the road to traffic (excluding any curing time) for a single construction closure.
Activity Mobilization or Demobilization	Construction activity mobilization refers to additional time to stage, prepare, or transport equipment, materials, or crew prior to beginning the activity. Similarly, activity demobilization refers to additional time to dismantle equipment or clean-up after the activity is completed. For concurrent construction, these lag times may include 'buffer' times required to maintain safe or adequate spaces between sequential construction activities.
Traffic Switch Time (Asphalt Paving only)	Traffic switch time is a lag activity for that refers to the amount of time required to re-mobilize equipment and materials to switch the lanes to be paved and the lanes open to traffic. This lag duration can be substantial with longer paving jobs because a paving machine must travel to the endpoints of a paving segment without advancing the overall construction progress.
Curing (Concrete Paving only)	Curing refers to the time required for a concrete-based pavement to cure before being considered structurally acceptable for handling live traffic loads, excluding any hours for closure demobilization. This duration is compared to the Closure Demobilization time to determine which activity governs the re-opening time after all paving activities are completed. For example, if curing time is shorter than closure

	demobilization, the closure demobilization time will determine the re-opening time."
Cooling (Asphalt Paving only)	Cooling refers to the duration of time required for an asphalt-based pavement to cool and gain sufficient structural capacity to be re-opened to live traffic loads, excluding any hours for closure demobilization. Similar to curing, this duration is compared to the Closure Demobilization time to determine which activity governs the re-opening time after all paving activities are completed.

Materials and Resources

Term	**Definition / Description**
Base and Subbase	Base refers to the the layer directly beneath asphalt or concrete pavement and above the subgrade. If present in a pavement design, a subbase lies between the base and subgrade. Both are typically composed of crushed aggregate rock. Subgrade: the existing soil beneath the base or subbase of a pavement
Subgrade	the existing soil beneath the base or subbase of a pavement
Pass	A pass refers to the number of times a construction unit must perform work over a particular area to reach a particular paving objective, such as compaction. The number of passes required increases the amount of time required to completely a construction activity.
Lift	A lift refers to the number of sequentially placed material layers required to reach the objective total layer thickness, such as with asphalt paving. The need to pave in lifts occurs as a result of paving equipment limitations and material properties, as paving machines can only place several inches of material per pass. The number of lifts is related to the number of passes, and ultimately influences closure productivity.
Resource or Productivity Rate	Road Scheduler assumes every layer in a construction activity is potentially associated with material, labor, and equipment. For materials or equipment, a resource rate can refer to the production, placement, or haul/delivery rate. For labor, the resource rate refers to how quickly a labor crew can complete a task. A construction activity may require multiple resources, but only one resource rate is considered limiting to the production rate of the activity.
Trucks per Hour (per team)	The number of trucks arriving each hour (for each team) influences how quickly delivery trucks can work towards meeting a paving objective. A job site's capacity to receive (or remove) material deliveries per hour is ultimately constrained by the duration of tasks specific to a construction activity (e.g. unloading, turn-around time, cleaning, etc.). It is important to note that the trucks per hour is not the same as a fleet size, which is not specified on a per hour basis.

Report / Results

Term	**Definition / Description**

Linear Productivity Diagram	The Linear Productivity Diagram visually conveys the progress made in a single closure as well as the duration and completion rate of each construction activity involved in the paving method. Each colored line represents a different activity where the slope indicates the overall completion rate of each construction activity (gentler slopes are slower activities). These line segments span the same vertical distance because each activity must make the same linear paving progress each closure. Horizontal bars that trail on the ends of each activity indicate lag times associated with activity mobilization or demobilization lags (closure mobilization and demobilization are colored separately since they are considered their own activity).
Gantt Chart	The Gantt Chart for a single closure provides a visual summary of construction activity durations and their sequencing relative to each other. The chart also indicates where lag activities occur, allowing you to identify potential spatial or scheduling conflicts and restrategize the closure as needed. It is important to note that Road Scheduler only includes critical path activities related to the pavement operation in the Gantt chart.
Confidence Interval	The 95% confidence interval refers to the range of overall closure productivities that will capture 95% of all simulated results (based on 2000 iterations). The width of this range is generally indicates the degree of variability in your distribution specifications for each probabilistic input. Narrower ranges indicate that you have specified your inputs with little variation, or those inputs do not affect the variation in results substantially.
Productivity Histogram (Required Number of Closures) (Probabilistic methods only)	The horizontal axis represents the closure productivity (feet per closure) and the vertical axis indicates the relative frequency (% of all iterations for the simulation). The bin width is found by taking the difference between the minimum and maximum productivity found in the simulation and dividing this into 10 equally spaced bins. 1 additional bin is added on either of these extrema for a total of 12 bins that completely capture the extents of simulation results.
Parameter Sensitivity	The Parameter Sensitivity table conveys how sensitive results are (per closure productivity) to a unit change of value for each parameter that you have specified with a probabilistic distribution (i.e. all non-deterministic inputs). Here, results are reported as Spearman coefficients (correlation) with a range of [-1, 1] and visualized in a tornado chart. If no parameters are specified as probabilistic, this chart will not appear.
Spearman Coefficient	In this case, the Spearman Coefficient conveys a measure of statistical dependence between the productivity (lane-miles per closure) and each probabilistic variable. Positive values suggest that increasing a parameter value will positively affect (increase) the overall closure productivity (positive correlation); conversely, negative values mean increasing a parameter value will reduce productivity (negative correlation). A coefficient of 1 indicates perfect correlations; a coefficient of -1 indicates perfect negative correlation.
Resource Utilization	The Resource Utilization table compares the theoretical productivity rates to the balanced rates found by identifying the slowest resource for each construction activity as implied by your specified resource characteristics. Additionally, the theoretical overall completion rate of each resource is reported and ranked.

	Allocated refers to the amount of resources you have specified for a given piece of equipment or labor crew. Utilized refers to the actual amount of resources used in the simulation based on the principle of balancing productivity rates for a given construction activity. This can occur when multiple resources are involved in the same construction activity: the activity can only progress as quickly as the slowest resource. This is important to understand in order to identify resource inefficiencies and limiters of closure productivity.
Effective Completion Rate	The Effective Completion Rate reports the theoretical linear rate at which a resource can work towards completing its scope within a single closure. The calculation considers that each pavement layer specified provides a different physical scope of work and that each resource can operate at different rates. The resulting values convey how quickly each machine could complete its task and are equal to the slopes implied in the Linear Productivity Diagram.
Constraining Resource	A constraining resource implies that its associated activity AND overall closure productivity will be affected by changing the nominal production value you have specified for that resource. It is essential to understand that a constraining resource is found on a per-activity basis rather than by-resource: slowing down a resource will not affect the completion rate unless it becomes the slowest resourced involved in a particular construction activity.
95% Confidence Interval	For a given parameter or result, the 95% confidence interval indicates a range between which 95% of the 2000 simulation iterations fall, and centered around the mean. The values of this range can be found by adding or subtracting 2 standard deviations from the mean value reported for the current Monte Carlo simulation.
Pavement Profile	The Pavement Profile summarizes geometric details of the paving job implied by your inputs. Note that the table includes only layers with thicknesses (e.g. rebar, bedding, curing, cooling are not included since they do not contribute to the overall pavement thickness). The table conveys more detailed information than the Project Scope section because it elaborates on the scope of work for each layer and the amounts of materials processed in each construction activity.

Weight versus Volumetric Units:
Equipment and resources specifications are sometimes expressed in terms of volume, while other times in weight. The units generally depend on whether one is referring to concrete-related resources, for which volumetric units are more commonly specified, or asphalt-related resource, for which weight units are more common.

Acronyms

CRCP	Continuously reinforced concrete pavement
CSBC	Crushed surface base course
CSOL	Crack, seat, and overlay (paving rehabilitation method)
CSTC	Crushed surfacing top course; a type of base material

FC	Full closure (asphalt paving)
HCFC	Half closure with full completion (asphalt paving)
HCPC	Half closure with partial completion (asphalt paving)
HMA	hot mix asphalt
JPCP	Jointed plain concrete pavement
LCA	Life-cycle assessment
LCCA	Life-cycle cost analysis
PCC	Portland cement concrete
RAP	Recycled asphalt pavement
RCP	Recycled concrete pavement
WMA	Warm mix asphalt

1.1.2. Pavement materials and geometry

Pavement Materials and Geometry define the physical project sizes and material quantities.

Road pavement operations fundamentally involve the removal (or repair) of material from an existing pavement section, followed by the addition of new (or recycling of existing) layers of materials to form a new pavement. In order to calculate and compare the physical quantities necessary to achieve the project objective, Road Scheduler requires the following geometric information and project details of:

(1) Road length
(2) Number of lanes, respective widths and directions of travel
(3) Material identity and densities
(4) Lift or layer thicknesses
(5) Changes in road geometry and elevation

These quantities are useful physical descriptors of project size that affect considerations in activity scheduling, project scoping, life cycle cost analysis (LCCA), and life cycle assessment (LCA), and alternative comparisons. With this information, useful comparisons can be made, including:

- Material quantities is returned to landfill, recycled, reused, or added
- Net change in material added or removed from a pavement
- Differences in material quantities among alternatives

User Guide 1.2 provides instructions on the specific physical and geometric data you should collect and describes how this information influences closure productivity.

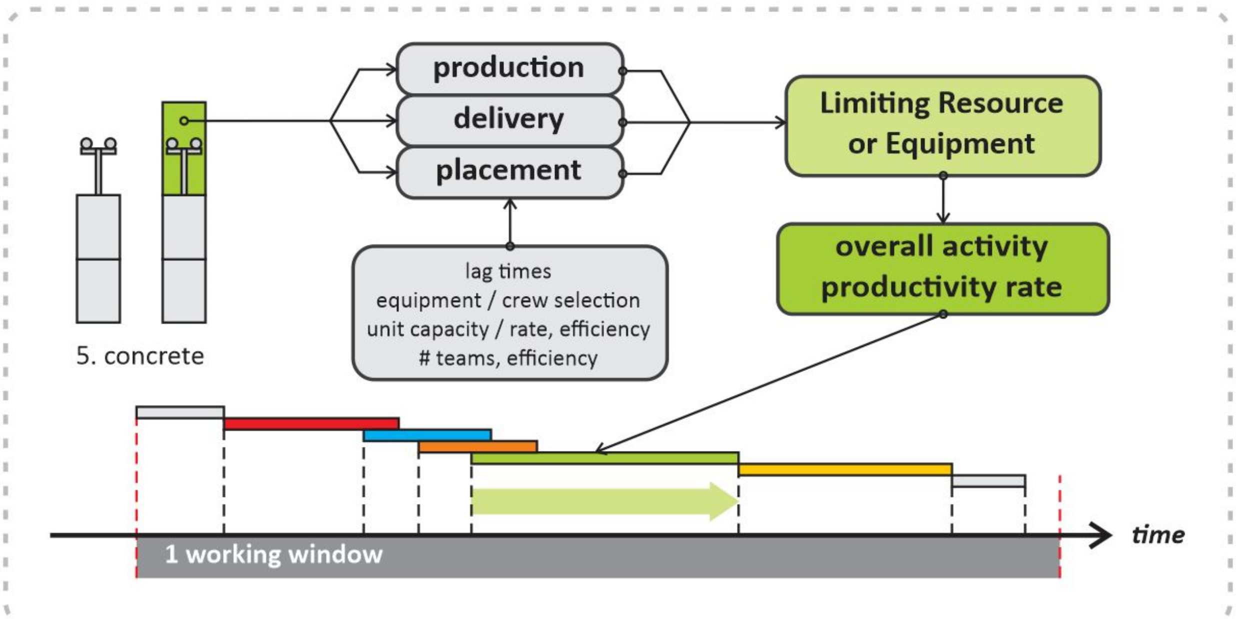
1.1.3 Balancing Productivity Rates

For activities involving multiple human or equipment resources, the overall activity completion rate is limited by the rate of the slowest or least efficient resource.

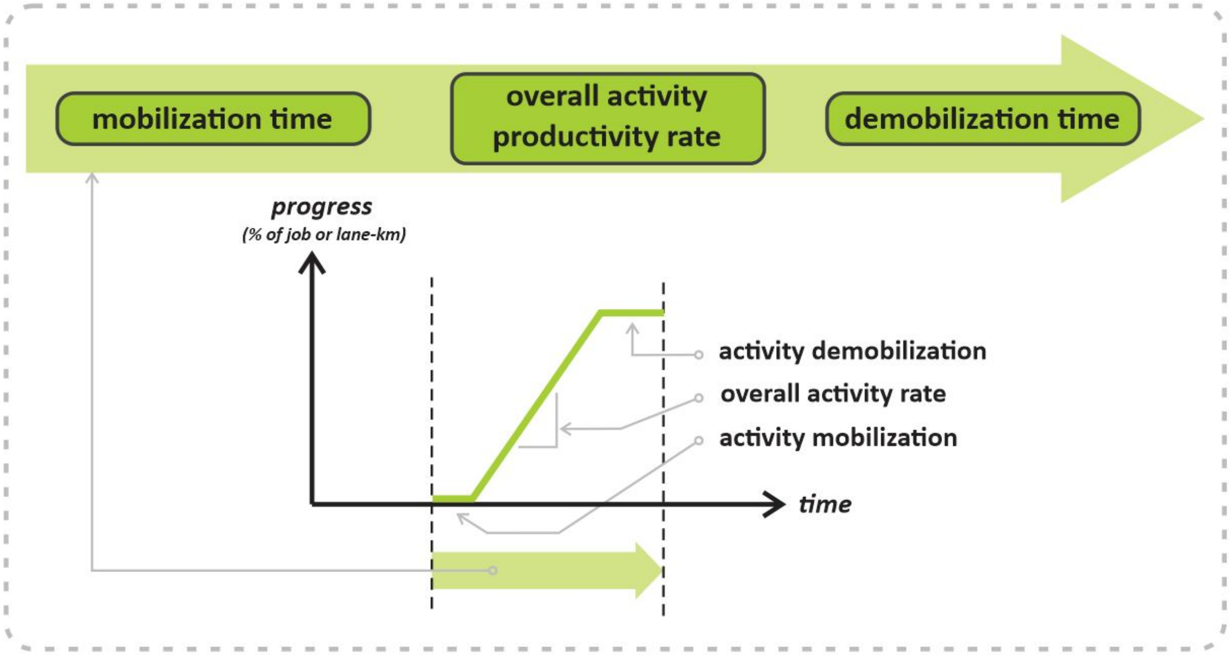
A core concept underlying the Road Scheduler simulation model is the principle of balancing productivity rates. In Road Scheduler, this translates into 4 constraints that dictate how the model effectively balances resource productivity rates based on your inputs:

- An activity can only be completed as quickly as the slowest resource involved - the corresponding resource is referred to as the limiting resource for that activity.
- The rate of the limiting resource for a given activity is responsible for the overall rate of the critical path construction activity
- Other resources involved in the activity must reduce their production rate to the limiting resource rate to avoid spatial or time conflicts; this may lead to some specified resourced being underutilized
- The activity is completed at a relatively linear rate implied by the limiting resource

This concept is depicted for a concrete paving activity in the figure below:



In this example, the activity highlighted in green is one of many critical path construction activities included in this paving operation. The activity's effective productivity rate is influenced by 3 resources: the batch plant production rate, the material delivery rate to the construction site, and the rate at which a paver can place materials. Road Scheduler considers your specifications for <u>each</u> involved resource (e.g. truck capacities, pavement geometry, teams, and efficiencies) and determines the equivalent linear rate at which construction may progress (i.e. feet or meters per hour). Road Scheduler then selects the smallest of these as the overall activity completion rate and the corresponding resource as limiting.



Additionally, Road Scheduler will reduce the productivity rates of other non-limiting resources involved in an activity. This is necessary because resources may otherwise operate too quickly and cause spatial or scheduling conflicts. In this example, if Road Scheduler determines that the delivery rate of paving materials is limiting, both the production rate of the batch plant and paver are reduced until they match the rate of the limiting resource. This implies that values specified for batch plant capacity and paver speed will be underutilized since both resources could have performed at higher rates if they were not limited by the material delivery rate. The determinations of limiting resources is reflected in Road Scheduler's report sections on resource utilization levels and listing of most constraining resources.

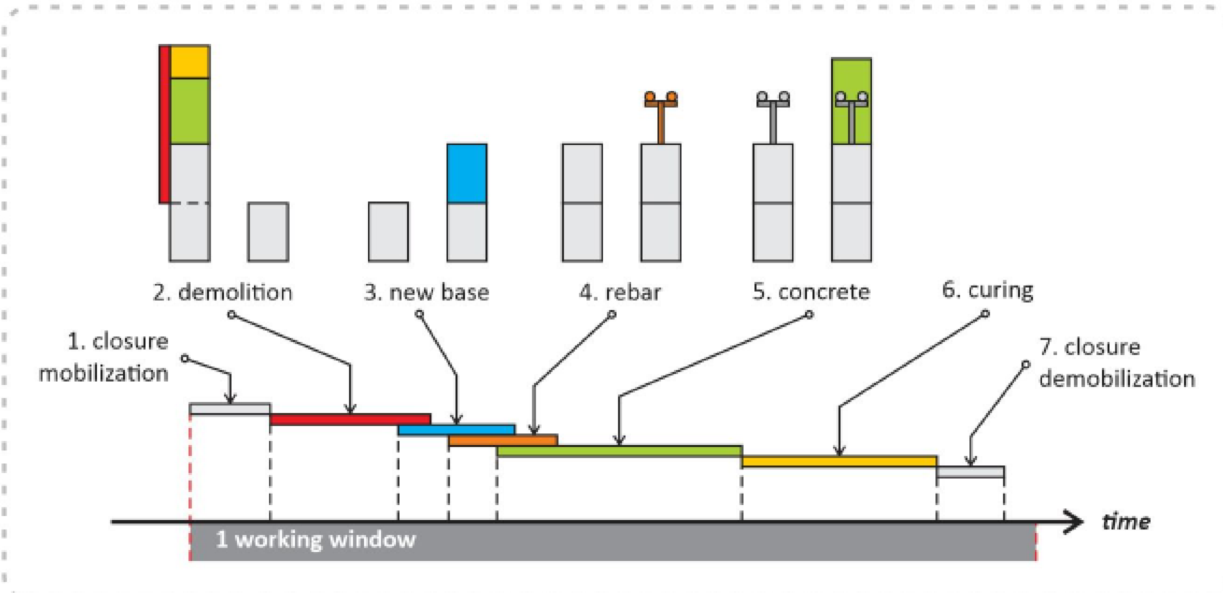
Finally, it is important to understand that Road Scheduler compares resource productivity rates based on their equivalent linear completion rate because it accounts for the possibility that resource rates are specified in a variety of different unit rates. For example, paver rates are specified in linear distance per unit time, and transportation-based resources specified in volume or tonnage capacity per unit time. By incorporating the physical geometry (depth, lanes numbers and widths) of your pavement project or commonly used density specifications for paving materials, Road Scheduler converts all rates into equivalent units (such as volume per hour) before determining the equivalent linear resource rate.

By understanding how Road Scheduler balancing production rates, you may develop a deeper conceptual understanding of the underlying model assumptions. This may be particularly true when trying to modify and improve the performance of your paving strategy when developing alternatives. In practice however, it is still possible to successfully run Road Scheduler without fully understanding the nuanced underlying model complexities.

1.1.4 Sequencing Pavement Layers and Lifts

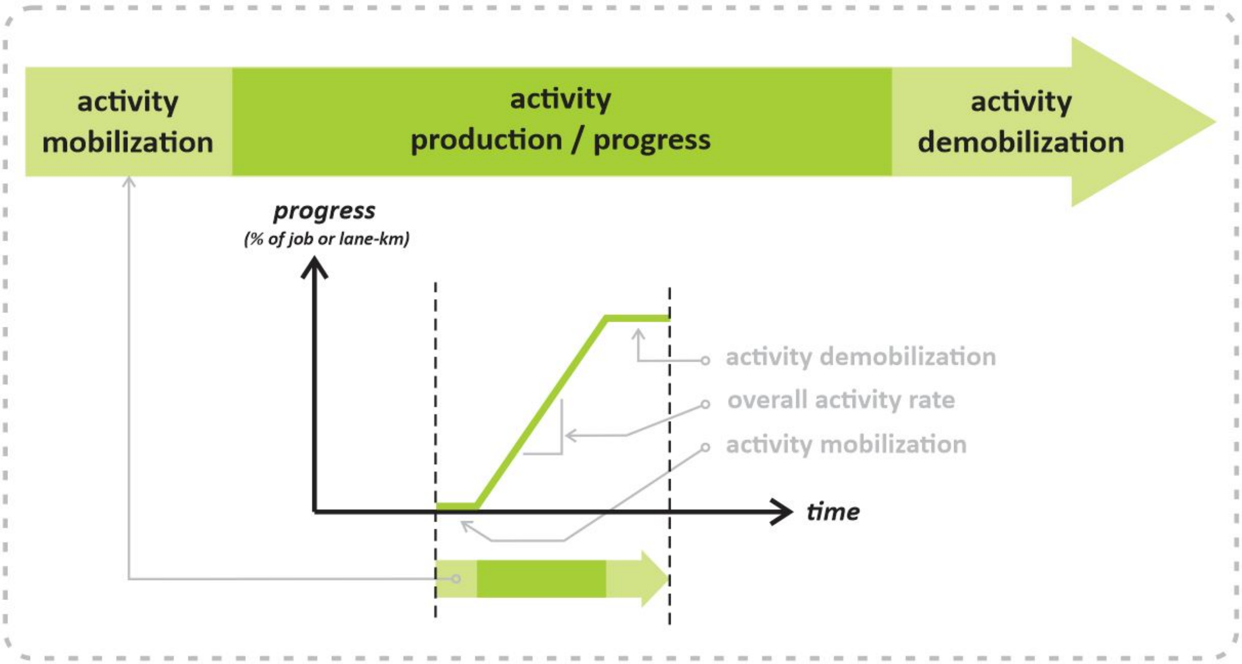
The sequence of pavement layers and lifts determines the order and type of construction activities.

The sequence in which materials are removed or placed is briefly discussed in this user guide because the order of material layers ultimately determines the order of construction activities. Furthermore, this section introduces you to linear productivity charts because they serve as useful tools for explaining how Road Scheduler visualizes construction activities. Consider a typical working window for a CRCP paving job below as depicted below:

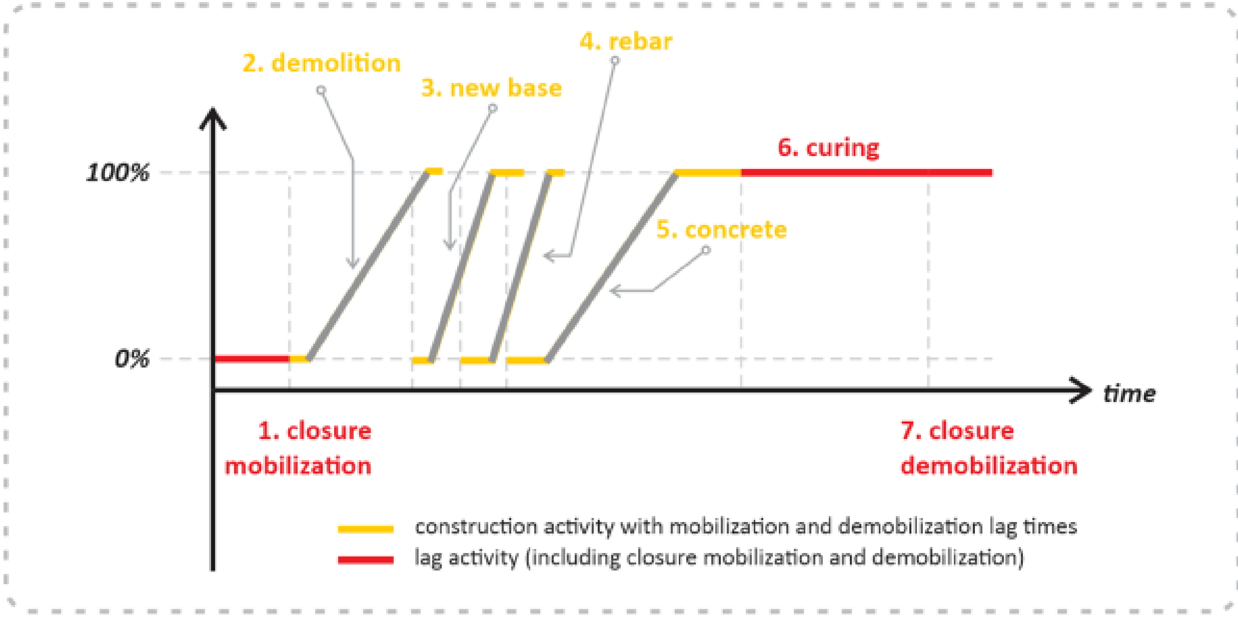


Although the sequence of construction activities depends on the paving method, Road Scheduler assumes closures include a closure mobilization and demobilization activity (activities 1 and 7). Otherwise, other critical path tasks within the closure can be a construction activity (activities 2-5) or a lag activity (activity 6).

Road Scheduler visualizes its results graphically using a linear productivity chart where the horizontal axis represents time and the vertical axis is progress measured in linear miles completed (or as a %). Lag activities are represented by horizontal segments because no progress in made on the actual pavement (activities 1, 6, and 7).



Additionally, construction activities are represented by sloped segments with horizontal bars on either end. Similar to lag activities, the horizontal bars represent mobilization and demobilization but are specific to a construction activity; the slope represents the rate at which the activity is completed as shown in the figures below.



Paving in Lifts for Asphalt Paving Methods

In some cases, a material layer may be placed in one pass while in others, the objective layer thickness must be achieved with multiple passes or 'lifts' (as is the case with asphalt paving operations). The lift thickness is a fraction of the layer's total thickness and generally constrained by the paving equipment's capabilities or mix design. By the end of a single paving closure, all lifts included in the operation must be the same length aside from tapering the ends of each lift to ensure continuity with the existing roadway elevation. In the current version of Road Scheduler, each lift is assumed to be the width of a single lane. Consequently, each lift is represented by a line segment rather in a linear productivity diagram (as opposed to a single line segment to represent the entire paving activity).

The overall paving activity may include an activity mobilization lag prior to the first lift and lane, and/or a demobilization lag activity following the final lane and lift. Additionally, each lift may also include its own lag time and is represented by typically short horizontal segments at the end of each lift, similar to activity mobilization/demobilization. This generally occurs for two reasons:

- First, because paving is always performed in the same direction, a paver must return to its starting point before beginning another lift. This travel time is often referred to as the 'paver turnaround time) incurs lag time because no construction occurs but is typically very short because pavers travel substantially higher velocities when travelling compared to paving.
- Second, each lift requires time to cool before an additional lift can be paved over it. If a paver is ready to proceed the lift below has not had sufficient time to cool, then the paver must wait. If this situation occurs, additional lag time is incurred and is sometimes referred to as the 'suspended time'

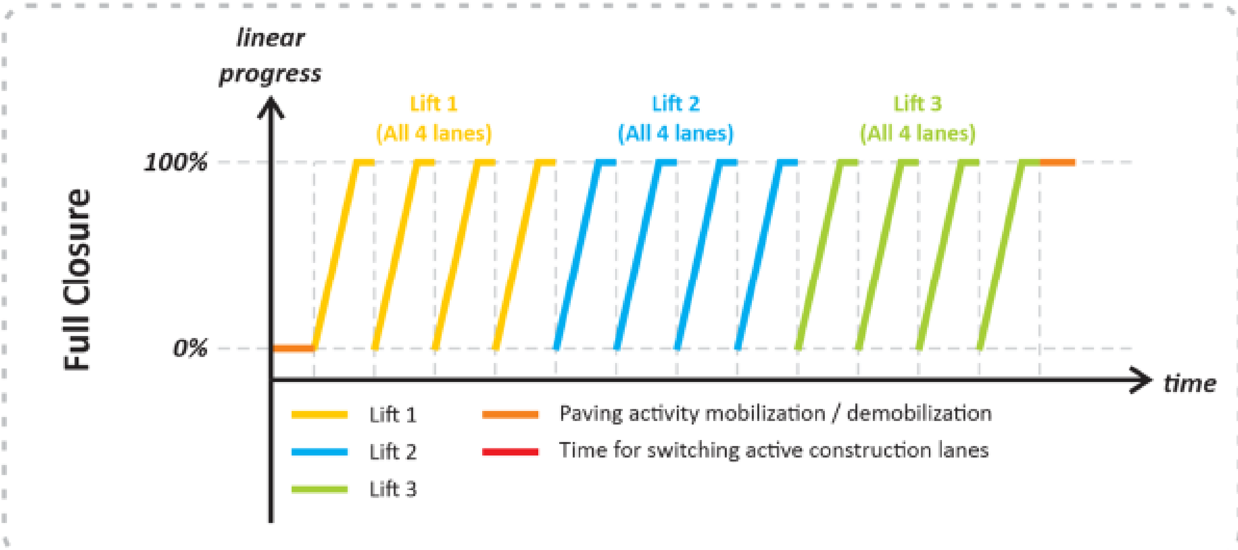
For asphalt paving methods, Road Scheduler includes 3 possible working methods that affect whether any lanes are available to traffic, how many lifts must be paved in a closure, and the overall duration of the paving activity within the closure.

For the purpose of demonstration, the examples in this guide feature identical lifts that have the same thickness and therefore take the same amount of time to pave. Shoulders are assumed to be pre-paved (paved in a separate closure) and therefore excluded from the model. *Finally, shoulders may be included in a paving operation if they are sufficiently wide enough to be effectively used as a lane (e.g. 9 ft, a common minimum lane width). This is referred to as simultaneously paving the shoulder (as opposed to pre-paving the shoulder).*

Additionally, the examples assumes that the lag time for each lift is attributed to paver turn-around time only (no suspended time for cooling). In all examples, the scope of work is assumed to be 4 lanes with 3 lifts for a total of 12 lifts.

Working Method 1: Full Closure

A full closure is the simplest case in which all lanes are closed to traffic. Consequently, the first lift of each lane is paved, followed by the next lift for all lanes, and so forth until all lifts are paved in each lane.



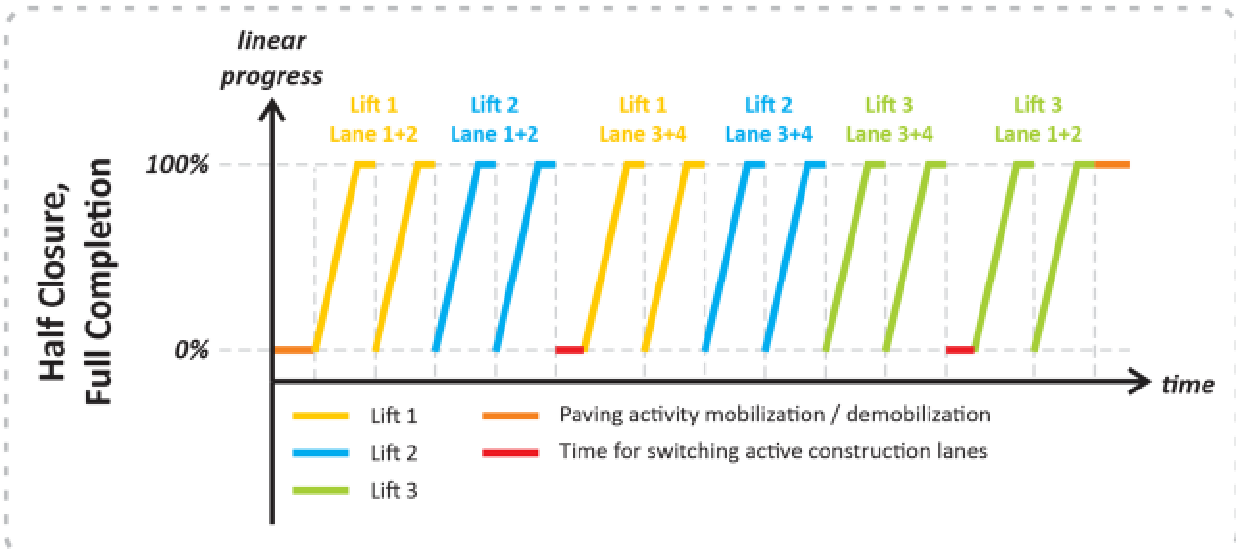
Each lift must have at least 1 additional adjacent lane available for a material supply truck. To represent this, Road Scheduler typically 'skips' lanes when it sequences lifts; for example, the lane sequence for the first lift may be 1, 3, 2, 4 so that the supply lanes are 2, 4, 1, 3 respectively. This pattern maximizes the amount of cooling time for a given lane and lift until a paver needs to begin the next lift layer.

Effectively, this working method yields the shortest overall paving time for a given scope of work. This is primarily because no additional considerations must be made for keeping lanes available to traffic during the closure.

Working Method 2: Half Closure, Full Completion

With this strategy, half the lanes are kept open available to traffic while the other half are being actively paved. If there are an odd number of lanes, Road Scheduler paves the 'larger' half first - even though this assumption does not affect the overall paving activity duration.

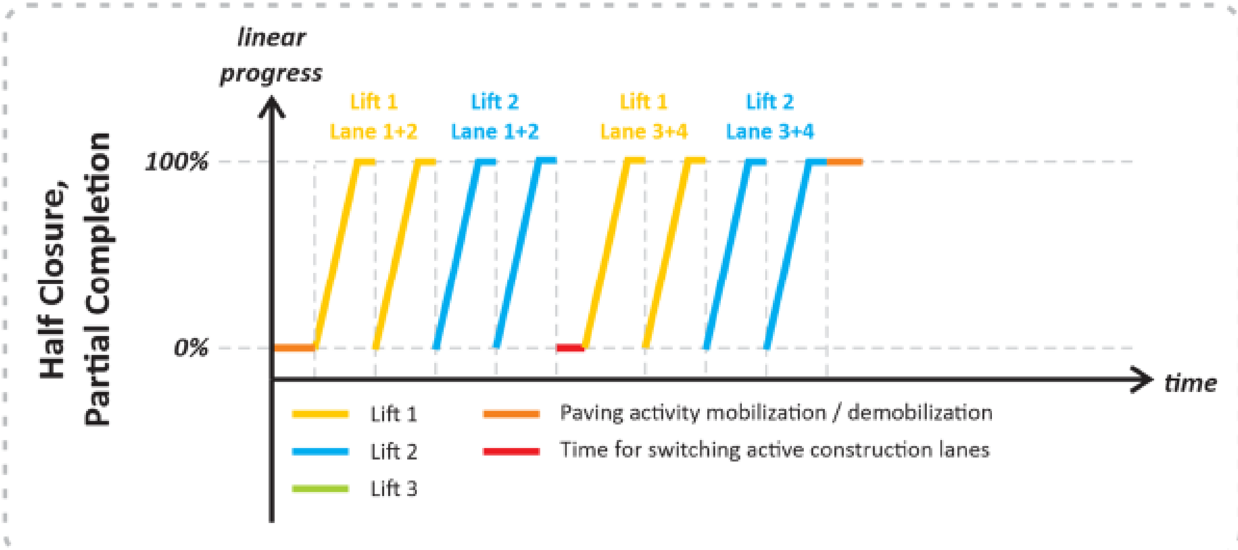
After a specified number of lifts are paved in the construction lanes, the lanes available to traffic and construction are switched, incurring a preparation lag time referred to as the 'traffic switch time.' After all lifts are paved under the switched lane configuration, a second traffic-switch time is incurred to revert the lane configuration back to the original settings. FInally, all remaining lifts are paved in original configuration.



In this example, the first two lifts are paved in Lanes 1 and 2 before the first traffic switch. Subsequently, all lifts are paved in Lanes 3 and 4. After the second traffic-switch reverts the lanes available for construction back to the original configuration, the third and final lifts are paved in Lanes 1 and 2.

Given the same paving objective, this strategy will always take longer than a full closure because of the traffic switch times. Put otherwise, this working method will result in smaller paving progress for the same closure durations but has fewer traffic impacts because some lanes are made available to traffic during the closure.

Working Method 3: Half Closure, Partial Completion
This method is basically an abridged version of the Half Closure, Full Completion method in that the sequence is identical but the activity concludes after the first traffic switch upon reaching the specified number of lifts before traffic-switch.



In this example again, the first two lifts are paved in Lanes 1 and 2 before the first traffic switch. Following this, the first two lifts are paved in Lanes 3 and 4 and the activity is concluded -- a second traffic-switch is unnecessary.

In this case, only 8 lift are paved compared to 12 lifts in the other working methods. This strategy reduces the relative time contribution of the paving activity within the closure or accordingly, increase the linear closure productivity. However, an additional simulation must be created to model the closure necessary to complete the remaining 4 lifts. Overall, this strategy may require more construction closures and time but allows the paving operation to be partitioned.

In general, it is important to understand that asphalt paving typically involves a more complex paving operation than concrete-related methods. For asphalt-related paving methods, it is also important to know that the chosen working method will not only impact closure productivity but also traffic impacts.

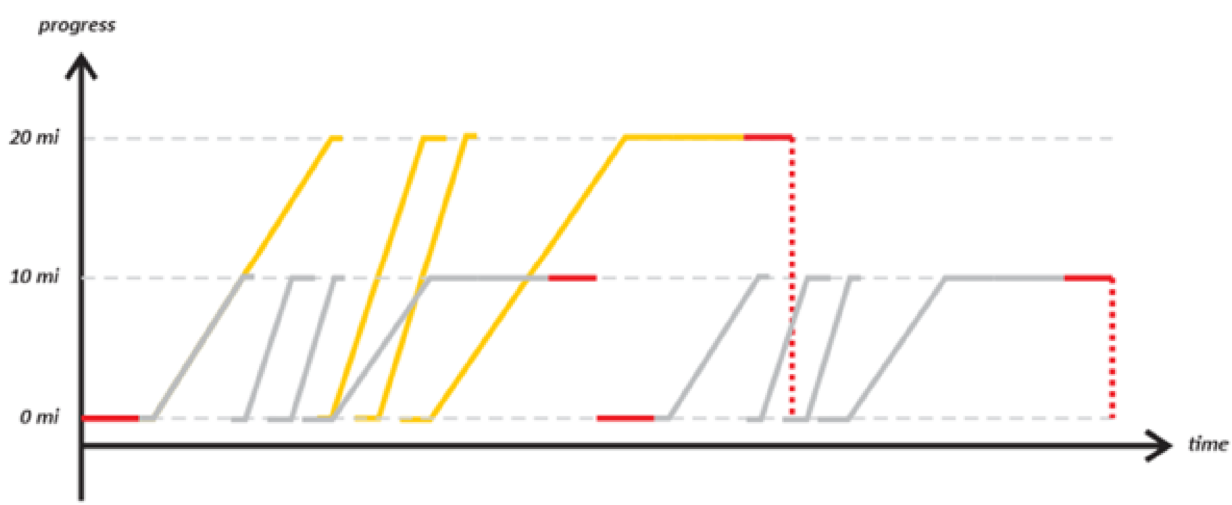
1.1.5 Closure Windows and Working Window Options

For the same job size, shorter working windows results in higher fractions of total time dedicated to mobilization, demobilization, and lag activities.

Road Scheduler calculates paving productivity on a per-closure basis and requires you to specify the length of a single closure, or ‘working windows.’ Road Scheduler assumes that each working window may consist of 1 *closure* mobilization and 1 *closure* demobilization activity. A working window may include multiple activities that include lag times, activity mobilization, or activity demobilization. Typically, the cumulative duration of lag activities from mobilization and demobilization prevent Road Scheduler from utilizing all hours of a specified working window.

This concept is portrayed in the illustration below, which compares a paving job completed in 2 working windows (grey) versus 1 longer continuous working window (gold). The red bars indicate closure mobilization and demobilization.

It is critical to comprehend this because specifying shorter working windows (higher # of closures) for a given job size means a greater fraction of the total construction time must be dedicated to mobilization and demobilization. Conversely, specifying longer working windows rather than multiple short windows results in shorter overall construction times because fewer closures would imply fewer mobilization and demobilization times across all closures. This is not necessarily optimal however as long, continuous closures may result in large traffic impacts to roadway users, despite yielding faster construction schedules.



Closure Options: Types of Working Windows

The working window (or closure time or closure duration) refers to the continuous length of time in which a section of pavement is closed to traffic and available for construction. Road scheduler assumes that all working windows begin with a closure mobilization and end with a closure demobilization lag activity. A working window may contain multiple lag or construction activities. It may not be possible to utilize the entirety of a working window because of resource constraints, and a pavement job may require multiple working windows to complete.

- **Weekend Closure**: This closure window implies that construction is continuously active for an entire weekend, spanning Friday evening to Monday morning. The window is at least 48 hours (Saturday and Sunday) plus any additional hours from Friday evening and Monday morning when the road is reopened to traffic. A typical weekend closure length is 55 hours, for example.

- **Nighttime Closure**: For this type of closure, construction is active for the duration of a single evening with a typical duration of about 10 hours until the road is reopened to traffic.

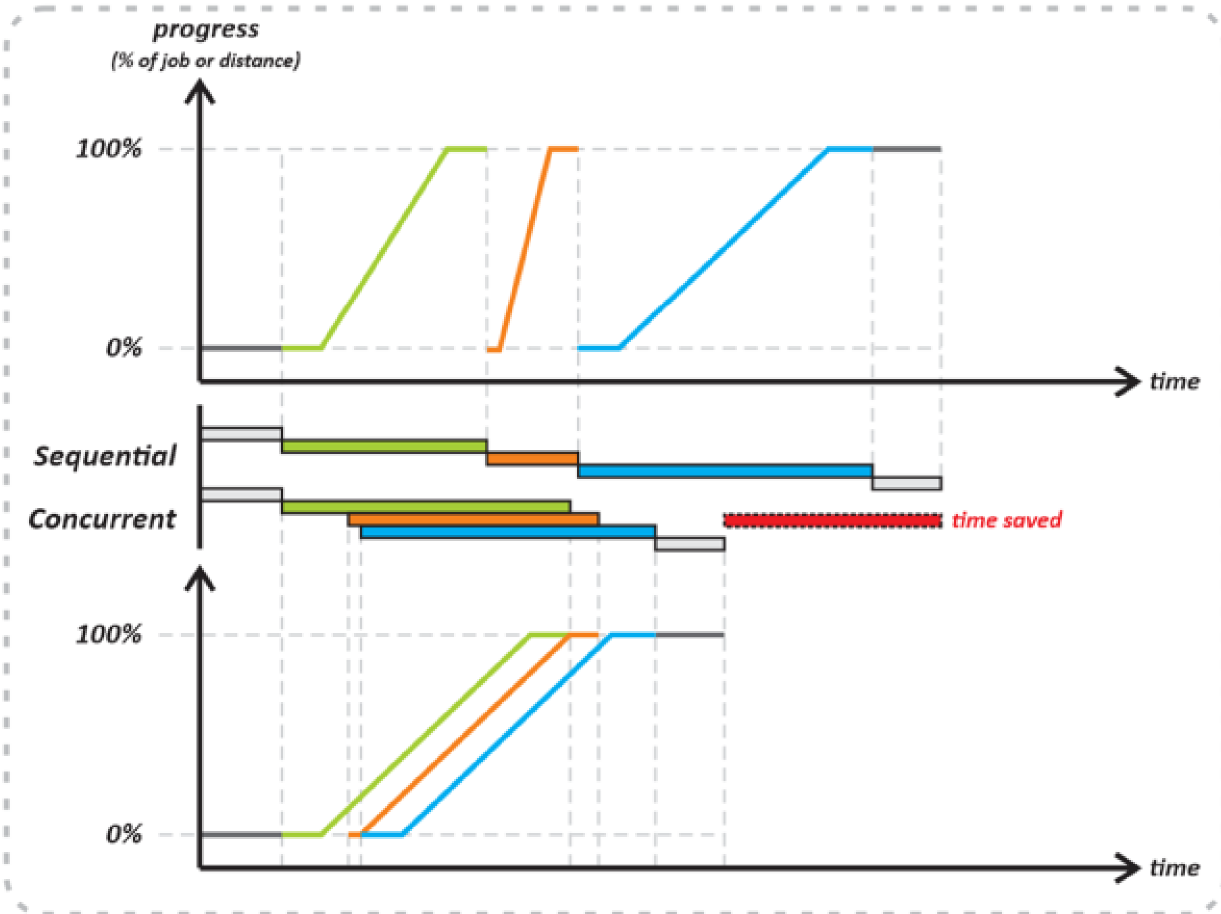
- **Continuous Closure (Continuous Operation)**: This type of closure refers to a working window in which construction is continuously active for the full duration and can span any number of hours. Although weekend and nighttime closures technically qualify as continuous closures, this type typically spans multiple days (more than a weekend).

- **Continuous Closure with Shift Operations**: In this type of closure, construction is allowed for only a certain number of hours for the day but the site otherwise remains closed to traffic for the entire duration of the closure. For example, if a shift operation is allowed for only 16 hours per day for a 72 hour closure, then a total of 48 hours will include active construction but the road is closed to traffic for entire closure duration.

While these window types are not explicit options in Road Scheduler, they are commonly referred to in a discussion of a closure strategy. Instead, Road Scheduler allows you to specify continuous closures (continuous operation) of any length in hours, and then specify whether the closure is a shift operation. If you designate your closure window as a shift operation, you will need to specify the available number of construction hours in addition to the total closure duration.

Concurrent Construction
In addition to specifying the closure duration, Road Scheduler allows you to choose whether construction activities may be concurrent with or sequential to (the default option) each other. Concurrent construction means that two sequential construction activities are allowed to work on the site simultaneously. In contrast, sequential implies that only 1 construction activity is allowed at any given time (including lag activities).

The figure below illustrates how concurrently scheduled activities may complete the same amount of work with fewer hours or equivalently, increase the overall paving progress per closure for a fixed closure duration.

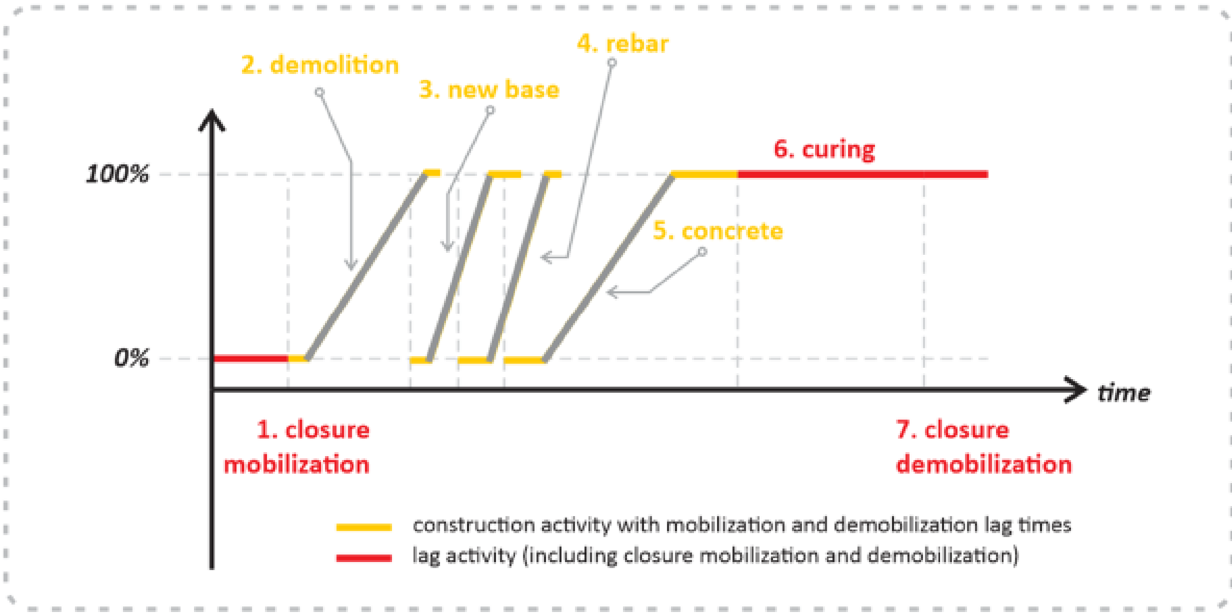


Concurrent construction may result in higher closure productivity or an overall short construction time because activities can be scheduled more closely together. The capacity to allow concurrent construction may be a function of contractor policy or constrained by available physical space. Road Scheduler will attempt to schedule construction activities concurrently, but this is not guaranteed as this depends on lag activity durations and productivity rates.

1.1.6 Closure vs. Activity Mobilization/Demobilization

A single construction window has a 1 closure mobilization and demobilization event (each), and potentially multiple activity mobilization and demobilization closures.

Road Scheduler addresses two types of mobilization and demobilization: closure and activity. Closure mobilization & demobilization activities refer to operations required to set up the job site and re-open the pavement for traffic, respectively. Activity mobilization & demobilization refer to operations to set up or complete specific work zone activities, such as a demolition, curing lag times, etc. While a construction window consists of exactly 1 closure mobilization and 1 closure demobilization activity, the construction window may have multiple activities and therefore multiple activity mobilization / demobilization events. This situation is depicted in an hypothetical productivity chart below:



1.1.7. Resource and Equipment Specifications

Equipment and resource specifications constrain the overall productivity of a construction activity

Each layer of material added or removed from a pavement corresponds to a set of resources (equipment, labor, materials, or time) that operate in critical path construction activities. Road Scheduler calculates productivity rates based on the availability of materials and resources dictated by the specific construction activity. The simulation compares how quickly materials can be produced, delivered, and placed and then determines which activity consists of the most limiting resources. The productivity rate of the limiting resource ultimately determines and constrains the overall productivity rate of the activity.

For each construction activity (and therefore material layer), you must provide Road Scheduler with the following resource specifications:

(a) The activity mobilization and demobilization requirements, as described previously.
(b) The rate at which materials be produced, delivered/hauled, and placed (where applicable)
(c) The number of teams (or units) that will perform a task
(d) The efficiency with which resources or equipment perform a task

Road Scheduler assumes that each construction activity may be constrained by up to 3 types of resources: those involved in material production, transportation, or paving/placement. Depending on the material and resource, not all questions may be required. For example, the production of rebar may not be required since it is delivered prior to and staged during the activity mobilization. Demolition only depends on hauling rates (no production or placement).

In this context, rates refer to the physical amounts of material that can be moved or produced by resources. For hauling and delivery trucks, this is captured through rated truck capacity and arrival rates. For material production, this is captured by available batch plant capacity. For placement, this is captured by the working rate of a resource: linear distance rate for pavers and area rate for rebar placement crews, etc.

The option to specify number of teams provides you with another layer of consideration: additional teams can increase a resource’s productivity, but may require additional physical space and timing considerations. (Discussed in more depth in User Guide 1.2.4). While this determination is ultimately left to your discretion, considerations should include adequate space for crew, material staging, and equipment maneuvering.

Finally, you may specify efficiency factors for resources to reflect personal experience or best-practice recommendations regarding effective / actual resource rates. For example, the packing efficiency of hauling trucks can be ~50% for demolished pavement, but nearly 100% for fresh concrete.

Once supplied with the required specification, Road Scheduler converts each construction activity into a productivity curve and attempts to sequence the construction activities based on the order of material layers in the pavement cross section. Since an job’s size may require more time than available in a single working window, Road Scheduler attempts to maximize productivity while adhering to constraints built into the activity lag times and productivity rates.

1.2.0 Simulation Model and Data Requirements

The sections in this user guide detail the specific types of information required to run a simulation in Road Scheduler based on the paving method selected.

This User Guide has three closely related objectives collectively intended to assist you in collecting the necessary data to successfully run a simulation in Road Schedule:

- The first is to provide technical details regarding how Road Scheduler synthesizes information and provides analysis results.
- The second is specify the types of information you should collect depending on your chosen paving method
- The third is to provide intuition how the information you collect may influence the results: a culmination of the previous two objectives

This user guide discusses data requirements in an order that reflects the way you would provide inputs to Road Scheduler and is similar to the ordering of User Guide 1.1. By following the structured recommendations in this user guide, you should be able to create a specific shopping list of data to acquire prior to running the application. Once fulfilled, you should be able to successfully enter this information and run a simulation in Road Scheduler (demonstrated in User Guide 1.3).

If you have experience with pavement construction, you experiences may allow you to provide reasonable input values with no further research. The user guides for this section nevertheless provides considerations and recommendations.

Alternatively, if you do not feel comfortable in your background knowledge of pavement construction, User Guide 1.1 provides a concise review of concepts necessary to understand the process of pavement construction.

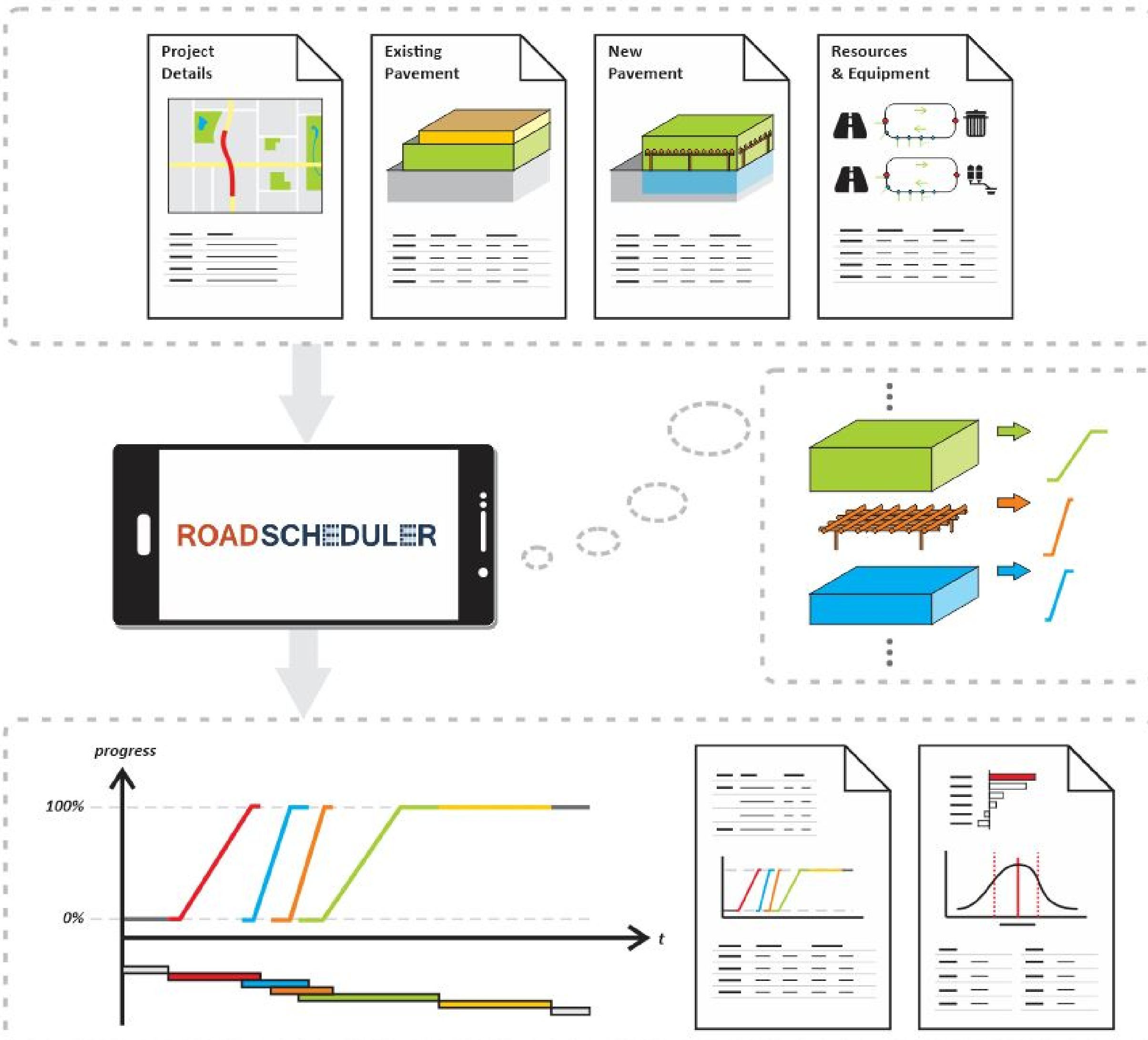
In particular, the user guides in this section will answer the following questions:
1.2.1: How does Road Scheduler process the input data provided by the user?
1.2.2: What information is important to consider even if not required for simulation?
1.2.3: What information should be collected regarding pavement materials and geometry?
1.2.4: What information should be collected regarding activity duration and scheduling?
1.2.5: What are important considerations when determining truck delivery rates?
1.2.6: What information should be collected regarding resources and equipment?
1.2.7: How should I determine which probabilistic model is best for an input?

1.2.1 Conceptual Simulation Model and Data Flow

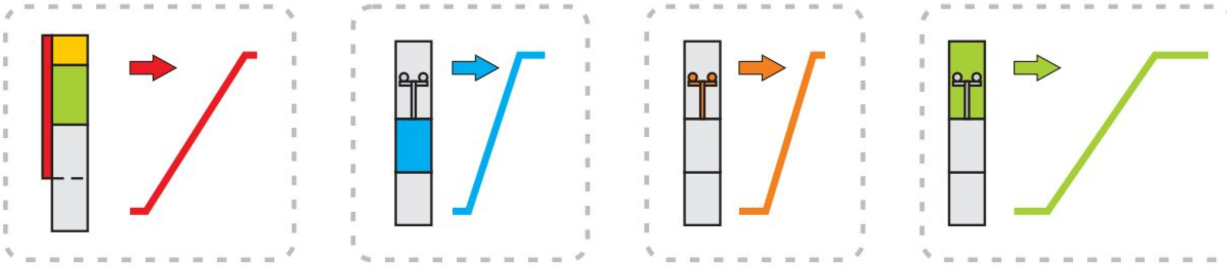
Road Scheduler interprets the pavement as a set of material layers that each require distinct construction operations and resources.

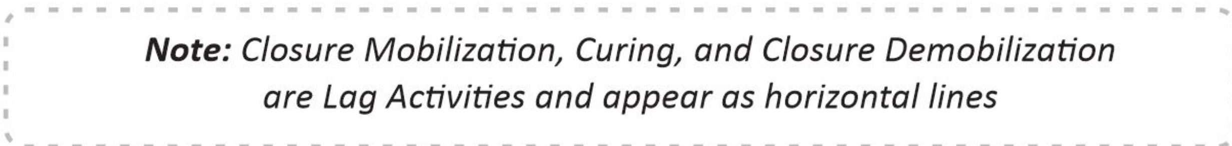
This activity provides a visual overview of the simulation model to convey how your collected data is translated into a set of productivity estimates in Road Scheduler. Sections 1.2.3-5 offer a detailed discussion of the specific data requirements for the project details, pavement materials and geometry, and resource specifications respectively. Understanding the underlying flow of data is important because it may improve your ability to identify alternatives, implement changes, and interpret results more accurately.

The figure below illustrates how Road Scheduler conceptualizes a paving project and alludes to the types of information you must provide.

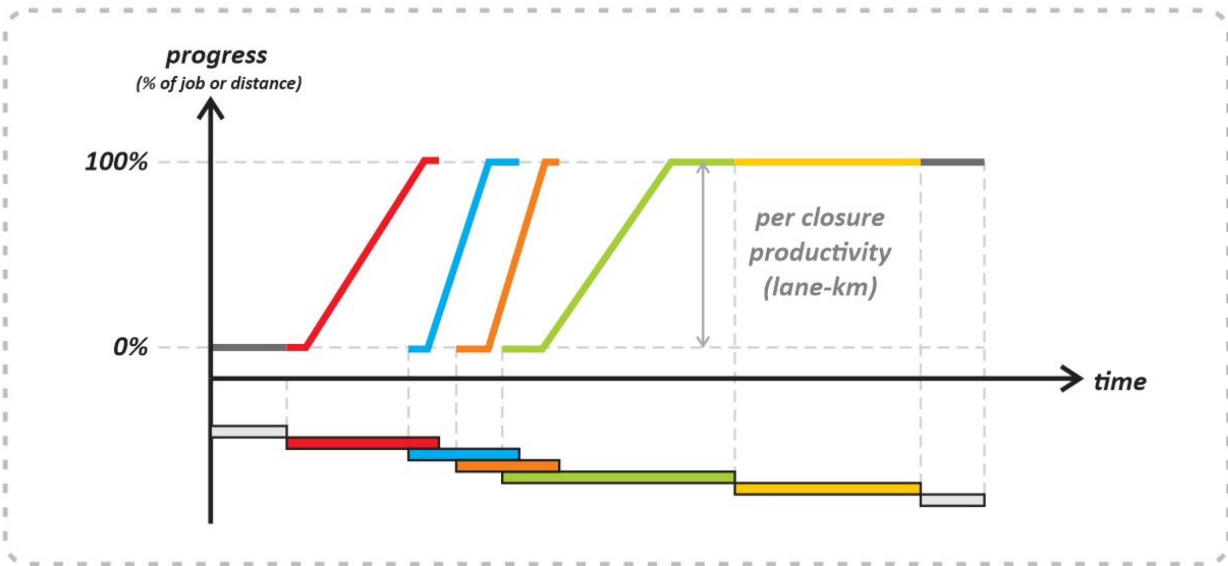


Starting with information you supply, Road Schedule interprets a pavement section as a set of material layers that each require some kind of construction activity, which in turn requires a different set of resources dictated by the material. After comparing factors that limit each activity's productivity, the application computes the activity rate of completion and optimizes the sequence of construction activities.



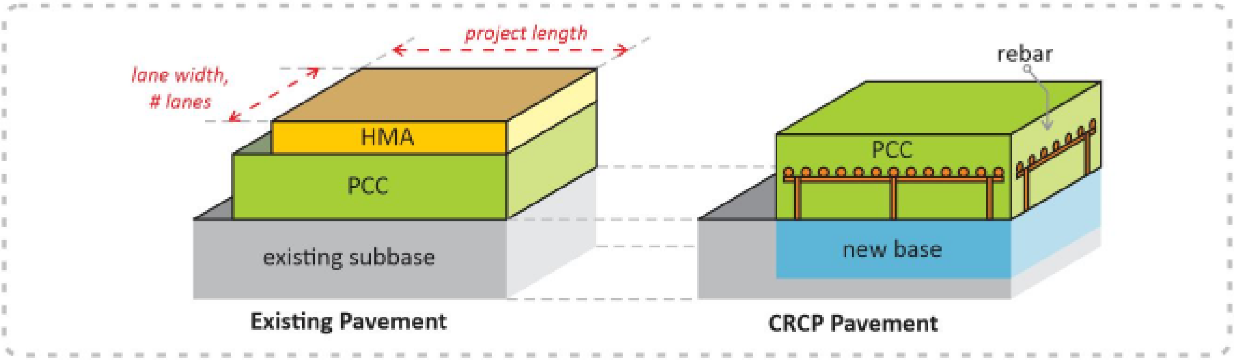


The application reports the simulation results to you through a mixture of tabulated and graphical information that describe overall and activity-specific performances, including a productivity chart below that visually summarizes all critical path activity for a single closure:

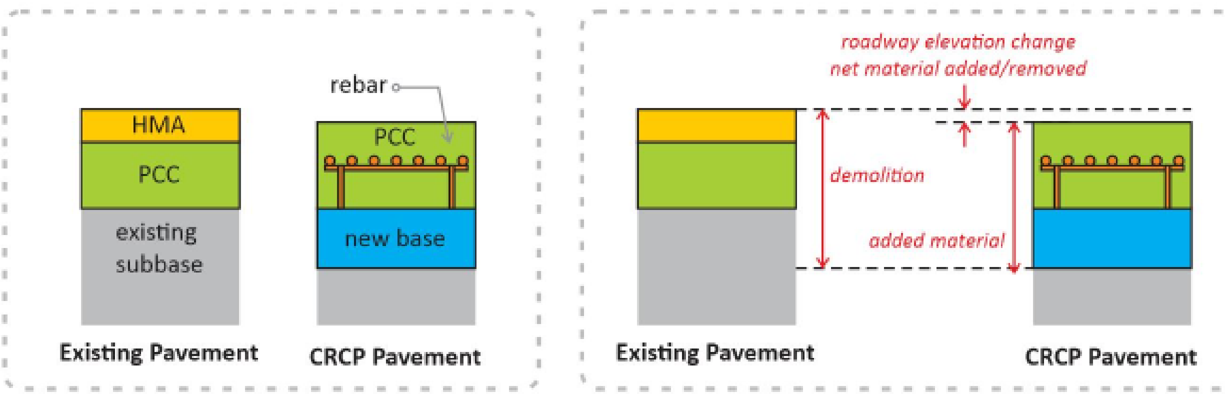


1.2.2 Data Considerations: Pavement materials and geometry

Road Scheduler requires you to calculate the quantity of materials added and removed in a paving job in order to estimate the duration of each construction activity and overall closure productivity. Consequently, the application requires you to provide physical and geometric details on both the existing and new pavement to be placed, as illustrated below:



The physical details include the material identity, material density, number of lanes, and overall change in roadway elevation. Geometric details include the project length, lane width, and thickness of each material layer or lift. Note that the application calculates project length using the specified mileposts which that define project extents. Collectively, this information allows Road Scheduler to calculate the total quantity of materials to be hauled from or added to the construction site (right figure, below).



The Data Collection Summary includes:

- # Lanes and lane width
- Project length or mileposts of project extents
- Material identity of each pavement layer (existing and new pavement) and density
- Thickness of each pavement layer (existing and new pavement)

1.2.3 Data Considerations: Sequencing Pavement Layers and Lifts

It is typical for the actual number of available hours for construction to be less than a closure duration due to the presence of lag activities associated with individual construction activities, closure mobilization/demobilization, and cooling/curing activities.

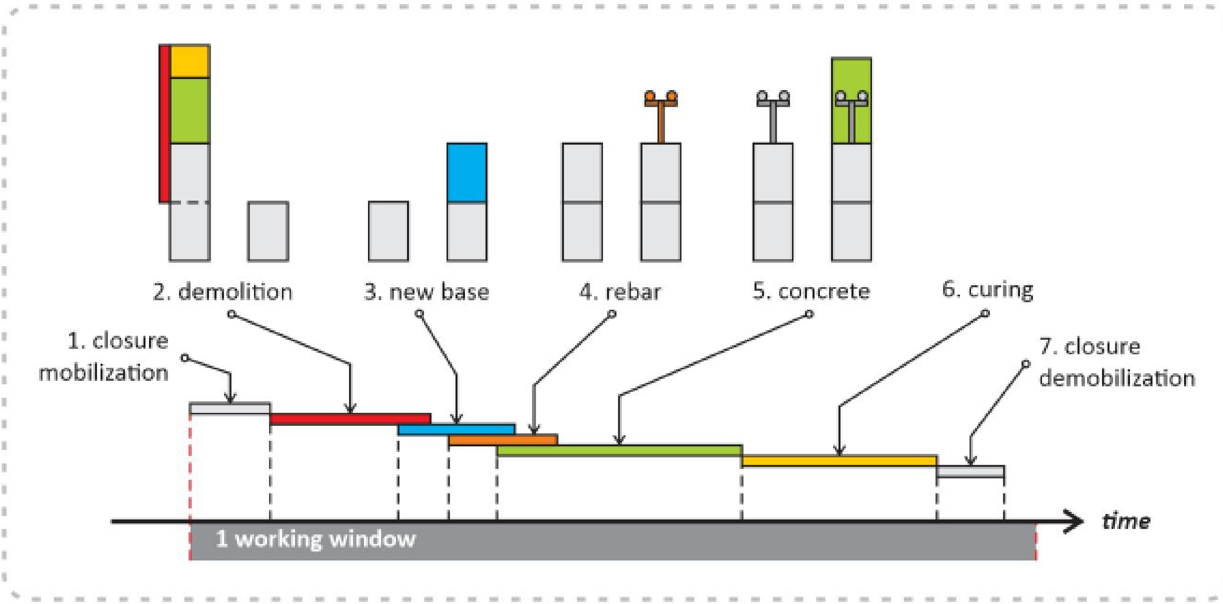
Road Scheduler requires you to specify information on activity lag times because they influence how closely consecutive construction activities can be placed next to each other without conflict. Consequently, you should understand where these lag times occur and how they can influence overall closure paving productivity. You may also use this section to scope the data collection effort required based on the paving method.

As discussed in User Guide 1.0.2, each paving method consists of a unique set of critical-path construction activities. While the pavement layer material determines the required equipment, the layer ordering determines the sequence of construction activities. The illustration below illustrates that, despite their differences, each paving method generally follows the same sequence (i.e. via the color legend).

Paving Methods and Critical Path Construction Activities Simulated

Color Legends	Closure Mobilization	Materials Removed	Materials Added (sub-layers)		Materials Added (pavement)	Material Setting Lag Times	Closure Demobilization
JPCP Rehabilitation	Closure Mobilization	Demolition	Base	Concrete Paving	Curing	Closure Demobilization	
CRCP Rehabilitation	Closure Mobilization	Demolition	Base	Rebar	Concrete Paving	Curing	Closure Demobilization
PreCast Rehabilitation	Closure Mobilization	Demolition	Base	Bedding	Slab Installation	Curing	Closure Demobilization
HMA - Overlay	Closure Mobilization	Asphalt Paving (Lifts)	Cooling	Closure Demobilization			
HMA - Mill and Fill (CSOL)	Closure Mobilization	Milling	Base	Asphalt Paving (Lifts)	Cooling	Closure Demobilization	
HMA - Full Depth	Closure Mobilization	Demolition	Asphalt Paving (Lifts)	Cooling	Closure Demobilization		

For example, a paving job featuring CRCP Rehabilitation includes a total of 7 critical path activities within a working window (illustrated below). Note that in this hypothetical CRCP paving job, certain critical path activities feature slack times or lag times (2, 3, 4, 5).



From this figure, you can determine that the paving operation will require specifications for up to 11 lag times. Remember that:

- Each working window includes a closure mobilization and demobilization time (Activities 1 and 7), yielding 2 variables
- All other lag activities (6) require a duration (1 variable)
- All other construction operations (2, 3, 4, 5) may include an activity mobilization and demobilization (8 variables)

For pavement jobs involving asphalt, multiple lifts may be required. In these cases, the lag time associated with each lift is determined by paving and non-paving travel speeds, and the cooling time needed for each lift. The non-paving travel speed determines the amount of time required for the paver to return back to the beginning of the paved section. The cooling time affects how much time must pass before an additional layer can be placed, which in turn is influenced by both the paving and non-paving travel speeds. To avoid suspended time, in which a paver must idle until a lift has cool, the time between lifts in a given lane must be at least as long as the cooling time of the underlying lift.

Additionally, the working method for asphalt paving also impacts the number of available hours for active construction time. Full closures will always yield higher per-closure productivity because no traffic switch-times are needed, but impacts may be severe since all lanes are closed to traffic. Half Closures with Partial Completion incur 1 traffic-switch time per closure whereas Half Closures with Full Completion incur 2 traffic-switch times. Accordingly, Half Closures (either type) will result in lower per-closure productivity but will have relatively smaller traffic impacts compared to Full Closures.

Data Collection Summary:
After selecting a pavement, determine the following durations (or related parameters):

1. Closure mobilization and demobilization lag durations
2. Any other lag activity durations
3. Construction activity mobilization and demobilization durations
4. For asphalt pavements with multiple lifts, determine the amount of cooling time needed as well as the paving and non-paving travel speeds of the paving machine

5. For Half Closures, you must also determine the amount of time needed for a traffic-switch operation as well as the number of lifts to be completed before the first traffic-switch. Be aware that selecting a Half Closure with Partial Completion implies that not all lifts will be paved in the simulation and consequently should be modelled in a separate simulation.

1.2.4 Data Considerations: Closure and Working Window Options

The overall project completion time is influenced by the the closure duration and whether concurrent construction activities are allowed.

The purpose of this user guide is to summarize considerations when specifying configurations related to a closure including various options that affect how construction activities are sequenced. In general, a closure window has two primary considerations you should address..

The first is the **closure duration**, and whether only some hours are available for construction (shift operation). Longer closure windows result in fewer closures required to complete a paving job and result in fewer occurrence of lag activities (e.g. curing, cooling, closure mobilization and demobilization activities). Accordingly, selecting a working window duration that completes a paving job in exactly 1 closure is optimal in terms of construction efficiency, but may result in intolerance and extended traffic impacts.

The second consideration is whether construction activities may operate **concurrently** (2 or more activities occurring simultaneously on the job site) **or sequentially**. Assuming your construction site has enough physical space and manpower for different activities to work safely and simultaneously, allowing concurrent construction activities will always result in a higher per-closure productivity. In concurrent construction, Road Scheduler assumes that the productivity rate of construction activities are reduced to the effective rate of the slowest activity. Doing this ensures that activities performed simultaneously will not result in spatial conflicts or overlap. To ensure worker safety, it is highly recommended that you add activity lag times to create adequate spacing between different construction activities and their associated crews.

Summary:
Regardless of the methods used, the inputs you choose should be able to address the following questions:

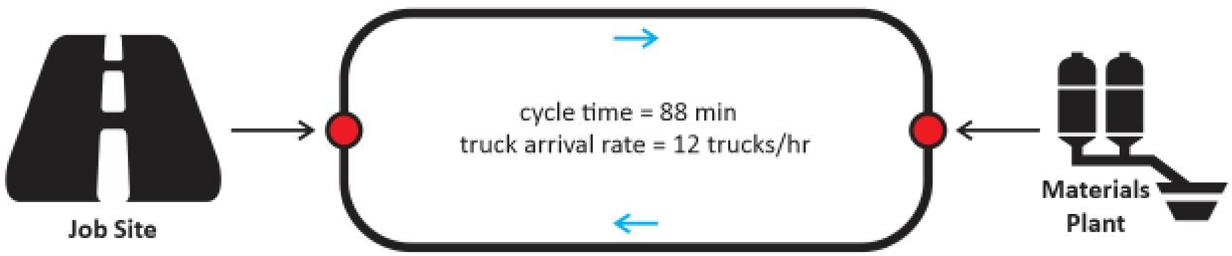
- How long may I extend a closure before I cause intolerable traffic impacts? Are all hours of this closure available for construction?
- Do I have enough space for concurrent construction activities? Is there an adequate physical or temporal spacing between activities to ensure worker safety / on-site conflicts?

1.2.5 Data Considerations: Resource Cycle-Time Considerations

Resource cycle-times influence both activity and overall closure productivity, even if this information is not directly requested by Road Scheduler to run simulations.

The purpose of this user guide is to provide considerations that clarify how certain inputs are determined for resource scheduling, namely truck arrival rates at the construction site. Although the arrival rate can be determined by experience or a variety of methods, it is crucial to recognize how the number of trucks, number of teams, truck arrival rates, and truck cycle times are all related. In other words, it is important to understand how the user's input choices influence both activity and overall closure productivity because these relationship may not be apparent from the order in which Road Scheduler requests information.

As discussed in User Guide 1.1, the productivity rate of critical-path construction activities is limited by the equipment or resources involved. For activities involving the transportation of materials to or from the construction site (e.g. paving materials, demolition), this rate is calculated from the arrival rate of trucks. Below is a discussion of how this arrival rate influences other variables that may constrain productivity. For the purpose of demonstration, consider the following example of a materials delivery activity:



On-site task durations determine minimum time between truck arrivals

In addition to round-trip hauling times, certain on-site procedures listed below may add to the total truck cycle time. While these activities may also be applicable off-site (e.g. at a landfill or batch plant), Road Scheduler only focuses activities within its project boundaries (on-site).

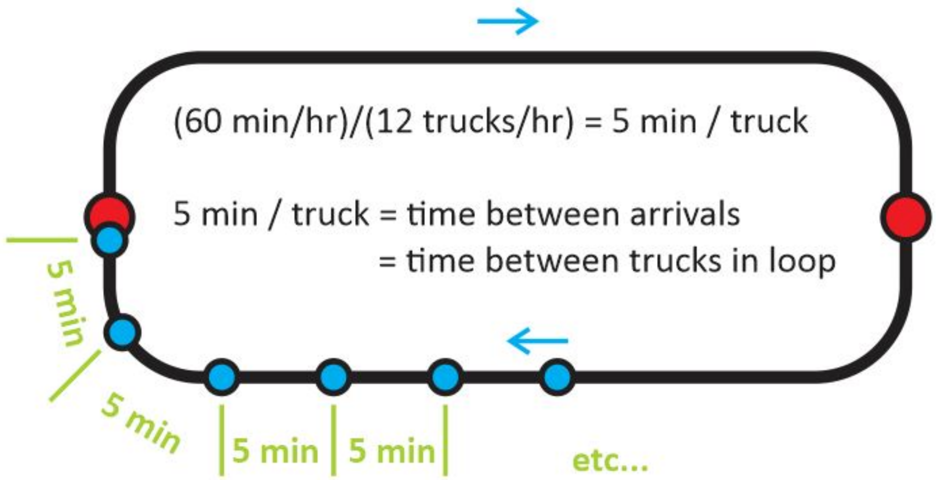
- Load Times
- Prep and Wait Times
- Ticket and Tarp
- Dump / Clean-Up

The total duration of these procedures determines the minimum time required before the next truck or unit may enter the site and complete it's task, i.e. the minimum time between truck arrivals (in minutes).

Time Between Truck Arrivals and Truck Arrival Rates (per team) are reciprocal

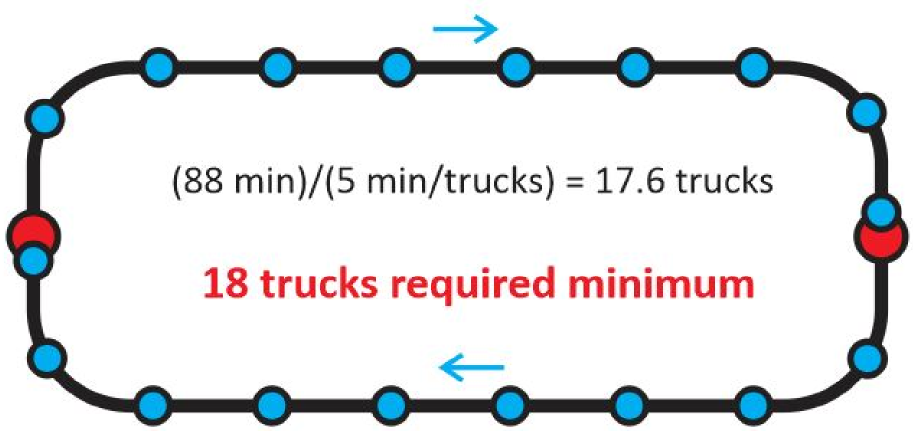
The minimum time between truck arrivals can be converted into an arrival by simply inverting the rate and converting minutes to hours. For example, if the truck arrival rate is 12 trucks / hr, then the time between truck arrivals is (60 min/hr)/(12 trucks/hr) = 5 min/truck. The time between arrivals is also approximately the time between trucks within the cycle in order to sustain the arrival rate. Overestimating the arrival rate may result in the formation of unanticipated equipment queues, while underestimating may result in inefficient use of resources.

(60 min/hr)/(arrival rate, trucks/hr) = (time between arrivals, in min/truck)

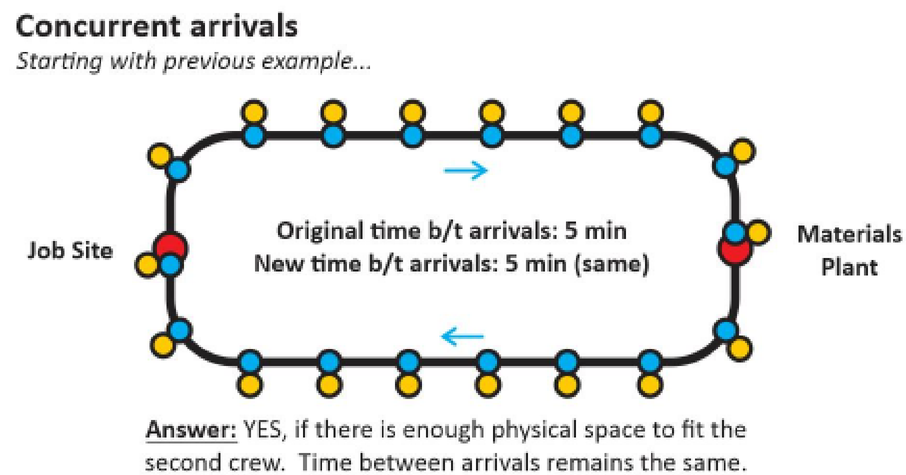


The minimum fleet size is the number of vehicles to sustain the time between trucks in the cycle
The truck arrival rate can be converted into a minimum truck fleet size if the total cycle time is known (including on-site, off-site, and hauling times). The minimum fleet size can be determined by dividing the total cycle time by the time between arrivals. From the example, an 88 minute cycle time with 5 minutes between arrivals implies a minimum fleet size of 18 trucks, rounding up to the nearest whole truck.

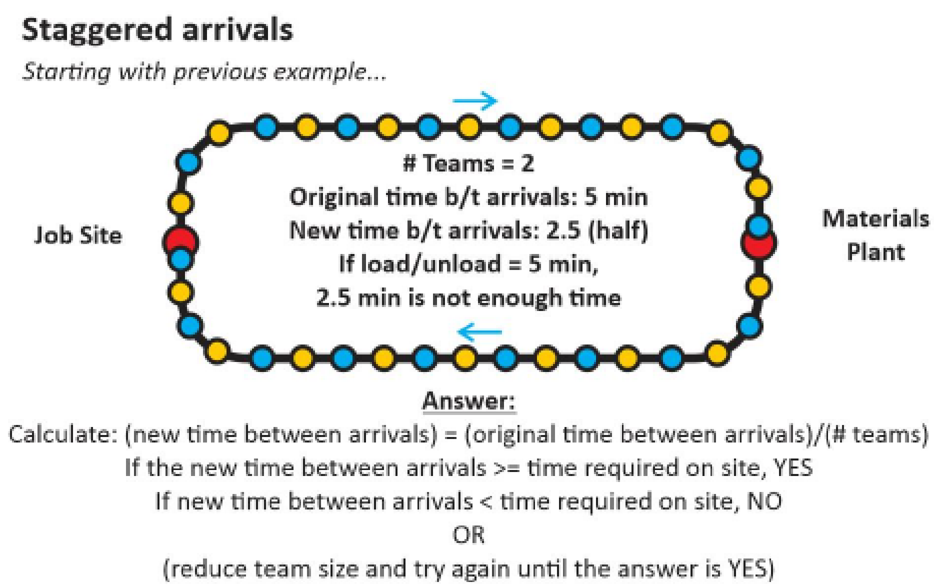
(cycle time)/(time between arrivals) = (minimum fleet size)



The number of teams is limited by spatial and temporal constraints
Specifying multiple teams for hauling/delivering depends in both spatial and temporal constraints. Adding an additional teams implies that the arrival of each team's equipment is concurrent or staggered. For concurrent arrivals, the user must decide if there is adequate space for crew to stage material and maneuver equipment from all teams simultaneously.



For staggered arrivals, the must realize that the time between arrivals is divided by a factor equal to the number of teams, e.g. staggering 2 teams each with 5 minutes between trucks implies that a truck from either team will enter the site every 2.5 minutes on average. The user must again ensure that this time is sufficient for a unit to complete its tasks prior to the next unit arrivals.



Summary:
Regardless of the methods used, the inputs should be able to satisfy the following 3 questions:

- Do I have enough time or space (to maneuver equipment, crew, and material) for multiple teams?
- Is the minimum required fleet size smaller than the available fleet size for job?
- Is the time between truck arrivals long enough to allow a unit to complete on-site tasks?

1.2.6 Data Considerations: Resource and Equipment Specifications

Each paving method includes different construction activities which in turn may have multiple equipment or human resources that ultimately determine the overall completion rate of an activity

The resources or equipment specifications required by Road Scheduler depend on the materials involved in the existing and new pavement, which in turn are determined by the paving method. These specifications are essential because they ultimately determine the maximum rate at which a construction activity can be completed. Expanding on the concepts in User Guide 1.1.6, this section provides you with a chart that specifically maps all possible combinations of paving methods, construction activities, and equipment combinations:

Paving Activities				Material Removal		Material Added						No Changes	
Pavement Method	Pavement Type	Total # Activities	Max # Resources	Demolition	Milling	Base	Bedding	Rebar	Concrete Paving	Asphalt Paving (Lifts)	Slab Installation	Curing	Cooling
JPCP Rehabilitation	Full Replacement	[3-4]	5	Y		Depends			Y			Y	
CRCP Rehabilitation	Full Replacement	[5]	6	Y		Y		Y	Y			Y	
PreCast Rehabilitation	Full Replacement	[3-4]	4	Y		Depends	Y				Y		
HMA - Overlay	Rehabilitation	[2]	3							Y			Y
HMA - Mill and Fill (CSOL)	Rehabilitation	[3-4]	6		Y	???				Y			Y
HMA - Full Depth	Full Replacement	[4]	5	Y		Y				Y			Y
Roadway Widening													

Resources and Equipment				Material Removal		Material Added						No Changes	
Resource	Specification	Efficiency	Multiple Teams Allowed	Demolition	Milling	Base	Bedding	Rebar	Concrete Paving	Asphalt Paving (Lifts)	Slab Installation	Curing	Cooling
Total # Resources				1	2	1	1	1	3	3	1	0	0
Hauling Truck	rated capacity trucks / hour / team	Packing	Y	Y	Y								
Material Delivery Truck	rated capacity trucks / hour / team	Packing	Y*			Y			Y	Y			
Milling Machine	machine class material type	Downtimes	Y		Y								
Batch Plant	available capacity / hour # units	n/a							Y	Y			
Work Crew	productivity / hour	n/a	Y				Y	Y			Y		
Asphalt Paver	non-paving travel speed	n/a								Y			
Concrete Paver	average effective paving speed # pavers	n/a							Y				

Notes: *Y* = only for PreCast*
All resources that allow teams must also specify a team efficiency
Total equipment units required should be multiplied by # of teams

need to consult

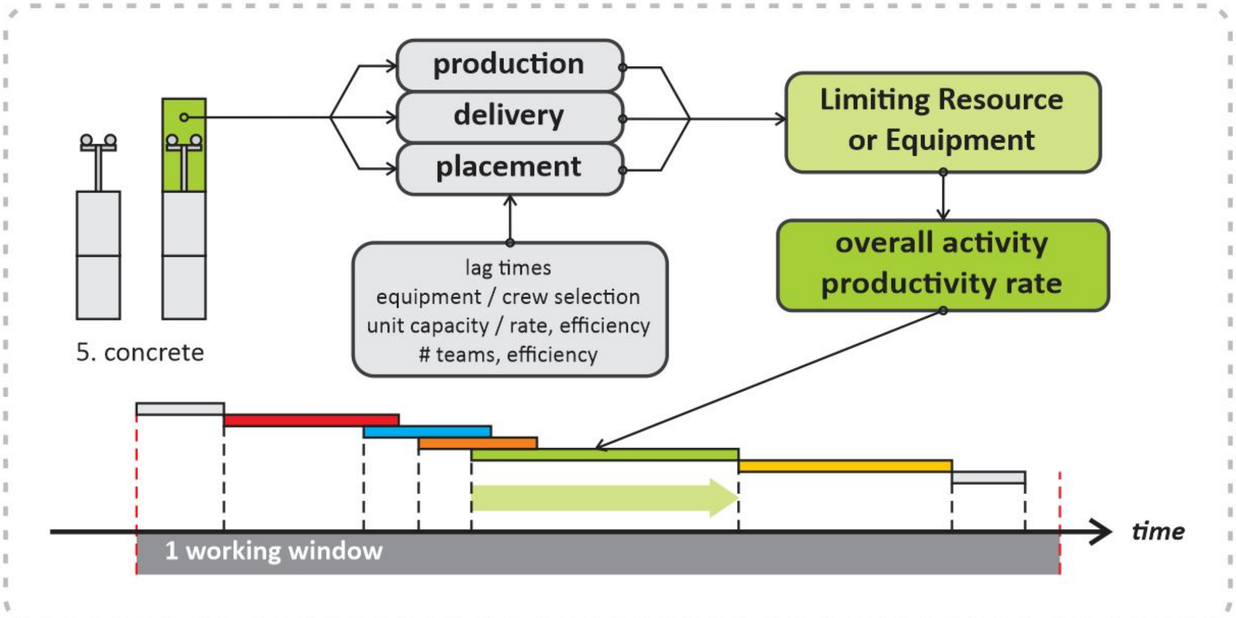
To demonstrate how to read this chart, assume that you are performing a CRCP Rehabilitation and are specifically interested in demolition and paving activities. The chart provides the following information:

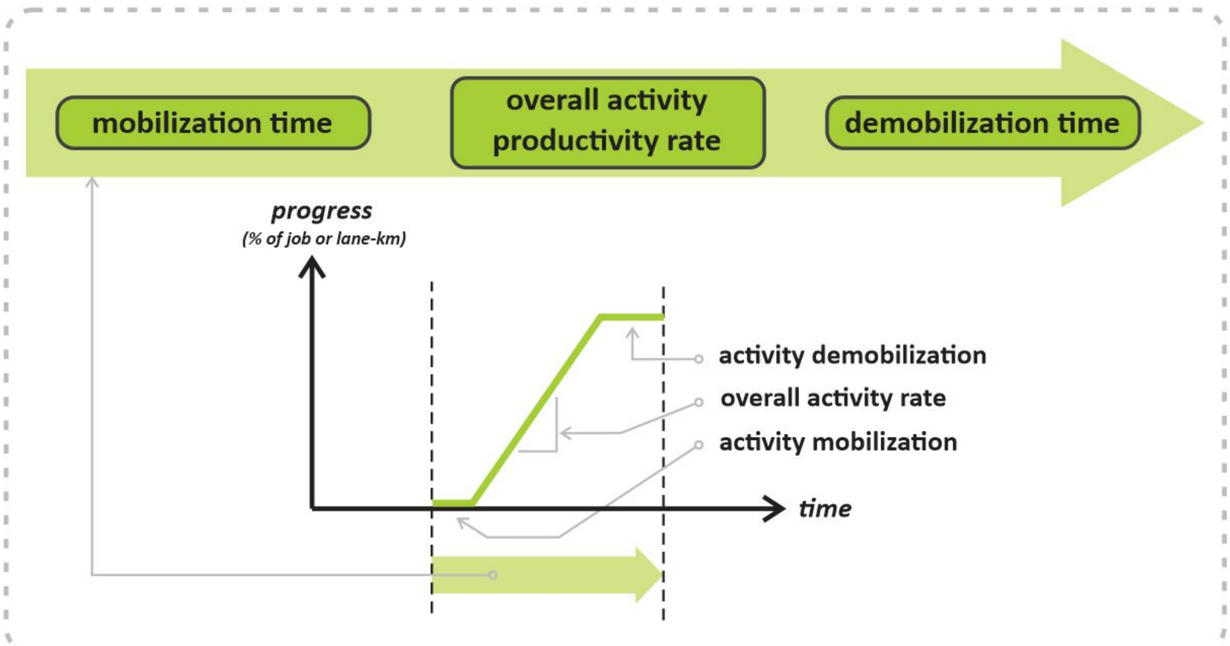
- In the "Paving Activities" table, the CRCP row indicates a total of 5 construction activities (excluding mobilization and demobilization), and specifications for up to 6 resources/equipment.
- In the "Resources and Equipment Table," the "Demolition" column indicates that only 1 resource may be constraining: the hauling truck (+5 variables total)
    - The "Hauling Truck" row of the second table indicates that 2 variables are required: rated capacity and truck / hour / team
    - The row also indicates a packing efficiency must be specified
    - The row finally indicates multiple teams are allowed, so the user must specify the number of teams and estimate the team's efficiency
- The Concrete Paving activity may be limited by 3 resources (+7 variables): the batch plant (production, material hauling truck (delivery), or paver (placement).
    - The materials delivery truck requires 2 specification, a packing efficiency, but no team specifications (only allowed for material delivery in PreCast paving methods)
    - The batch plant requires 2 specifications only (capacity, number of units)

- The concrete paver requires 2 specifications only (speed, number of units)

After supplying the required information, Road Scheduler calculates and compares the effective productivity rate of each resource and determines the most limiting (typically the lowest). Based on the principles of balancing productivity rates, this limiting rate becomes the effective productivity rate of the construction activity in general.

The two figures below illustrate how Road Scheduler processes input information for the concrete pavement activity (continuing from the above example):





1.2.7 Data Considerations: Probabilistic Inputs

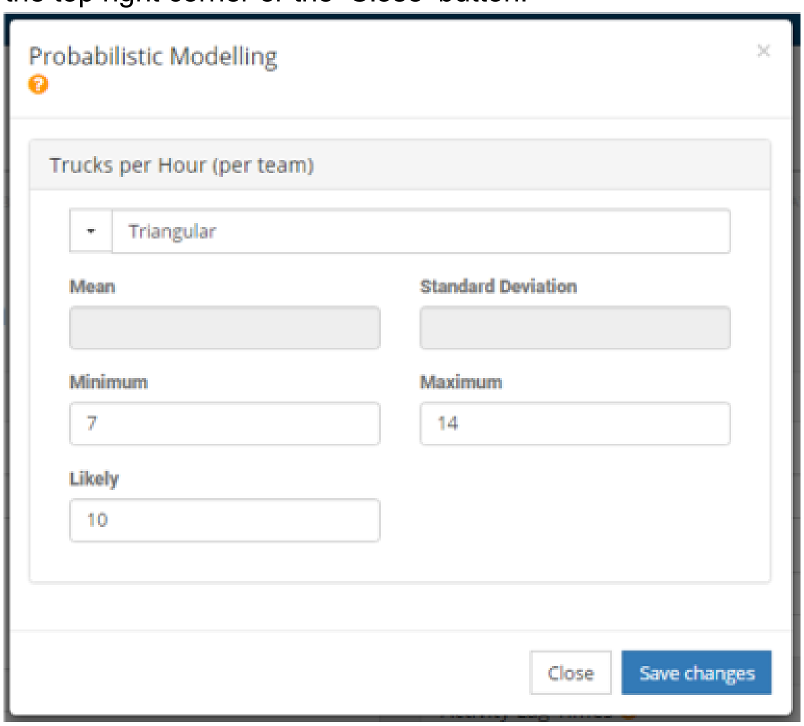
The goal of this guide is to provide additional considerations when specifying probabilistic inputs in a Road Scheduler simulation. This section is extends the discussion of the features introduced in Chapter 1.0.3, which explains the basic difference between deterministic and probabilistic simulations. More specifically, the guide explains how the model incorporates probabilistic inputs into the Monte Carlo simulation and how your specifications may impact the quantitative results.

Creating a Probabilistic Simulation

In this context, a probabilistic simulation means that the values of some parameters are randomly determined by statistical parameters rather than a single value (deterministic). If at least 1 variable is specified as probabilistic, the entire simulation will be considered probabilistic and a Monte Carlo Simulation will be performed. Accordingly, if all variables are assigned deterministic values, the Road Scheduler will perform a single calculation to determine outputs. Although many inputs can be specified as probabilistic, this choice is optional.

Variables that can be specified as probabilistic will feature a gear icon next to the input field. To specify a probabilistic variable, click the gear icon and a small pop-up window will appear and allow you to choose a distribution and specify its associated statistical parameters.

The options for distributions are the same for all inputs that can be specified as probabilistic. hen you are done, you must click ‘Save changes’ and close the box by pressing the ‘X’ button in the top right corner or the ‘Close’ button.



Upon closing the probabilistic modelling window and returning to the main input wizard, Road Scheduler will fill the input field with a value randomly calculated based on the distribution you have chosen. In this example, Road Scheduler will the ‘Trucks per Hour per Team’ field with a random value determined by a triangular distribution with a mode of 10 trucks per hour, based on a min/max range of [7,14].

Monte Carlo Simulation Model

For probabilistic analyses, Road Scheduler uses a Monte Carlo Simulation in which probabilistic inputs are randomly computed each iteration based on the distribution (and associated parameters) assigned to it. Since simulation may consist of many probabilistic inputs each specified with a different distribution, the closure productivity for each iteration will differ and result in a histogram of total closures required to complete the job.

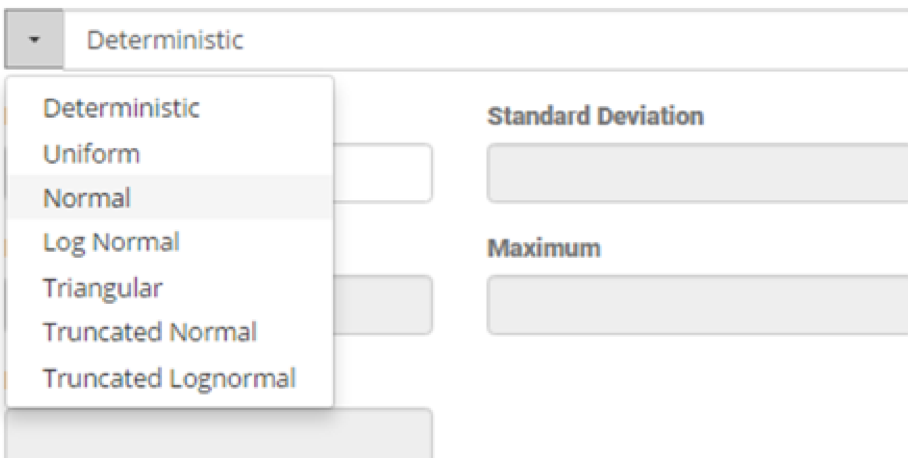
The simulation may run for a maximum of 2000 iterations, but may converge with fewer iterations based on a tolerance criteria. After each iteration, Road Scheduler calculates a new mean closure productivity and standard deviation and compares previous value to calculate a convergence error. When this convergence error drops below a certain threshold (90% confidence), the simulation will terminate. Otherwise, the analysis will terminate when the maximum number of iterations is reached.

Road Scheduler also performs a sensitivity analysis for probabilistic analyses by calculating the Spearman Correlation coefficient for each probabilistic input. The Spearman Correlation Coefficients conveys a measure of statistical dependence between the productivity (lane-miles per closure) and each probabilistic variable. Since the number of closure windows is directly determined from the closure productivity, this correlation also applies to the total construction time. For these probabilistic simulations, Road Scheduler provides additional report sections that are not otherwise available in deterministic analyses. The sections include a statistical summary of the Monte Carlo simulation, including a histogram of required closures as well as the results of the sensitivity analysis discussed above.

Distributions for Probabilistic Inputs
The reporting results of the Monte Carlo Simulation and sensitivity analysis can provide you with an understanding of how variance or uncertainty in parameter values will affect the overall productivity of your paving strategy. For example, variables specified with excessively large ranges may also result in a wide range of required closures.

It is important to note that specifying a variable as probabilistic indicates that a parameter exhibits variability or uncertainty that cannot be conveyed with a single value. While average values or modes may be used, it is recommended that you specify probabilistic variables whenever supporting information or data is available (e.g. the packing efficiency of a truck). Conversely, assigning deterministic inputs reflect a relative confidence or uniformity in a parameter's value (e.g. the nominal capacity of a truck). However, a deterministic analysis cannot produce a histogram or sensitivity analysis.

In Road Scheduler, probabilistic inputs can be assigned one of six different distributions (aside from deterministic, the default option implying no distribution).



Although the specific numerical may values vary due to the unique circumstances of each paving job, proper selection of a distributions can help provide constraints that yield more meaningful results. The table below summarizes important characteristics that may help you determine which distribution to select, even if you may be uncertain of the numerical values.

Distribution	Considerations
Deterministic *(n/a)*	The input value has a single, fixed value that will not change between iterations (no statistical calculation). Choosing this means you are fairly confident that the value will not change, such as design parameters. *e.g. the number of teams for an activity is relatively fixed*

Uniform *(min, max)*	In this case, all values within a range have an equally likely chance of occurring. Use this distribution when you are confident in the minimum and maximum values, but have no additional information to describe the likelihood of values in between. *e.g. the packing efficiency of paving materials may exist on a narrow range of 90-100% and historical records indicate that values within this range are likely to occur*
Normal *(mean, std)*	In a normal distribution, there is no limit on the minimum or maximum value but extreme values are highly unlikely to occur. Use this distribution when an average can be determined along with a general variance, but you do not want to limit the minimum or maximum values. Additionally, the distribution is symmetric, so the tendency to randomly choose a value above or below the mean is equal. *e.g. a batch plant may provide an average production rate, with a standard deviation equal to 10% of the average and no particular limitations to the maximum or minimum values.*
Log-Normal *(mean, std)*	The considerations for a log-normal distribution are similar to the normal distribution, except that the distribution is not symmetric. Rather, there is a tendency for values to be above or below the specified mean. e.g. *you know the average productivity rate for rebar placement and have evidence to believe that actual rates tend to lie at or above the average rate in practice. You do not want to limit the minimum or maximum value either.*
Triangular *(mode, min, max)*	In a triangular distribution, you define strict limits for the minimum and maximum like a uniform distribution. Additionally, you also have information regarding the most common value (mode) but no other information regarding the likelihood of values between. In this case, the likelihood drops linearly between the mode and maximum or minimum. *e.g. from previous jobs, you have observed truck arrivals anywhere between 4 to 10 minutes, indicating 6-15 trucks/hour. You also have observed the most common arrival rate every 8 minutes, indicating a mode of 7.5 trucks/hour.*
Truncated Normal *(mean, std, min, max)*	The considerations for this are identical to a normal distribution, but with additional constraints that strictly limit the minimum and maximum values possible. This is similar to a triangular distribution but the probability of choosing a value between the mean and min/max is non-linear.
Truncated Lognormal	The considerations for this are identical to a log-normal distribution,

(mean, std, min, max)	but with strict limits on the minimum and maximum values. This again is similar to a triangular distribution except that the probability of choosing a value between the mean and min/max is non-linear.

1.3.0. Best Practice Example: CRCP Productivity

The sections in this user guide provide a walkthrough of a deterministic, concrete-based productivity analysis simulated Road Scheduler while briefly discussing best practice considerations pertaining to each step.

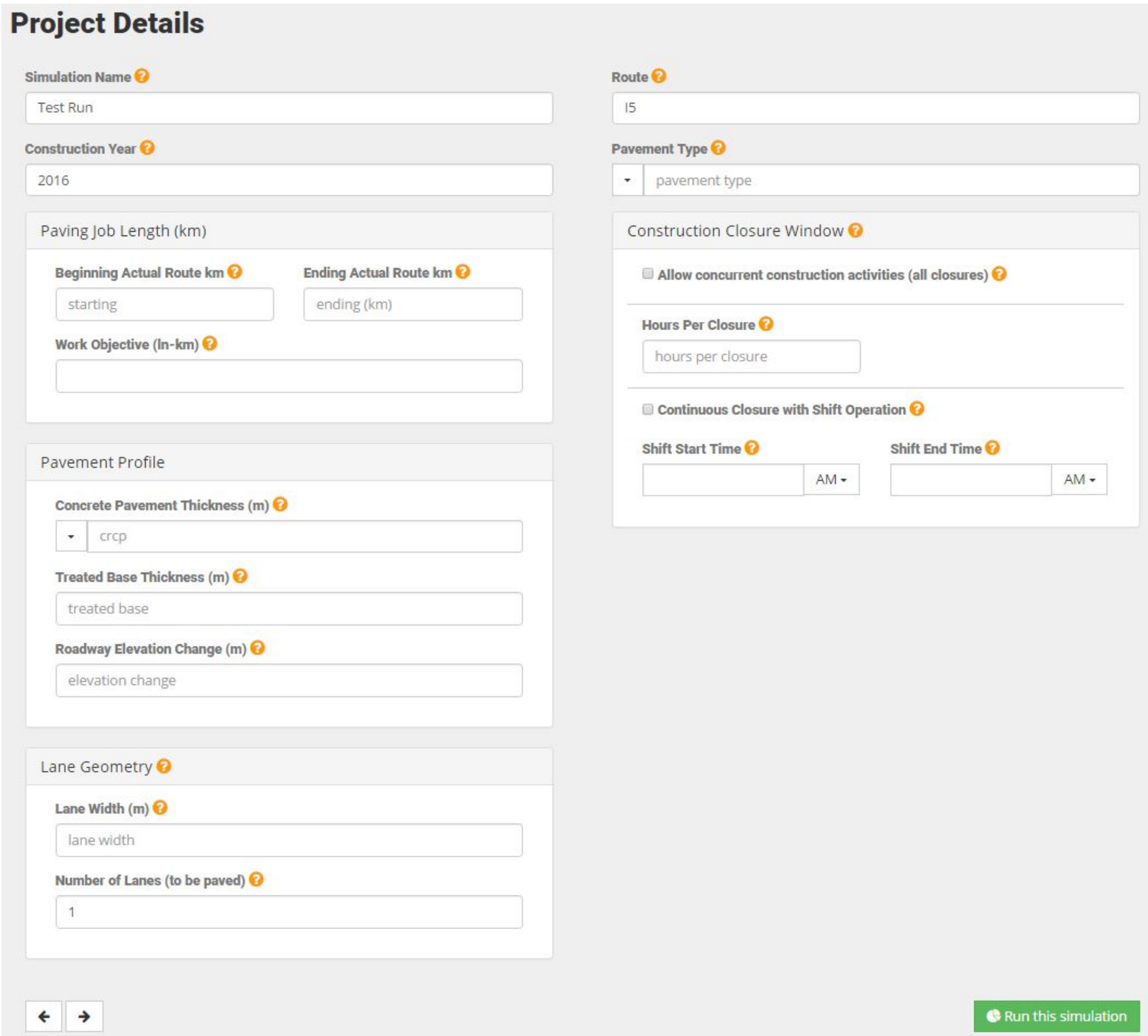
Each step included in the demonstration is accompanied with brief discussions of considerations and assumes that all necessary data has already been collected. These discussions frequently refer to concepts presented in Chapter 1.1 (Definitions and Background Knowledge) and Chapter 1.2 (Simulation model and Data Requirements), which are intended to demonstrate how best practice considerations for inputs can influence results.

By understanding the results of this demonstration, you will also have a better understanding of Road Scheduler's results. The user guides in the previous chapter are intended to explain how input parameters influence both each other and the overall construction productivity. In contrast, this user guide focuses on application and interpretation.

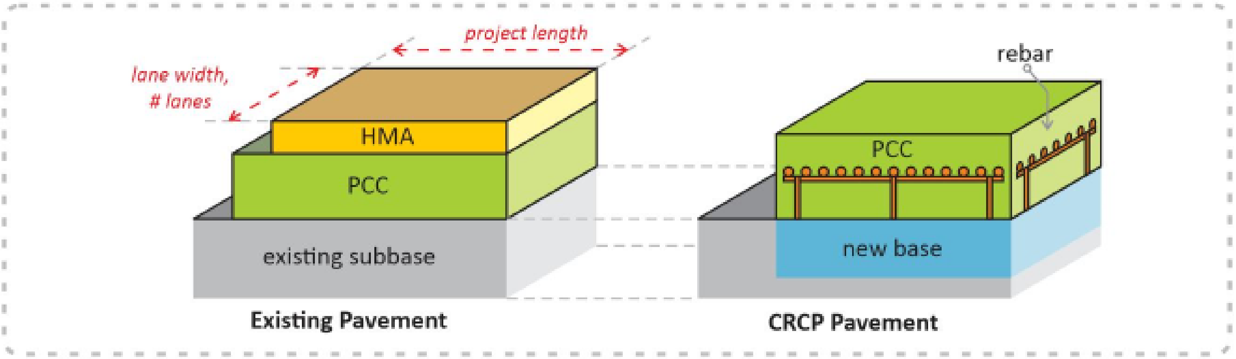
Using a CRCP Productivity paving job as a demonstration, the user guides in this section will address the following questions:
1.3.1 Project Details - How does the application identify the project and define its size?
1.3.2 Working Window - How do I specify the length of closure?
1.3.3 Activity 1: Mobilization - How much time is required to prepare the construction site for a closure?
1.3.4 Activity 2: Demolition - How do I specify how material is demolished and removed?
1.3.5 Activity 3: New Base - How do I specify how base material is added?
1.3.6 Activity 4: Rebar - How do I specify the construction of rebar, an intermediate layer?
1.3.7 Activity 5: Concrete Paving - How do I specify how pavement materials are placed?
1.3.8 Activity 6: Curing - How much time does the material require before it can support live activity?
1.3.9 Activity 7: Demobilization - How much time is required to clean up and re-open a construction site for traffic?

1.3.1. Project Details

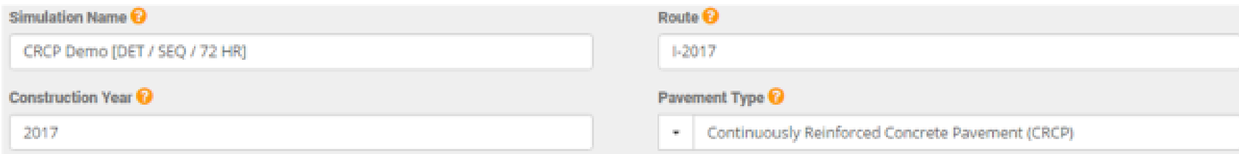
The Project Details section captures basic project information which describes the physical project size and extent, as well as identifies the project name and location. Collectively, this information is vital because Road Scheduler uses it to quantify the amounts of materials in each layer of the existing and new pavement, i.e. the objective of each activity within the closure.



Specifically, the Project Details section captures the important physical and geometric information discussed in User Guide 1.1.2. The illustration from section 1.1.2., shown below, helps clarify this connection. Completing the working window feature is discussed in User Guide 1.3.2 and conceptually described in User Guide 1.1.4.



Basic Project Details

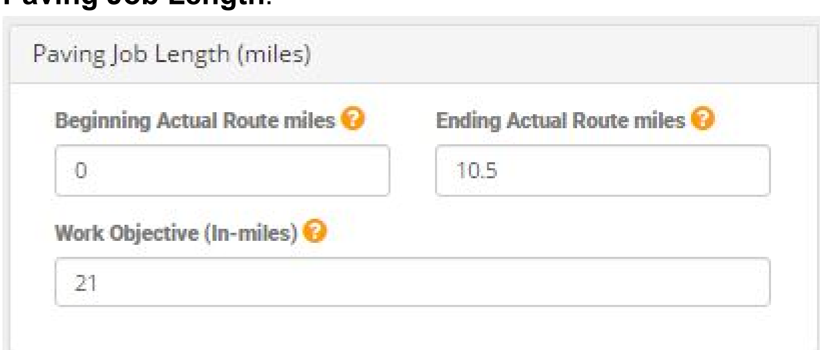


Provide the name and route for your simulation in the Simulation Name and Route field respectively. This name should be descriptive enough to distinguish your project easily, even between alternative analysis methods or options for the same project. The Route should provide helpful technical information regarding the project location, such as the route number or a local name for the road.

In the Construction Year field, enter the year of intended construction. Note that the intended year of construction may differ from the year in which this simulation is created.

Next, select one of the 6 available Pavement Methods from the dropdown menu included in this version of Road Scheduler. In this example, we will demonstrate a simulation for a continuously reinforced concrete pavement (CRCP). Upon selecting a method, notice that new data entry sections (each representing unique construction activities) appear at the top of the simulation.

Paving Job Length:



Next, enter the mileposts that define the boundaries of the pavement project as well as the work objective in lane-miles (the linear road length times the number of lanes). Road Scheduler does not automatically calculate the job length based on these mileposts because the post numbers may not necessarily correspond to accurate lengths.

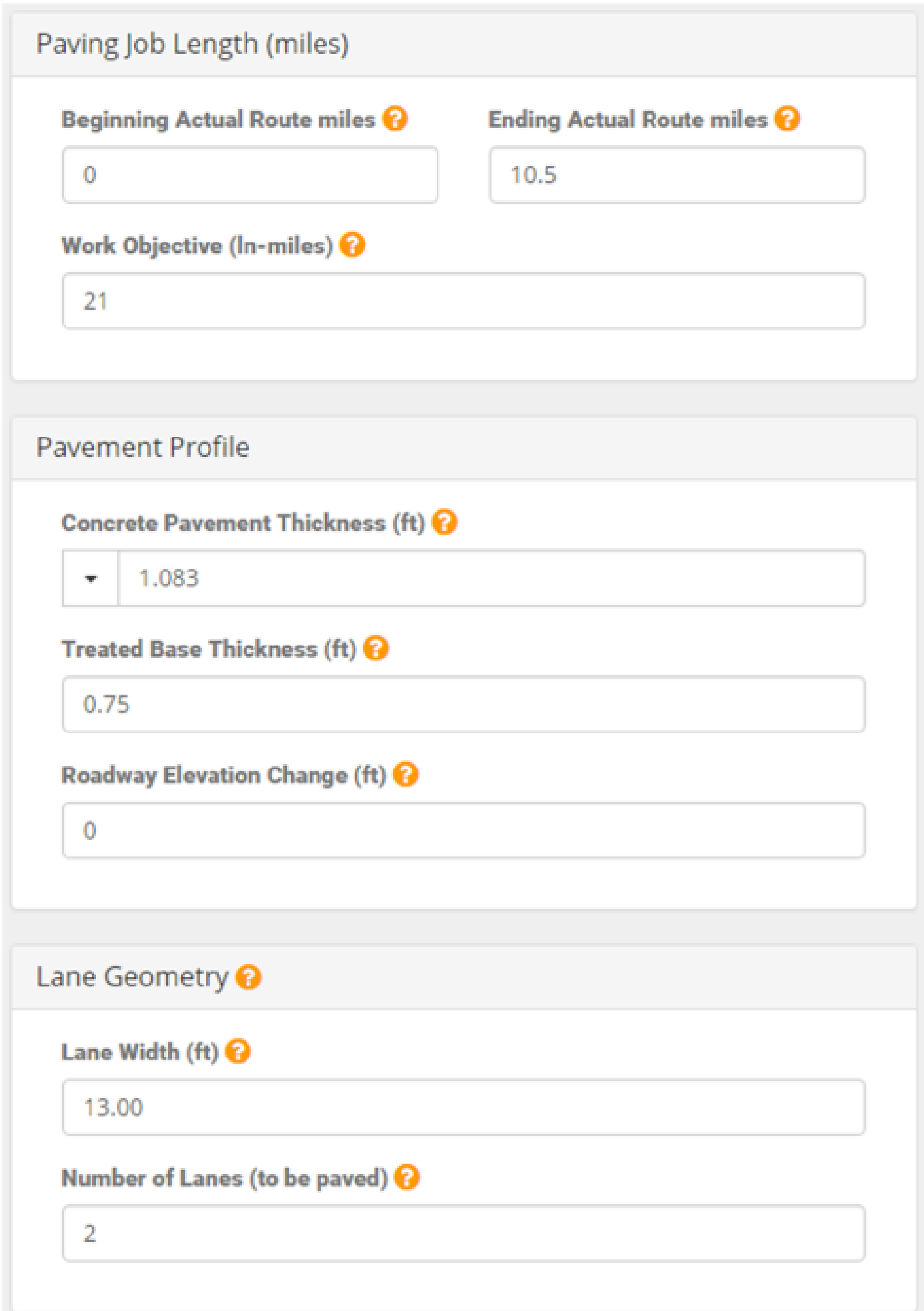
Pavement Profile:

In Pavement Profile fields, enter information regarding the thicknesses of each material layer within the cross section of your pavement. Additionally, you must specify how much the completed pavement will change the roadway elevation (relative to the existing pavement): a positive value indicates the surface elevation will increase whereas a negative value implies the elevation will decrease. These inputs are essential to specify because Road Scheduler assumes that each material corresponds to a different construction activity whose order and rate of completion depend on the paving method and material quantities.

In this example, the CRCP pavement has only two materials with a thickness but the number of layers may change depending on the paving method you select. Depending on the activity, the scope of work and rate of completion may be based on length, area, or volume. For example, the rebar layer is embedded in the CRCP pavement and therefore does not contribute to depth. Consequently, rebar is calculated on an area basis (rather than volumetric).

Lane Geometry

Finally, specify the lane width and number of lanes so that Road Scheduler can determine the overall project size and the objective of each construction activity. At this point, you have provided enough information for Road Scheduler to calculate the physical scope of your paving job.



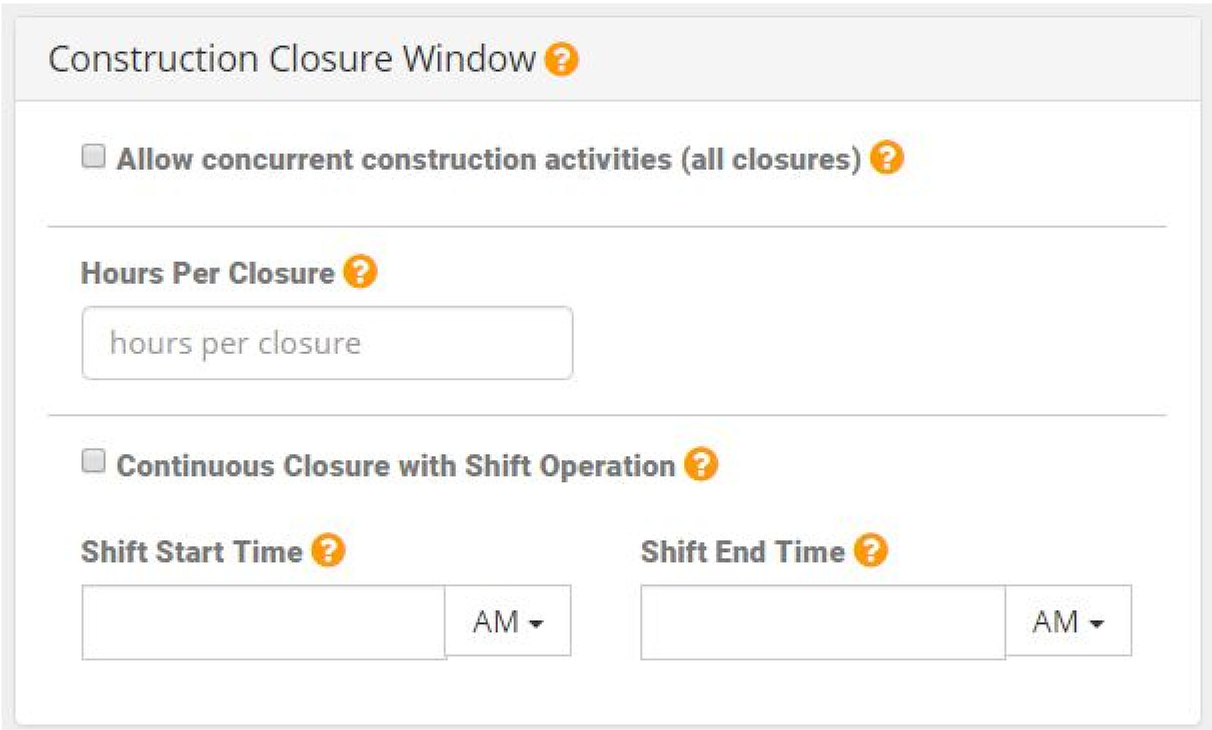
Next Section...

To complete the Project Details, move on to the next guide in the chapter to view instructions on specifying inputs for the Construction Closure Window.

If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button (shown below):

1.3.2. Working Window

The working window field specifies the length of time allocated to a single closure. Road Scheduler will attempt to maximize the productivity during this working window, but multiple windows may be required to complete a specified job.

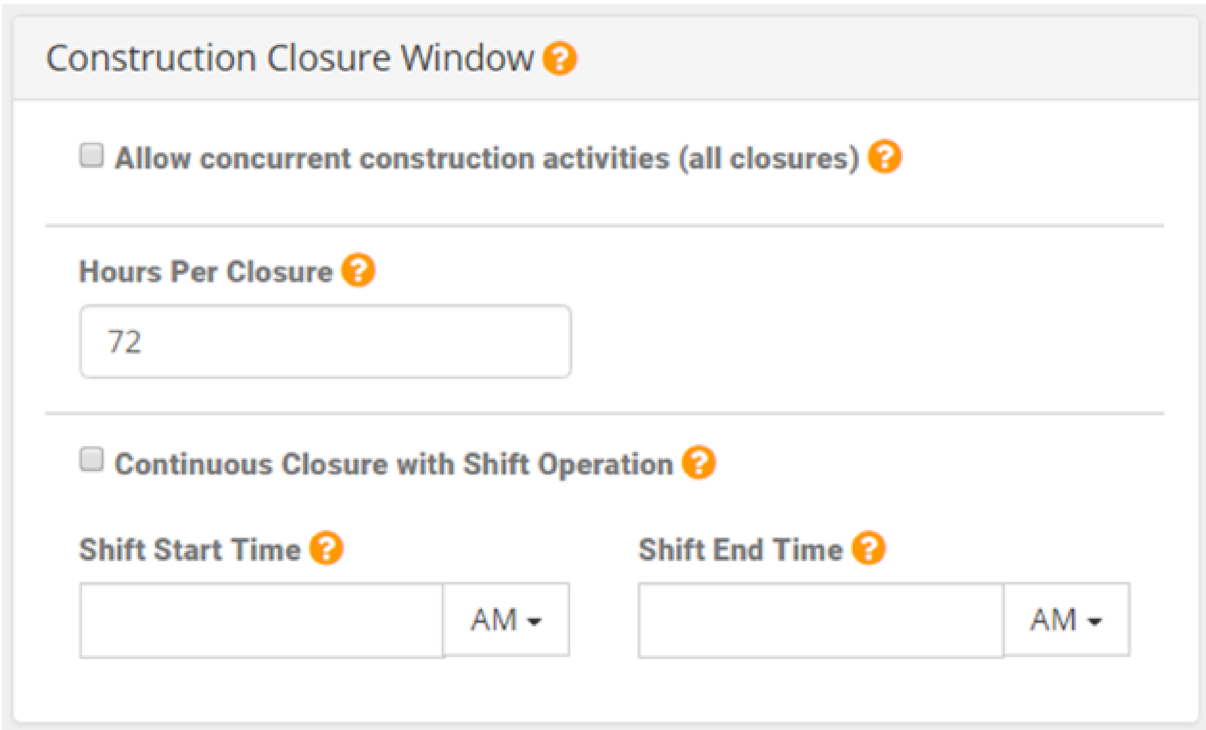


It is important to consider the length of a working window because this can influence the total amount of time required to complete a paving job. Because each working window includes a closure mobilization and demobilization activity, pavement jobs completed with a higher number of shorter length windows typically incur a longer total construction time. On the other hand, specifying a longer continuous window may result in a shorter overall construction time but may result in poorer public reception. For example, you may finish the same paving job faster with a continuous 7-day closure rather than 3 or 4 weekend closures, but the public may prefer spreading out the closures to avoid delays during the weekdays.

Enter the number of hours allowed for each working window or closure, or use a commonly used window size discussed in Chapter 1 (Closures and Working Windows). The value entered will influence the closure productivity, rate of completion, and total number of working windows required to complete the paving job objective.

Additionally, you may also specify two additional options for your closure. First, you may allow concurrent construction activities (for all closures) by selecting the checkbox. This generally means that multiple activities can occur simultaneously somewhere on the job site (assuming spatial and maneuverability requirements are met) which increases the overall per closure productivity. If left unchecked (default), Road Scheduler will assume that your activities are sequential - only 1 activity may occur onsite at any given moment.

The second option is whether each closure should be considered a shift operation. A shift operation means that the road is closed to traffic throughout your closure, but active construction occurs only between the hours you specify.



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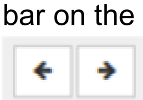
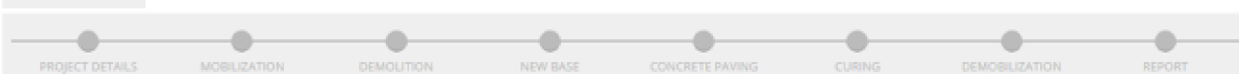
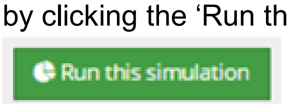
Click the arrow to the right to continue to the next step or choose an activity from the navigation bar on the top.

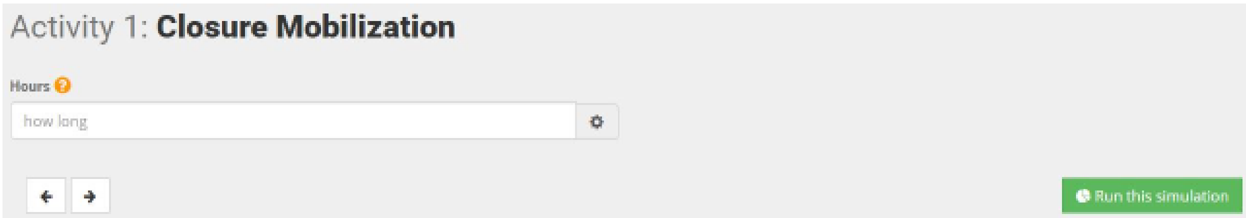




If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:



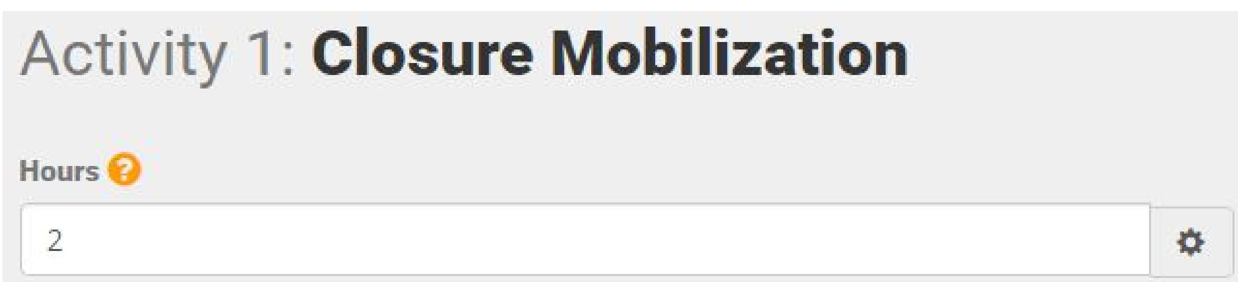
User Guide 1.3.3 Mobilization
Activity 1: Closure Demobilization captures the amount of time required to initially set up or stage equipment, materials, and/or crew for a single paving closure (specified in the Project Details).



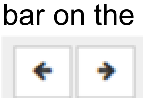
Enter the number of hours required in the Hours field.

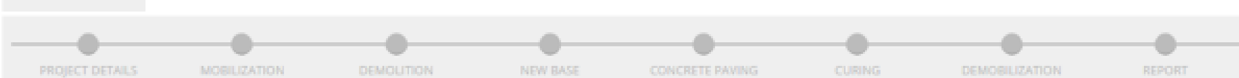
It is important to complete this field because the time allocated for closure mobilization is a lag activity that reduces the available time per closure for actively constructing the pavement. Mobilization is an example of a lag-time activity because no actual progress is made on the construction of the pavement, but the time is necessary to include as a critical path activity in the paving operations schedule.

It is also important to distinguish closure mobilization from activity mobilization: Activity mobilization refers to set-up for a single construction activity, while closure mobilization refers to activities that prepare the road for closure itself. Individual construction activities may include separate mobilization or demobilization requirements, but *a single closure consists of only one closure mobilization and closure demobilization activity*.



Next:
Click the arrow to the right to continue to the next step or choose an activity from the navigation bar on the top.



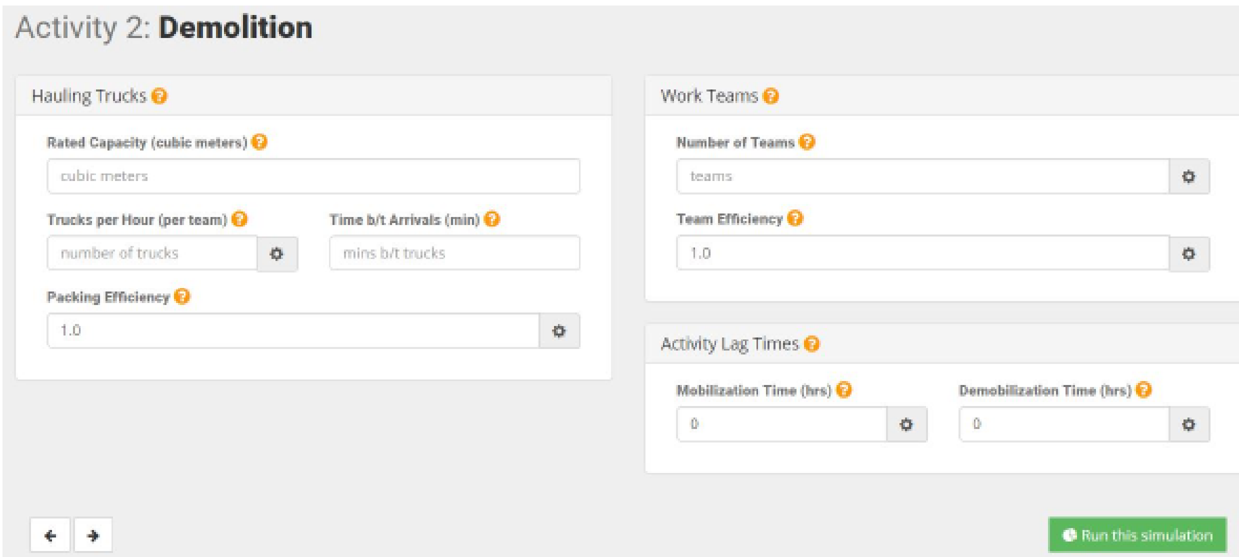


If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:

Run this simulation

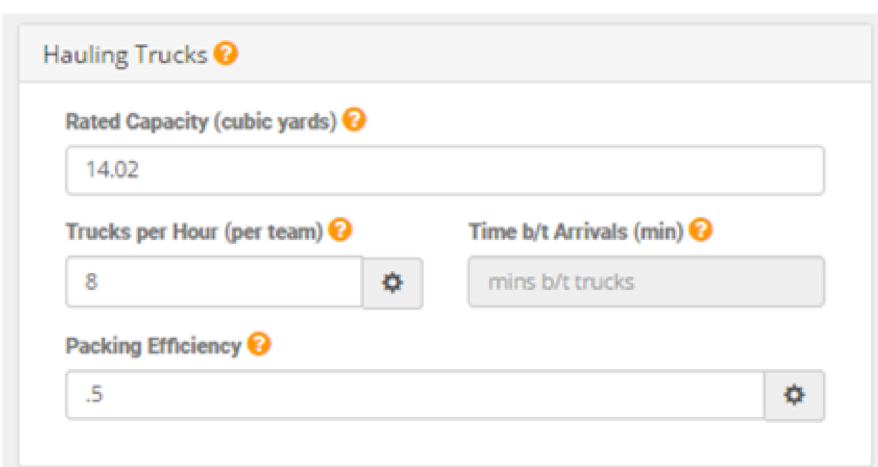
1.3.4 Activity 2: Demolition

Activity 2: Demolition is designed to simulate the removal of existing pavement using variables by describing the hauling equipment capacity, the work team, efficiency factors, and lag times. Indirectly, you have specified the demolition depth in the Project Details section: it is calculated as the sum of the new pavement and treated base thicknesses, minus the change the roadway elevation.



The dumping destination and fleet sizes are not required inputs because they impact conditions outside the simulation boundary and do not directly impact the construction of the pavement itself.

This step is important because these variables influence or constrain the overall productivity of the demolition activities. Road Scheduler compares and balances the overall productivity of each resource and activity to determine how closely adjacent activities can be placed, and which activities may constrain the overall closure productivity.

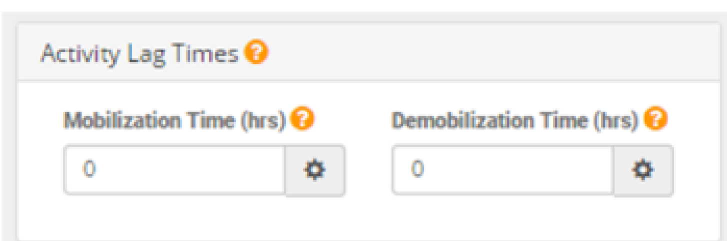


The first category you need to complete is Hauling Trucks. After entering a rated hauling capacity, consider limitations to the Truck per Hour (per team). Calculate the arrival rate between trucks by dividing 60 by the Trucks per Hour per team (e.g. 15 Trucks per Hour means 4 minutes between arrivals). The time between arrivals should be at least as large as the time required for a single hauling truck to complete its on-site tasks (e.g. loading, cleaning, tarping). Finally, recall that packing efficiency for hauling trucks tends to be low due to the size gradation of rubblized pavement (50-60% efficiency is not uncommon).

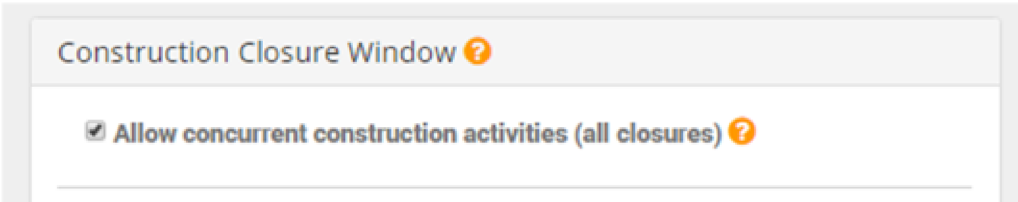
The Demolition step also requires that you account for work teams by entering values into the Number of Teams and Team Efficiency fields.

The number of teams is limited by the amount of maneuverable space available for crew and equipment on the job site. Specifying multiple teams implies one of the following conditions is true: truck arrivals are staggered, trucks arrive concurrently, or a mixture of the two.

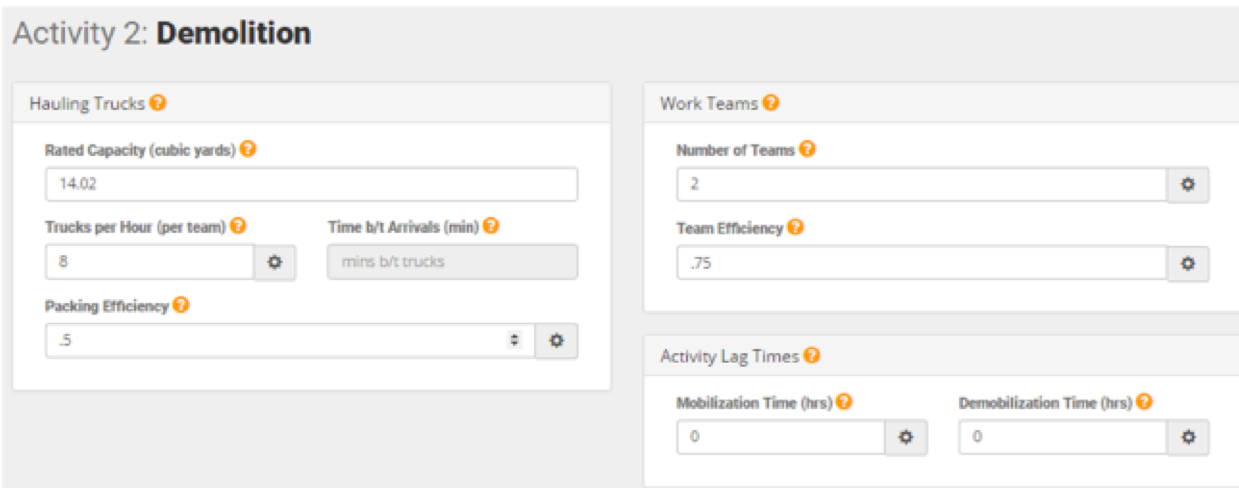
- With staggered arrivals of multiple teams, the actual arrival rate between trucks decreases by a factor equal to the number of teams. The user should ensure this new arrival rate is not too fast.
- With concurrent arrivals, the actual arrival rate between trucks remains the same but the user must ensure that there is sufficient physical space for all teams (crew, materials, equipment maneuvers).



The final fields to complete in the Demolition step are the Activity Lag Times fields. These lag times refer to the time required to set up or dismantle equipment, crew, or materials for the demolition phase only, not the overall closure. They may also capture small follow-up activities required before the new base is placed because the application uses these lag times to determine the minimum spacing between sequentially scheduled activities.



If you selected ‘Allow concurrent construction activities’ for your closure windows, then you should consider allocating extra demobilization time for demolition or extra mobilization time for the new base (next activity) to avoid conflicts between activities. Adding this lag time will effectively stagger these activities, allowing the activities to maintain a spatially feasible or safe working distance between them.



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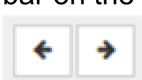
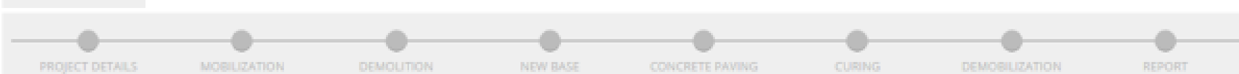
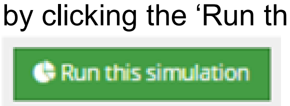


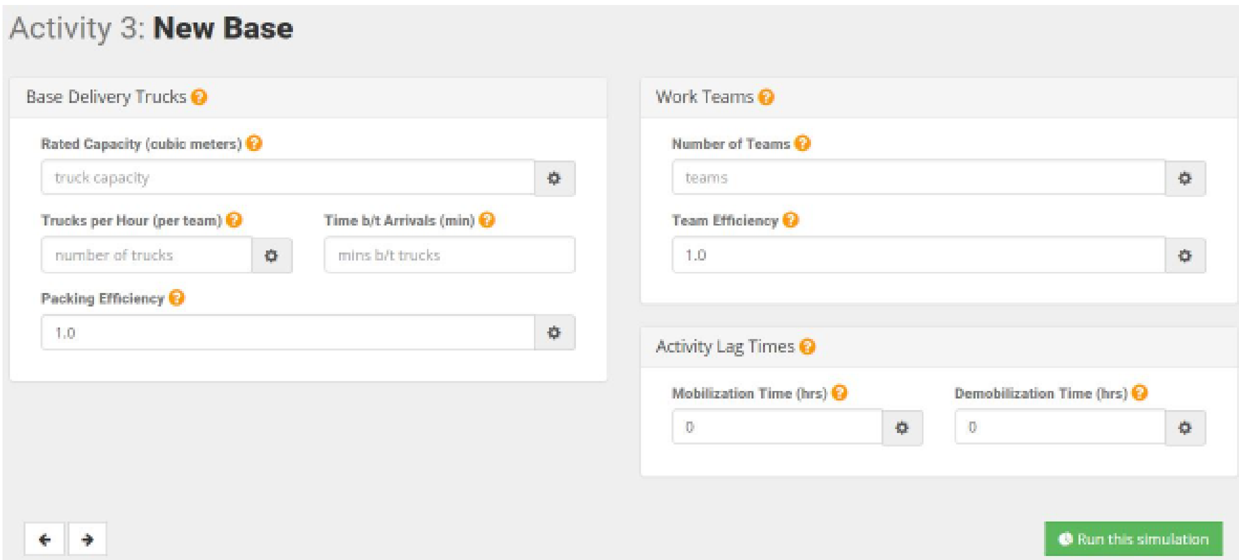


If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:

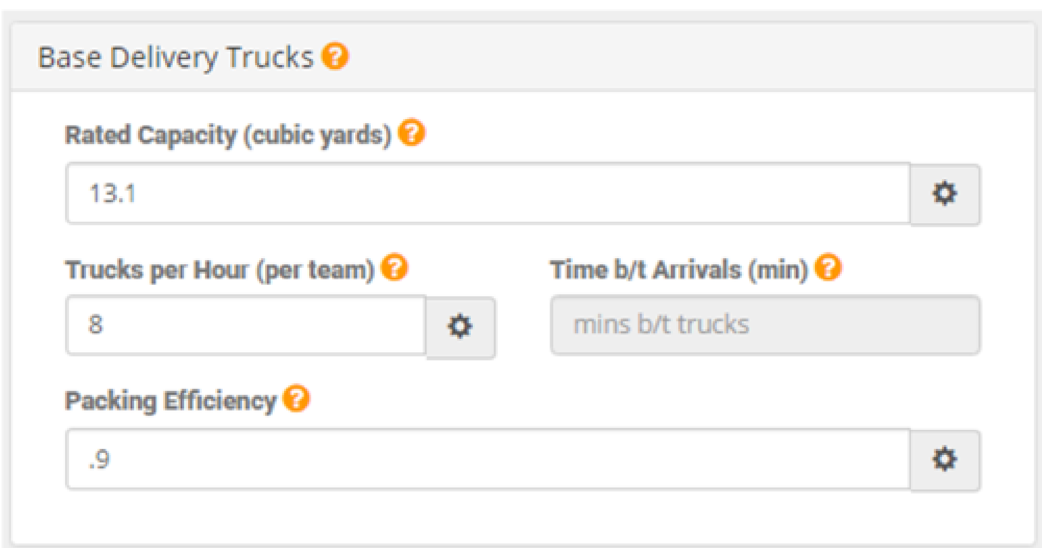


1.3.5 Activity 3: New Base

In Work Phase 3: New Base, you will be prompted to provide details about how base materials will be delivered to the job site. This is important because base delivery trucks influence how quickly base materials are delivered and subsequently, how soon reinforcing or paving activities can begin.

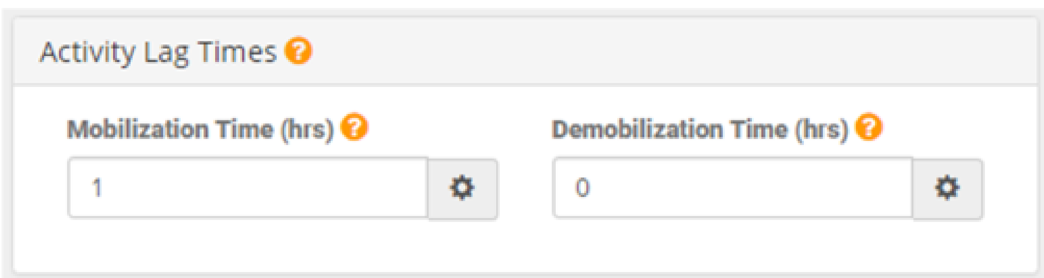


The first fields you complete in New Base reside within the Base Delivery Trucks box, which describe how quickly materials can be delivered to the project site for a single team or fleet.

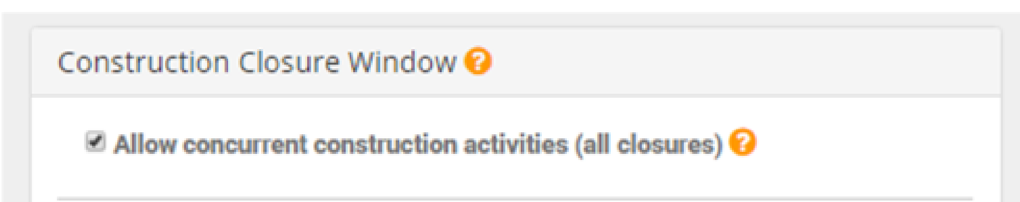


To complete this section, you should also consider how Trucks per Hour translates into an arrival rate by dividing 60 minutes by the number of Trucks per Hour. The arrival rate, in minutes between arrivals, should be at least as long as the time required for a single delivery truck to complete it's on-site tasks (e.g. unloading, cleaning, ticketing). The packing efficiency of material delivery trucks is generally high since the base usually consists of well graded aggregate.

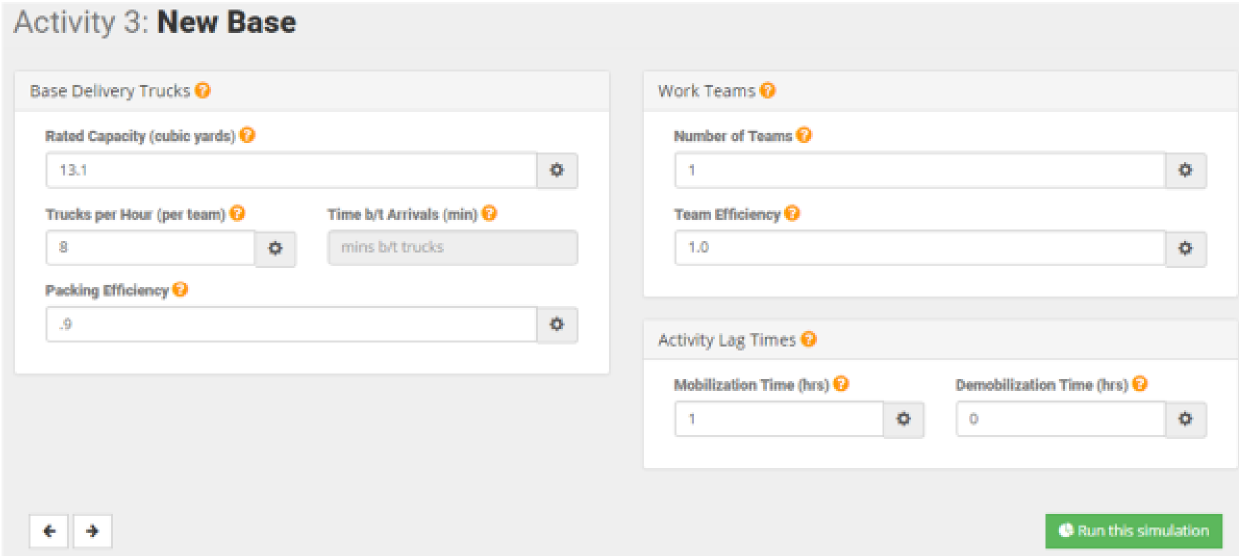
Similar to the Demolition activity, you can also specify the number of teams or fleets you have available for the New Base activity. Enter the number of teams available and the efficiency rate based on the number of minutes per hour that can be effectively utilized for work.



Now complete the Lag Times fields by determining the amount of time required to set up or dismantle equipment, crew, or materials specifically related to the New Base work phase activity. The simulation uses these lag times to determine the minimum spacing between sequentially scheduled activities.



If you selected ''Allow concurrent construction activities' for your closure windows, then you should consider allocating extra demobilization time for demolition or extra mobilization time for the new base to avoid conflicts between activities. Similarly, you may want to allocate extra demobilization time for new base to avoid conflicts with the rebar placement work crew (next activity). Adding this lag time will effectively stagger these activities, allowing the activities to maintain a spatially feasible or safe working distance between them.



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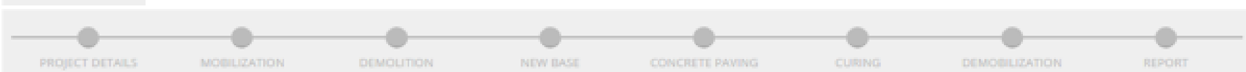
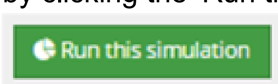
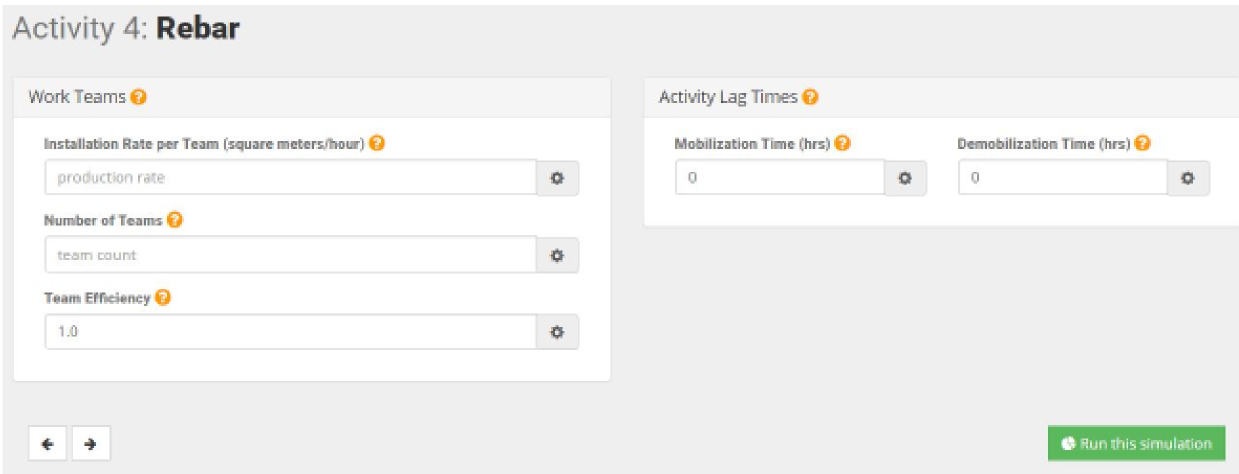


If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:



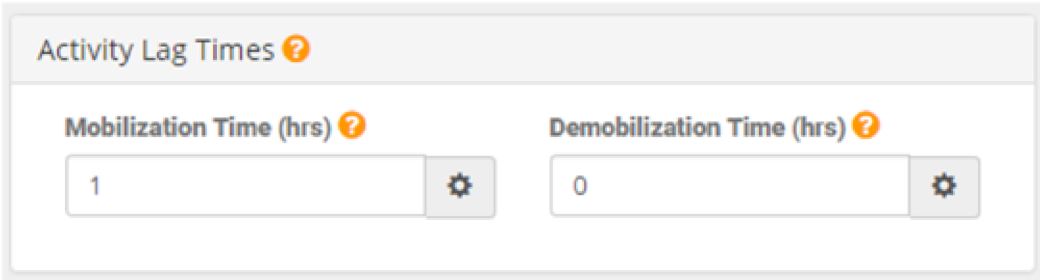
1.3.6 Activity 4: Rebar

In Activity 4: Rebar, you will be able to specify how quickly rebar can be placed (area per hour) in preparation for the paving activity. This is a labor intensive operation that does not require the use of heavy non-road equipment. It is assumed that you have already selected a team size that satisfies spatial constraints on the construction site.

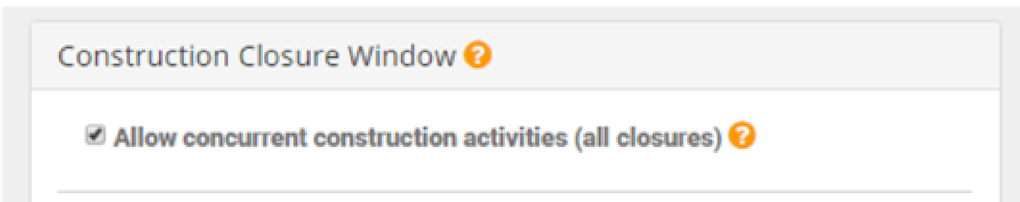


This is a critical path activity because rebar placement productivity determines how soon concrete paving operations can begin.

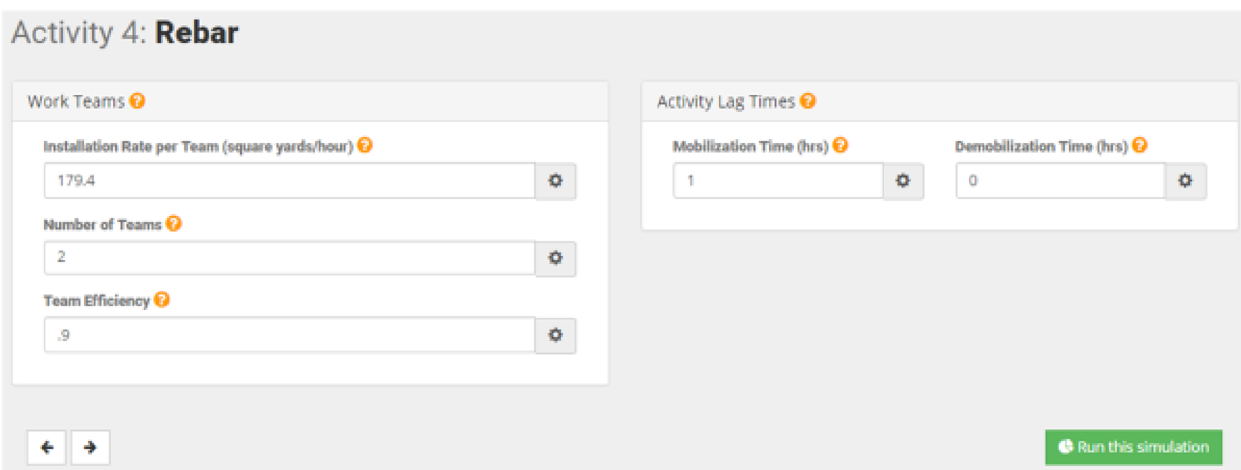
Complete the Work Teams fields by first estimating the nominal rate at which rebar can be placed by a single team. Specify a number of teams by carefully considering how many crews can physically fit on a work site, including space for staging materials and safely maneuvering. Road Scheduler calculates the overall activity rate (effective area of rebar laid per hour) as the product of the per-team production rate, the number of teams specified, and team efficiency. The team efficiency is influenced by a variety of factors (e.g. experience level, working conditions) so that value is left to your discretion.



Complete the Lag Times fields by determining the amount of time required to stage crew and materials and clean up materials for mobilization and demobilization lag. They may also capture small follow-up activities required before the new base is placed because the application uses these lag times to determine the minimum spacing between sequentially scheduled activities. The simulation uses these lag times to determine the minimum spacing between sequentially scheduled activities.



If you selected ‘‘Allow concurrent construction activities’ for your closure windows, then you should consider allocating extra mobilization time for rebar placement (or extra demobilization time for the the new base) to avoid conflicts between activities. Similarly, you may want to allocate extra demobilization time for rebar placement to avoid conflicts with the subsequent paving activity. Adding this lag time will effectively stagger these activities, allowing the activities to maintain a spatially feasible or safe working distance between them.



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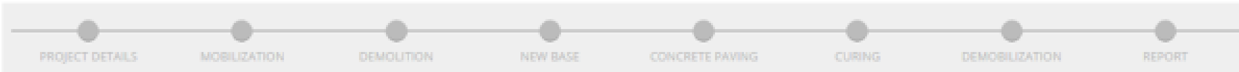
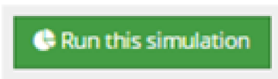
bar on the top.

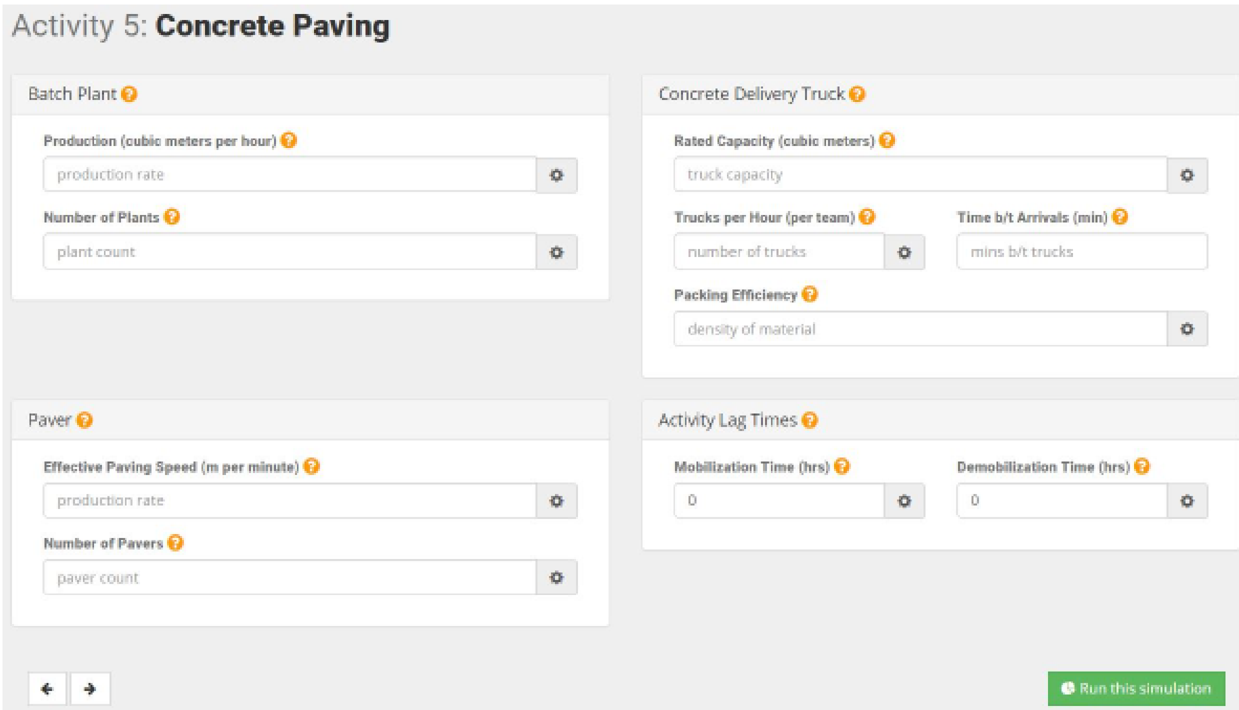


If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:

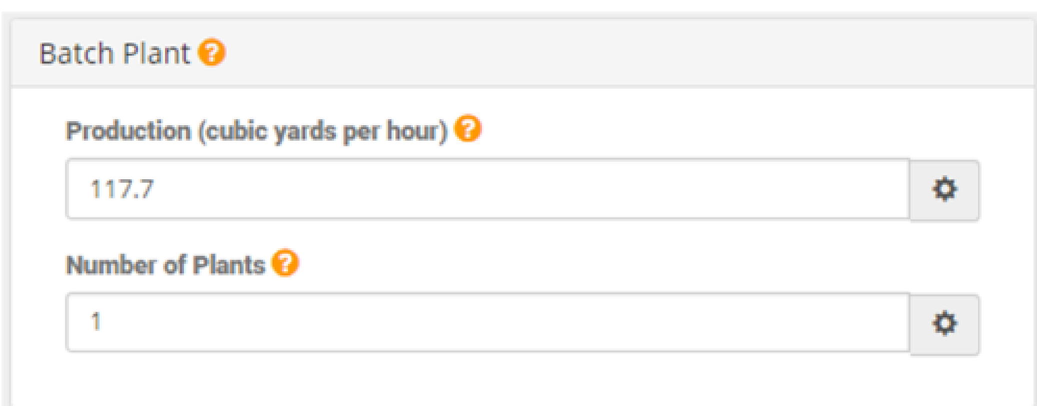


1.3.7 Activity 5: Concrete Paving

In Activity 5: Concrete Paving, you will specify information on the resources involved in the material production at the batch plant, the subsequent delivery of material to the job-site, and the placement of your pavement (paving). This information is essential because the individual rates of each resource must be balanced as the overall rate of the paving activity is determined by the 'slowest' supporting activity.



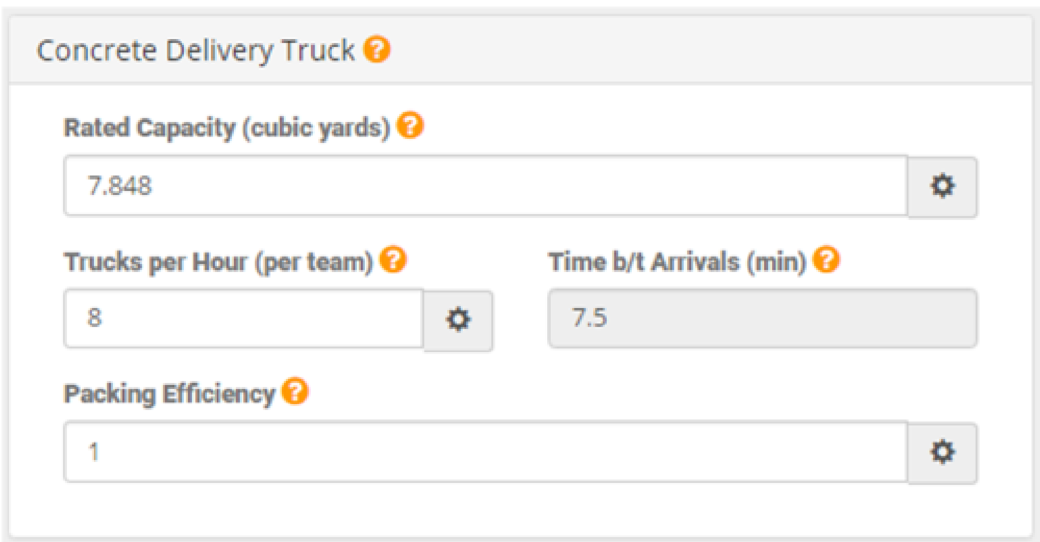
While Road Scheduler will automatically determine and balance these rates, you must specify information regarding the batch plants material availability, the size and delivery rate of your delivery trucks, and the effective paver speed.



Before you complete the batch plant field, consider the availability of local batch plants and their respective maximum rates of production available for the specific project. Note that the batch plant's maximum production capacity is not necessarily the amount available for the project.

After this determination, enter in a value that is less than or equal to this amount.

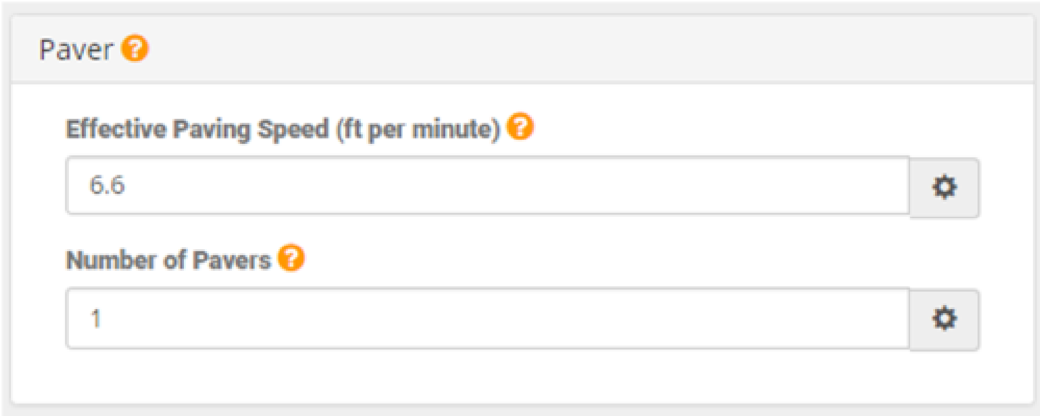
Complete the Number of Plants field. This value is frequently 1, but multiple plants require a more complex consideration of available space within the work zone due to potentially simultaneous deliveries. These spatial considerations are currently outside the scope of Road Scheduler's simulation boundaries, but the number of plants can be changed at your discretion.



In the Concrete Delivery Truck area, you can complete the Capacity field based on the fleet available for this project. As with demolition or base delivery, you should also consider converting your deliveries per hour into time between intervals. This interval must be at least as large as the time to offload a single truck, for example.

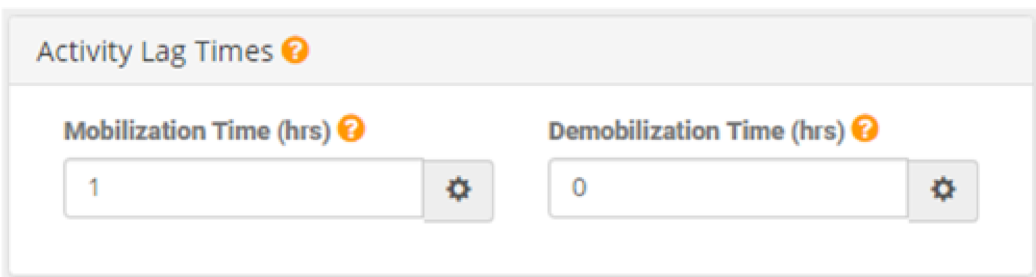
Additionally, be aware that the number of trucks per hour is not the minimum fleet size required to complete this paving activity. Nevertheless, the delivery rate is influenced by travel distance and time as well as the maximum fleet size (but none of these 3 parameters are required by road scheduler since they affect activities outside the physical job site).

When completing the Packing Efficiency field, enter a value that reflects the fact that paving material packs very well, but carries the risk of caking if concrete setting occurs prematurely. If concrete sets prematurely within the delivery trucks, it can cause longer handling times (lag), reduce the truck's effective capacity as well as the amount of materials available for use.

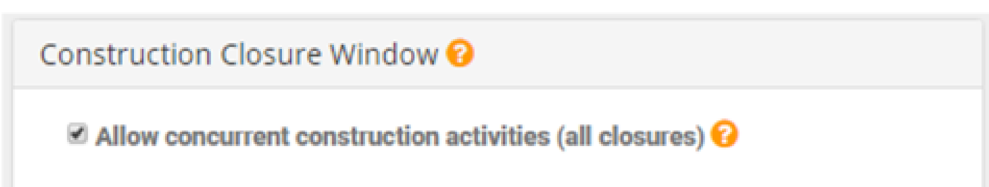


In the Paver box, you can enter a Speed value in meters per minute. This refers to the average rate the paver places material, rather than the non-paving driving speed of the equipment. The Number of Pavers field allows you to select the number of pavers which is limited by available space, depending on the width of the paver relative to the width of the pavement section.

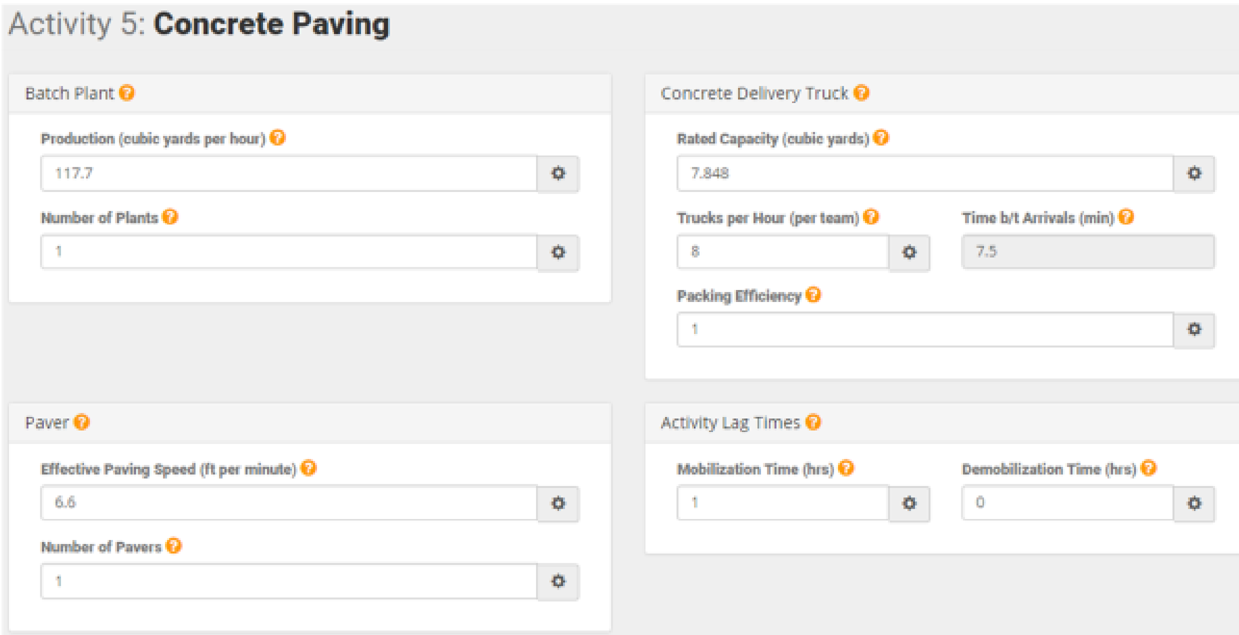
Due to the multiplicity of variables affecting paver productivity, Road Scheduler assumes you have factored in efficiency into your input value. The value should reflect the rate at which a single machine is capable of paving and is typically between 5-10 ft/min.



In the Activity Lag Times fields, you can enter values for Preparation and Post-Work Lag. In the Preparation Lag field, enter a value that reflects the amount of time to stage equipment for a paving activity. Finally, enter a value in Post-Work Lag that represents the time required to dismantle the equipment for the paving activity.



These activity lag times are particularly important to specify for concrete paving if you selected the ‘Allow concurrent construction activities’ options for the Construction Closure Window in the Project Details section. Although some operations could potentially begin ‘concurrently’ by adjusting their effective rate, they must actually be staggered with some distance (or time) to avoid spatial conflicts. For example, concrete pavers may postpone their operation by 1-hour to maintain a safe working distance from the rebar workers. This can be simulated by adding 1 hour to your Mobilization Time for paving or equivalently adding 1 hour to the Demobilization Time for the rebar activity.



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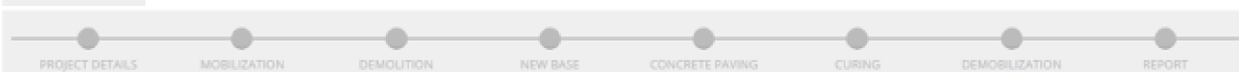
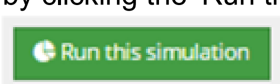
Click the arrow to the right to continue to the next step or choose an activity from the navigation bar on the top.

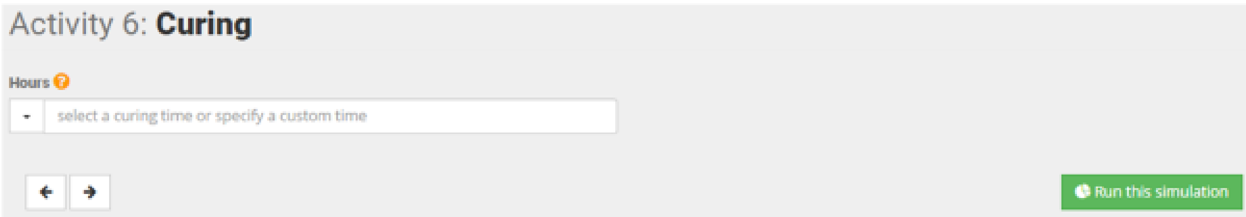


If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the 'Run this Simulation' button:



1.3.8 Activity 6: Curing

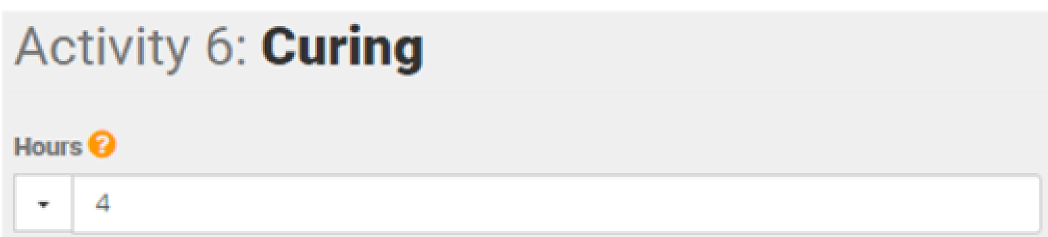
The Activity 6: Curing field allows you to specify the number of hours required for a concrete-based pavement to cure before being structurally acceptable to handle live traffic loads.



Incorporating curing in your simulation is important because concrete curing times can be long and limit when the roadway can be reopened to traffic. The curing time is compared to the paving activity and closure demobilization times to determine which activity is limiting.

Regardless of whether the user allowed concurrent construction for their simulation, Road Scheduler assumes that Curing (concrete based) and Demobilization activities occur simultaneously and that the longer of the two determines the end of the closure window. For example, if the Curing time is longer than the time required to Demobilize the closure and re-open the work zone to traffic, then Curing will be the ‘last’ activity of the closure.

To complete the Hours field, enter in a value that is based on the structural properties of the concrete mix design or those specified in transportation agency standards. This value should <u>not</u> include time allocated for paving activity demobilization or overall closure demobilization.



Next:
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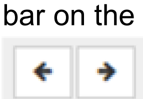
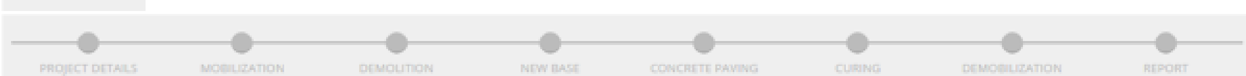
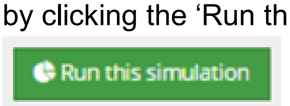


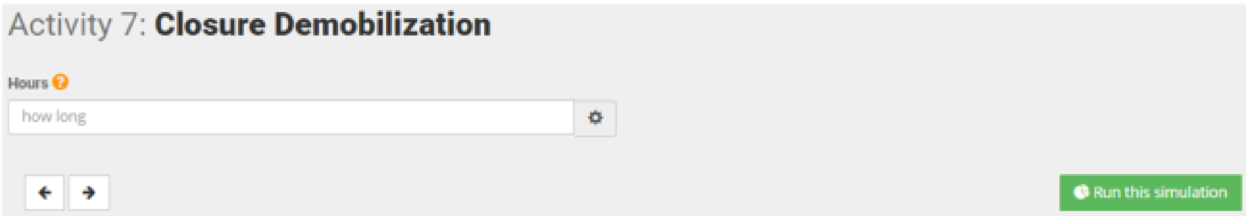


If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:



1.3.9 Activity 7: Closure Demobilization

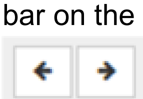
Activity 7: Closure Demobilization allows you to include the total amount of time required to dismantle equipment or materials, clean up the job site, and/or transport crew and subsequently reopen the roadway to traffic after a single closure. In Pre-Cast Concrete operations, you may include Grouting with Demobilization hours if you have not otherwise accounted for this time in the slab placement activity or elsewhere in the simulation.

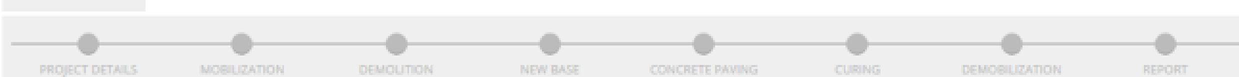


Closure Demobilization is important to include because it may potentially be the final activity in a paving closure that determines when traffic can be reopened. Closure demobilization is the final lag-time activity considered in the simulation and collectively, lag-times determine the absolute minimum size for a feasible construction window.

When you complete the Hours field, remember that the closure demobilization time and curing times are compared since both are potentially limiting critical path activities that follow after the paving phase. Regardless of whether the user allowed concurrent construction for their simulation, Road Scheduler assumes that Curing (concrete based) and Demobilization activities occur simultaneously and that the longer of the two determines the end of the closure window. For example, if the Closure Demobilization time is longer than the time required for the concrete to cure and reach adequate strength for traffic, then Closure Demobilization will be the 'last' activity of the closure.

Next:
Click the arrow to the right to continue to the next step or choose an activity from the navigation bar on the top.





If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:

1.4.0. Best Practice Example: Full Depth HMA Productivity

The sections in this user guide provide a walkthrough of an probabilistic, asphalt-based productivity analysis simulated Road Scheduler while briefly discussing best practice considerations pertaining to each step.

Each step included in the demonstration is accompanied with brief discussions of considerations and assumes that all necessary data has already been collected. These discussions frequently refer to concepts presented in Chapter 1.1 (Definitions and Background Knowledge) and Chapter 1.2 (Simulation model and Data Requirements), which are intended to demonstrate how best practice considerations for inputs can influence results.

By understanding the results of this demonstration, you will also have a better understanding of Road Scheduler's results. The user guides in the previous chapter are intended to explain how input parameters influence both each other and the overall construction productivity. In contrast, this user guide focuses on application and interpretation.

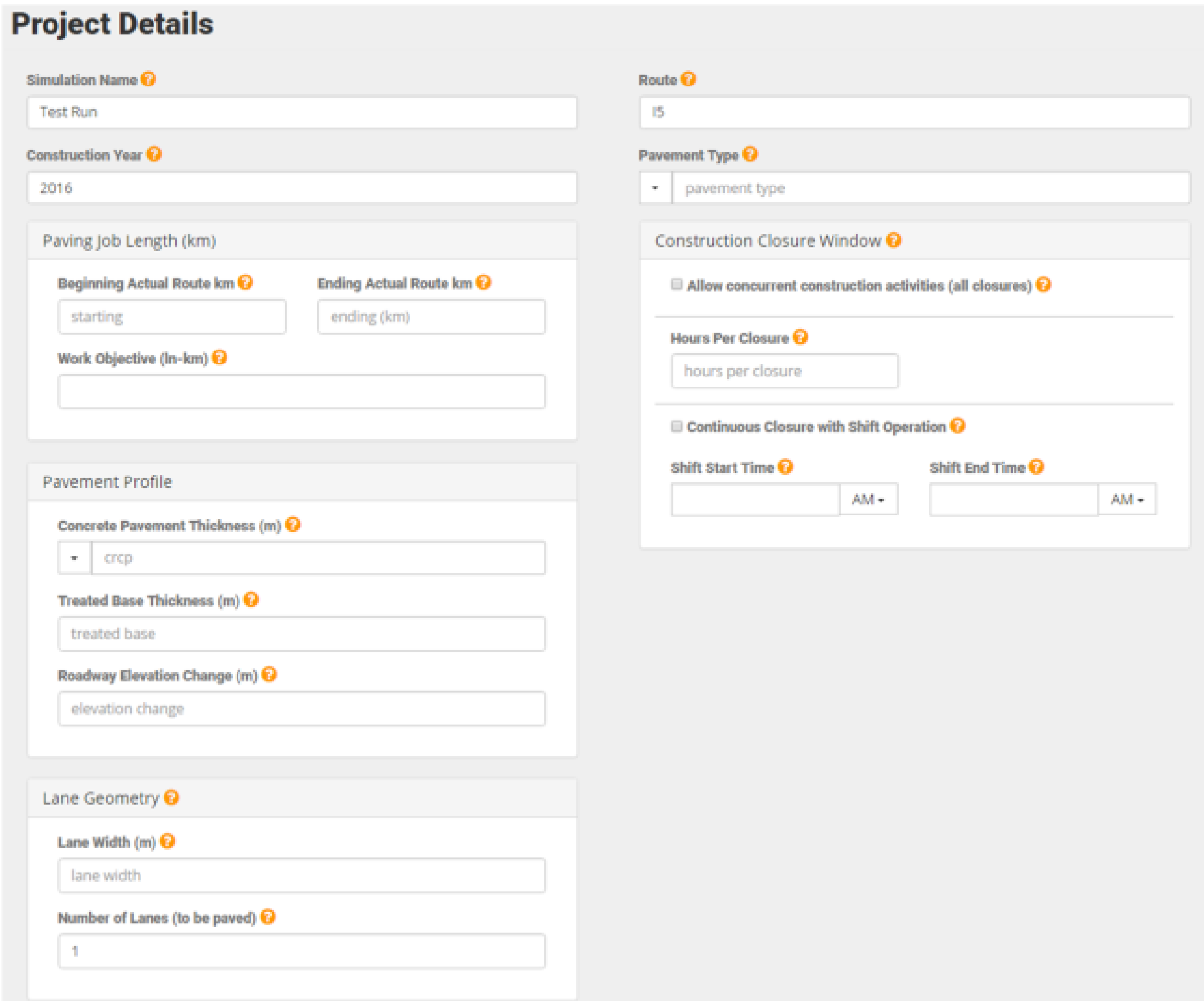
Finally, this walkthrough differs from the one presented in Chapter 1.3 because it includes additional considerations for entering probabilistic inputs and features an asphalt paving method that includes different activities absent in a concrete-based method.

Using a Full Depth HMA paving job as a demonstration, the user guides in this section will address the following questions:

1.4.1 Project Details - How does the application identify the project and define its size?
1.4.2 Working Window - How do I specify the length of closure?
1.4.3 Activity 1: Mobilization - How much time is required to prepare the construction site for a closure?
1.4.4 Activity 2: Demolition - How do I specify how material is demolished and removed?
1.4.5 Activity 3: Asphalt Paving - How do I specify how pavement materials are placed?
1.4.6 Activity 4: Demobilization - How much time is required to clean up and re-open a construction site for traffic?

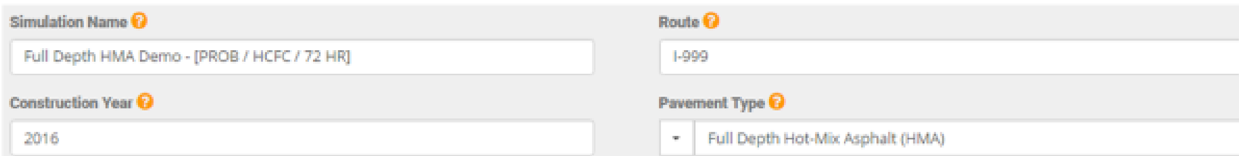
1.4.1. Project Details

The Project Details section captures basic project information which describes the physical project size and extent, as well as identifies the project name and location. Road Scheduler uses this information to quantify the physical scope of materials need for each layer of the existing and new pavement.



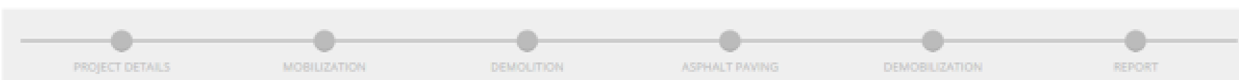
For more detailed information regarding terminology or background knowledge related to asphalt paving, please refer to Chapter 1.1. For detailed considerations regarding how Road Scheduler models the asphalt paving process (and supporting activities) please refer to Chapter 1.2.

Basic Project Details
Provide the name and route for your simulation in the Simulation Name and Route field respectively. This name should be descriptive enough to distinguish your simulation from others associated with the same project. This may include a defining feature of the simulation, such as the paving method, analysis type, or working window. The Route should provide helpful technical information regarding the project location, such as the route number or a local name for the road.

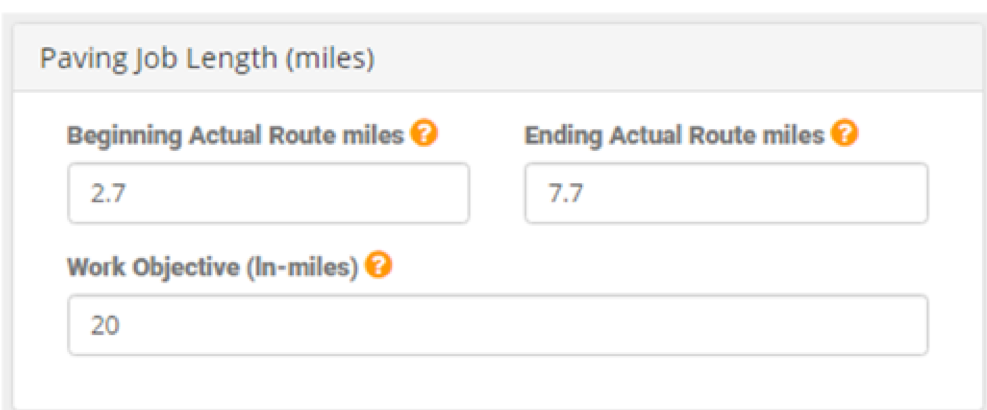


In the Construction Year field, enter the year of intended construction. Note that the intended year of construction may differ from the year in which this simulation is created.

Next, select one of the 6 available Pavement Methods from the dropdown menu included in this version of Road Scheduler. In this example, a Full Depth Hot-Mix Asphalt (HMA) simulation is chosen for the purposes of demonstration. Upon selecting this method, notice that new data entry sections (each representing unique construction activities) appear at the top of the simulation.

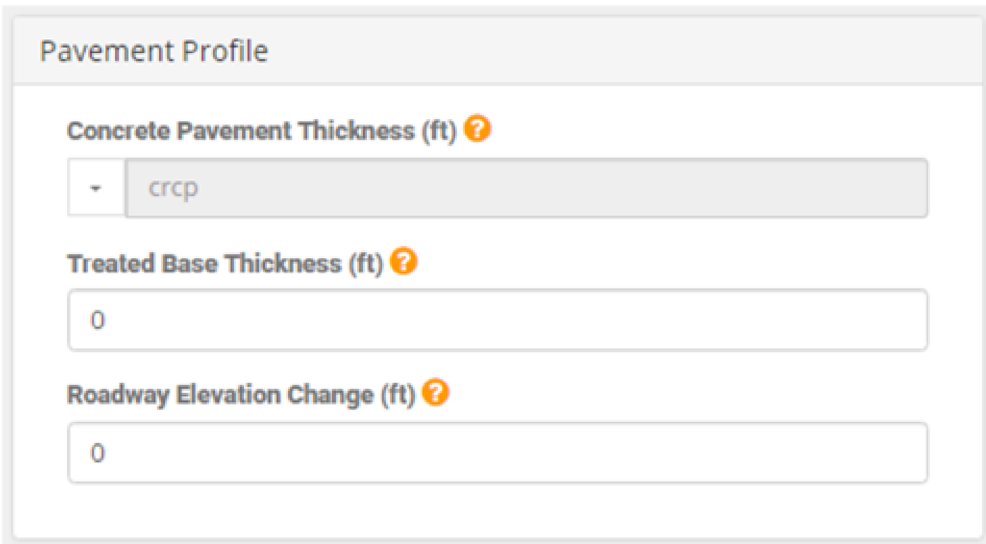


Paving Job Length:
Next, enter the mileposts that define the boundaries of the pavement project as well as the work objective in lane-miles (the linear road length times the number of lanes). Road Scheduler does not automatically calculate the job length based on these mileposts because the post numbers may not necessarily dictate the actual project length. In this example, the difference in mileposts implies a linear paving distance of only 5 miles, but the scope is actually 20 lane-miles. This implies the presence of 4 lanes.



Pavement Profile:

In Pavement Profile fields, enter information regarding the thicknesses of each material layer within the cross section of your pavement. Additionally, you must specify how much the completed pavement will change the roadway elevation (relative to the existing pavement): a positive value indicates the surface elevation will increase whereas a negative value implies the elevation will decrease. These inputs are essential to specify because Road Scheduler assumes that each material corresponds to a different construction activity whose order and rate of completion depend on the paving method and material quantities.



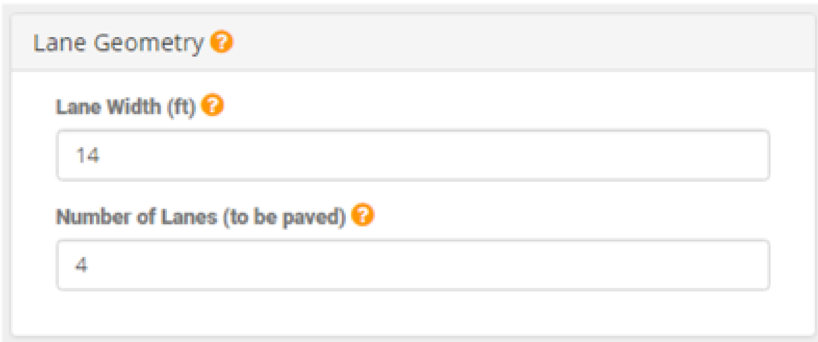
In this example, the ‘Concrete Pavement Thickness’ field is unavailable as this relates only to concrete paving methods (including Pre-Cast pavements). In other words, Road Scheduler assumes there is no concrete included in the three available HMA-related methods.

For this demonstration, set both the treated base and roadway elevation to a thickness of 0 ft. If your new pavement does include a treated base, enter a non-zero value for this field and a new input section (New Base) will be available to capture necessary information. If your new pavement results in an increase in roadway elevation, enter a positive value; for decreases, enter a negative value.

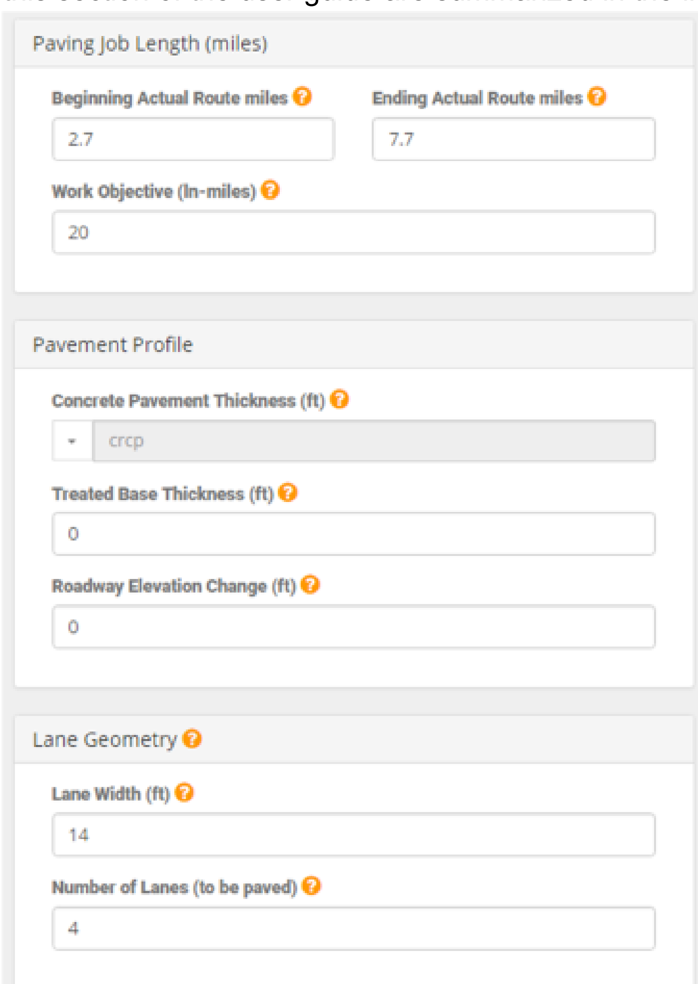
The base thickness impacts the number of construction activities included and also the required amount of demolition. Similarly, an elevation change will affect the scope of the demolition activity, but not the number of activities.

Lane Geometry

Finally, specify the lane width and number of lanes so that Road Scheduler can determine the overall project size and the objective of each construction activity except asphalt paving. The total thickness of the asphalt pavement in the 'Asphalt Paving' section later discussed in this chapter.



In this example, 4 lanes are included and each lane has a width of 14 ft. All inputs entered in this section of the user guide are summarized in the in a figure below:

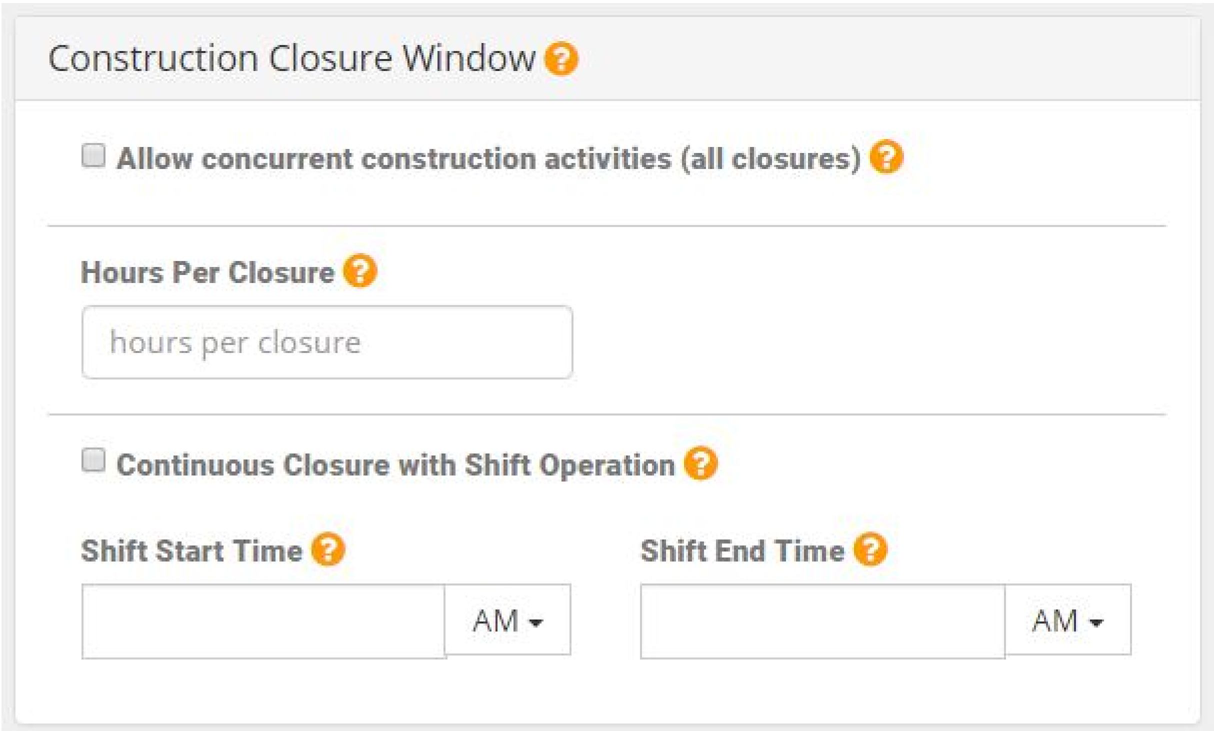


Next Section...
To complete the Project Details, move on to the next guide in the chapter to view instructions on specifying inputs for the Construction Closure Window.

If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:

1.4.2. Working Window

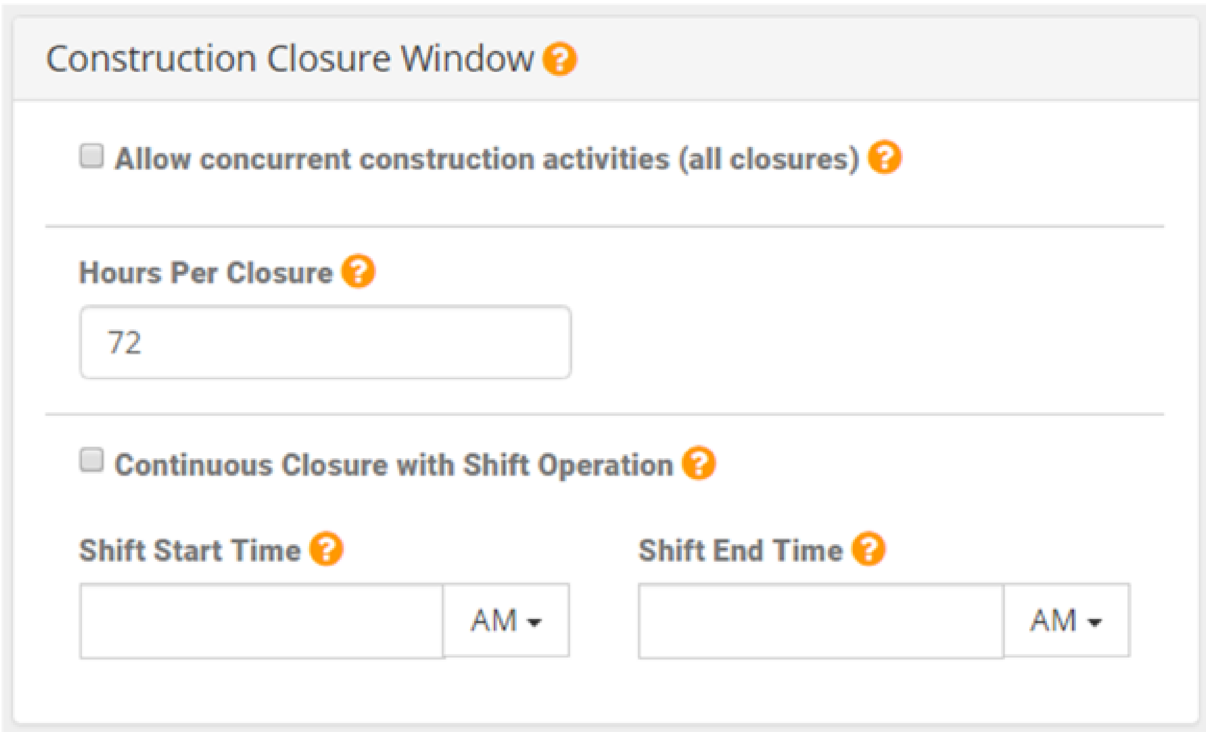
The working window fields specify the length of time allocated for a single closure. Road Scheduler attempts to maximize the productivity during this working window, but multiple windows may be required to complete a specified job. Regardless of the paving method chosen, Road Scheduler ensures that the linear progress made by each construction activity is equal.



It is important to consider the length of a working window because this can influence the total amount of time required to complete a paving job. Because each working window includes a closure mobilization and demobilization activity, pavement jobs completed with a higher number of shorter length windows typically incur a longer total construction time. On the other hand, specifying a longer continuous window may result in a shorter overall construction time but may result in poorer public reception. For example, you may finish the same paving job faster with a continuous 7-day closure rather than 3 or 4 weekend closures, but the public may prefer spreading out the closures among multiple weekends to avoid traffic impacts during weekdays.

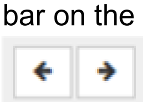
Enter the number of hours allowed for each working window or closure, or use a commonly used window size discussed in Chapter 1 (Closures and Working Windows). The value entered will influence the closure productivity, rate of completion, and total number of working windows required to complete the paving job objective. For asphalt paving methods, the option for allowing concurrent construction activities is disabled and is only available to concrete related paving methods (including pre-cast pavements).

You may specify whether each closure should be considered a shift operation: that is, the road is closed to traffic throughout your closure, but active construction occurs only between the hours you specify.

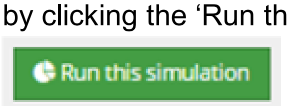


In this example, a closure window of 72-hours is selected and does not feature a shift operation (consequently, the checkbox and fields are left blank).

Next:
Click the arrow to the right to continue to the next step or choose an activity from the navigation bar on the top.

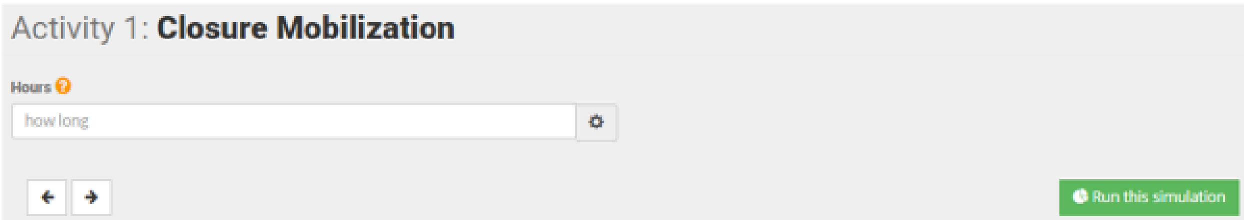


If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:



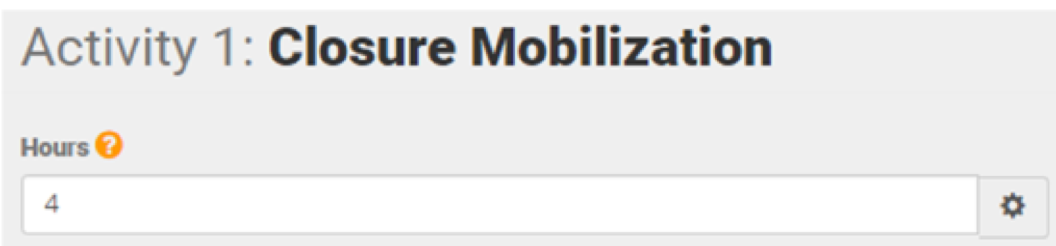
User Guide 1.4.3 Activity 1: Closure Mobilization

Activity 1: Closure Demobilization captures the amount of time required to initially set up or stage equipment, materials, and/or crew for a single paving closure (specified in the Project Details). Enter the number of hours required in the Hours field.



It is important to complete this field because the time allocated for closure mobilization is a lag activity that reduces the available time per closure for active pavement construction. Closure mobilization is an example of a lag-time activity because no actual progress is made on the construction of the pavement, but the time is necessary to include as a critical path activity in the schedule of paving operations.

It is also important to distinguish closure mobilization from activity mobilization: Activity mobilization refers to set-up for a single construction activity, while closure mobilization refers to activities that prepare the road for closure itself. Individual construction activities may include separate mobilization or demobilization requirements, but a single closure consists of only one closure mobilization and closure demobilization activity.



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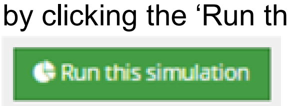
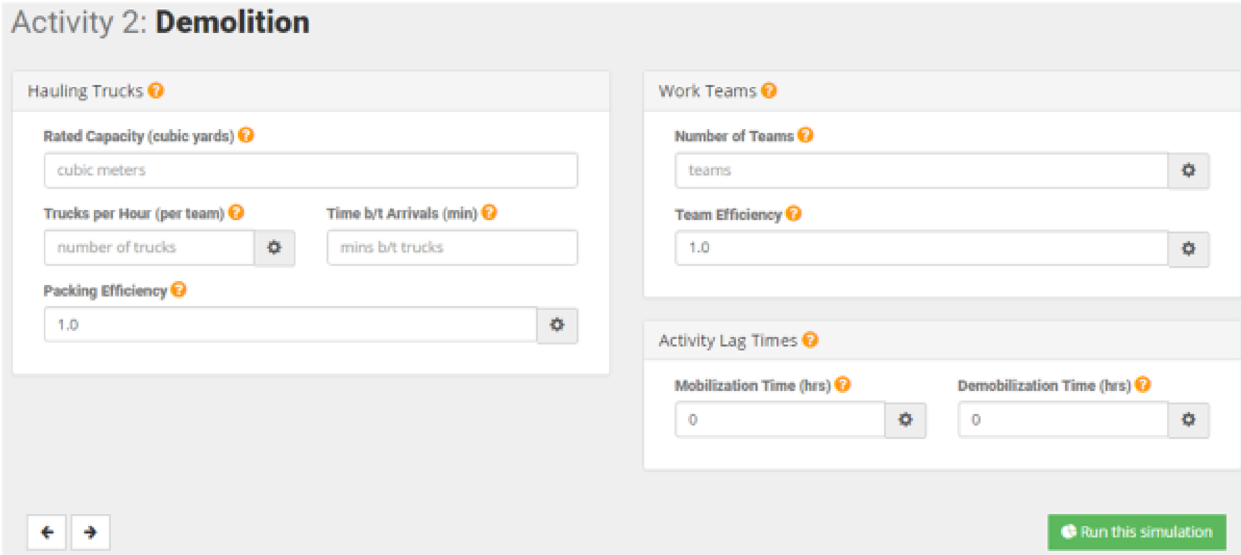
Click the arrow to the right to continue to the next step or choose an activity from the navigation bar on the top.

If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:



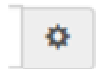
1.4.4 Activity 2: Demolition



Activity 2: Demolition is designed to simulate the removal of existing pavement using variables by describing the hauling equipment capacity, the work team, efficiency factors, and lag times. Indirectly, you have specified the demolition depth in the Project Details section: it is calculated as the sum of the new pavement and treated base thickness (if specified), minus the change the roadway elevation.

The dumping destination and fleet sizes are not required inputs because they impact conditions outside the simulation boundary and do not directly impact the construction of the pavement itself.

Specifying Probabilistic Input Values
In this demonstration, multiple inputs will be specified with probabilistic values, which effectively means that the parameter value is randomly determined by statistical parameters rather than a single value (deterministic). Input values that can be specified as probabilistic will feature a 'gear' shaped icon on the right side of the field.

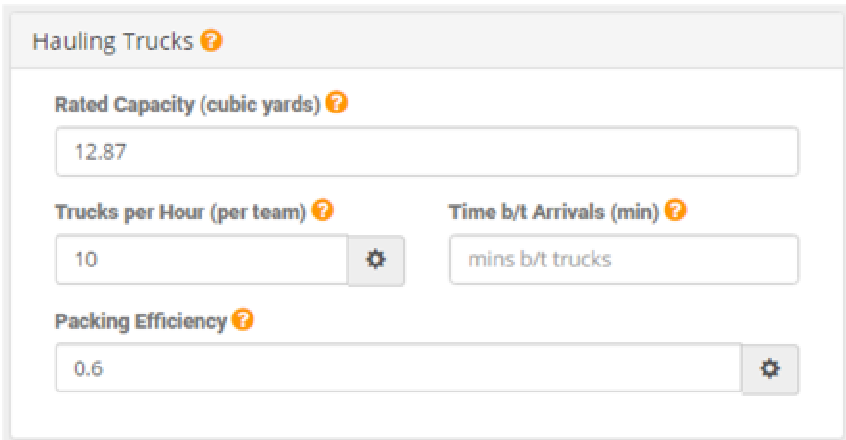


It is not necessary to specify all variables as probabilistic (where possible). However, if at least 1 variable is specified as probabilistic, the entire simulation will be considered probabilistic (as opposed to deterministic). For probabilistic analyses, Road Scheduler uses a Monte Carlo Simulation with 2000 iterations in which probabilistic inputs are randomly computed each time based on the distribution (and associated parameters) assigned to it.

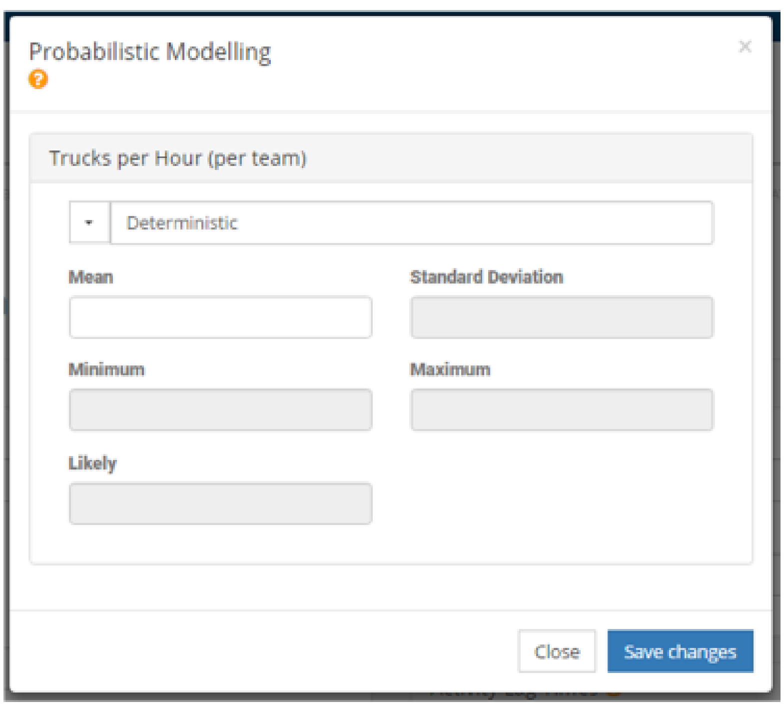
It is important to note that specifying a variable as probabilistic indicates that the parameter exhibits variability or uncertainty that cannot be conveyed with a single value. While average values may be used, it is recommended that you specify probabilistic variables whenever supporting information or data is available (e.g. the packing efficiency of a truck). Conversely, assigning deterministic inputs reflect a relative confidence or uniformity in a parameter's value (e.g. the nominal capacity of a truck).

Finally, Road Scheduler provides additional sections in the report that are not otherwise available in deterministic sections. The sections include a statistical summary of the Monte Carlo simulation, including a histogram of required closures to complete the paving job as well as a sensitivity analysis of probabilistic variables.

Hauling Trucks
The first category you need to complete is Hauling Trucks. This step is important because these variables influence or constrain the overall productivity of the demolition activities. Road Scheduler compares and balances the overall productivity of each resource and activity to determine how closely adjacent activities can be placed, and which activities constrain the overall productivity of each closure.



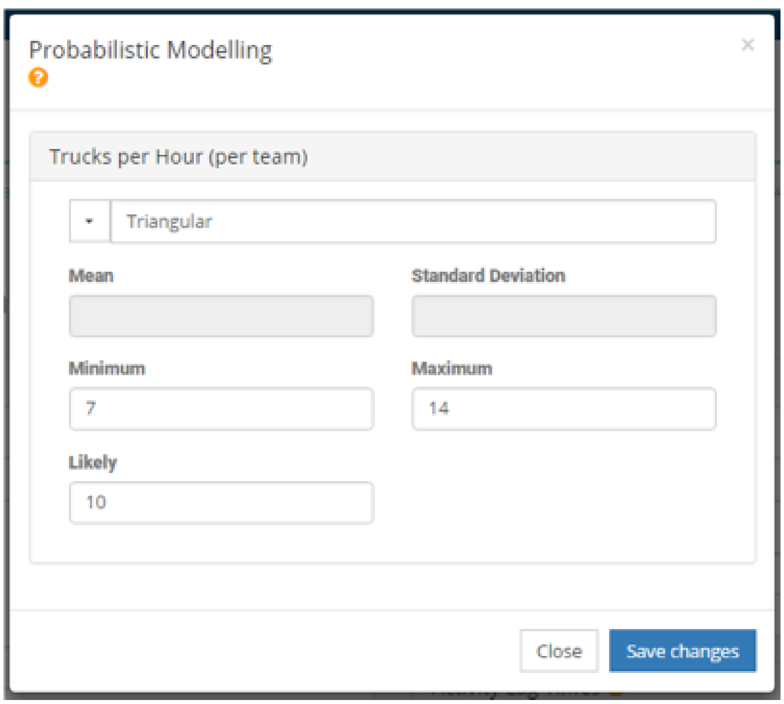
After entering a rated hauling capacity, click on the gear icon next to the ‘Trucks per Hour (per team)’ field. A new pop-up window will display the available options for specifying a distribution.



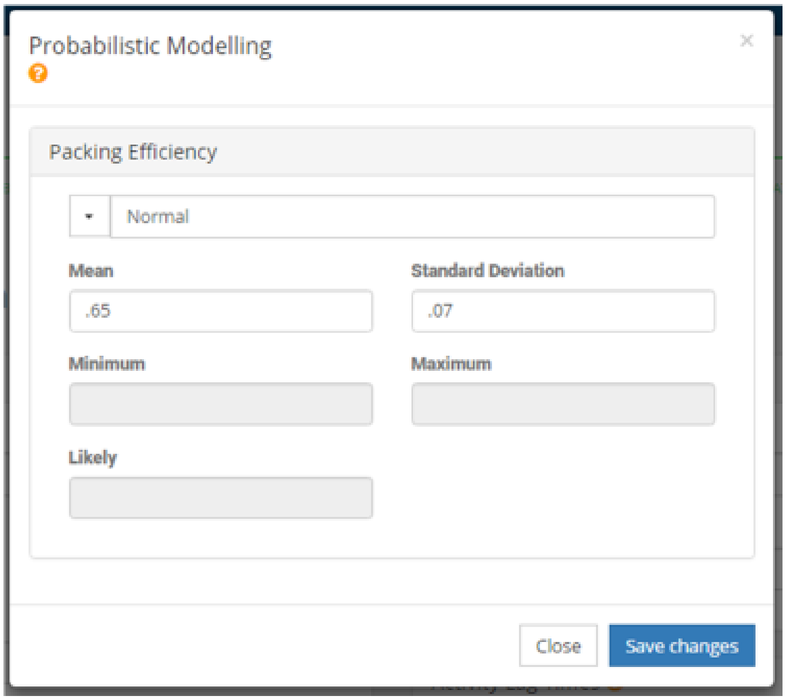
Consider limitations to the Truck per Hour (per team):

- Calculate the arrival rate between trucks by dividing 60 by the Trucks per Hour per team (e.g. 15 Trucks per Hour means 4 minutes between arrivals).
- The time between arrivals should be at least as large as the time required for a single hauling truck to complete its on-site tasks (e.g. loading, cleaning, ticketing, tarping).
- Determine a suitable distribution for your variable using recommendations from case studies and literature, based on expertise, or supporting data. For example, are there practical minimum/maximum limits for each parameter? Are there trends towards higher or lower values, or is the value relatively uniform between extremes?

In this demonstration, we choose a triangular distribution because a set of truck tickets indicates a range of 7-14 truck arrivals per hour (4.3 to 8.6 minutes between arrivals), with the most common rate of 10 trucks per hour (6 minutes between arrivals). Since we may not have additional information to describe the tendency of truck arrivals to ‘favor’ values higher or lower than 10 trucks per hour, but are fairly confident that the true value will exist within 7-14 trucks, a triangular distribution is the most appropriate.



When you are satisfied with your specifications, be sure to click ‘Save changes’ before closing the window. Returning to the Hauling Trucks category, notice that Road Scheduler has randomly assigned a value to this input based on the distribution and parameters assigned to it. Enter the ‘Packing Efficiency’ variable as probabilistic by clicking the associated gear icon.



In this demo, the packing efficiency is specified with a normal distribution. Recall that the packing efficiency for hauling trucks tends to be low due to the size gradation of rubblized pavement (50-60% efficiency is not uncommon).

We expect that the average efficiency is 0.65 of the normal capacity, with a standard distribution equal to 10 percent of the average (0.07). Effectively, this means we are 95% confident that the true value will lie somewhere within 2 standard deviations of the mean (0.51-0.79). The normal distribution allows for the simulated value to exist this range, but with a low probability for each iteration.

When you are done, save changes and close the window.

Work Teams
The Demolition activity also requires that you account for work teams by entering values into the Number of Teams and Team Efficiency fields.

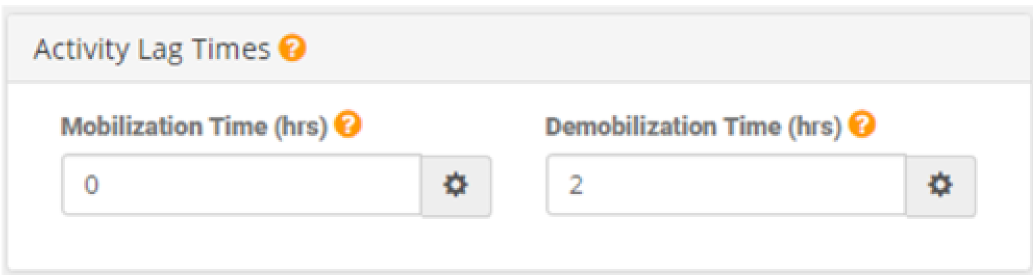
Additional teams can multiply the overall activity productivity but is limited by the amount of maneuverable space available for crew and equipment on the job site. Specifying multiple teams implies one of the following conditions is true: truck arrivals are staggered, trucks arrive concurrently, or a mixture of the two.

- With staggered arrivals of multiple teams, the actual arrival rate between trucks decreases by a factor equal to the number of teams. The user should ensure this new arrival rate is not too fast.
- With concurrent arrivals, the actual arrival rate between trucks remains the same but the user must ensure that there is sufficient physical space for all teams (crew, materials, equipment maneuvers).

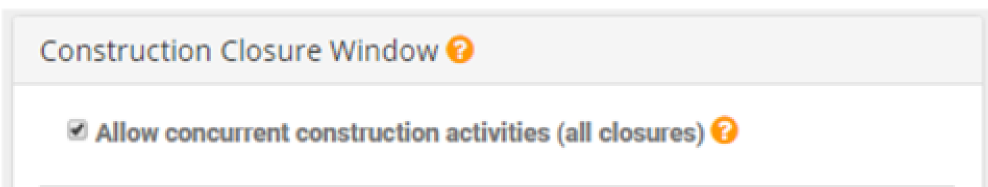
Although the Number of Teams may be specified as a probabilistic variable, it is left as a deterministic value because we are certain that 2 teams will be present. However, the team efficiency is specified with a normal distribution with a mean of 0.7 and a standard deviation of 0.07.

Activity Lag Times

The final fields to complete in the Demolition step are the Activity Lag Times fields. These lag times refer to the time required to set up or dismantle equipment, crew, or materials for the demolition phase only, not the overall closure. They may also capture small follow-up activities required before the new base is placed because the application uses these lag times to determine the minimum spacing between adjacent scheduled activities.

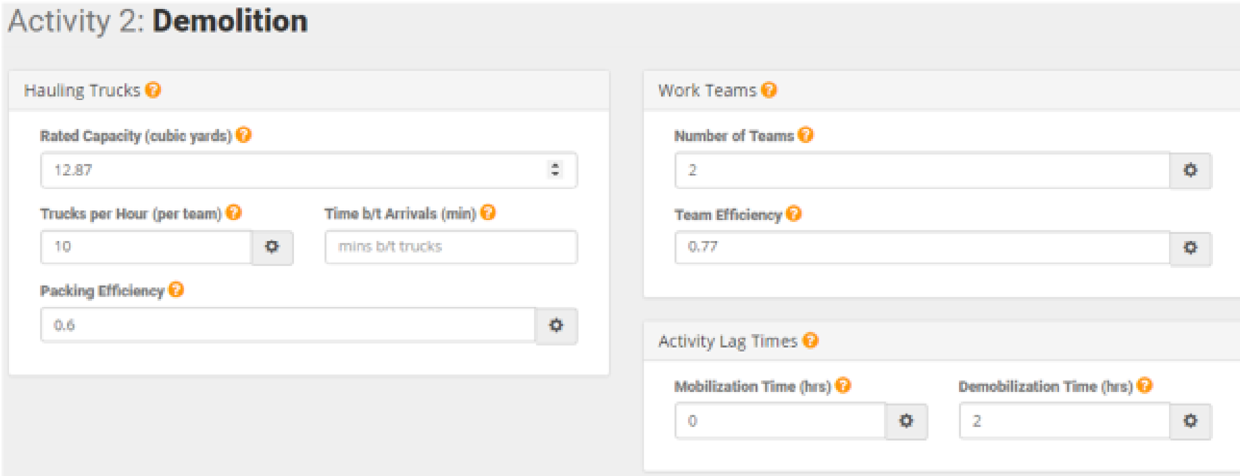


Although both values may be specified as probabilistic, they are left here as deterministic. Although the activity demobilization time may be less than 2 hours, it may be wise to specify this value as a single maximum value to ensure that sufficient time is allocated.



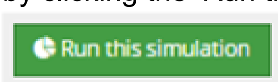
If you selected 'Allow concurrent construction activities' for your closure windows, then you should consider allocating extra demobilization time for demolition or extra mobilization time for the new base (next activity) to avoid conflicts between activities. Adding this lag time will effectively stagger these activities, allowing the activities to maintain a spatially feasible or safe working distance between them.

At this point you have completed entering all inputs for the demolition activity demonstration.



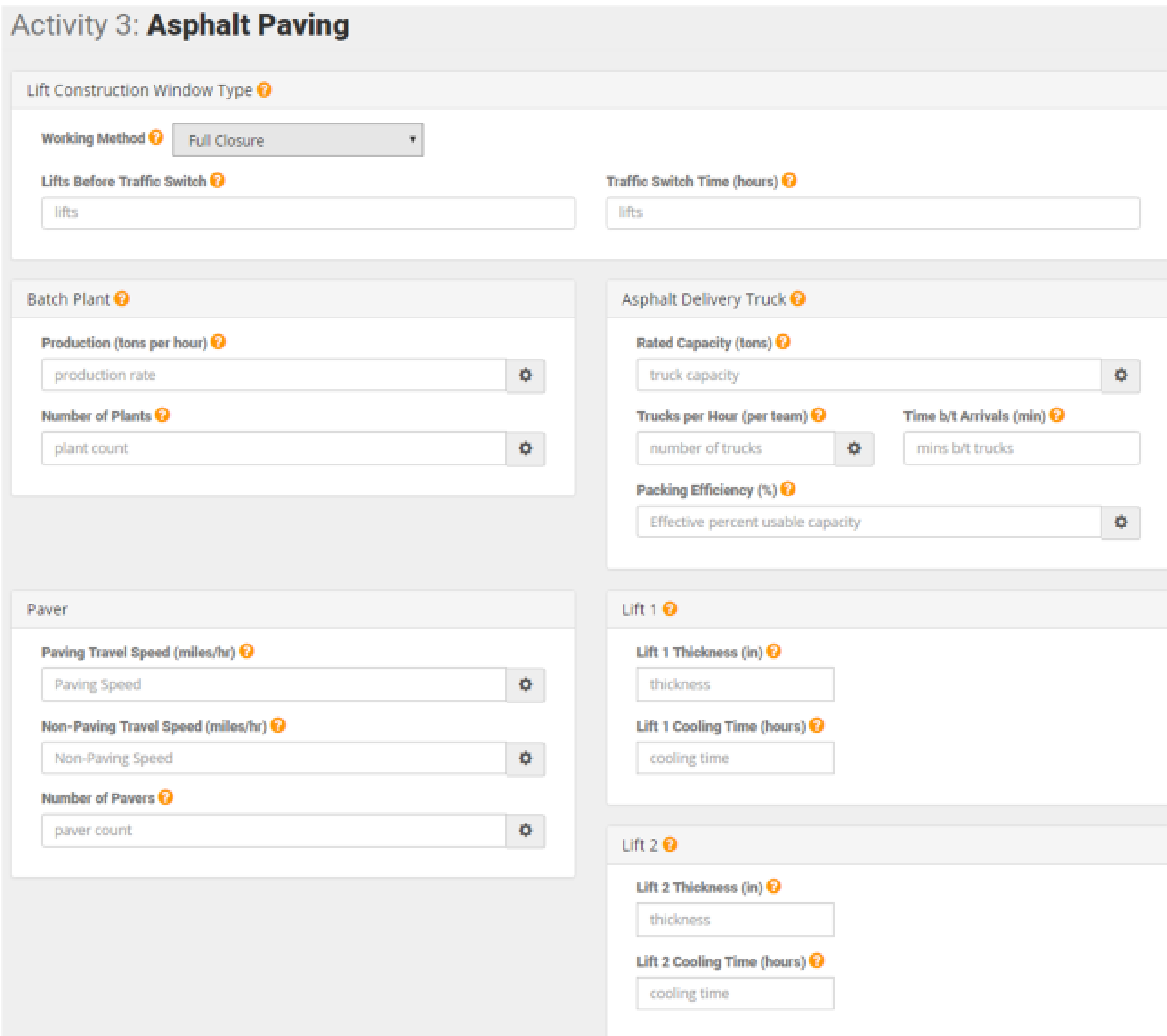
Next:
Click the arrow to the right to continue to the next step or choose an activity from the navigation bar on the top.

If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:



1.4.5 Activity 3: Asphalt Paving (and Cooling)

In Activity 3: Asphalt Paving, you will specify information on the resources involved in the material production at the batch plant, the subsequent delivery of material to the job-site, and the placement of your pavement (paving). This information is essential because the individual rates of each resource must be balanced as the overall rate of the paving activity is determined by the 'slowest' supporting activity. Unlike the concrete curing which is specified in a separate activity, the cooling of asphalt pavement is integrated into the paving operation inputs.

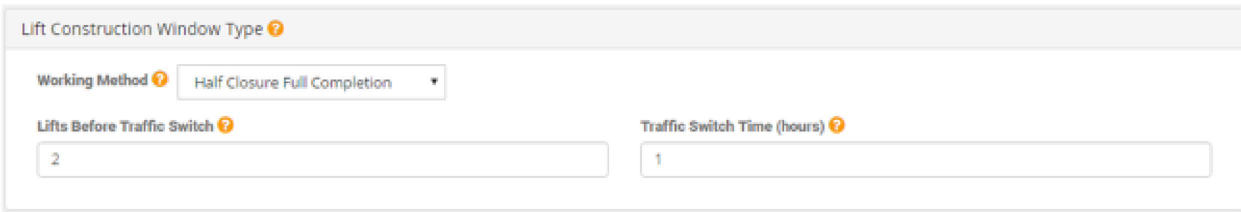


While Road Scheduler will automatically determine and balance these rates, you must specify information regarding the batch plants material availability, the size and delivery rate of your delivery trucks, and the paving and non-paving travel speed. Additionally, you will need to specify the thickness and the cooling time required for each lift (up to 10 lifts) and any activity mobilization or demobilization activities.

Lift Construction Window Type

In Road Scheduler, asphalt-related paving methods include 3 options for paving lifts:

- A full closure, in which all lanes are closed to traffic
- A half closure with full completion, in which half of the lanes are always open to traffic and all lifts are paved
- A half closure with partial completion, in which half of the lanes are open to traffic but only a specified number of lifts are paved (a second simulation may be needed to model the paving of remaining lifts)



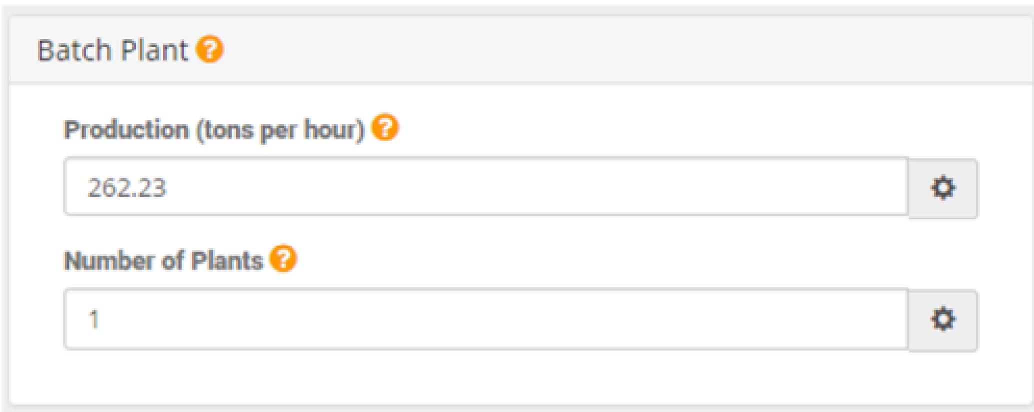
In your consideration, it is important to recognize the general impact that the working method may have on your overall paving productivity. While a full closure will always result in a faster paving job, it will result in larger traffic impacts as no traffic may pass through the work zone. In contrast, a half-closure will be slower but can result in more tolerance traffic impacts since some lanes will still be open to traffic. Half-closures require two additional inputs: the traffic switch time and the number of lifts before the traffic switch.

Select a working method. In this example, a Half-Closure with Full Completion is selected, where 2 (out of 4 total) lifts are paved before the first traffic switch. The traffic switch swaps which lanes are available for traffic and closed for construction. After the switch, all lifts are paved in the closed lanes before a second traffic switch (same duration) and the remaining lifts are paved.

A more detailed discussion of lift paving sequences can be found in Chapter 1.2 of the Road Scheduler user guides.

Batch Plant

Before you complete the batch plant field, consider the availability of local batch plants and their respective maximum rates of production available for the specific project. Note that the batch plant's maximum production capacity is not necessarily the amount available for the project.

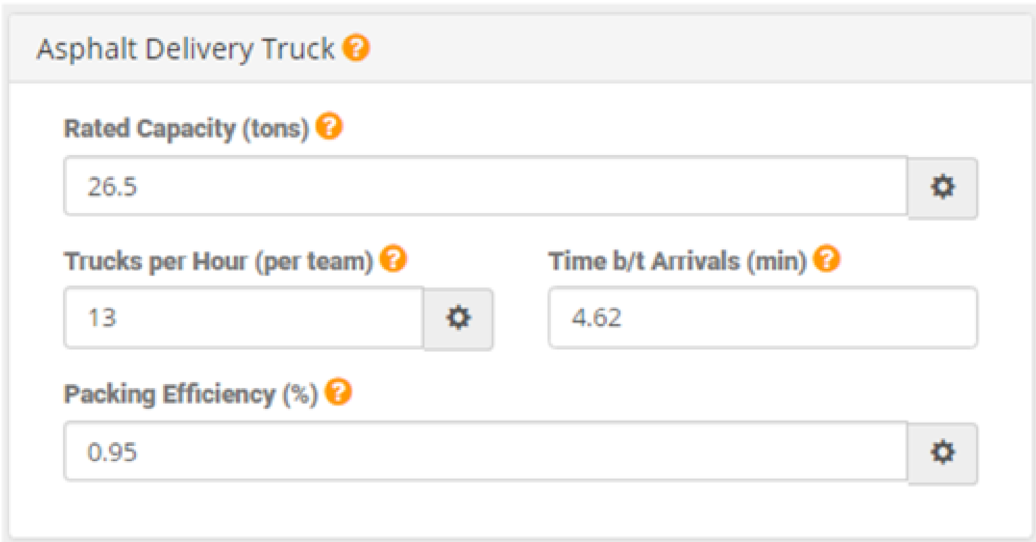


After this determination, enter in a value that is less than or equal to the available capacity for your job. In this case, the batch production is specified as a probabilistic variable with a normal distribution with a mean of 287 tons per hour and a standard deviation equal to 10% of this value.

Complete the Number of Plants field. This value is frequently 1, but multiple plants require a more complex consideration of available space within the work zone due to potentially simultaneous deliveries. Since this is the only plant contracted for paving materials, the number of plants remains 1 plant (deterministic) in this example. These spatial considerations are currently outside the scope of Road Scheduler's simulation boundaries, but the number of plants may be changed at your discretion.

Asphalt Delivery Trucks

In the Concrete Delivery Truck area, you can complete the Capacity field based on the fleet available for this project. As with demolition or base delivery, you should also consider converting your deliveries per hour into time between intervals. This interval must be at least as large as the time to offload a single truck, for example.

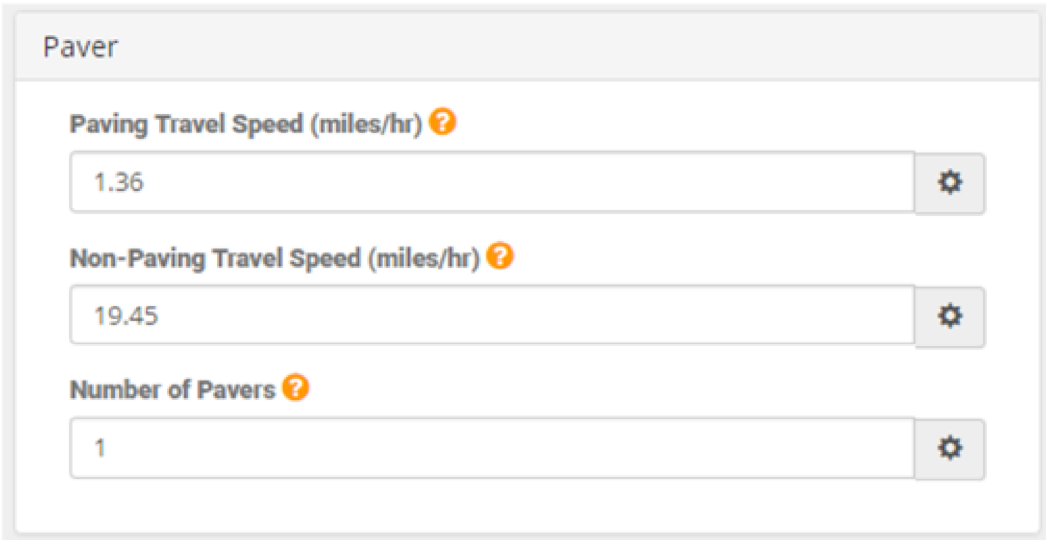


Additionally, be aware that the number of trucks per hour is not the minimum fleet size required to complete this paving activity. Nevertheless, the delivery rate is influenced by travel distance and time as well as the maximum fleet size (but none of these 3 parameters are required by road scheduler since they affect activities outside the physical job site). Please consult Chapter 1.2.5 for an expanded discussion of how cycle time and fleet size may impact your specifications for truck delivery rates.

When completing the Packing Efficiency field, enter a value that reflects the fact that paving material packs very well, but carries the risk of cooling prematurely. This situation may result in lowered productivity overall for material delivery due to longer handling times (lag), reduce the truck's effective capacity, and reduced workability.

In this demonstration, the truck rated capacity is relatively fixed and is left as a deterministic value 26.5 tons. Similar to the base delivery trucks, the trucks per hour is specified as probabilistic using a triangular distribution with a mode of 13 trucks per hour and a min/max range of 9-16 trucks (3.75 to 6.8 minutes between arrivals). The packing efficiency is also specified with a triangular distribution with a mean of 0.95 and a min/max range of 0.80 to 1.00.

Paver
In the Paver box, you may notice that two speeds are requested in addition to the number of pavers: the paving travel speed (same as concrete) and the non-paving travel speed. This paving speed refers to the average rate the paver places material and is specified in miles per hour, typically much smaller than the non-paving travel speed.



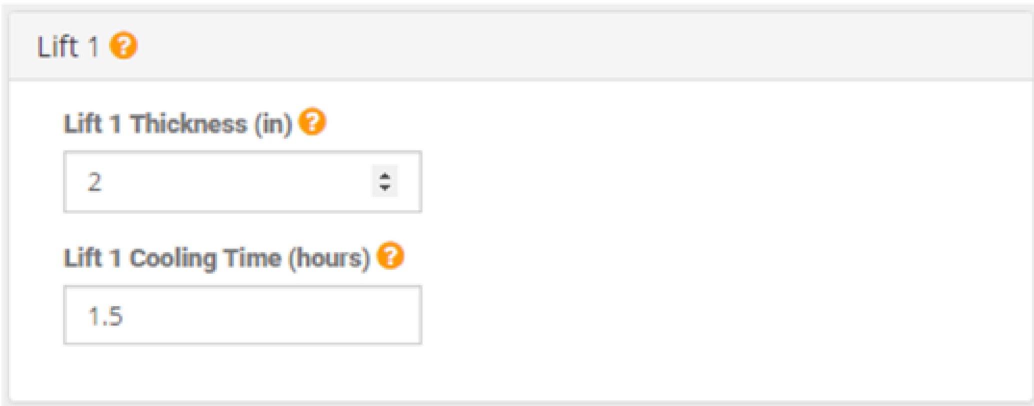
Due to the multiplicity of variables affecting paver productivity, Road Scheduler assumes you have factored in efficiency into your input value. The value should reflect the rate at which a single machine is capable of paving and is typically between 1 and 5 miles per hour.

The non-paving travel speed is necessary for lift paving because the paver must turn around and return to the beginning of a pavement section before continuing onto the next lift. This turn-around lag time occurs after each lift is paved and affects the amount of cooling time available until the next lift is paved on top. Note that the final lift of the paving activity does not include a turn-around time as the pavement is complete.

Finally, the Number of Pavers field allows you to select the number of pavers which is limited by available space, depending on the width of the paver relative to the width of the pavement section.

In this demonstration, the paving speed is assumed to follow a normal distribution with a mean of 1.7 mi/hr and a standard deviation of 0.25 mi/hr. Similarly the non-paving travel speed is assumed to be normally distributed with a mean of 20 mi/hr and a standard deviation of 2 miles per hour. We are confident in the number of pavers, which is set to a deterministic value of 1 paver.

Lifts
Road Scheduler can include up to 10 lifts in your pavement job, allowing you to specify a different thickness and minimum cooling time for each. The lift thickness will affect the overall scope of paving materials to be placed and the cooling time determines how long you must wait before the next lift can be paved in a given lane.



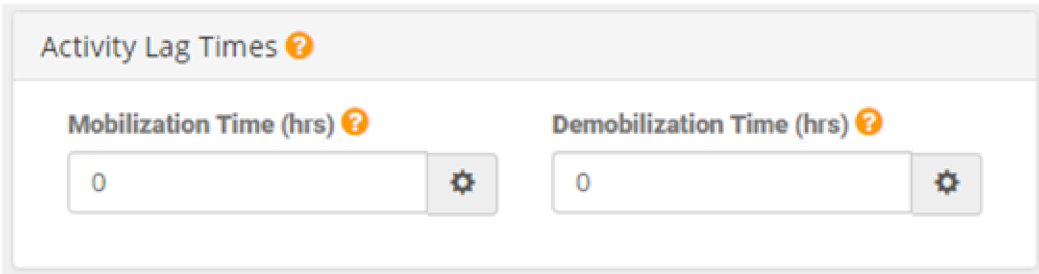
The actual time between adjacent lifts in a lane is determined as the maximum of two considerations:

- The cooling time of the underlying lift
- The time until the paver is ready to pave the next lift in the lane, which in turn is affected by the turn-around time and paving speed.

If the former is longer, the paver must wait until the lift is cooled before continuing - this lag time is sometimes referred to as the ‘suspension time.’ If the later is longer, no suspension time is incurred and the paver can proceed whenever it is available.

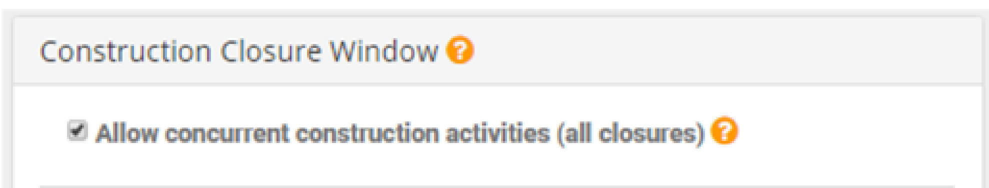
In this example, four lifts are specified with a thickness of 2 inches and a cooling time of 1.5 hours each for simplicity.

Activity Lag Times
Finally, in the Activity Lag Times fields, you can enter values for Preparation and Post-Work Lag. In the Preparation Lag field, enter a value that reflects the amount of time to stage equipment for a paving activity. Finally, enter a value in Post-Work Lag that represents the time required to dismantle the equipment for the paving activity.



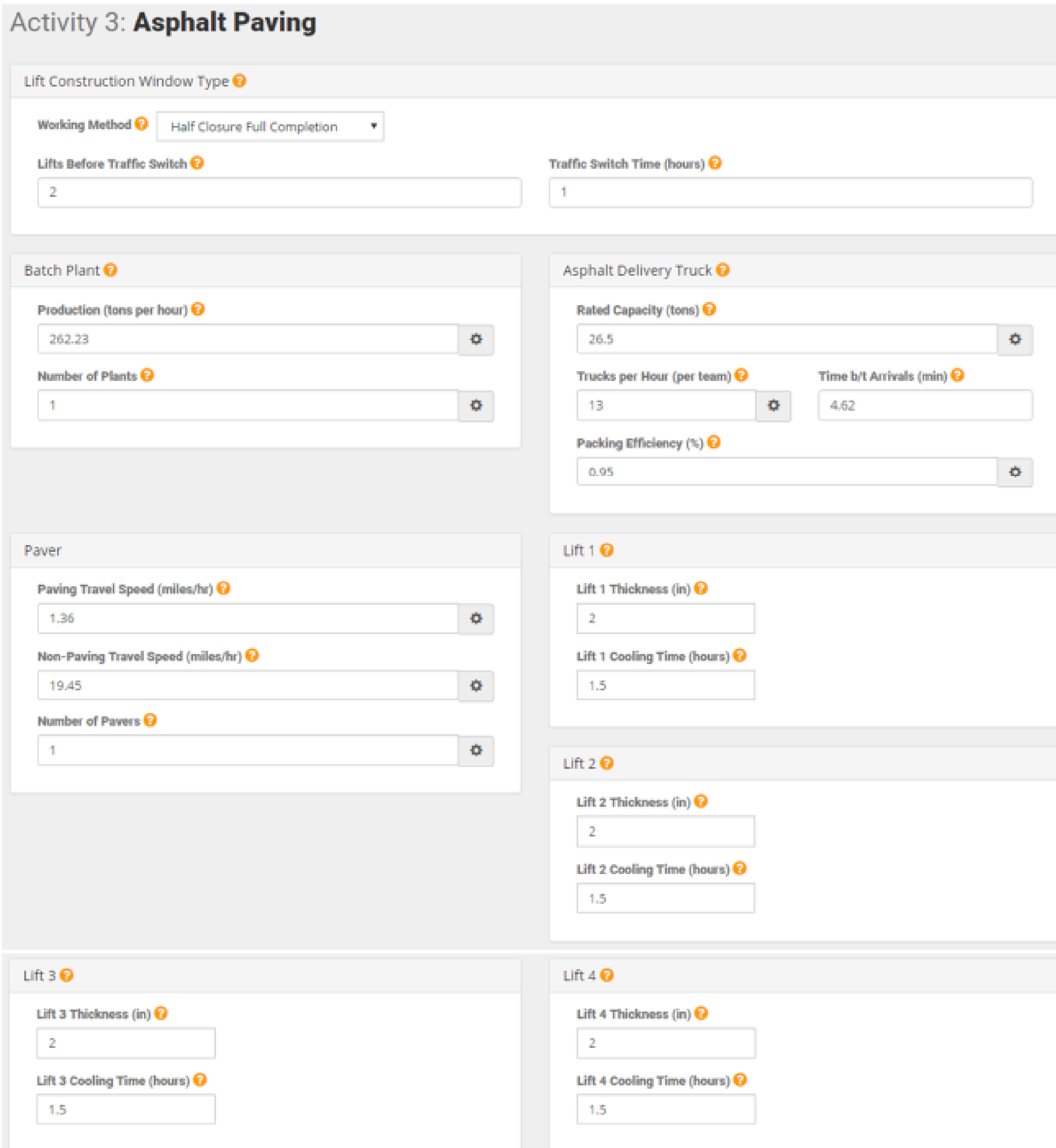
In general, the demobilization time should be long enough that the last lift has sufficient time to cool before the pavement is reopened to traffic. Alternatively, this time can be allocated in the closure demobilization rather than the activity demobilization time so as long as the value is at least the duration of the final lift's cooling time.

In this demonstration, both the activity mobilization and demobilization time are set to 0 hours (deterministic).



These activity lag times are particularly important to specify for concrete paving if you selected the 'Allow concurrent construction activities' options for the Construction Closure Window in the Project Details section. Although some operations could potentially begin 'concurrently' by adjusting their effective rate, they must actually be staggered with some distance (or time) to avoid spatial conflicts. For example, concrete pavers may postpone their operation by 1-hour to maintain a safe working distance from the rebar workers. This can be simulated by adding 1 hour to your Mobilization Time for paving or equivalently adding 1 hour to the Demobilization Time for the rebar activity.

At this point you have completed entering all inputs for the Asphalt Paving activity demonstration.

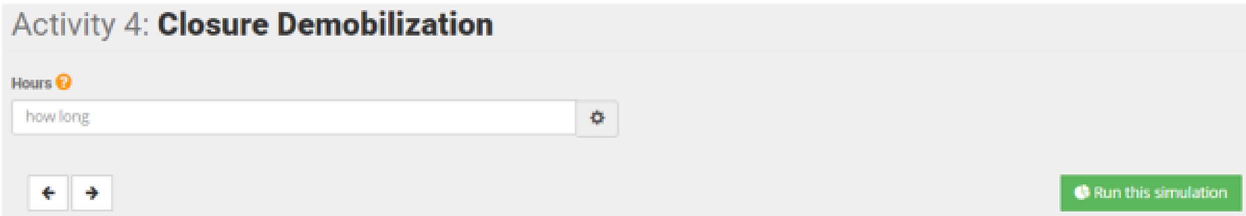


Next:
Click the arrow to the right to continue to the next step or choose an activity from the navigation bar on the top.

If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:

User Guide 1.4.6 Closure Demobilization

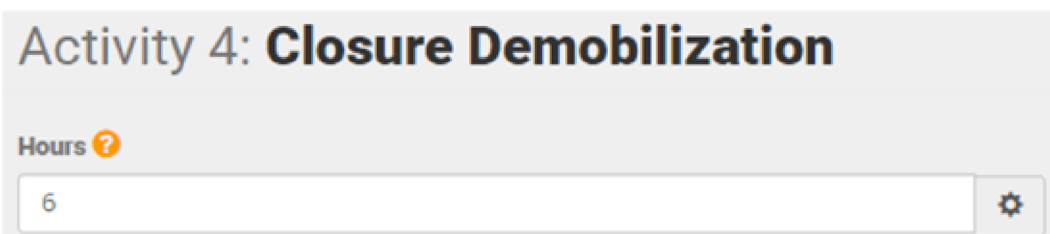
Activity 4: Closure Demobilization allows you to include the total amount of time required to dismantle equipment or materials, clean up the job site, and/or transport crew and subsequently reopen the roadway to traffic after a single closure.



Closure Demobilization is important to include because it may potentially be the final activity in a paving closure that determines when traffic can be reopened. Closure demobilization is the final lag-time activity considered in the simulation and collectively, lag-times determine the absolute minimum size for a feasible construction window.

Specifying closure demobilization time for asphalt methods differs slightly from concrete methods, which feature a curing activity that is separate from the paving activity. In contrast, the cooling time is integrated into the lift paving sequence except for the final lift. If no activity demobilization time was specified for the preceding paving activity, you may choose to include it here to ensure that the final paving lift has sufficient time to cool.

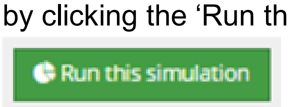
In this example, closure demobilization is specified with a deterministic value of 6 hours.



Next:

Click the arrow to the right to continue to the next step or choose an activity from the navigation bar on the top.

If you have already entered all other inputs for the simulation, you may also run the simulation by clicking the ‘Run this Simulation’ button:



1.5.0. Interpreting Detailed Productivity Reports

The sections in this user guide provide a walkthrough of interpreting and understanding the outputs of a detailed productivity report after running a simulation in Road Scheduler.

Road Scheduler's detailed reports generally provide the same information regardless of the specific options selected in a simulation. However, certain analyses or tables become possible (or non-applicable) depending on two primary simulation characteristics:

(1) If any variables were specified as distributions, the analysis is <u>probabilistic</u>; the analysis <u>deterministic</u> otherwise
(2) If the paving method primarily involves <u>concrete</u> (JPCP, CRCP, and Pre-Cast), or <u>asphalt</u> (HMA Mill and Fill, Full Depth, or Overlay).

The table below shows the combination of results available in the report depending on simulation characteristics (red circles indicate unavailability):

Asphalt	Concrete	Deterministic	Probabilistic		
x	x	x	x	**1.4.1**	Project Details
x	x	x	x	**1.4.2**	Linear Productivity Diagram
x	x	x	x	**1.4.3**	Project Scope and Overall Results
x	x	x	x	**1.4.4**	Single Closure Gantt and Schedule
x	x	o	x	**1.4.5**	Closure Productivity and Parameter Sensitivity
x	x	x	x	**1.4.6**	Resource Utilization

To cover discuss all possible result types, 2 simulation reports are presented in this guide simultaneously. For each report section, two versions are presented where applicable:

1. Part 1 will discuss a CRCP simulation with deterministic outputs
2. Part 2 will discuss an HMA Full Depth simulation with probabilistic outputs

Using these two paving jobs as demonstrations, the user guides in this section will address the following questions:

1.5.1 Project Details - What general details uniquely identify my simulation and project?

1.5.2 Linear Productivity Diagram - How much time does each activity occupy for each closure?

1.5.3 Project Scope and Overall Results - How much work does my project consist of, how much progress is made per closure, and how quickly can I complete the project?

1.5.4 Single Closure Gantt and Schedule - How much time does each activity take to complete and how are activities scheduled?

1.4.5 Closure Productivity and Parameter Sensitivity - How much variation can I expect in my closure productivity and parameters affect productivity the most for a given percent change in value?

1.4.6 Resource and Pavement Profile - How is each resource specified and how much material does each activity concern?

1.5.1. Project Details

The first section of the report is the Project Details, which contains information used to identify and distinguish you simulation and project. Since a single paving project can be the subject of multiple simulations, information such as the paving strategy, analysis method, and other identifiers that may be particularly helpful when trying to distinguish your results from another simulation.

Project Details

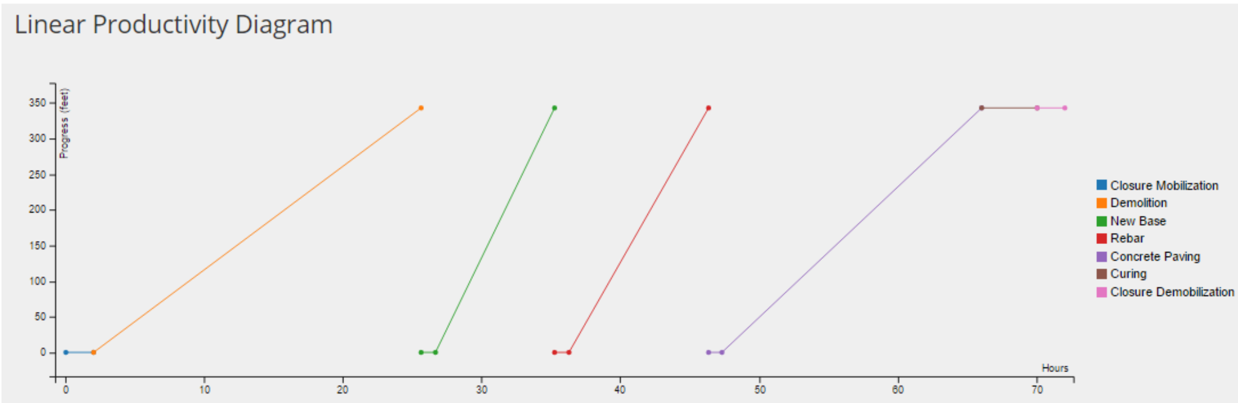
Project Name	0000-0000 CA4PRS Validation Case Studies
Simulation Name	CRCP Validation - 20170111a [DET]
Paving Strategy	Continuously Reinforced Concrete Pavement (CRCP)
Analysis Method	Deterministic
Last Modified	2017-02-16 05:39
Date Created	2016-09-21 10:51
Route	I5
Construction Year	2016

This section of the report will look the same regardless of the analysis options selected for the simulation.

1.5.2 Linear Productivity Diagram

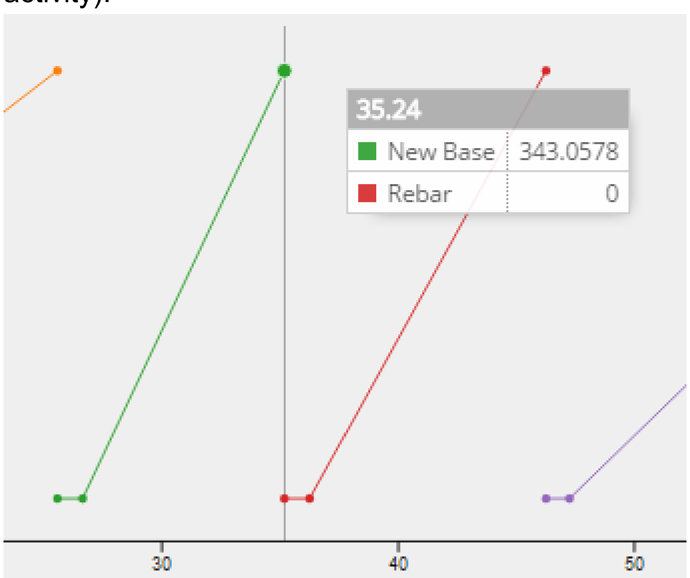
Part I: Deterministic Simulation for a Concrete Paving Method

The next section of all simulation reports is the Linear Productivity Diagram, which visually conveys the progress made per closure as well as the duration and completion rate of each construction activity involved in the paving method (in this case, CRCP).



The horizontal axis indicates time in hours and extends far enough to include a single closure window (in this case, 72 hours). The vertical axis displays construction progress in linear feet (or meters) and extends tall enough to include the length of pavement progress in a single closure.

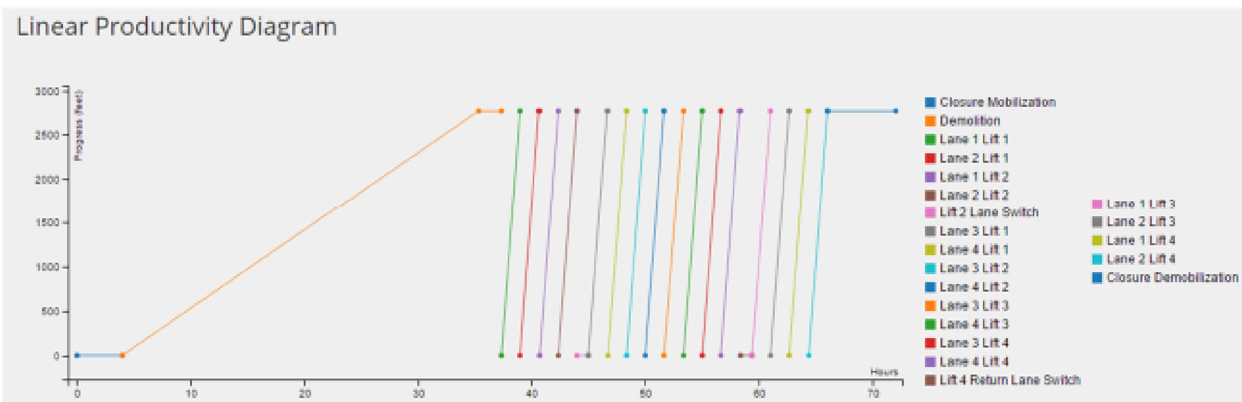
Each colored line represents a different activity as indicated by the legend to the right of the figure. The sloped lines provide a visual narrative for the relative rates of completion for each activity (gentler slopes represent slower activities). Horizontal bars that trail on the ends of each activity indicate lag times associated with activity mobilization or demobilization lags (closure mobilization and demobilization are colored separately since they are considered their own activity).



Hovering your cursor over each point (shown as dots) will reveal a pop-up table that provides additional information regarding the current time within the construction window and the linear progress level (distance) of each activity that is active (or imminently occurring) at that time. In the example above, the base placement completed 343 ft of progress by hour 35 of the closure window, and the rebar activity is imminently beginning.

Part II: Probabilistic Simulation for an Asphalt Paving Method

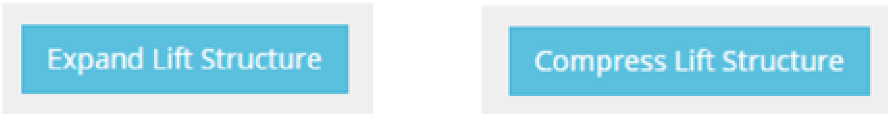
The example is intended to highlight report differences for a probabilistic simulation for an asphalt paving method in Road Scheduler (in this case, Full Depth HMA). To clarify, the previous example demonstrates the deterministic simulation for a concrete related paving method. While analysis type (deterministic or probabilistic) does not affect the display of the linear productivity chart, the method of calculation is slightly different and the display of results requires a slightly different interpretation.

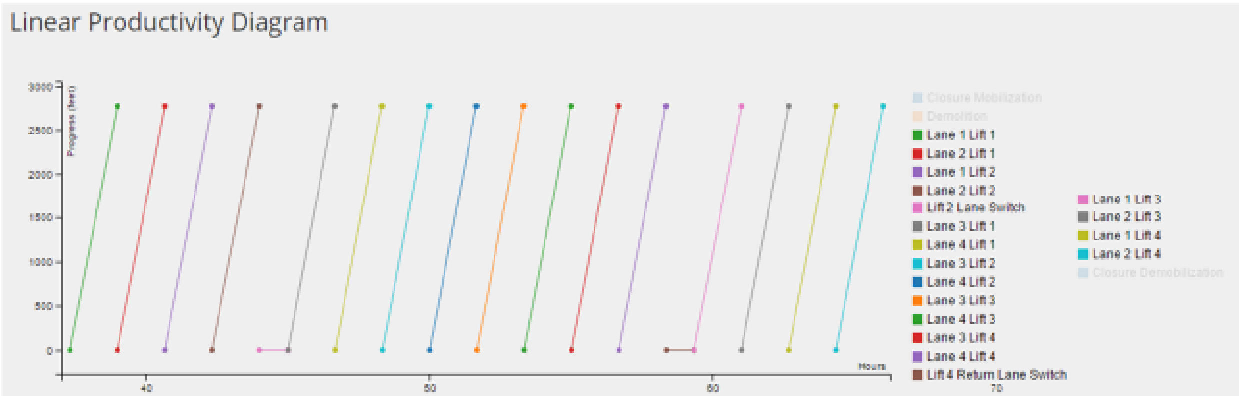


For probabilistic simulations, the linear productivity diagram is generated from the productivity rates (slopes) based on the last iteration of a Monte Carlo simulation (assuming resource inputs are specified as probabilistic with distributions). In Road Scheduler, the Monte Carlo Simulation allows a maximum of 2000 iterations but will terminate earlier if the level of deviation from the mean drops below 1%.

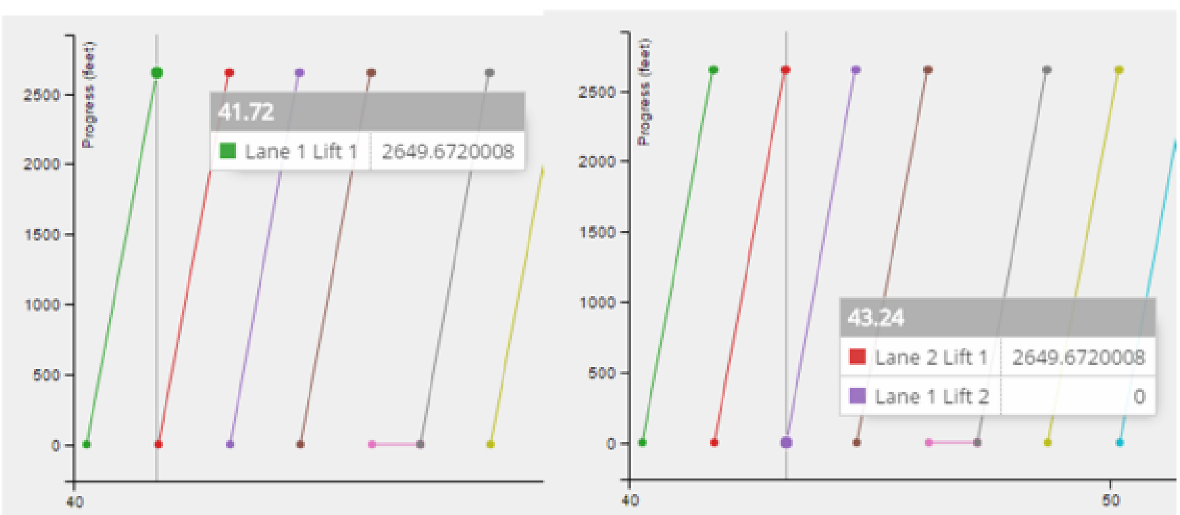
This is in contrast to deterministic simulations, in which productivity rates are calculated definitively from single values rather than a distribution. Otherwise, the linear productivity diagram should be interpreted the same way as a deterministic simulation.

For asphalt related paving methods (Full Depth, Mill and Fill, and Overlay), the paving activity is not represented by a single line segment but a set of lines that each represent the paving of a single lift in one lane. Pressing the ‘Expand Lift Structure’ button sets the horizontal axis limits to only include only lifts - notice how Closure Mobilization, Demolition, and Closure Demobilization are hidden from view. Return to the original view by pressing the ‘Compress Lift Structure’ button.





When paving asphalt lifts, recall that a paver must return to the starting point prior to beginning its next lift because paving progresses in the same direction. These durations are represented by the very short (nearly invisible) bars at the front or end of each lift segment in the linear productivity diagram. Their horizontal length is found by dividing the linear paving distance per closure by the non-paving travel speed. Depending on these values, the time required for a paver to turn around after a lift and travel back to its starting point is often much smaller (minutes) compared to the time required to pave the same lift (usually hours).



Additionally, the time between lifts performed in the same lane must be greater than or equal to the required time for each lift to cool, otherwise a paver must suspend its progress until the previous lift has cooled sufficiently. In this case, Lane 1 Lift 1 ends at 41.72 hours and Lane 1 Lift 2 begins at 43.24 hours, a difference of 1.52 hours. Since the cooling for for Lift 1 was specified as 1.5 hours have elapsed, Lane 1 Lift 1 will have finished cooling and is available for paving the next lift. If less than 1.5 hours had elapsed between Lane 1 Lift 1 and 2 (e.g. only 1 hour), then paving of Lift 2 would have been ‘suspended’ for an additional 0.5 hours until Lift 1 was sufficiently cooled.

Paving lifts can temporarily result in uneven roadway elevations between adjacent lanes, but all lanes must be of equal elevation by the end of a closure. In this example, the working method was specified to ‘Half Closure, Full Completion’ which means that only half the lanes are closed at any given time while other lanes remain open to traffic during construction. In order to achieve a pavement with equal elevations, the open and closed lanes must be ‘switched’ part way through a closure, then switched back to finish any unfinished lifts. These lag times are also represented by horizontal bars prior to the lift and lane delayed by the traffic switch operation. This is in contrast to other asphalt working methods: in full closures, no traffic switches are needed since all lanes are closed to traffic. In the ‘Half Closure, Half Completion’ method, only 1 traffic switch is needed since only half the lifts are paved for all lanes.

Beyond the differences presented in this section, the linear productivity diagram can be interpreted in the same manner as deterministic simulations, regardless of the paving method.

1.5.3 Project Scope and Overall Results

The next section of the simulation report includes 2 tables side-by-side that summarize the scope of work and performance results of the simulation strategy specified.

Project Scope

Scope / Objective	110879.73 lane-ft
# Lanes	2 lanes
Project Length	55439.86 ft
Lane Width	12.99 ft
Treated Base Thickness	0.75 ft
CRCP Thickness	1.08 ft
Demolition Thickness	1.83 ft
Elevation Change	0 ft
Project Surface Area	160036.39 square yards
Project Material Volume	97622.15 cubic yards
Net Materials Added	0 cubic yards
Net Materials Removed	97622.15 cubic yards
Most Contraining Resources	1. Demolition 2. Delivery Rate 3. Rebar 4. Production Plant 5. New Base 6. Paver Rate

The Project Scope (left) summarizes the geometric scope of work based on how you specified the inputs in the project details, including the physical length, change in elevation, lane configurations, and surface area. The table also includes information on the amount of materials (area or volume) involved in the pavement job, including the total amount of materials removed or added.

Overall Analysis Results

Required Closures	49.14
Progress Per Closure	1128.27 ft
Working Window	72 hours
Actual Working Window	61 hours
Preparation Time	2 hours
Post-Work Time	6 hours

The Overall Analysis Results (right) summarizes how much progress is made each closure, the resulting number of closures to complete the project scope, and basic details regarding the closure window and effective hours available for construction. Note that the options for the Closure Type differ depending on whether the chosen method was asphalt related or concrete related. For concrete paving methods, the working method can be specified as sequential or concurrent; this example indicates that the concurrent option was selected.

In this example, only 61 hours of the 72 scheduled involve active construction time; the remaining hours include lag activities related to mobilization or demobilization and curing. Within a 72-hour closure, 1128 feet of pavement can be finished (equivalent 0.426 lane-miles since given 2 lanes). This means that the project scope (21 lane-miles) can be completed in approximately 50 closures of the same type. Since each closure is 72 hours, the total project requires 72x50 = 3600 hours of construction time (not necessarily continuously).

Pro-Tip: You will always be able to complete a paving job with fewer hours using longer closure windows. Since lag activities present themselves once per closure or activity, a substantial number of hours can be regained for active construction with fewer closure windows. However, excessively long closure windows may generate unacceptable levels of traffic and incur public disapproval and large costs in terms of the time-value of a roadway user.

Part II: Probabilistic Simulation for an Asphalt Paving Method

This example is intended to highlight report differences for a probabilistic simulation for an asphalt paving method in Road Scheduler (in this case, Full Depth HMA). To clarify, the previous example demonstrates the deterministic simulation for a concrete related paving method.

Regardless of the analysis or paving method selected, the interpretation of the values in in the Project Scope remain unchanged.

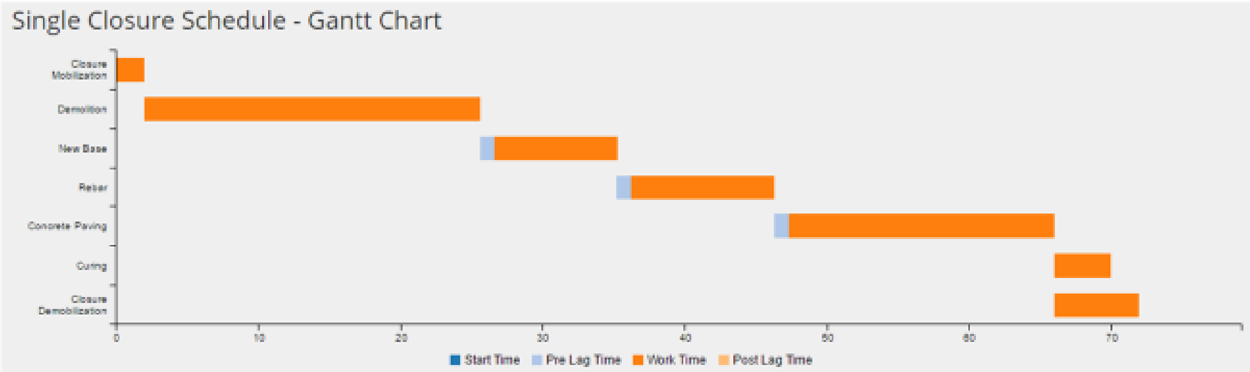
The Overall Analysis Results will also appear the same regardless of the analysis or paving method, but the values for Required Closures and Progress Per Closure must follow a slightly different interpretation for probabilistic methods. These values show the results of the last Monte Carlo iteration of Required Closures and the mean Progress Per Closure. In other words, it is the results of the last iteration rather than a single calculation based on deterministic values. The Monte Carlo simulation used in Road Scheduler converges to an answer based on a 1% tolerance and uses a maximum number of 2,000 iterations.

Additionally, the Closure options for working method differ between asphalt and concrete related paving methods. For asphalt paving methods, Road Scheduler allows 3 options for working method (Full Closure, Half Closure / Full Completion, Half Closure / Half Completion). This is in contrast to concrete paving methods where the options are concurrent or sequential construction. All asphalt methods are assumed to be sequential in this version of Road Scheduler)

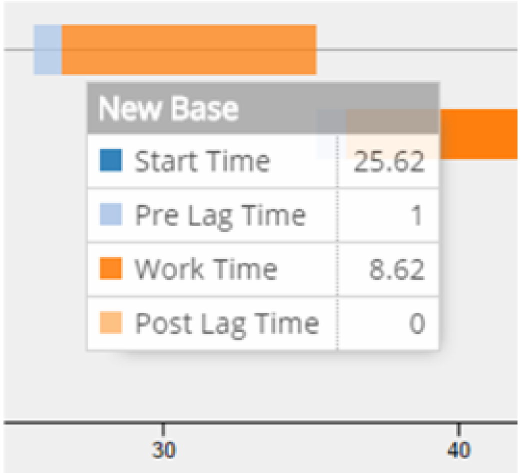
1.5.4 Single Closure Gantt and Schedule

Part I: Deterministic Simulation for a Concrete Paving Method

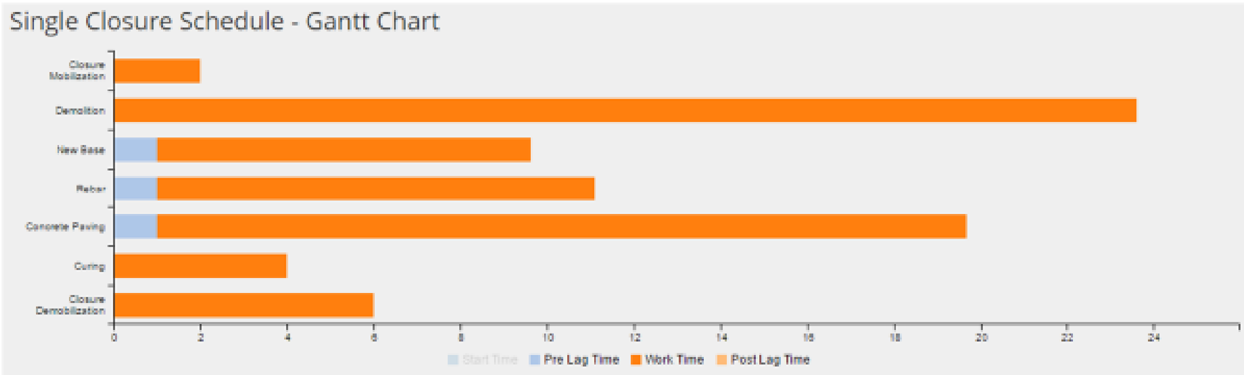
The next section provides more details regarding the sequencing of each construction activity through a Gantt chart and its associated data table. Recall that Road Scheduler only includes critical path activities related to the pavement operation in the Gantt chart.



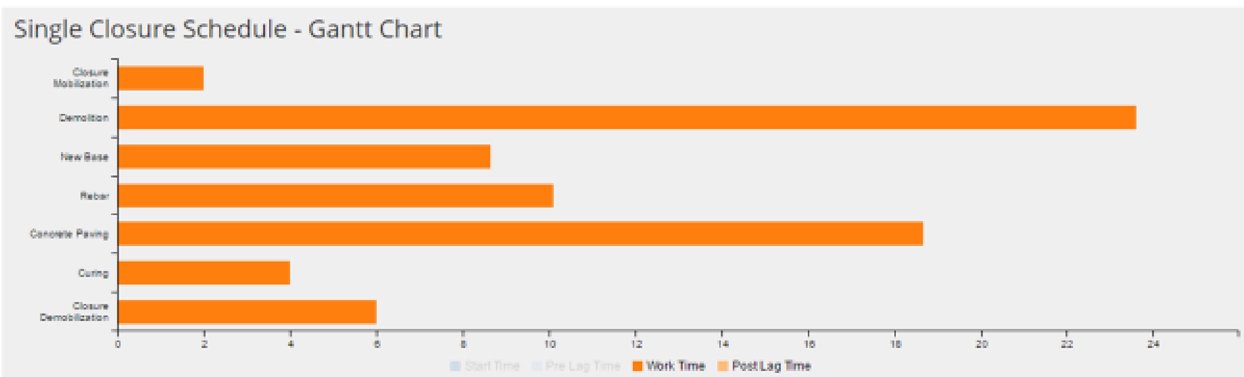
The Gantt chart (top) shows each construction activity on the vertical axis (the first activity, closure demobilization, is at the top of the list). Like the linear productivity diagram, hours within the closure window are shown on the horizontal axis. The length of each bar visually conveys the duration of each activity and is partitioned into pre-lag (light blue), post-lag (light orange), and active construction work time (dark orange).



Hovering your mouse over an activity will reveal additional information about the scheduling of that specific activity. The starting time of the activity is indicated in the first line next to the dark blue square. The pop-up window also shows the duration of active work time (in hours) as well as the pre- and post- activity lags.



By clicking on the ‘Start Time’ entry in the legend below the graph, you can compare each activity based on its duration, as demonstrated in the figure above. Clicking the ‘Start Time’ entry again will restore the gaps for start times and restore the figure back to a Gantt timeline.



Clicking any other legend entry will have a similar effect, adding or removing that type of activity from the display. In the figure above, all other types are hidden except active work time, clearly indicating that demolition and paving are the longest activities. We can also see that curing is longer than demobilization activities, and re-opening the work zone to traffic is limited by the curing phase.

Single Closure Schedule - Details

Activity	Lag Pre (hours)	Start Time	End Time	Lag Post (hours)	Activity Duration (hours)	Total Duration (hours)	Actual End Time (hours)
Closure Mobilization	0	0	2	0	2	2	2
Demolition	0	2	25.62	0	23.62	23.62	25.62
New Base	1	26.62	35.24	0	8.63	9.63	35.24
Rebar	1	36.24	46.33	0	10.09	11.09	46.33
Concrete Paving	1	47.33	66	0	18.67	19.67	66
Curing	0	66	70	0	4	4	70
Closure Demobilization	0	66	72	0	6	6	72

Below the Gantt chart is a table that includes the results of the scheduling algorithm featured in Road Scheduler. The data is sufficient to completely reproduce the Gantt chart visualization and can be copied to a spreadsheet or another scheduling software for further review.

Part II: Probabilistic Simulation for an Asphalt Paving Method

Both the Gantt chart and associated scheduling details will appear the same regardless of the analysis and paving method chosen. Recall that for probabilistic simulations, 10000 iterations are performed since one or more parameters are specified with distributions rather than single values. Accordingly, the Gantt Chart and scheduling details are determined using the mean productivity rates calculated from these iterations.

Otherwise, Road Scheduler offers the same functionality for the Gantt Chart as deterministic analyses or concrete paving methods, and can thus be interpreted in the same way.

1.5.5 Closure Productivity and Parameter Sensitivity

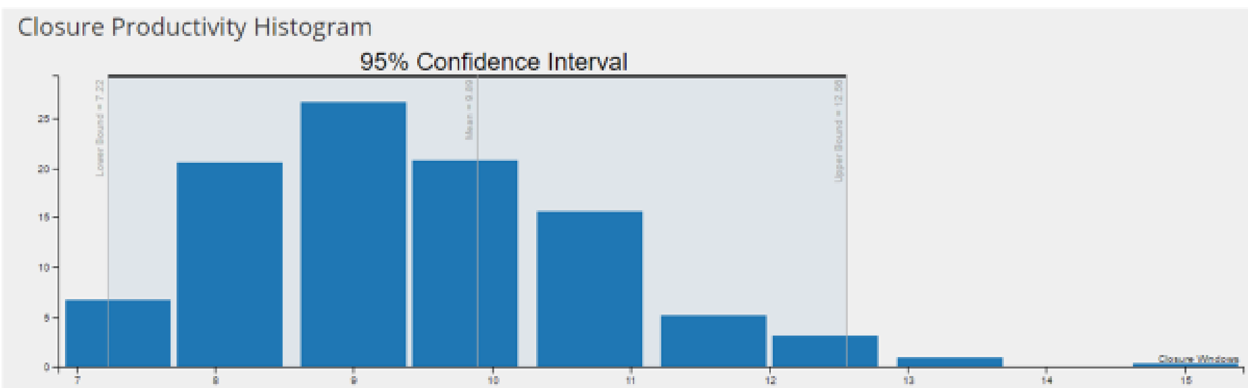
Part I: Deterministic Simulation for a Concrete Paving Method

This report section only appears for probabilistic simulations, regardless of the paving method selected. Please continue to Part II if this applies to your simulation.

Part II: Probabilistic Simulation for an Asphalt Paving Method

This section provides a histogram that summarizes the overall closure productivity across all iterations of the probabilistic simulation and a table that summarizes the sensitivity of each input parameter specified with a distribution. If no parameters are specified as probabilistic, this section will not appear.

The histogram shows the results of your probabilistic (Monte Carlo) simulation based on the per closure productivity of each iteration. Road Scheduler by default generates 2,000 iterations for each simulation and uses 10 bins to capture the distribution of results, which are reported with a 95% confidence interval.



The horizontal axis represents the closure productivity (linear distance per closure) and the vertical axis indicates the relative frequency (% of all iterations for the simulation). The bin width is found by taking the difference between the minimum and maximum productivity found in the simulation and dividing this into 10 equally spaced bins.

The 95% confidence interval refers to the range of overall closure productivities that will capture 95% of all simulated results (based on 2,000 iterations). The width of this confidence interval may indicate several characteristics of your simulation:

The width may indicate the degree of variability in your distribution specifications for each probabilistic input. Narrower ranges indicate that you have specified your inputs with little variation, that only a few variables were specified with a distribution (probabilistic), or that the probabilistic inputs do not substantially affect the overall closure productivity.

The Parameter Sensitivity Analysis provides additional information that may explain which parameters contributes the most to the variation in overall closure productivity.

Parameter Sensitivity Analysis

packingefficiency	0.118	Demolition
paverspeed	0.071	Paving
plantproduction	0.064	Paving
plantrate	0.039	Paving
teamefficiency	0.010	Demolition
paverspeedreturn	-0.031	Paving

The Parameter Sensitivity Analysis table conveys how sensitive results are (per closure productivity) to a unit change of value for each parameter that you have specified with a probabilistic distribution (i.e. all non-deterministic inputs).

In Road Scheduler, sensitivity is represented by Spearman Correlation Coefficients, which conveys a measure of statistical dependence between the productivity (lane-miles per closure) and each probabilistic variable. The table includes the top 10 most sensitive parameters (or fewer if less than 10 inputs are specified as probabilistic) and the coefficients have a range of [-1, 1]. A coefficient of 1 indicates perfect correlation; a coefficient of -1 indicates perfect negative correlation.

Positive values suggest that increasing a parameter value will positively affect (increase) the overall closure productivity (positive correlation). For example, Trucks per Hour (for hauling trucks associated with demolition) is the largest coefficient and indicated moderate to strong correlation (absolute value > 0.5) with closure productivity. If you were to increase the trucks per hour available for demolition, this will likely result in a moderate improvement in overall closure productivity. Similarly, you would also expect an increase in overall closure productivity for increasing the paver travel speed, but the extent this improvement would be smaller relative to the truck delivery rate for demolition.

Conversely, negative values mean increasing a parameter value will reduce productivity (negative correlation). For example, activity demobilization for paving has a negative but small coefficient (absolute value < 0.5). This suggests that increasing the demobilization will result in a reduction in overall closure productivity, but the extent of this change may not be very great.

If you want to alter your inputs to improve the overall closure productivity, the Parameter Sensitivity Analysis chart allows you to identify the parameters which would have the largest impact for a given percent-change in value. In this example, the table would indicate that your efforts would be best spent improved the first 3-5 parameters listed in the table. This is particularly true if a parameter is also associated with a constraining resource identified in the Project Scope table (User Guide 1.4.1 Project Details).

1.5.6 Resource and Pavement Profile

Part I: Deterministic Simulation for a Concrete Paving Method

In the next report section, the Resource Profiles and Pavement Profile tables provide summaries of the inputs used to describe each resource involved in the paving job.

Resource Profiles

Resource	Parameter	Value
Demolition	Rated Capacity (cubic yards)	14.02
	Trucks per Hour (per team)	8
	Packing Efficiency	.5
	Number of Teams	2
	Team Efficiency	.75
New Base	Rated Capacity (cubic yards)	13.11
	Trucks per Hour (per team)	8
	Packing Efficiency	.9
	Number of Teams	1
	Team Efficiency	1.0
Rebar	Installation Rate per Team (square yards/hour)	179.4
	Number of Teams	2
	Team Efficiency	.9
Concrete Paving	Production (cubic yards per hour)	117.7
	Number of Plants	1
	Rated Capacity (cubic yards)	7.85
	Trucks per Hour (per team)	8
	Packing Efficiency	1
	Effective Paving Speed (ft per minute)	6.59
	Number of Pavers	1

While these tables do not provide any new information or results, they are necessary details to reproduce the same deterministic results. This is important because the inclusion of this data allows another user to completely reproduce the results independently of this simulation. These details are particularly important for probabilistic simulations in which resource parameters are specified as a distribution rather than a single value. Please see the second half of this user guide to see an example of a probabilistic version of this report section.

Part II: Probabilistic Simulation for an Asphalt Paving Method
For probabilistic simulations, resource parameters are specified as a distribution rather than a single deterministic value and therefore inputs shown represent the last simulated for each.

Additionally, for asphalt related simulations, additional information is shown for each lift involved in the paving job, specifically the lift thickness, cooling time, travel speed, and non-paving travel speed.

Resource Profiles

Resource	Parameter	Value
Demolition	Rated Capacity (cubic yards)	12.87
	Trucks per Hour (per team)	10
	Packing Efficiency	0.68
	Number of Teams	2
	Team Efficiency	0.66
Paving	Lifts Before Traffic Switch	2
	Traffic Switch Time (hours)	1
	Production (tons per hour)	325.24
	Number of Plants	1
	Rated Capacity (tons)	26.5
	Trucks per Hour (per team)	15
	Packing Efficiency (%)	1
	Paving Travel Speed (miles/hr)	1.56
	Non-Paving Travel Speed (miles/hr)	13.06
	Number of Pavers	1
	Lift 1 Thickness (in)	2
	Lift 1 Cooling Time (hours)	1.5
	Lift 2 Thickness (in)	2
	Lift 2 Cooling Time (hours)	1.5
	Lift 3 Thickness (in)	2
	Lift 3 Cooling Time (hours)	1.5
	Lift 4 Thickness (in)	2
	Lift 4 Cooling Time (hours)	1.5

Otherwise, the interpretation of the Resource Profiles table should not change depending on the paving method selected.

1.6.0 Generating Comparison Reports

In this user guide, you will learn how to generate a comparison report for completed Road Scheduler simulations, what is included in a comparison report, and how one might interpret the results in a comparison report. The intention of a comparison report is to provide a tabular summary of key characteristics and outputs among two or more simulations and otherwise hide most of the supporting, detailed information found in detailed reports for single simulations.

Requirements for Comparison

There are three basic requirements in order for simulations to be comparable:

1. Simulations must belong to the same project
2. Simulations must belong to the Road Scheduler app - comparisons are currently unavailable for Work Zone Traffic and Cost Estimator simulations
3. Simulations must be 'completed' which means that all necessary inputs are provided and you have successfully run the simulation at least once

Information Included in Comparison Reports

The comparison report consists of two sections. The first section is a table that summarizes key characteristics and outputs of selected simulations, including:

- Paving method
- Analysis options (closure and working methods)
- Closure window duration
- Cooling time (per lift) or Curing time
- Linear productivity per closure
- Total number of closure windows and hours to complete a paving job
- Top 3 most constraining resources

Below the summary table are sections (one per simulation) that provide additional details which distinguish the project in terms of scope and overall performance. These sections include the following information for each simulation selected in the comparison tool:

Included Characteristics	Basic Description
Route	Name of route in which paving project occurs
Work Length	Linear physical road length
Total Closures	Number of closures to complete total paving job
Total hours per Closure	Total hours allocated for each closure
Effective Hours per Closure	Active hours spent on construction for each closure
Total Hours	Total hours required to complete paving job
Progress Per Closure (linear)	Linear paving progress for each closure (all lanes)

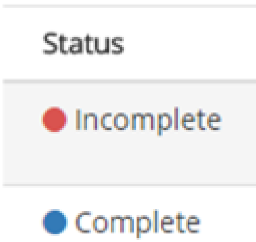
Progress Per Closure (lane-miles)	Lane-miles completed per closure
Pavement Type	Paving methods selected for simulation
Concurrent Construction	Indicates if simultaneous activities are allowed
Shift Operation	Indicated if simulation includes shift operations
Lane Profile	Number and lanes and average lane width
Lifts	Number of lifts to pave (asphalt only)
Asphalt Thickness	Thickness of pavement layer (sum of all lifts for asphalt)
Base Thickness	Thickness of base layer involved in paving job
Volume Removed	Demolition volume
Mass Removed	Demolition approximate weight
Units	Indicates whether units are imperial or metric
Date Created	Original creation date of simulation

Steps for Generating a Comparison Report

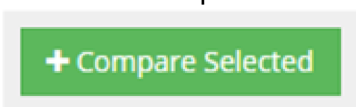
Start by completing at least two Road Scheduler simulations and navigating to the directory of simulations for your current project, similar to the example figure shown below:

Select	Simulation Name	Paving Method	Last Modified	Status	Actions
	CRCP Validation - 20170111a [DET]	Unspecified	2017-03-29	Incomplete	
	JPCP Validation - 20170111b [DET]	Jointed Plain Concrete Pavement (JPCP)	2017-02-17	Complete	
	Precast Validation - 20170112b [DET]	Pre-Cast Pavement	2017-02-02	Complete	
	HMA Full Depth Validation - 20170126b (HCFC) [DET]	Full Depth Hot-Mix Asphalt (HMA)	2017-03-01	Complete	
	Overlay Simulation - 20170126 [DET]	Hot-Mix Asphalt (HMA) - Overlay	2017-01-30	Complete	
	HMA Full Depth Validation - 20170126c (FC) [DET]	Full Depth Hot-Mix Asphalt (HMA)	2017-01-27	Complete	
	CRCP Validation - 20170127a [PROB]	Unspecified	2017-03-23	Incomplete	
	JPCP Validation - 20170127a [PROB]	Jointed Plain Concrete Pavement (JPCP)	2017-02-16	Complete	

Select two completed simulations using the checkboxes in the ‘Select’ column of the directory (first column). You can tell whether a simulation is ‘complete’ based on the ‘Status’ column:



Blue circles in the status column indicate that a simulation includes all necessary information and has been run successfully at least once. A red circle in the status column indicates that either information is missing or that the simulation has not been successfully run. Once you have selected at least two successfully completed simulations, press the ‘Compare Selected’ button at the top of the directory table:



In this example, a HMA full depth simulation is compared to a CRCP paving job for the same road configuration and objective length (5 miles, 4 lanes):

☑	HMA Full Depth Validation - 20170126b (HCFC) [DET]	Full Depth Hot-Mix Asphalt (HMA)	2017-03-01	Complete
☐	Overlay Simulation - 20170126 [DET]	Hot-Mix Asphalt (HMA) - Overlay	2017-01-30	Complete
☐	HMA Full Depth Validation - 20170126c (FC) [DET]	Full Depth Hot-Mix Asphalt (HMA)	2017-01-27	Complete
☑	CRCP Validation - 20170127a [PROB]	Continuously Reinforced Concrete Pavement (CRCP)	2017-03-31	Complete

Pressing the ‘Compare Selected’ Button will create your comparison report to appear in a new pop-up window:

Comparison Tool

Simulation Name	Method	Analysis Option	Window	Cooling/Curing Time	Closure Productivity	Total Windows	Total Hours	Constraining Resources
HMA Full Depth Validation - 20170126b (HCFC) [DET]	Full Depth Hot-Mix Asphalt (HMA)	Series Continuous HalfClosureFullCompletion	72.00 hours	1.5 hours	2752.46 feet	9.59	556.2	Demolition Production Plant Delivery Rate
CRCP Validation - 20170127a [PROB]	Continuously Reinforced Concrete Pavement (CRCP)	Parallel Continuous	72.00 hours	4 hours	609.58 feet	43.31	2771.8	Demolition Delivery Rate Production Plant

HMA Full Depth Validation - 20170126b (HCFC) [DET]

Route:	I5	Concurrent Construction:	Yes
Work Length:	5.00 miles	Shift Operation:	No
Total Closures:	9.59	Lane Profile:	4x14.01 feet
Total Hours Per Closure:	72.00	Lifts:	4
Eff. Hours Per Closure:	58.00	Asphalt Thickness:	0.66 feet
Total Hours:	690.48	Base Thickness:	0.00 feet
Progress Per Closure (linear):	2752.46 feet	Volume Removed:	550.49 cubic feet
Progress Per Closure (lane-miles):	11.01	Mass Removed:	9287.18 tonnes
Pavement Type:	Full Depth Hot-Mix Asphalt (HMA)	Units:	imperial
		Date Created:	2017-03-01

CRCP Validation - 20170127a [PROB]

Route:	I5	Concurrent Construction:	Yes
Work Length:	5.00 miles	Shift Operation:	No
Total Closures:	43.31	Lane Profile:	4x14.01 feet
Total Hours Per Closure:	72.00	Lifts:	0
Eff. Hours Per Closure:	64.00	Asphalt Thickness:	0.00 feet
Total Hours:	3118.32	Base Thickness:	2.46 feet
Progress Per Closure (linear):	609.58 feet	Volume Removed:	1115.53 cubic feet
Progress Per Closure (lane-miles):	2.44	Mass Removed:	18819.77 tonnes
Pavement Type:	Continuously Reinforced Concrete Pavement (CRCP)	Units:	imperial
		Date Created:	2017-03-31

When you are done viewing the comparison report, you may close the window by clicking the ‘X’ button in the top right corner of the screen. Doing so will return you back to the directory of simulations for the project.

Considerations and Interpretations of Comparison Reports

Simulations may vary widely in terms of their specific details, so it is important to have a general idea what results you wish to compare prior to making a comparison. For example, you may want to compare simulations that include different paving methods but have the same objective length. Alternatively, you may want to compare simulations with different working methods but have the same paving method and objective length. Or perhaps you are attempting to phase your project by comparing the paving efficiency for multiple segments with different objective lengths but each simulation consists of the same paving method and pavement geometry. In short, you will want to ensure that simulations you select are comparable in some manner because comparison simulations with no commonality will not produce a useful report.

In the example presented in this user guide, the objective length, number of lanes and lane widths, as well as closure duration are the same between both simulations compared. Based on the summary table, this means that the CRCP method will take 4 times longer to complete compared to the HMA Full Depth method. Upon closer inspection however, it is clear that the concrete paving method includes a base and a thicker pavement cross section. The thicker profile may be one explanation why the HMA alternative can be paved substantially faster.

Another factor may be that concrete pavement curing yields less available time for construction per closure, resulting in 6 fewer hours available for construction compared to the asphalt method.

If you are unsatisfied or surprised by the results, the comparison tool can help you identify inputs worth re-examining or editing. In this example, the scope of demolition work is twice as great for the concrete method, and demolition is a constraining resource for both simulations. Consequently, it may be worth examining how resources allocated for the concrete paving method could be improved to decrease the overall paving time needed.

Otherwise, you may decide that the asphalt paving method is the more efficient alternative for your paving job. In either case, it may be worth performing a work zone traffic analysis (using R3) for both simulations to examine whether the resulting traffic impacts are at acceptable levels for either alternative.

2.0.0. Overview of Features and Functionality

The chapter of this user guide identifies the primary purpose of the Traffic Impacts application, its primary features, and outline the underlying conceptual model.

The Traffic Impacts model is the second model in the R3 application suite that allows you to estimate the work-zone traffic impacts resulting from a paving strategy. With this model, you can compare the performance of different closure scenarios by identifying the most severe hours and extent of traffic congestion, as well as the implied value of time lost by roadway users.

Once you determine your paving strategy, use this application to determine whether your project yields acceptable levels of traffic with performance metrics such as maximum queue length, user cost, the time of maximum queue, and additional travel time. As a result, the Traffic Impacts module is intended to complement the results of Road Scheduler but may be used independently as a standalone application.

The application requires information regarding general traffic and operating conditions before and during construction as well as an hourly profile of daily traffic demands. The module allows you to adjust traffic capacities and demands based on characteristics specific to your project using methods from the 2000 Highway Capacity Manual (HCM) by AASHTO. Finally, using methods from 1998 FHWA Technical Bulletin on Life Cycle Cost Analysis and NCHRP Report 133 of 1972, the model quantifies the number of vehicles that encounter different flow conditions and estimates the corresponding cost to roadway users (including vehicle operating costs or VOCs).

Together with the results of the Road Scheduler and the Cost Estimator module, this application facilitates the creation of Traffic Management Plans (TMPs) by providing indicators of traffic performance or impacts associated with a paving strategy.

Because the data requirements to run the simulation can be complex, the overarching goal of the user guides is to provide you with a structured explanation of:

Chapter 2.0 What the application can do (current chapter)

Chapter 2.1 What conceptual knowledge is required understand and use the application

Chapter 2.2 What information must be specifically collected and what considerations should be included to generate a traffic impacts report

Chapter 2.3 How to run a simulation with a walkthrough demonstration

Chapter 2.4 How to interpret the results included in the report

The user guides in this chapter will address the following questions:
2.0.1: Underlying Analysis Methods - How does the model adjust traffic capacity and demand for conditions specific to a paving project?
2.0.2: Components of User Cost - What is included in user and vehicle operating costs?
2.0.3: Simulation Boundaries and Model Assumptions - What are key model assumptions and how do they limit the model application?
2.0.4: Reporting Features - What indicators of traffic performance does the model produce in the detailed report?

2.0.1 Underlying Analysis Methods

The chapter of this user guide identifies the core methods used in the Traffic Impacts model and conceptually explains how vehicle capacity and demand volumes are translated into user costs.

The Traffic Impacts module relies on the user to provide traffic information to generate a 24-hour profile of traffic demand and capacity prior to and during construction. Based on these specifications, the module executes a series of adjustments that reflect work zone conditions you specify for your paving job, including speed limits, number of lanes, and closure strategy.

In order to tailor the analysis to job-specific conditions, the application allows you to adjust lane capacities using methods described in the 2000 Highway Capacity Manual based on physical conditions such as terrain, lane width, the presence of shoulders, speed limits, and traffic composition by vehicle type and percent contribution to total daily traffic volumes. Additionally, historical traffic demand data is adjusted based on the data and construction year, as well as traffic mitigation measures intended for your project (i.e. detours and cancelled trips). You may use these adjustment techniques or simply specify values directly.

After adjusting demand and capacity volumes to project-specific conditions, the module separates traffic volumes into different types of flow expected due to the presence (or absence) of a work zone, including vehicles affected by speed reductions, stopped or queued vehicles, and vehicles that traverse the work zone or queue. This process of quantifying vehicles by flow type and vehicle type is based on methods described in the 1998 FHWA Technical Bulletin on Life Cycle Cost Analysis and NCHRP Report 133 of 1972.

Ultimately, these methods allow the application to estimate meaningful indicators of traffic performance, including the time and extents of the maximum queue and the user costs associated with different types of flow. It is important to understand the basics of the underlying simulation model because it may influence how you collect data or specify inputs for your simulation. As the model may be considered complex, it may be helpful to understand that the analysis is a synthesis of 3 distinct sequential calculations:

[1] Capacity and demand adjustments
[2] Quantification of traffic volumes by vehicle type and flow condition
[3] Conversion of traffic delays and queue lengths into user costs and vehicle operating costs

2.0.2 Components of User Cost

This section of the chapter briefly identifies the different types of flow responsible for generating user costs in the presence of a construction work zone, including vehicle operating costs.

User cost is a component often included in life-cycle cost analysis (LCCA) that attempts to capture implicit costs incurred by roadway users as they collectively suffer additional traffic delays, wear-and-tear from vehicle operation, or crash costs due to the presence of a work zone. The total user cost associated with a paving project is the difference between user costs before and during construction for the entire project duration. In this module however, only delay-related user costs and (optionally) vehicle operation costs are included.

A core concept underlying the Traffic Impacts module is that each vehicle's time can be converted into a monetary value and that the unit value of time is different for each class of vehicle. Consistent with the methods recommended by the FHWA and AASHTO, this module includes 2 vehicle classes: passenger vehicles, and trucks. It is important to note that while FHWA has identified up to 13 different vehicle classes, including all classes is impractical in terms of its data requirement.

Regardless of the vehicle class however, there are 2 flow conditions responsible for the incurrence of user costs. For more detailed explanations on how user costs arise from these flow conditions, please refer to Chapter 2.1 or the FHWA Technical Bulletin on LCCA

Free Flow Conditions:
When a work zone is present under free flow conditions, vehicles may be required to alter their speeds but do not need to stop because the presence of a queue. The combined result is that additional delay and operation costs are incurred decelerating to and accelerating from reduced speeds as vehicles traverse the work zone.

Forced Flow (LOS F) Conditions:
When a work zone is present under forced flow conditions, a queue may or may not be present upstream. The absence of a queue implies that vehicles must reduce their speeds ever further prior to traversing the work zone. On the other hand, the presence of a queue necessitates that vehicles both reduce their speed and stop to enter the queue, idle as they pass through the queue and eventually traverse the work zone. Addition delay or operating costs are incurred from the combined effect of decelerating or stopping, idling in the queue, and accelerating after traversing the work zone.

2.0.3 Simulation Boundaries and Model Assumptions

What are key model assumptions and how do they limit the model application?

The Traffic Control module makes several assumptions that may affect how you specify information to the model. This guide identifies key simulation boundaries to clarify model limitations and provide insight on how results may be interpreted from the detailed report. More detailed discussions of the underlying model concepts and data input considerations are presented in the next two chapter (Chapters 2.1 and 2.2)

Analysis Period

The application uses traffic demands and capacities over a typical 24-hour period to calculate daily user costs for each direction, which are then scaled up for multi-day closures and the total number of closures required for your project. This implies that traffic conditions are assumed to ‘reset’ each day, i.e. queues assumed to be empty at the beginning of each 24-hour period at midnight. Furthermore, the typical 24-hour period is applied to all days within a closure regardless of whether the specified traffic data reflects weekend or weekday.

Vehicle Types

The current version of the model, vehicle types are divided into two categories: passenger vehicles and trucks (including both single unit trucks, combination trucks, RVs, trailers, and buses). Consequently, the contribution of trucks to total user costs represents an average across all truck types.

Traffic Growth

When performing quantitative vehicle flow calculations, the model first inflates traffic demand from the data year to the current year of construction. This method is similar to monetary inflation in that vehicle demand is compounded annually by a growth rate specified as a percentage. For example, a paving project set to commence in 2017 with demand data from year 2012 will be inflate the demand over 5 years based on the user-specified growth rate percentage. As a consequence, your data year must be equal or prior to the year of construction.

Free Flow Velocity and Speed Limits

In this model, the speed limits specified before and during construction (through the work zone) are interpreted as the the free-flow velocities. This is noteworthy because these speed limits are used in subsequent calculations of costs associated with delays and vehicle operating costs (VOCs).

Lane Capacity Adjustments

The model uses methods from the Highway Capacity Manual (2000) to adjust lane capacities before and during construction for single and multi-lane roadways. Specifically, the model includes adjustments for the following conditions or roadway characteristics:

- The number of lanes available for travel in a given direction, where multi-lane facilities have higher capacities on a per-lane basis compared to single-lane facilities.

- Presence of heavy vehicles, which is affected by the percent contribution of trucks in the traffic mix (converted into equivalent passenger cars) and the road terrain
- Lane widths, in which narrower lanes reduce lane capacity
- Presence of shoulders and lateral clearance, which increase lane capacities when present

Accordingly, you may choose to use base level capacities, specify your own calculated lane capacities directly, or use the methods embedded in the application.

Lane Capacities Calculations By Hour

For each hour of a typical 24-hour day, the model assigns lane capacities based whether a work zone is indicated as active. When a work zone is active, the 'during construction' lane capacities are used; when a work zone is not active, the 'before construction' lane capacities are used. Naturally, this implies that individual lane capacities are higher when no construction is active.

Unit User Costs

In the model, several different unit user costs are applied to convert time delays into user costs, including VOCs. Most of these units costs are inferred from FHWA literature and specified on the basis of vehicle type (passenger vehicle, single unit truck, combination truck). These referenced unit costs include:

- Added hours of delay per 1000 affected vehicles
- Added user cost per 1000 affected vehicles
- Idling costs per vehicle-hour

You must also specify the unit delay cost per vehicle-hour for each vehicle type, regardless of whether VOCs are included in your analysis. Your specified values have a substantial impact on results because the majority of total user costs are typically generated from delay-related user costs.

It is important to understand that unit user costs values were originally recommended in NCHRP 133 in 1972 and repeatedly adjusted using the consumer price index (CPI) for the transportation industry in subsequent related research by FHWA. Consequently, you must indicate a CPI for the current or construction year in order to scale the unit costs appropriately. Furthermore, the unit delay costs you specify for each vehicle type should already incorporate any CPI adjustments. As results are sensitive to these unit delay costs, the prices or associated CPI should be consistent with the year of construction.

Differences in User Cost Before and During Construction

When presenting the results of the traffic impacts analysis, the model calculates user costs prior to construction (under existing conditions), during construction (in the presence of work zone), and the difference between the two. This difference should be considered the primary result of the analysis as it is a better reflection of the marginal traffic impacts produced by the presence of your work zone (as opposed to the user costs during construction only). Furthermore, subsequent reporting features detailing the nature of user costs are based on this difference.

2.0.4 Reporting Features

This section of the chapter briefly explains what results are included in the detailed report section of the Traffic Impacts model.

The current version of the Traffic Control module includes 3 sections in the detailed report: a summary table of traffic impacts, a visualization of traffic demand/capacity for a 24-hour period before and during construction, and finally a summary of user cost contributions incurred by different categories of traffic flow. Regardless of the options selected when configuring the model, all reports for this module include the same level of detail.

The summary table includes primary traffic impact for each direction of traffic involved, before and during construction, and the difference between the two. Performance metrics included are the maximum delay duration and expected time of occurrence, maximum queue length, minimum speed, daily user cost, per-closure user cost, and total user cost. Most importantly, the difference in values before and during construction is a particularly important result because it subtracts impacts that occur under existing operating conditions.

The next report feature plots the user-specified traffic demand and capacity data over a 24 hour period during a typical construction closure. The intent of the visualization is to provide clues as to when traffic impacts will be most severe and how the presence of a work zone can limits a road facility's ability to serve typical traffic patterns.

The report concludes with a breakdown of the difference in user costs (before and during construction) in each direction of travel. These user costs primarily include delays associated with reduced speed limits traversing a work zone, additional time spent for acceleration/deceleration, additional detour time, and waiting in queues. If the option is selected, the total user cost may also include vehicle operating costs (VOCs) such as those related to idling, stopping, and reduced speed.

Collectively, the results presented in the reporting system enable you to assess the extent of traffic impacts associated with your closure strategy. Moreover, the daily capacity/demand profile and user cost breakdowns provide additional details that allow you to identify the primary contributors to traffic impacts and adjust your closure strategy to mitigate them.

2.1.0 Definitions and Background Knowledge

What background knowledge is needed to understand the Cost Estimator model?

The purpose of this chapter is to provide you with a practical understanding of background concepts and knowledge underlying the traffic control module. This includes interpretations or definitions for key terminology in the context of the application as well as clarifying remarks about underlying methodologies.

Users experienced with traffic flow calculations or concepts included in the Highway Capacity Manual 2000 (Freeway Facilities and Basic Freeway Segments) may skip to the Conceptual Model user guide (2.2) for guidance on entering inputs.

More specifically, the user guides in this section will address the following questions:
2.1.1 Key Terminology - What knowledge and concepts are necessary to adequately run the WZT analysis module?
2.1.2 Lane Capacity Adjustments- How is roadway capacity adjusted in the model?
2.1.3 Road User Cost and Vehicle Operating Costs - How are user costs incurred by roadway users and what do they include?
2.1.4 Cost and Price Adjustments - Why should the unit user costs be adjusted to reflect local conditions or changes to currency value?

References for this model:

National Cooperative Highway Research Program (NCHRP). NCHRP Report No. 133 - Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects. 1972.

Walls, James III, Smith, Michael R.Life-Cycle Cost Analysis in Pavement Design - Interim Technical Bulletin. 1998.

American Association of State Highway and Transportation Officials (AASHTO), United States Federal Highway Administration (FHWA). Highway Capacity Manual (HCM) 2000. 2000.

2.1.1 Key Terminology and Concepts

What knowledge and concepts are necessary to adequately run the WZT analysis module?

This user guide provides you with a quick reference of concepts and input definitions used in the traffic control module. They are divided into sections that reflect the order in which inputs are entered into the application.

For more detailed considerations regarding input values, please refer to Chapter 2.2, which provides more technical descriptions and considerations on how results are calculated and affected by input choices. For convenience, note that much of this information can also be found directly in the user interface's tooltips.

Operating Conditions

Term	**Definition / Description**
Number of Lanes	For conditions before construction, this refers to the number of lanes available to traffic under normal operating conditions in both directions. If only a single direction is analyzed, you may set the number of lanes to 0 in that direction not being analyzed. During construction, this refers to the total number of lanes available in each direction during construction (open or closed). The value is not necessarily equal to the available lanes before construction since it is possible to add or subtract lanes during a closure.
Speed Limit	Before construction, the speed limit affects the rate at which traffic can dissipate under normal operating conditions and is ultimately compared to the speed limit during construction in order to calculate the relative traffic impacts during a closure. During construction, the speed limit affects the rate at which traffic can dissipate (capacity) and is typically less than or equal to the speed limit before construction.
# Impacted Closures (Both Directions)	The number of impacted closures indicates how many closures the work-zone traffic calculations should apply to. Since not all closures may follow the same closure patterns, this value is not necessarily equal to the total number of closures required to complete the paving job.
Year of Construction	The year of construction may differ than the year on which traffic data is based. Since traffic patterns (demands and capacities) may change between years, it is necessary to indicate how long that gap may be so that traffic adjustments can be made. Additionally, the year of construction is used to inflate referenced unit user cost data along with the transportation consumer price index (CPI)

Closure Term	Closures are considered short-term if their duration is under 24 hours, and extended if their duration exceeds 24 hours. The selected closure term ultimately affects the basic and adjusted capacity of the roadway during construction.
Closure Duration	Closure duration refers to the amount of time allocated to a single closure. For short-term closures, this should be specified in hours and less than 24. For extended-closures, this should be specified in days.
Physical Closure Length	The physical closure length refers to the total linear length of the work-zone closed to traffic during construction. Be careful to specify this value in length (miles or km) rather than lane-miles or lane-km.

Lane Capacity Adjustments

Term	**Definition / Description**
Base Lane Capacity (Before Construction)	This refers to the general capacity of a single lane in terms of passenger cars per hour (pc/ln/hr) and applies to both single lane (2-lane highways with 1 lane for each direction of travel). The HCM recommends a basic capacity of 1700 pc/ln/hr before adjusting for location or job-specific factors. If you prefer to specify the lane capacity directly without applying HCM-based adjustments, select the "use unadjusted capacity" checkbox. For multi-lane highways, HCM recommends a basic capacity of 2200 pc/ln/hr before adjusting for location or job-specific factors. If you prefer to specify the lane capacity directly without applying HCM-based adjustments, select the "use unadjusted capacity" checkbox.
Base Lane Capacity (During Construction)	This refers to the general capacity for single lane highways (1 lane per direction). For short term-closures, the HCM recommends 1200 pc/h/ln. For extended closures, HCM recommends a basic capacity based on the difference in the number of lanes available prior to and during construction, ranging from 1350 to 1500 pc/h/ln. For roadway facilities with more than 2 lanes per direction, recommendations are similar. For short term-closures, the HCM recommends 1600 pc/h/ln. For extended closures, HCM recommends a basic capacity based on the difference in the number of lanes available prior to and during construction, ranging from 1350 to 1500 pc/h/ln.
Adjusted Lane	The actual lane capacity is affected by job or location-specific factors such as terrain or density of trucks. This model follows HCM's recommendations for adjusting the basic lane capacities

	you have specified to provide a more accurate prediction of the real capacity. To allow this adjustment calculation based on HCM, make sure the "use unadjusted capacity" checkbox is unselected. It is important to note that adjusted lane capacities are calculated for both conditions before and during construction.
Capacity Calculation Type	By selecting the "Use adjusted capacity" option, you are indicating that the basic lane capacities should be adjusted according to HCM's recommendations. If you prefer to use the unadjusted or custom basic lane capacity, select the "Use basic or custom capacity" option.
Percent Trucks (%)	This refers to the density of trucks (as a percent of total traffic) within the traffic prior to construction. Trucks affect roadway capacity differently than passenger vehicles because of their ability to maneuver under different driving conditions. In general, increasing this value will result in a reduced lane capacity after adjustments
Terrain	The terrain of the roadway affects a vehicle's ability to accelerate, decelerate, or maneuver. In particular, this affects the ability of larger vehicles to maneuver traffic, which in turn can impact the overall flow of traffic for passenger and other vehicle types. Rolling and mountainous terrains ultimately reduce the capacity of a lane.
During Construction	Similar to the road capacity prior to construction, this module uses a simplified version of the Highway Capacity Manual (2010) to adjust the basic roadway capacity. The inputs to adjust roadway capacity during construction are identical to those before construction, but with the additional required specification of lane width.
Capacity Calculation Type	By selecting the "Use adjusted capacity" option, you are indicating that the basic lane capacities should be adjusted according to HCM's recommendations. If you prefer to use the unadjusted or custom basic lane capacity, select the "Use basic or custom capacity" option.
Percent Trucks (%)	Similar to the corresponding input before construction, this refers to the density of trucks (as a percent of total traffic) within the traffic during construction. Trucks affect roadway capacity differently than passenger vehicles because of their ability to maneuver under different driving conditions. In general, this value will be the same prior to and during construction, but you may specify them differently.
Terrain	The terrain of the roadway affects a vehicle's ability to accelerate, decelerate, or maneuver. In particular, this affects the ability of larger vehicles to maneuver traffic, which in turn can impact the overall flow of traffic for passenger and other vehicle types.

	Rolling and mountainous terrains ultimately reduce the capacity of a lane.
Lane Width	The HCM assumes that lane widths affect a driver's perception of clearance and maneuverability and that lane width only affects the basic lane capacity during construction. In general, a reduced lane width ultimately results in a smaller lane capacity.

Traffic Demand

Term	**Definition / Description**
Traffic Year	This indicates the year in which your traffic data was collected. If this year differs from the intended year of construction, the module will inflate the traffic demand based on this difference and the specified annual growth rate.
Pattern Type	For a given location, traffic demand patterns are thought to follow 4 distinct patterns depending on the day of week (weekday or weekend) and the general location of traffic (urban or rural). Select the pattern that most similarly corresponds to your work zone conditions.
Growth Rate	This indicates the assumed annual traffic growth rate. If the construction and data years differ, the module will inflate the traffic demand based on this difference at the traffic growth rate you have specified.
Percent Trucks	This refers to the density of trucks present (as a percent of total traffic) specifically in the data set used to characterize the hourly traffic demands. This value is not necessarily the same as the density of trucks used in the road capacity section: the data source may not correspond to the specific location of the work zone.
Traffic Mitigation Goals During Construction	Traffic control measures (e.g. public outreach efforts by transportation agencies) can ultimately lower traffic demands. You may specify traffic mitigation goals (detours and cancellations/no-shows as a percent of total traffic) to predict or compare alternative traffic scenarios in the work zone during construction.
No Show Percent	No-shows refers to the percentage of vehicles (per hour) that you assume will cancel their trip through the work zone as a result of your traffic mitigation efforts.
Detour Percent	Detours refer to the percentage of vehicles (per hour) that you assume will use detours in response to work zone closures. Unlike no-show vehicles, these vehicles may still affect surrounding traffic and therefore your work zone indirectly.
Additional Detour Travel Time	In addition to specifying the percentage of vehicles using detours, you must also specify or estimate the additional travel associated with the

	detour around a work zone (compared to the normal, pre-construction travel time through the work zone)
Data Entry method	This refers to how you would like the model to calculate the vehicle count for each hour in each direction of travel. The "vehicle count" option means that you will specify the vehicle count directly. The "percent of average daily traffic" option means you will specify the vehicle count indirectly as a percent of the daily total for each hour.
Traffic AADT	If you selected the "by percent of average daily traffic" option for the data entry method, you must also specify the total average daily traffic (ADT) for each direction of travel. By providing a total daily traffic volume, the vehicle count can be calculated using the percentages you specify for each hour.
Vehicle User Costs	These are the implied monetary costs incurred by roadway users due to delays / detours, vehicle operation, and crash costs influenced by closures and work zones. The costs are influenced by specific work zone conditions, characteristics of traffic demand, and the monetary valuation associated with a vehicle user's time.
Unit User Delay Cost - Passenger Car	This refers to the perceived value of an average passenger car's time in dollars per hour (of travel time). This value is often subjective and greatly depends on the specific location of the work zone. As of 2007, Caltrans recommends 11.51 $/hr based on an occupancy rate of 1.1 and a base rate of 10.46 $/hr/occupant.
Unit User Delay Cost - Commercial Truck	This refers to the perceived value of an average commercial truck's time in dollars per hour (of travel time). This value is often subjective and greatly depends on the specific location of the work zone. As of 2007, Caltrans recommends $27.83 for a commercial truck.
Vehicle Operating Cost	These are costs associated with changes in driver behavior due to the presence of work zones or closures. They include price factors associated with delays due to idling, stopping, speed changes (compared to original speeds in the absence of the work zone). The cost factors used in this model are based on values presented in NCHRP Report 133 from 1970, The FHWA's 1998 technical report on life cycle cost analysis, and FHWA's website on user costs (2010).
Hourly Traffic Demand	If you selected the "by vehicle count" option for the data entry method, enter the total vehicle demand per hour for each direction; the percents will be automatically calculated. For the "by percent of ADT" option, you must specify the percent of the daily traffic demand for each hour and direction; the vehicle counts will be automatically calculated. When using percents, be sure that the sum of percentages over all hours totals to 100% for each direction.

Lane Opening Pattern

Term	Definition / Description
Lanes Open During Construction	For each direction, you can specify the effective number of lanes available for both driving and/or construction for a given hour and whether the lanes should operate under pre-construction or work-zone/construction conditions. Your choices will affect the calculation of construction capacity in the capacity preview box.
# Lanes (Both Directions)	By default, this will be the same as the number of lanes you specified in the operating conditions section of the model. You may override this default value in some circumstances, such as temporary lanes from shoulder usage, altering lane widths to produce another lane, or the strategic inclusion of express lanes.
WZ? (Work Zone Presence)	By selecting this checkbox for each hour and direction, you indicate that the lanes are operating under work-zone / construction conditions. If left unchecked, you are indicating that the lanes operate under pre-construction conditions. Your choices will affect the calculation of construction capacity in the capacity preview box.

Results

Term	Definition / Description
Max Delay	The maximum delay refers to the longest duration a vehicle would be delayed as a result of the presence of the construction work zone, including the hour at which the model predicts this delay will occur. Results are separated by direction and before/during construction conditions and the difference is indicated in the two right-most columns.
Max Queue Length	The maximum queue refers to the longest physical queue length that forms on a typical day before and during construction and for each direction of travel. The model determines the hour in which the greatest number of vehicles are queued based on the physical capacities and demands of the roadway facility. The implied travel speeds from slowdowns and stops are then used to determine the physical length of the queue. It is important to note that the model assumes that the max queue is formed during the same hours indicated in the maximum delay row of the table.
Min Speed	The minimum speed refers to the lowest speed a vehicle traversing a section of the roadway must slow down to as a result of daily traffic demand and capacity profiles. Before construction, slowdays may or may not occur depending on whether hourly traffic demands exceed capacity on a typical day. During construction, more extensive slow downs (if not stops) will occur as a consequence of overall reduced roadway capacity (e.g. from reduced lanes, speed limits).
Daily User Cost	The daily user cost is the sum of user delays incurred in each hour of

	a typical 24-hour day based on the traffic demand and capacity profiles you have specified. For each hour, the model quantifies how many vehicles encounter different flow conditions and then converts these values into costs based on conversion factors recommended by the FHWA and the user costs you have specified.
Per Closure User Cost	The daily user cost is scaled to determine the user cost per closure since a closure may consist of more or less than 24 hours. If your closure is less than 24 hours, this is found by summing the user costs per hour for the hours in which your work zone applied. For extended closures longer than 24 hours, the per closure user costs are found by multiplying the number of days or hours you have specified for your closure.
Total User Cost per Direction	The total user cost per direction is found by simply by multiplying the per closure user costs by the number of closures you have specified in your simulation. This is performed for each direction of traffic before and during construction, and the difference is shown in the two right-most columns.

User Guide 2.1.3 Road Capacity Adjustment

How is roadway capacity adjusted in Road Scheduler?

This section of the user guide identifies which methods from the Highway Capacity Manual (HCM 2000) for freeways are used to adjust lane capacities. The goal of this section is to explain why these methods are included in the application and their context in the overarching methods for estimating user costs. Although these adjustment methods are embedded in the application, you may choose to skip these calculations and instead specify your own lane capacities directly.

Base Lane Capacities

HCM 2000 includes recommended basic highway lane capacities before construction (no work zone present) and during construction (work zone present), and for multi-lane and two-lane highways (referred to as single-lane highways here when considering a single direction of travel).

For conditions before construction, HCM 2000 recommended an average basic capacity of 1800 passenger vehicle per lane per hour (pvphpl or pcphpl) for single-lane and 2200 pcphpl for multi-lane highways.

For conditions during construction, HCM provides two recommendations depending on the presence of median cross-overs or lane-drops only. When median cross-overs is present, the single and multi-lane capacities are 1100 and 1600 pcphpl respectively; when there are lane-drops only, the capacities are slightly higher at 1200 and 1800 pcphpl for single and multi-lane facilities, respectively.

Adjusted Lane Capacities

The recommendations for base capacities reflect averages across various highway facilities across the United States and may vary depending on locale or conditions specific to a paving job. HCM 2000 includes methods for adjusting basic lane capacities to accommodate site-specific conditions and provide a greater degree of accuracy for any subsequent analyses, including traffic flow calculations.

The overall adjustment factor is the product of all individual adjustment factors. Put otherwise, the adjusted lane capacity is the base lane capacity multiplied by the overall adjustment factor. The traffic control module currently incorporates 3 separate individual adjustment factors and are discussed in more detail below.

Adjustment Factor: Presence of Shoulders / Lateral Clearance

In general, the presence of shoulders increases a driver's perceived amount of space to maneuver their vehicle. If both shoulders are present, the adjustment factor is unity and does not affect the base capacity. Conversely, have one or no shoulders present yields an adjustment factor less than 1, effectively reducing a lane's capacity to serve vehicles. The table below summarizes the factors recommended from HCM 2000

Condition	Adjustment Factor
Both sides existing	1.00
One side existing	0.95
No side existing	0.90

HCM 2010: Shoulder / Lateral Clearance Factors

Finally, the presence of shoulders may differ before and during construction, potentially yielding different adjustment factors for each condition.

Adjustment Factor: Heavy Vehicle Factor

The heavy vehicle adjustment factor captures the influence that trucks, buses, RVs, or trailers may have on the flow of traffic (and therefore on lane capacity) based on their ability to operate on different terrains. The HCM assumes that heavy vehicles (trucks) reduce free flow speed and capacity compared to passenger cars, despite being a typically smaller percentage of the driver population.

The Heavy Vehicle Factor is a function of two conditions: the percent contribution of each vehicle type to the traffic mix, and their corresponding passenger car equivalent (PCE). The PCE is a multiplier that accounts for the notion that heavy vehicles (busses, trailers, 3+ axle vehicles and RVs) have a greater impact on traffic flow compared to passenger cars. The table below shows the recommended PCE values based on vehicle class and terrain:

Vehicle Type	Level	Rolling	Mountainous
Single Unit	1.5	2.5	4.5
Combination	1.2	2.0	4.0

HCM 2010: PCE as a function of vehicle class and terrain (Exhibit 11-10, Page 11-15)

The HCM also provides definitions for these terrains in Chapter 11.2 and are paraphrased here to guide your selection:

Terrain	Selection Criteria

Level	Terrain consists of short grades (<2%). Heavy vehicles can operate (accelerate/decelerate) in a similar capacity to passenger cars, effectively allowing them to keep up with traffic.
Rolling	Heavy vehicles cannot perform as well as passenger vehicle specifically due to road grades or alignment at some segments. To operate safely at some segments, trucks must go at crawl speeds uphill or downhill (substantially slower than passenger car traffic). However, the length or frequency of crawl-speed segments is not significant.
Mountainous	Grade or road alignment causes vehicles to operate at crawl speeds frequently or for long distances. This terrain is rarely used in analysis.

Terrain Definitions (Paraphrased from HCM 2010, Chapter 11.2)

Ultimately, the heavy vehicle factor is indirectly proportional to both PCE and the percent contribution of trucks. Steeper terrains and larger percent contributions from trucks reduce the heavy vehicle factor below unity, effectively resulting in smaller lane capacities. If there are no trucks (any type) present in your traffic mix, the heavy vehicle factor will be unity regardless of the terrain.

Adjustment Factor: Changes in Lane Width

The lane width adjustment factor is applied based on the width of the roadway and captures the notion that narrower lanes (compared to a standard 12 ft. wdith) will reduce lane capacity. These factors are summarized in the table below:

Lane Widths (U.S.)	Lane Widths (Metric)	Adjustment Factor
>= 12 ft	> 3.66 m	1.00
10.0-11.9 ft	3.05-3.66 m	0.91
9.0-9.9 ft	2.74-3.05 m	0.86
< 9 ft	< 2.74 m	Use field obs.

HCM2010: Lane Width Adjustment Factors (Page 10-28)

It is important to note that lanes at least 12 ft wide will yield a unity adjustment factor and not impact the lane capacity. Lanes less than 12 ft wide will yield adjustment factors less than 1, implying that lane capacity is reduced in these cases.

Adjustments: Other Capacity Adjustment Factors

You may decide to apply an additional factor for f_{LW} manually by choosing “use base capacity” to override the automatic calculation. HCM 2010 includes recommendations for adjusting capacity based on other conditions, including:

- Weather and environmental conditions
- Accidents and breakdowns
- Road saturation conditions
- Ramp presence and density
- Lateral clearance and shoulders

However, none of these factors are included in the current version of the application and must be calculated separated if you desire to include them. Users familiar with the HCM may be interested to know how the methods used in this model specifically differ from HCM for adjusting roadway capacity. Advanced users may choose to modify the input assumptions based on their own experience, expertise, or capacity to collect information.

User Guide 2.1.3 Road User Costs and Vehicle Operating Costs

How are user costs incurred by roadway users and what do they include?

This section of the user guide defines the concept of road user costs in greater detail and identify how they are generated based on the number of vehicles encountering different flow conditions throughout a typical 24-hour period. The goal of this section is to provide practical definitions that will enable you to better utilize the application without necessarily knowing the technical details of the calculation methodology or underlying research. Such details can be found on FHWA's website, FHWA's 1998 technical bulletin on life cycle cost analysis, and NCHRP 133.

User costs traditionally include monetary valuations of time associated with delays, costs associated with vehicle operation (VOCs) due to physical roadway characteristics or conditions of operating, as well as crash costs. The traffic control module incorporates FHWA and NCHRP's methods for estimating both delay costs and VOCs, but excludes crash costs. It is also important to note that the calculation of VOCs is optional in this application -- all remaining user costs are referred to as delay costs.

Different types of user costs are generated depending on traffic flow conditions. In this model, traffic flow is separated into two categories: free flow and forced flow (level of service condition F).

Free Flow Conditions:
Under these conditions, flow is generally uninterrupted because no queues are formed and so stopping is not required. When a work zone absent under free-flow conditions, no user costs are generated. When a work zone is present under free flow conditions, vehicles may be required to reduce their speeds to traverse the area. In this case, 3 types of users costs can be generated:

> **[1] Speed Change Delay Costs**: Additional delay costs are incurred because vehicles upstream of a work zone must decelerate as they approach and accelerate after they traverse the work-zone. Such maneuvers result in added travel time that would not occur in the absence of a work zone.
>
> **[2] Speed Change VOC Costs**: For reasons similar to speed change delay costs, additional operating costs are incurred because because vehicles upstream of a work zone must decelerate / accelerate after they traversing the work-zone. In the absence of a work zone, vehicles would not otherwise be required to adjust how they are operating their vehicle.
>
> **[3] Reduced Speed Delay (Work Zone Traversal)**: Additional delay costs resulting from the reduced speed limit within a work zone compared to conditions prior to construction in free flow conditions. That is, vehicles would spend less travel time without speed restrictions due to the work zone.

Forced Flow (LOS F) Conditions:
These conditions apply when traffic demand exceeds capacity and queues are generated directly upstream of a work zone. Even if a work zone is absent, flow may still be restricted due to the lasting impact of queues already formed in the network from previous hours. When queues are formed, 4 additional user costs are imposed on vehicles who enter the queue.

It is important to understand that the 3 user-costs under free flow conditions still apply in forced flow conditions. Vehicles that approach a queue must still reduce their speed, and accelerate back to normal speed limits when they eventually traverse the work zone.

In summary,4 additional user costs are generated in the presence of queues:

[1] Stopping Delay Costs: Vehicles that encounter an existing queue must come to a complete stop prior to entering the queue to traverse the work zone, as well as accelerate back to normal speeds after traversing the work zone. As a result of both, additional delays are imposed on vehicles.

[2] Stopping VOCs: Similar to stopping delay costs, vehicles are forced to stop their vehicle as they enter a queue and accelerate as they leave the work zone. Because such maneuvers would not be required in the absence of a work zone, additional operating costs are generated by these vehicles.

[3] Queue Traversal Delay: Vehicles that are in a queue will incur additional driving time and consequently delay costs from waiting in the queue.

[4] Idling VOCs: As vehicles slowly traverse a queue via stop-and-go driving, they incur additional VOC costs from idling. This is opposed to travelling at reduced speeds when a work zone is present, or at free-flow speeds in its absence)

Detour Delay Costs:
Vehicles that take detours will not pass through a work zone but may suffer additional delay costs due to the extra driving time required to avoid the work zone. Consequently, there is also a user cost associated with detours, regardless of flow conditions through the work zone. No VOC costs are associated with detours.

User Guide 2.1.4 Unit Cost Price Adjustments

Why should the unit user costs be adjusted to reflect local conditions or changes to currency value?

This guide provides a brief discussion of unit user costs that are applied to convert delay times and calculate VOCs depending on flow conditions and vehicle type. For the analysis to be consistent, it is important to ensure that unit delay costs specified reflect predictions for prices in the year of construction as closely as possible.

The original underlying research for calculating user costs are based on recommendations from NCHRP Report 133 published in 1972. The FHWA has updated these prices over time to reflect more current conditions and uses the consumer price index (CPI) for the transportation industry. For example, NCHRP Report 133 uses 1970 USD (CPI of 37.5), and FHWA used 1996 dollars (CPI of 142.8) in their technical report on life cycle cost analysis. The most recent unit values found on FHWA's website on user cost calculations are based on 2010 USD with a CPI of 193.396. If the construction year occurs in 2010, then the adjustment factors for unit prices is simply the ratio of CPIs (193.396/37.5 = 5.16). In this application, the CPI is used to scale unit costs recommended by the FHWA to the chosen year of construction. More specifically, these unit costs are:

Idling VOCs ($/veh-hr) - Unit costs depending on vehicle class and applied to determine idling VOCs when vehicles traverse a queue under forced flow conditions. In general, trucks are assumed to carry larger unit costs than passenger vehicles.

Added VOCs ($/1000 affected vehicles) - In addition to recommending unit delay times (hrs/1000 affected vehicles), the FHWA also provides unit VOC costs (per 1000 affected vehicles) for passenger cars, single unit trucks, and combination trucks for speeds ranging from 0 to 80 mph. These unit costs are used to determine reduced speed VOC costs and stopping VOC costs.

Reduced Speed Delay Costs ($/veh-hr) - This refers to delay costs (added travel time) from all sources, including delays from acceleration/deceleration (reduced speed, stopping), queue delay, traversing the work zone at lower speed limits, and added travel time from detours. Although FHWA includes recommendations for these costs based on vehicle type, these unit costs are specified by the user directly in this model. Consequently, you should manually adjusts your unit costs using an appropriate CPI. Careful selection of these unit costs is important because the majority of total user costs typically arise from these delay costs as opposed to VOC or idling costs.

In general, unit user costs for trucks are higher than passenger vehicles. However, since the percent contribution of trucks to traffic mixes is relatively smaller, user costs from passenger vehicles typically dominate the total user costs. For example, FHWA has provided example unit delay costs of $11.58 for passenger vehicles, $18.54 for single unit trucks, and $22.31 for combination trucks (2010 USD).

2.2.0 Conceptual Model

How is input data used in the traffic control module and what are important data considerations?

The purpose of this chapter of the user guide is to outline the underlying methodology specifically used in the traffic control module of R3, including important data entry considerations for each section of the application. By understanding the concepts in this chapter, you can achieve greater insight regarding how the technical model works, specify more appropriate inputs, and understand how your choices may impact the model results.

Nevertheless, it is not necessary to understand all the technical details of the methodology to successfully simulate traffic impacts in this model. Rather, the chapter is intended as a reference manual to users who simply want to successfully generate reasonable simulations.

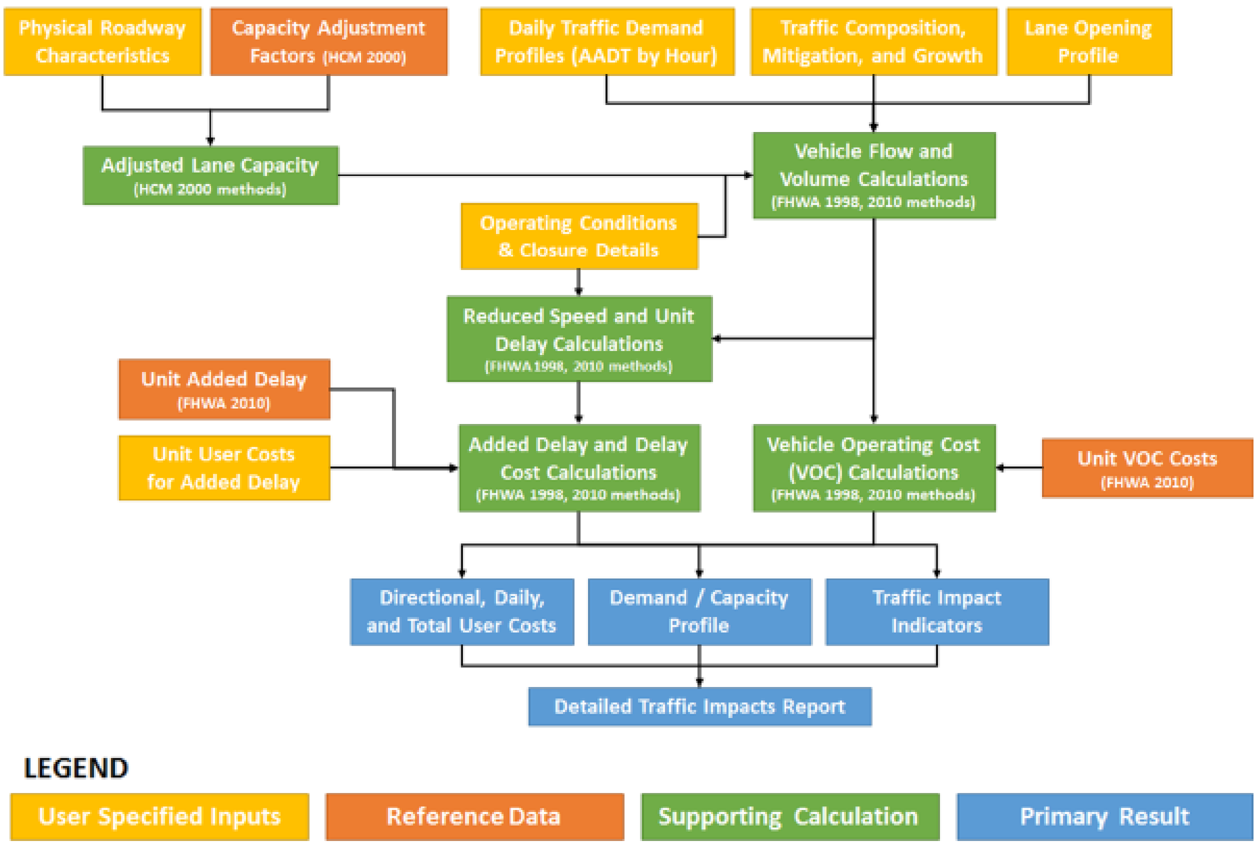
If you would like to improve your understanding of lane capacity adjustments, vehicle flow calculations, or the types and application of user costs, it is recommended that you review the previous chapter (2.1) which elaborates on this background knowledge.

In particular, the user guides in this chapter will answer the following questions:

2.2.0: Conceptual Model - What concepts are included in this chapter?
2.2.1: Data Requirements and Flow - How do model inputs interact with each other and affect results?
2.2.2: Data Considerations: Operating Conditions - How do physical roadway characteristics and roadway operating conditions affect the underlying methodology?
2.2.3: Data Considerations: Road Capacity - How is road capacity determined and adjusted to project-specific conditions?
2.2.4: Data Considerations: Traffic Demand - How do I provide a daily traffic demand profile?
2.2.5: Specifying Lane Availability - How do I specify lane configurations for each hour of a typical 24-hour period during construction?

2.2.1 Data Requirements and Flow

The intent of this section is to outline and clarify the underlying methodology of the traffic control algorithm to estimate user costs for a pavement construction project. The figure below visualizes how inputs are used in the model and identifies which inputs are involved in different intermediate calculations.



You may notice how different sets of input (yellow boxes) are used exclusively in different parts of the calculation. In particular, it is important to understand that capacity adjustments calculations are separate from flow calculations and the assignment of user costs.

Reference data (orange boxes) refer to values embedded into the algorithm based on recommendations from the FHWA or the Highway Capacity Manual (2000). Although these are considered input values, they are scaled appropriately based on inputs you provide.

Key intermediate calculation steps (green boxes) ultimately work together to produce the results (blue boxes) displayed in the report section. Users interested in the specific steps of application’s method should pay particular attention to these intermediate calculations because they are performed in the background and do not directly appear in the reporting section.

General Methodology

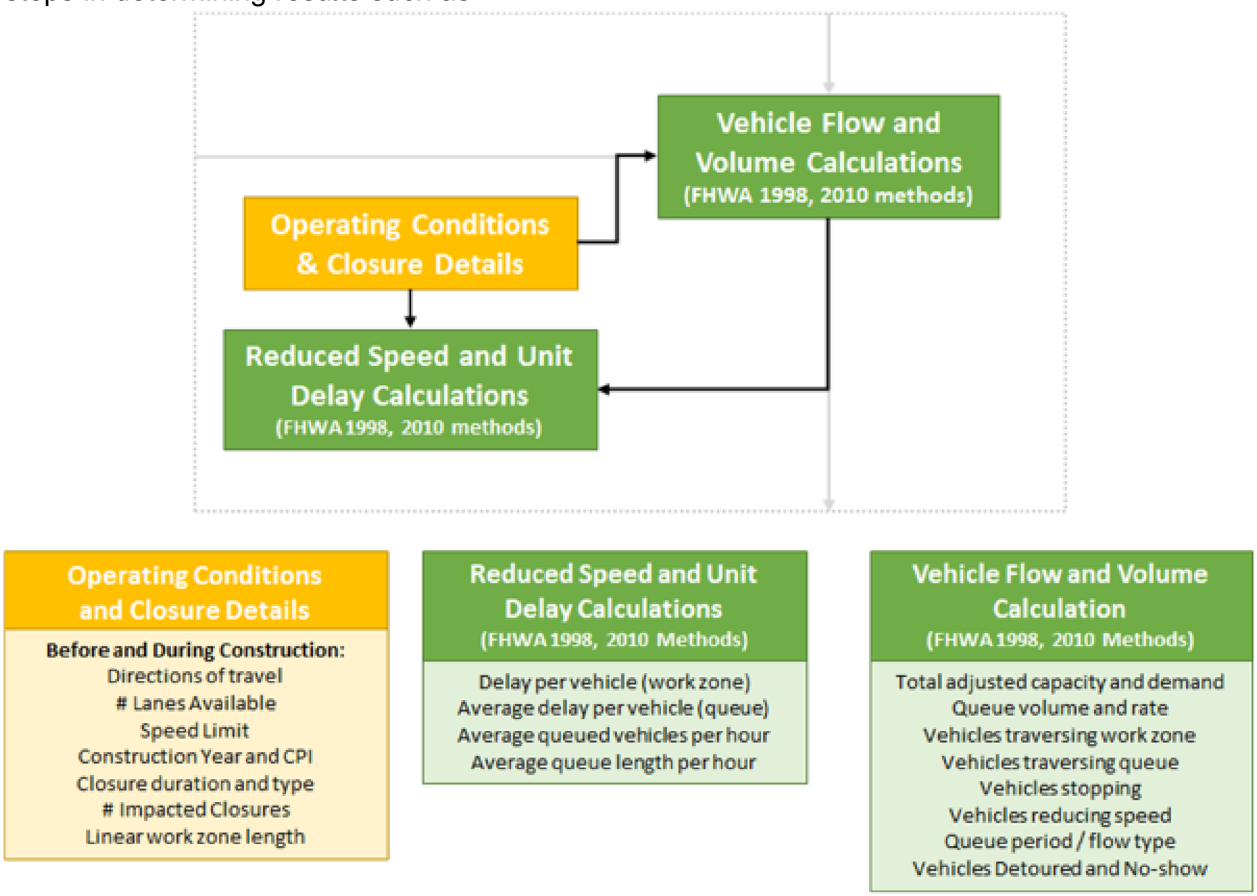
Inputs related to roadway characteristics and operating conditions before and after construction are required to adjust lane capacity. Once you have identified lanes available for traffic during construction, specified traffic mitigation members, the model can generate daily traffic profiles for total roadway demand and capacity. Based on these traffic profiles, the model quantifies the number of vehicles affected from different flow conditions, including travelling at reduced speeds, stopping, and idling in queues that can form. Subsequently, delay times, and user costs (including vehicle operating costs or VOCs) are applied to vehicles under each flow condition to determine the user costs and other indicators of traffic performance for a 24-hour period. These user costs are then scaled up to determine total user costs on a per-closure basis in each direction as well as the total user costs for the entire project duration.

Understanding the overarching methodology may generally help you recognize how inputs you provide will affect the outcome of the traffic control module and help you identify how you might improve your construction strategy. The user guides contained within this chapter will present a deeper discussion of data considerations when specifying inputs for each major step of the calculation. Nevertheless, it is possible to successfully run the model and interpret the results without understanding the technical details presented in this chapter.

2.2.2 Data Considerations: Operating Conditions

The purpose of this user guide is to describe data considerations for the first general set of inputs required by the traffic control module. Operating conditions refers to inputs that describe how the roadway functions prior to and during construction, including speed limits, closure duration, number of closures, physical work zone length, and construction year. Collectively, these parameters describe local conditions that allow the model to tailor the analysis specifically to your project.

As shown in the figure below, it is particularly important to notice that these inputs specifically affect the intermediate calculations related to vehicle flow calculations and the determination of unit delays and costs associated with reduced speeds. Both of these calculations are critical steps in determining results such as



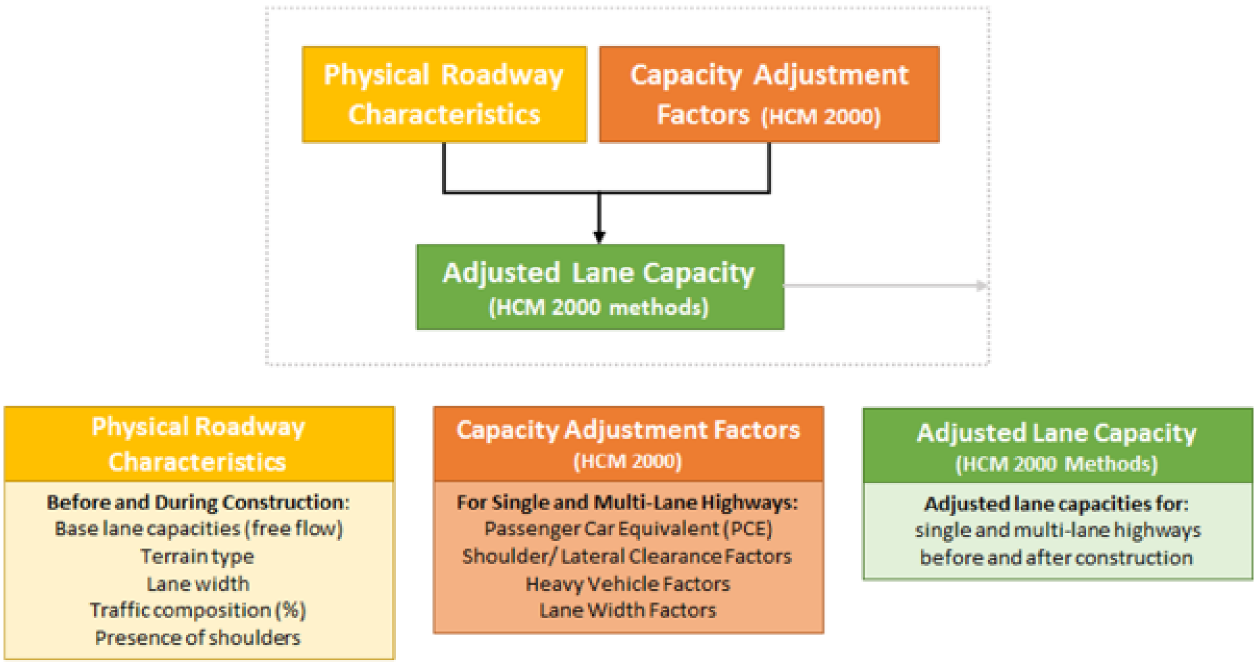
Compared to conditions prior to construction, speed limits are typically reduced through the work zone during construction. Reduced speed limits are a source of delay because vehicles are otherwise forced to deccelerate as they approach the work zone, traverse the work zone (and potentially a queue leading to the work zone) at reduced speeds, then accelerate back to free-flow speed limits. Larger reductions in speed limit from pre-construction conditions yield larger units user costs. In the case of vehicles stopping to enter a queue, a ‘reduced speed’ of 0 mph is used and yields the largest unit user costs given the same pre-construction speed limit.

When specifying the number of closures and closure duration, it is important to note that these inputs allow the model to scale estimates of daily user cost to per closure and total project levels (for each direction of travel).

The construction year and consumer price index (CPI) for transportation is important to specify because it may differ from the year in which traffic demand data was collected as well as the time at which you perform this analysis. That is, traffic demand is inflated to the construction year by a fixed growth rate (specified in a different section) prior to the calculation of vehicles operating under different flow conditions. Additionally, unit user costs referenced from the FHWA are scaled to the construction year using the transportation industry CPI.

2.2.3 Data Considerations: Roadway Capacity

This user guide conveys important considerations when providing inputs related to adjusting the lane capacities using HCM 2000 methods. Although these adjustments are optional, they allow you to tailor the analysis to project-specific conditions based on physical roadway characteristics. In the traffic control module, these inputs are requested in the second of the application following operating conditions, prior to specifying traffic demand profiles. The figure below summarizes inputs related to lane capacity adjustments in the context of the overall methodology:



Lane Adjustments Based on Physical Roadway Characteristics

By default, the traffic control module uses methods based on HCM 2000 which uses physical roadway characteristics to make adjustments. These methods are described in more detail in User Guide 2.1.2, which explains how adjustments are made.

The Capacity adjustment factors are taken directly from HCM 2000 and the methods are automatically applied in the background to the base lane capacities you specify. Although the HCM provides recommendations for base lane capacities, you are required to specify these values directly. In general, lane capacities are smaller for 2-lane roadway facilities (1 lane in each direction) than multi-lane roadway facilities (2+ lanes in each direction). Additionally, lane capacities are typically larger for construction conditions (work zone is present) compared to pre-construction conditions.

Recall that the model includes 3 common adjustment factors whose product yields the final overall adjustment factor applied to each lane's capacity: heavy vehicle adjustment, lane width adjustment, and shoulder / lateral clearance adjustment.

<u>Characteristics Related to the Heavy Vehicle Adjustment Factor</u>

When specifying the percent of trucks in a traffic mix, remember that passenger vehicles are assigned the balance (as a percent) of the traffic mix. These values are not necessarily the same before and during construction because freight / truck access may be restricted on the roadway during construction.

When considering the terrain corresponding to your roadway, consider how it will impact the ability of different vehicle classes to maneuver up or downhill. In general, trucks are assumed to have a reduced ability to slow down when travelling downhill, accelerate when travelling uphill, and may negotiate curves at reduced speeds. In technical terms, this means that trucks are treated as equivalent to the presence of multiple passenger vehicles, referred to as the passenger car equivalent (PCE).

Regardless of the traffic mix, specifying a steeper terrain tend to reduce the capacity of each lane and will affect truck type vehicles to a greater extent than passenger vehicles. Collectively, the traffic mix and terrain are used together to determine the Heavy Vehicle Adjustment Factor. A factor of 1 implies that no adjustments are made to lane capacity; factors less than unity imply a reduced lane capacity results from truck and terrain contributions.

<u>Characteristics Related to the Lane Width</u>

The Lane Width Adjustment Factor assumes that lanes less than 12 ft (a standard for most locations) tend to reduce lane capacity because there is presumably less physical space for vehicles to adjust their driving habits accordingly. Specifying a lane width of 12 ft results in an adjustment factor of 1 (effectively no adjustments are necessary for lane width).

The lane widths before and during construction are not necessarily equivalent. For example, a strategy may attempt to 'produce' another lane by decreasing the width of existing lanes, utilizing the shoulder as an added lane, or a combination of the two.

<u>Characteristics Related to the Presence of Shoulders</u>

According to the HCM, the presence of shoulders on your roadway facility can provide additional lateral clearance for vehicles. When both shoulders are present, no adjustments are necessary and the shoulder adjustment factor is unity. When only one or no shoulders are present, the adjustment factor drops below 1 and lane capacity is reduced. Like the lane width adjustment, shoulder presence need not be the same before and during construction.

Manual Capacity Adjustments

By default, Road Scheduler uses simplified methods based on HCM 2000, but provides the option for you to enter a custom calculated capacity. The HCM provides recommendations on adjusting traffic capacity based on a variety of conditions not included in Road Scheduler. Users who are concerned about the following issues, or have the capacity to obtain the proper data may want to refer to the methods described in HCM 2000. For example, you may decide to manually calculate these capacity adjustments based on the more detailed methods described in HCM 2000, or choose other factors based on local or specific transportation agency requirements.

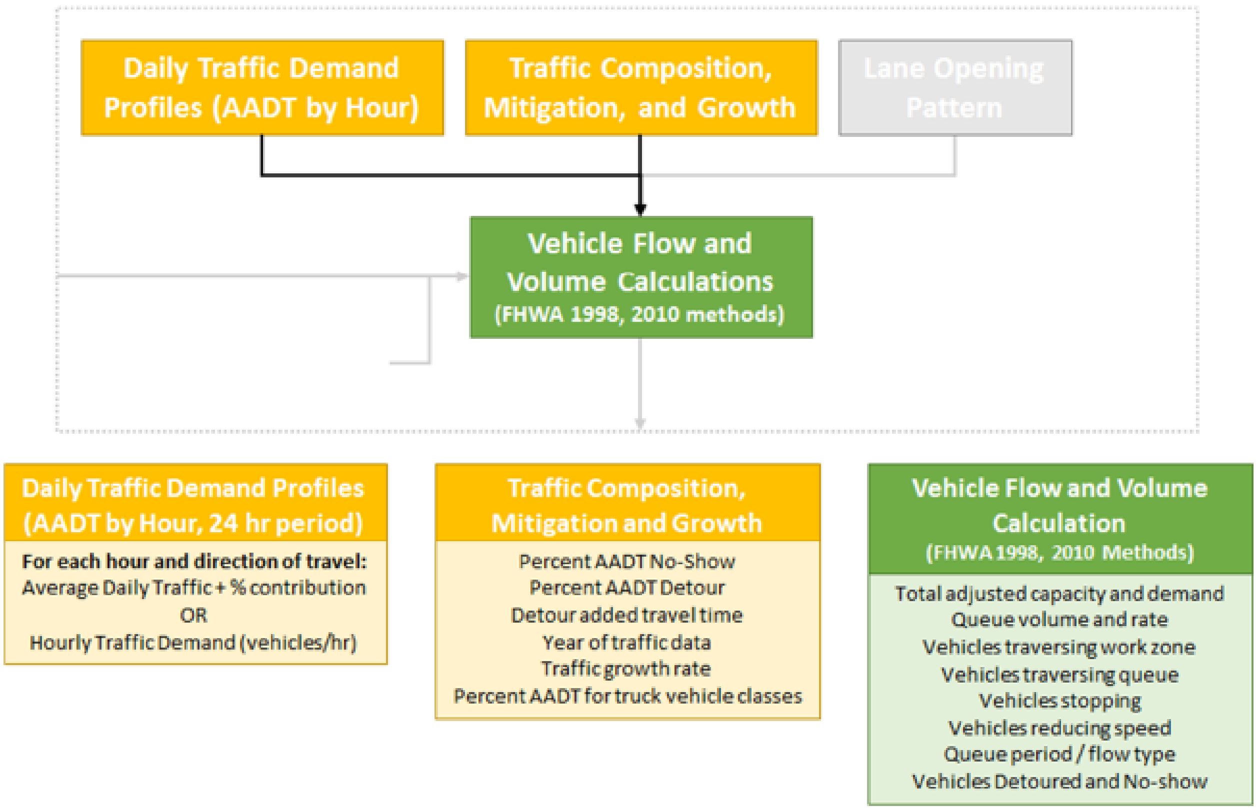
In these cases, you should select the “basic” capacity adjustment method option instead of the “adjusted” option. In this case, the simulation will take the value entered in the “base capacity” and will not perform any additional adjustment calculations.

In either case, it is strongly advised that the user adjust the capacity manually or use the built-in adjustment calculator; it is not recommended that you simply use a roadway’s nominal base capacity because it lacks any kind of adjustment based on specific local conditions.

2.2.4 Data Considerations: Traffic Demand

This user guide explains different options for specifying a daily (24-hour) traffic demand profile and how your choices will impact the resulting process of determining road user costs or VOCs. The traffic demand inputs are requested in the third section of the application after road capacity adjustments and prior to specifying lane availability during construction.

The figure below indicates how inputs request in this section affect intermediate calculations for vehicle flow / volume calculations.



Traffic Composition, Mitigation, and Growth

When providing hourly data for vehicle demand, you must specify the percent contribution of trucks, the year in which the data was collected, and the assumed traffic growth (escalation) rate. The model will inflate traffic demand by the number of years between the year in which traffic demand data was acquired and the year of construction using the growth rate. The growth rate is typically small (less than 5% but should be specific to your particular location).

Depending on the data year, keep in mind that the percent of trucks is not necessarily the same as those used to adjust lane capacities. It is entirely possible that the contribution of trucks typical for your traffic mix have have changed between the data year as well as conditions prior to and during construction.

Additionally, you may also specify anticipated traffic mitigation goals during construction resulting from your public outreach efforts. No-Show vehicles refers to the anticipated percent of traffic that you expect to cancel their trips as a consequence of construction closures. Specifying this value as 0 implies that you assume no vehicles will cancel their trip; a non-zero values implies that these vehicles will be subtracted from hourly demands prior to flow calculations.

When specifying additional detour travel time, the value will not affect calculations unless the percent of vehicles expected to detour is greater than 0. Otherwise, detoured vehicles will incur additional user delay costs based on the additional number of vehicle-hours spent detouring.

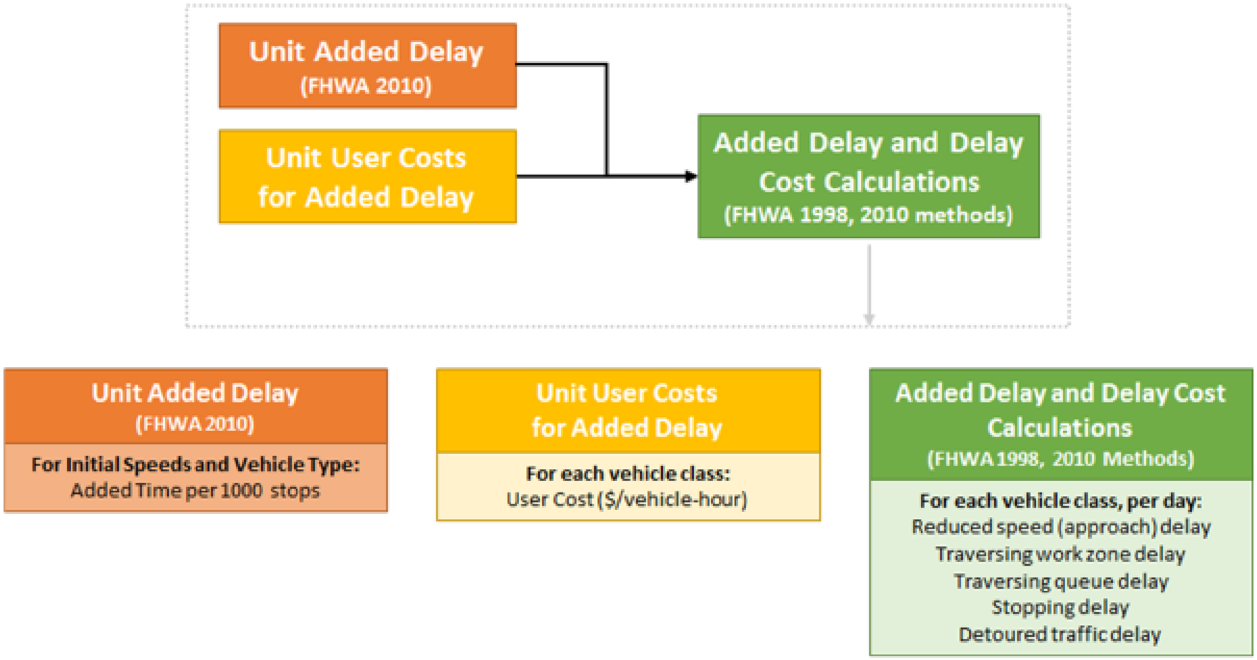
Since both no-show and detoured vehicles are goals rather than observed values, this may lead to uncertainty. You may want to explore different outcomes of traffic mitigation efforts by running multiple iterations of your simulation with different values to generate a range of predicted user cost values.

Daily Traffic Demand Profiles
In this section, you will need to provide information that describes the volume of traffic demand for each hour of a 24-hr period for each direction of travel included in your analysis. In the module, this can be done in two manners:

Option 1: Direct specification of vehicles per hour
If traffic data is available for each hour directly, choose the 'Vehicle Count' data entry method. You will will then be asked to transcribe these values into a table for each direction and hour each day. It is important to note that traffic mitigation factors are not yet applied to the data you enter in this section.

Option 2: Percent of average daily traffic volumes
If you prefer to enter traffic volumes for each hour as a percent of the total average daily traffic, select the 'Percent of Average Daily Traffic' data entry method. In this case, you are required to provide the total daily traffic volume for each direction of travel and the sum of hourly contributions must add up to 100% in each direction. The application will automatically convert the percent contribution for each hour into a volume.

Road User Costs
The final set of inputs for this section involve specifying whether VOC calculations should be included and the unit costs associated with delays for each vehicle type (passenger vehicles and trucks). The figure below shows the context of these unit costs in the overall methodology and how they specifically affect the determination of delay cost calculations.

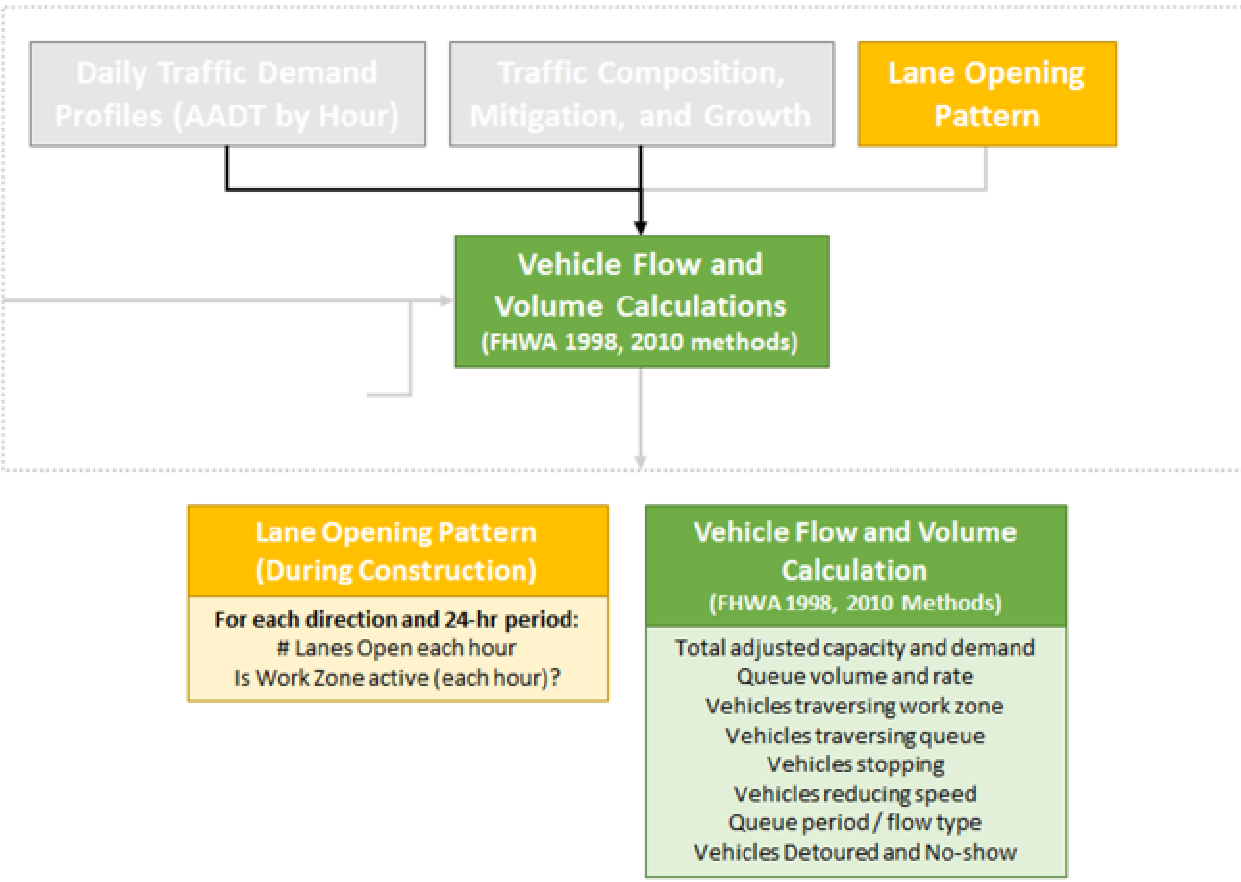


It is recommended that you include VOCs, although their total contributions to user cost are typically small compared to user costs associated with delays (typically ~10% of total user costs). As discussed previously in User Guide 2.1.3, unit VOC costs are embedded into the application based on FHWA's most current values from 2010 and inflated using the specified construction year CPI.

Unit costs associated with added delays must be specified directly and should be manually inflated to construction year dollars. Recall that unit costs for passenger vehicles are substantially smaller than unit costs for trucks. Passenger vehicles typically contribute more to total user costs than trucks however because they compose the majority of traffic mix.

2.2.5 Specifying Lane Availability

This section describes the importance of specifying lanes available for traffic for each hour of the day and for both directions of flow. After specifying a lane opening pattern (the last input section of the model) the application can generate daily demand/capacity profiles that are used to quantify vehicles subject to different flow conditions and subsequently their user costs. The figure below provides context for these inputs in the overarching methodology and what information can be produced using this information.



By default, the traffic control module automatically populates the number of available lanes during construction using the number of lanes specified in the Operating Conditions section of the model. As the number of lanes available for traffic may vary throughout the day, you may now finely adjust the number of lanes for each hour of the day. For example, the work zone may not be present for all hours of a day and consequently, more lanes may be available to traffic during those hours.

You may specify the presence of a work zone for a particular hour and direction by selecting the checkbox next to each hour of the day.

In the WZ? box is left unchecked, the application automatically replaces the available number of lanes with the value specified in the Operating Conditions section prior to construction. In this case, the capacity of each lane is determined using the adjusted lane capacities for conditions prior to construction. If the WZ? Box is checked, you may alter the number of available lanes as needed. In this case, the adjusted lane capacities for conditions during construction are applied to each lane.

In either condition, when the number of lanes is 1 for a given direction of travel, single lane capacities are used; conversely, multi-lane capacities are used when the number of lanes is 2 or more.

After completing the lane opening pattern table for all hours and directions of travel, the application will generate a daily traffic capacity profile based on all of your inputs. Along with adjusted demand, the traffic capacity profile is visualized in the reporting system for each direction of travel. The inclusion of this table allows you to audit your inputs related to capacity prior to generating the simulation report.

2.3.0. Best Practice Example: Work Zone Traffic Impacts

The sections in this user guide provide a walkthrough of the traffic impacts analysis simulated in the Work Zone Traffic (WZT) module while briefly discussing best practice considerations pertaining to each step.

Each step included in the demonstration is accompanied with brief discussions of considerations and assumes that all necessary data has already been collected in advance.

These discussions frequently refer to background knowledge presented earlier in Chapters 1 and 2 of the Work Zone Traffic User Guides. These user guides are intended to explain how input parameters influence both each other and the overall work zone traffic impacts. On the other hand, this chapter of the user guide focuses on application and interpretation.

By understanding the results of this demonstration, you will gain a better understanding of the WZT module's results, and how best practice considerations for inputs influence the model outputs.

Using a Pre-Cast paving job as a demonstration, the user guides in this section will address the following questions:

2.3.1 Operating Conditions – What kind of lane configurations and characteristics affect traffic impacts before and during construction?

2.3.2 Road Capacity – How do the physical characteristics of the traffic and roadway affect lane capacity before and during construction?

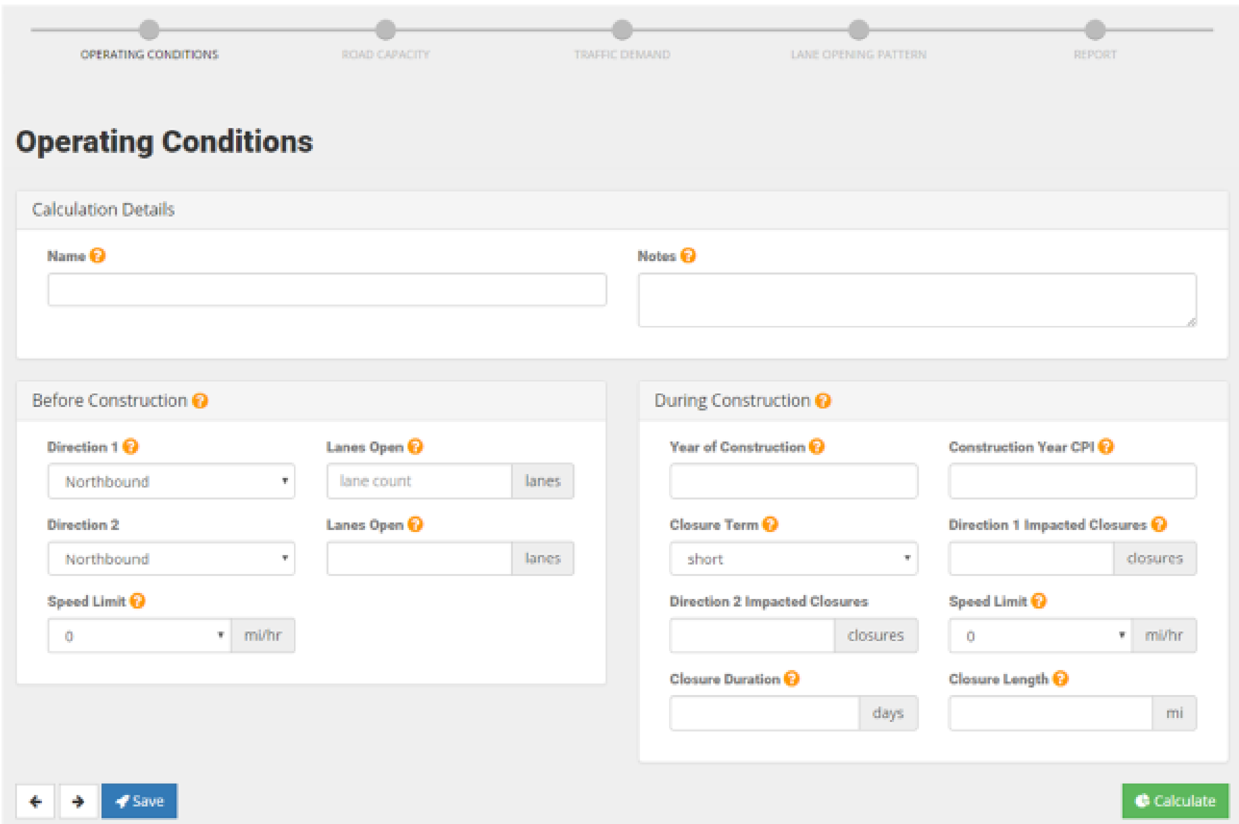
2.3.3 Traffic Demand – What traffic data is needed to quantify traffic impacts associated with the presence of a work zone?

2.3.4 Lane Opening Pattern – How can I specify how lanes operate during the presence of a work zone for each direction of traffic flow?

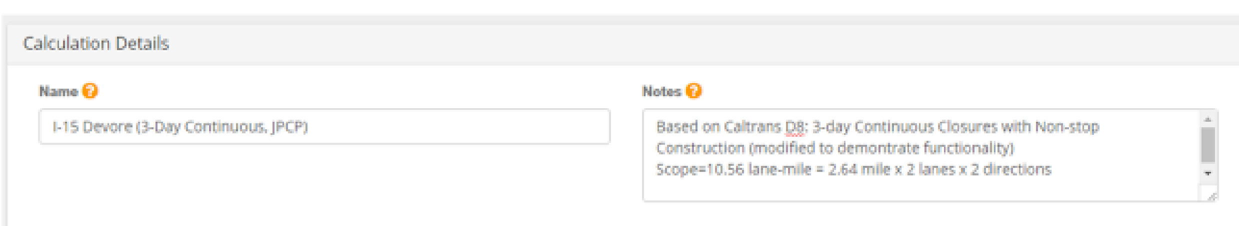
1.3.1 Operating Conditions

The first section of the Work Zone Traffic (WZT) model is intended to capture information about the physical configuration of the roadway, closure duration, and characteristics of the closure strategy before and during construction. Inputs for most sections of the model are separated into before and during construction conditions to reflect that the model compares traffic performance under these conditions.

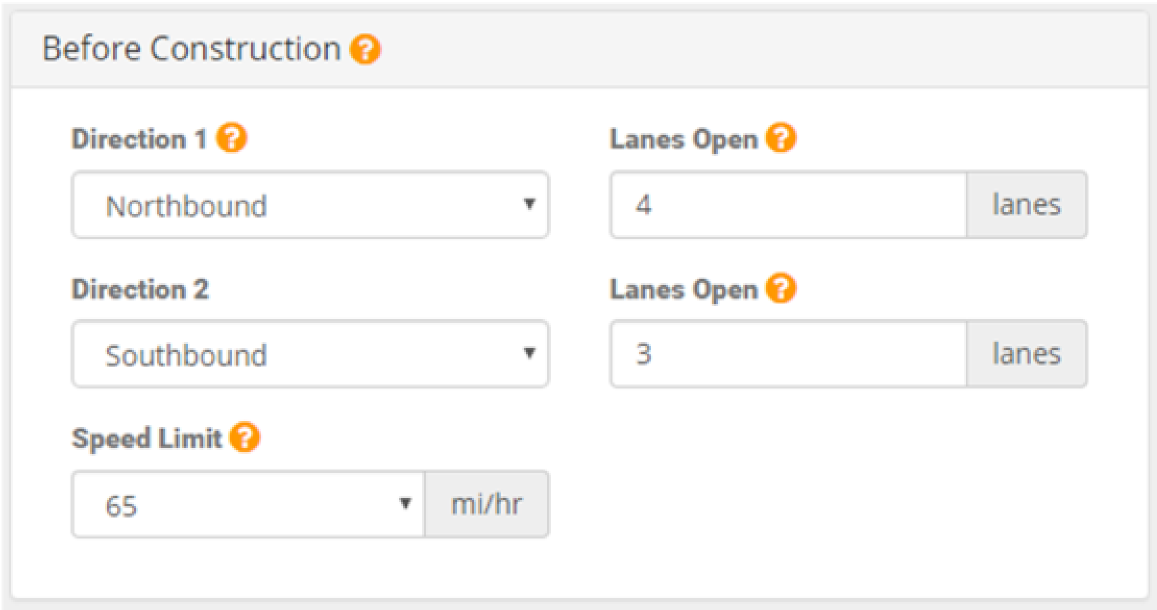
These inputs are essential to specify because they influence how lane capacity is estimated, how traffic demands are escalated, and how traffic impacts are translated into user costs (including vehicle operation costs).



Begin by giving your simulation a descriptive title that may distinguish it from other simulations associated with your paving project. If you need to add more precise details to help you distinguish or characterize your simulation, you may provide additional text in the Notes field.



In the Before Construction box, indicate the direction and total number of lanes available before construction at the site of your paving project. These values will be used to determine the total roadway capacity before and during construction. Use the drop-down menu to select a speed limit prior under normal operating conditions (prior to the presence of a construction work zone).



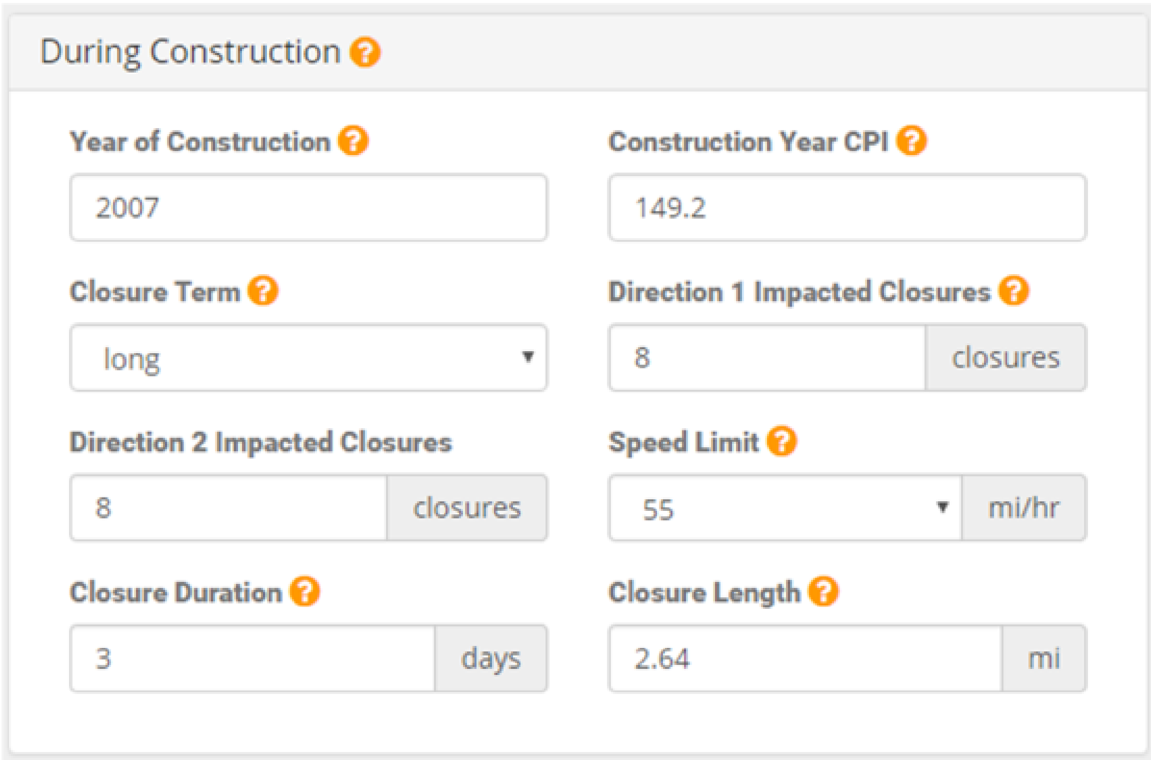
In the During Construction box, enter the number of closures in which the presence of a work zone will impact traffic conditions for each direction of travel. These values may not be equal to the total number of required closures to complete your paving job as traffic, particularly if certain operations only apply to a single direction. This total number of closures can be estimated using the Road Scheduler application, but it is not necessary to run the productivity simulation to complete the WZT model.

Continue by entering the work zone speed limit for your paving project during construction which will influence the extent of traffic delays experienced by road users in the evaluation of traffic impacts.

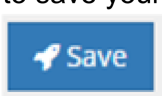
Enter the year of intended construction which will be compared to the year in which traffic demand data was collected and subsequently used to escalate traffic volumes.

Next select a Closure Term from the drop-down menu: if you choose a short-term closure (less than 24 hours), you will enter the closure duration in hours; if you select a long-term closure (greater than 24 hours), you will enter the closure duration in days. The closure duration type will affect how the lane capacity is adjusted based using a simplified version of the methods described in Chapter 23 of the Highway Capacity Manual (HCM 2000).

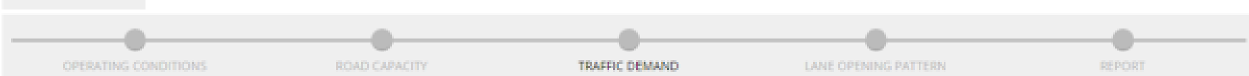
Finally, enter the physical length of your work zone, which may be different than the physical length of your project depending on how your project scope is scheduled or phased. The length of your work zone will influence the amount of traffic that can be queued during construction in the quantification of traffic impacts.



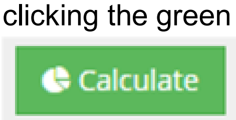
Next Steps...
Once you have filled in all fields in the Operating Conditions section of the WZT model, be sure to save your changes by clicking the blue save button on the bottom of the screen.



When you are ready to proceed to the next section, navigate to the Road Capacity section by clicking the corresponding node in navigation bar on the top of the browser, or using the navigation arrows on the bottom of the browser.

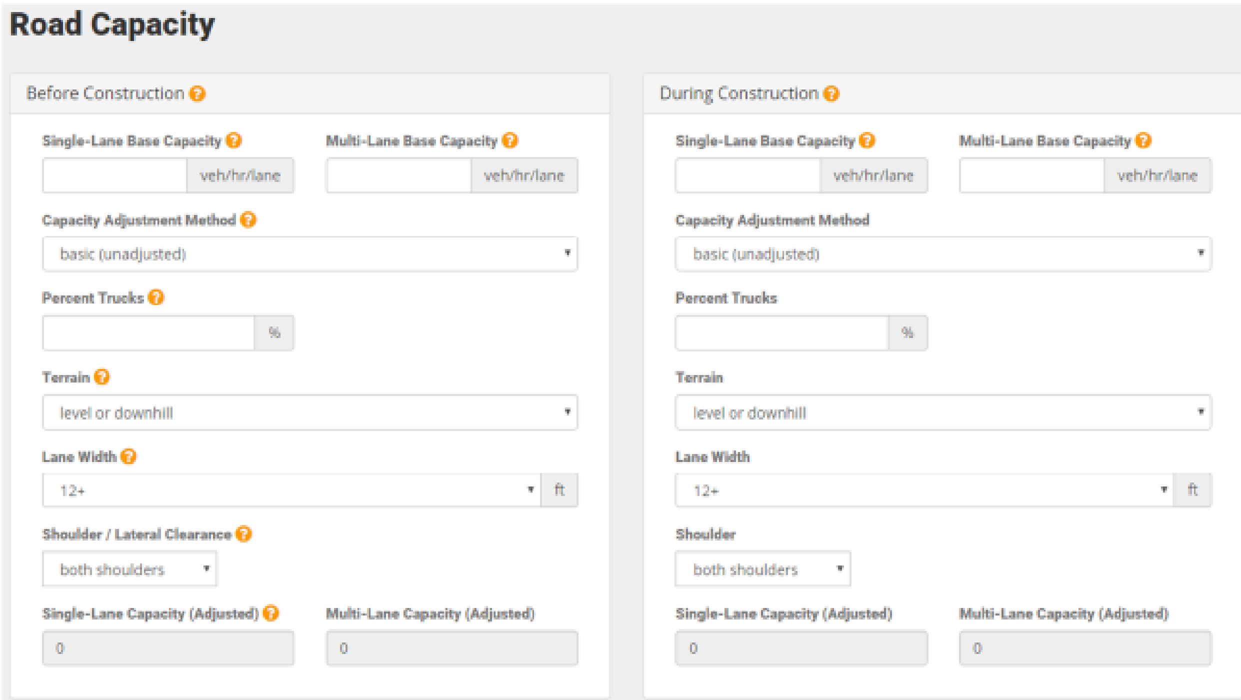


If you have already filled out the inputs from other sections, you can re-calculate your results by clicking the green Calculate button and skip to the Report section.



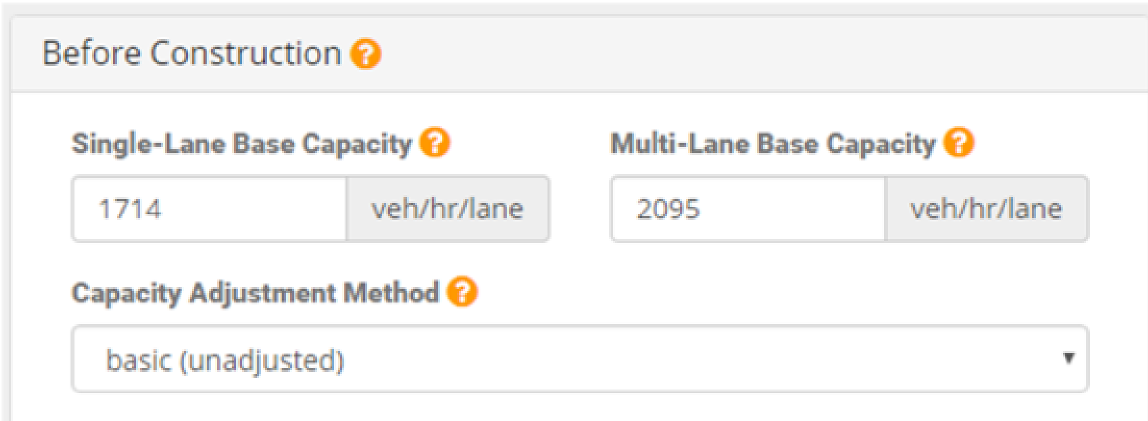
1.3.2 Road Capacity

The Road Capacity section of the Work Zone Traffic (WZT) model allows you to specify the per-lane capacity prior to construction and in the presence of your work zone during construction. The road capacities will influence how quickly the roadway facility may allow cars to traverse a section of highway, as well as how quickly queues can be dissipated. The methods for adjusting capacity are based on the 2000 version of the Highway Capacity Manual.



In the Before Construction box, specify the per-lane capacity for single-lane highways and multi-lane highways in units of vehicles per hour per lane (vphpl). The model will automatically determine which capacity to use based on how you configure the number of lanes before and during construction.

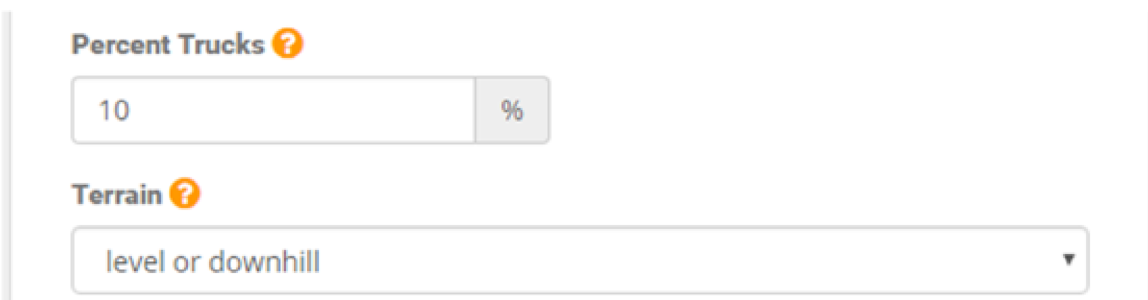
Select a Capacity Adjustment Method using the drop down menu. 'basic (unadjusted)' means that the base capacities you specified above will be used in traffic impacts analysis. 'adjusted' means additional information you provide on the physical characteristics of your work zone will be used to adjust the lane capacities. Because local conditions may vary substantially depending on the specific circumstances for your paving project and work zone, it is recommended that you select the option to adjust your capacities. In this demonstration, the 'adjusted' capacities method is selected.



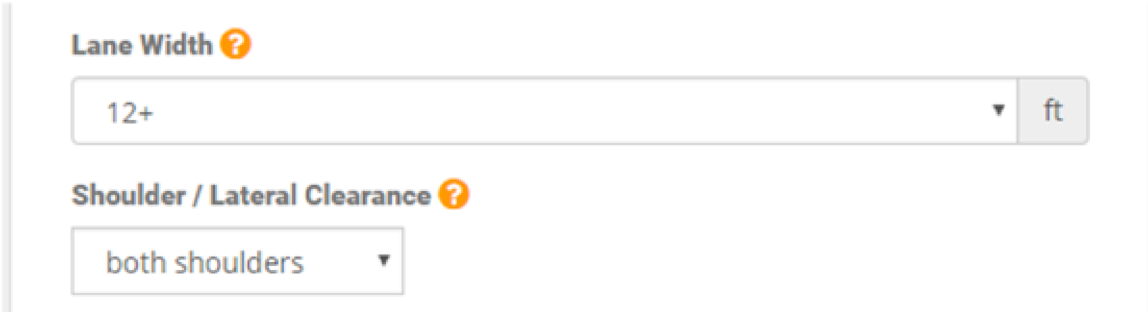
Next, enter the Percent Trucks, which refers to the density of trucks that typically comprise the traffic flow (as a percent of total traffic). Trucks affect roadway capacity differently than passenger vehicles because of their ability to maneuver under different driving conditions. In general, increasing this value will result in a reduced lane capacity after adjustments.

Select the type of terrain that applies to your roadway from the drop down menu. The terrain of the roadway affects a vehicle's ability to accelerate, decelerate, or maneuver. In particular, this affects the ability of larger vehicles to maneuver traffic, which in turn can impact the overall flow of traffic for passenger and other vehicle types. Rolling and mountainous terrains ultimately reduce the capacity of a lane.

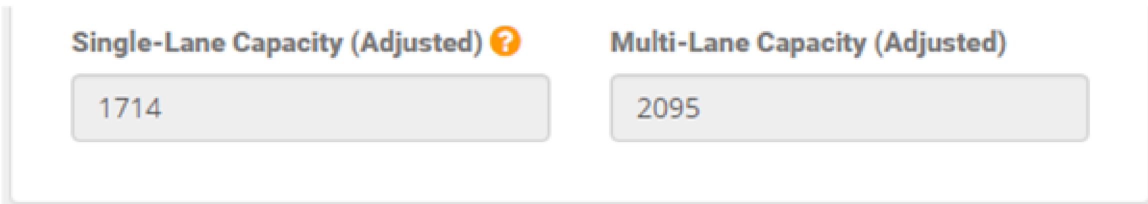
In terms of the underlying algorithm, the HCM methods for adjusting lane capacity will use the percent trains and terrain to convert the truck portion of traffic into a passenger car equivalent (PCE).



The ‘adjusted’ capacity method also adjusts the lane capacity based on the average lane width and presence of shoulders on your roadway. The HCM assumes that lane widths affect a driver's perception of clearance and maneuverability and consequently, wider lanes and the presence of shoulders tend to increase the capacity of your lanes because they increase each vehicle’s ability to maneuver. Using the drop down menus, select the lane width that best corresponds to your pavement as well as the presence of shoulders.

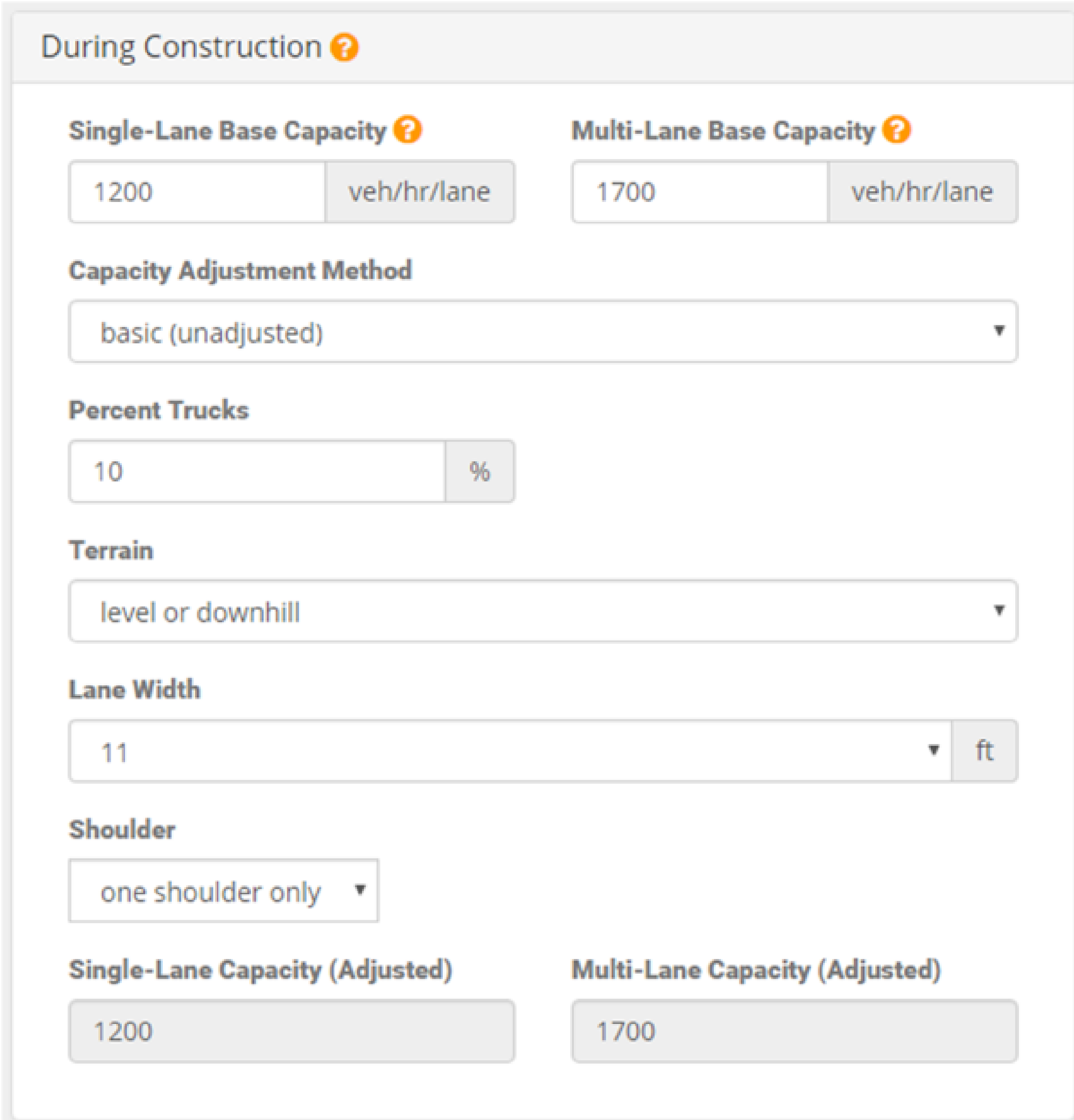


You may notice that the adjusted lane capacities (both single and multi-lane) automatically update based on your selections and input values.



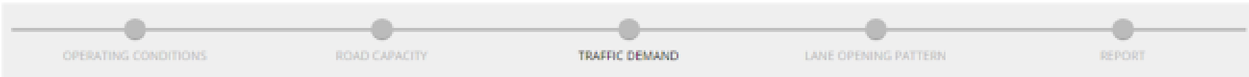
Similarly, you will apply the same types of considerations to fill in the road capacity parameters in the During Construction box. Depending on how you specify your inputs, both the Percent Trucks and Terrain may be the same under both conditions.

However, the lane width and shoulder clearances may differ prior to and during construction based on the closure strategy. For example, lane widths and shoulder widths may be altered for construction to generate additional space for another lane of traffic, or increase maneuverable storage space for construction equipment.

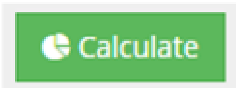


Next Steps...
Once you have filled in all fields in the Road Capacity section of the WZT model, be sure to save your changes by clicking the blue save button on the bottom of the screen.

When you are ready to proceed to the next section, navigate to the Traffic Demand section by clicking the corresponding node in navigation bar on the top of the browser, or using the navigation arrows on the bottom of the browser.



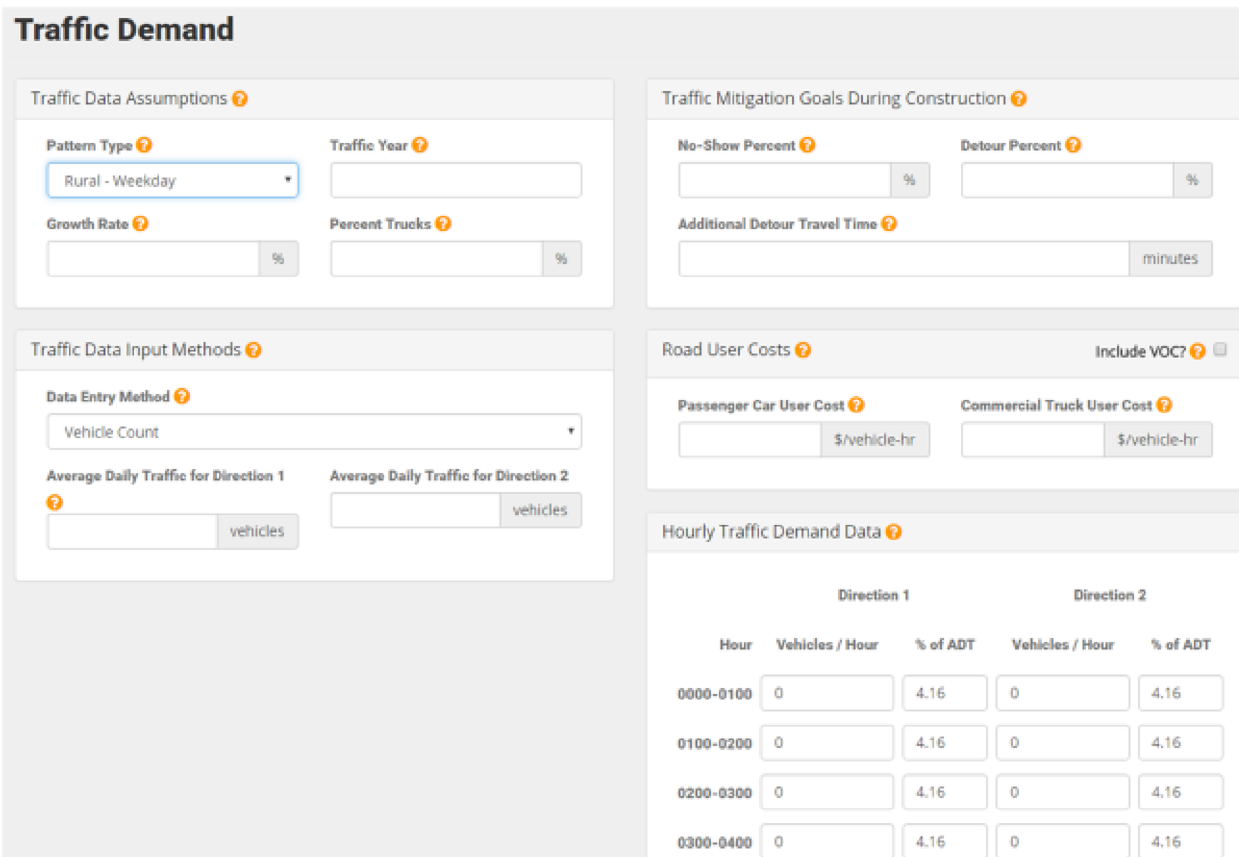
If you have already filled out the inputs from other sections, you can re-calculate your results by clicking the green Calculate button and skip to the Report section.



1.3.3 Traffic Demand

The Traffic Demand section of the Work Zone Traffic (WZT) model is intended to capture a typical daily profile of traffic demand in your work zone's location, characteristics of the traffic data itself, and the valuation of time based on vehicle type.

These parameters are collectively used to escalate traffic demand data to the year of construction and the escalated traffic demand is compared against the roadway capacities. This comparison allows for the quantification of vehicles expected to be impacted, the nature and extent of delays experienced by impacted vehicles, and ultimately the conversion of delays into user costs.

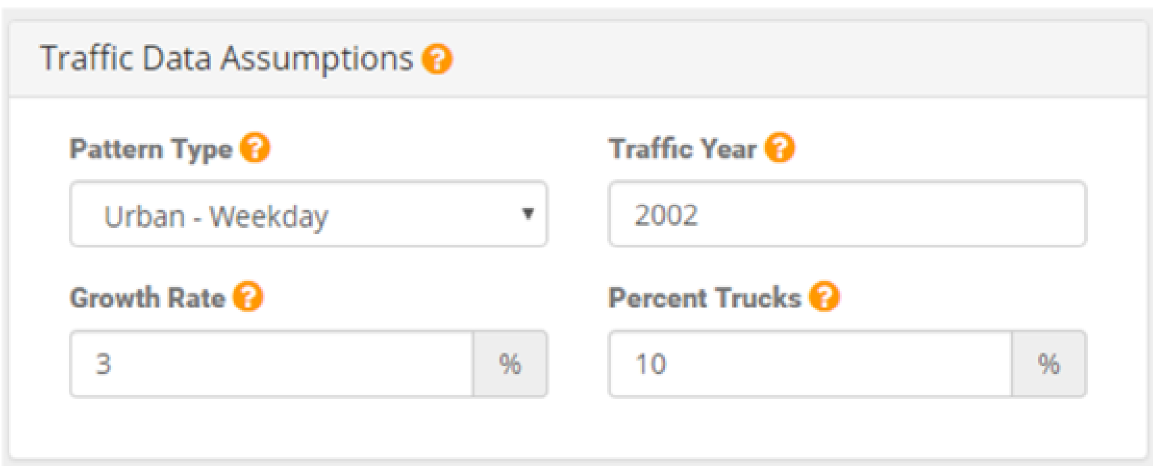


Begin by describing your traffic data by specifying inputs in the Traffic Data Assumption box. Indicate the general traffic pattern type using the drop down menu to generate a typical hourly traffic demand data set for each hour of the day. The pattern types are classified by general location (urban or rural) and type of day (weekday or weekend). Urban and weekday patterns tend to yield higher traffic demand volumes and weekdays also exhibit different patterns during morning and afternoon rush hours.

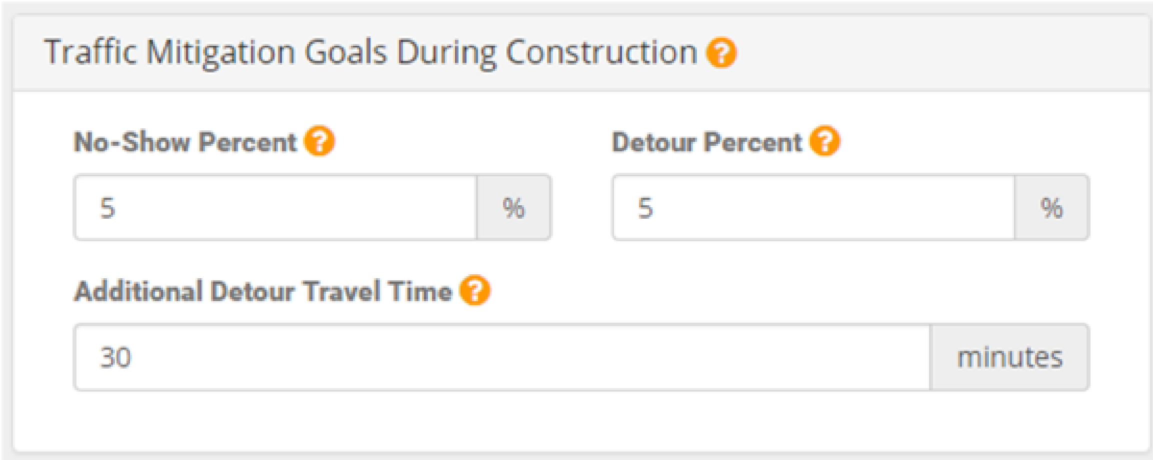
After selecting a pattern type, you may notice that the fields in the Hourly Traffic Demand data are automatically pre-filled. It is important to note that you may replace the pre-filled values with values that reflect your work zone more specifically.

Enter the year in which your traffic data was originally collected and a traffic growth rate that should be applied to your traffic data. If you are using the default traffic demands, the year should be set to 2013. These inputs are important because traffic demands will be inflated based on the difference between the traffic data year and construction year as well as the growth rate.

Finally, indicate the percent trucks that characterize the data set you are using (10% by default). In this case, the percent trucks refers to the density of trucks within your data set, which may be different than the percent trucks you expect to be present prior to or during construction. This may be particularly true if you are using a data set that does not correspond to your exact work zone location but is analogous for the general area surrounding your work zone.

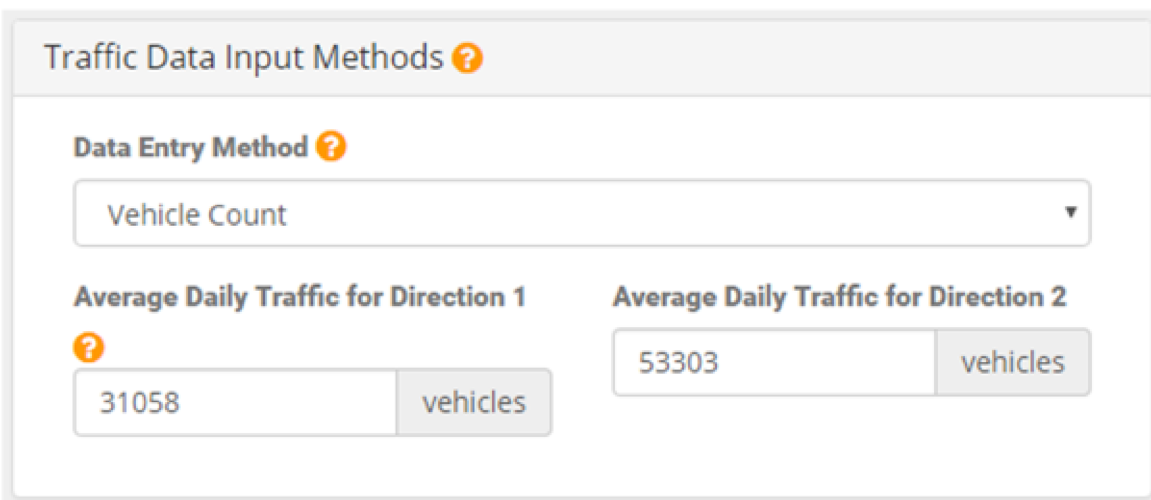


Next, complete the fields in the Traffic Mitigation Goals box by estimating the level of traffic reduction or detours that may result from public outreach efforts. No-show refers to the percent of vehicles you believe may cancel their trip or otherwise adjust their travel plans to avoid traversing your work zone. Detour refers to the percent of vehicles that you believe may take a detour around the work zone but still contribute to the overall traffic demand through the area. Finally, specify the average additional amount of time (in minutes) you believe that a detour route around your work zone would add to a vehicle's trip compared to pre-construction conditions.



Prior to entering the Hourly Traffic Demand Data, specify which data entry method you prefer in the drop down menu in Traffic Data Inputs Methods box. If you select the option ‘Percent of Average Daily Traffic,’ you will be asked to provide the total average daily traffic volume in each direction of flow and specify the hourly traffic demand as a percent (all lanes included). In other words, assuming the total flow in each direction per day is 100%, you must specify the percent contribution of each hour to this total demand. With this option, the vehicle demand per hour will be calculated based on the total and percent specified for each other.

Alternatively, if you specify ‘Vehicle Count’ then you will directly specify the traffic demand for each hour and direction manually. In this case, you will not need to specify the total average daily traffic for each direction since this can be calculated directly, as well as the percent contribution for of each hour.



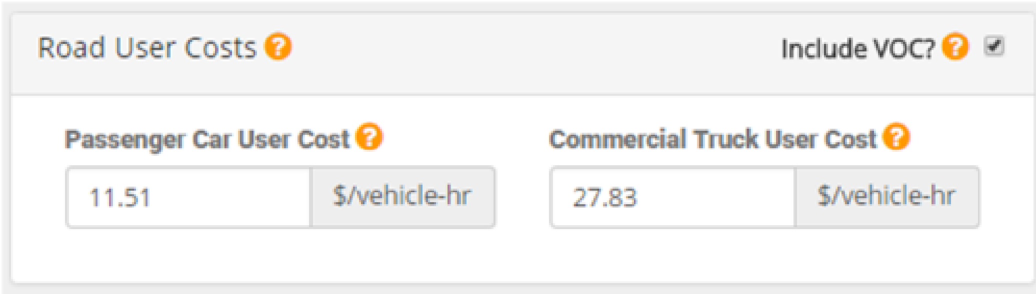
Now, complete the Hourly Traffic Demand Data table based on the method you selected in the Traffic Data Input Methods box. Note one column with be locked for entry depending on the option you selected. For this demonstration, the ‘Vehicle demand per hour’ option is used, so the percent of average daily traffic (% of ADT) column is greyed out. The hourly demand values used for this demonstration are summarized in the table below:

Hourly Traffic Demand Data

	Direction 1		Direction 2	
Hour	Vehicles / Hour	% of ADT	Vehicles / Hour	% of ADT
0000-0100	221	0.7	556	1
0100-0200	121	0.4	608	1.1
0200-0300	78	0.3	935	1.8
0300-0400	91	0.3	2251	4.2
0400-0500	192	0.6	3740	7
0500-0600	558	1.8	4419	8.3
0600-0700	1390	4.5	4281	8
0700-0800	2013	6.5	2985	5.6
0800-0900	2129	6.9	2596	4.9
0900-1000	1872	6	2536	4.8
1000-1100	1719	5.5	2498	4.7
1100-1200	1648	5.3	2522	4.7
1200-1300	1615	5.2	2932	5.5
1300-1400	1613	5.2	2937	5.5
1400-1500	1751	5.6	3041	5.7
1500-1600	2004	6.5	3138	5.9
1600-1700	2219	7.1	2903	5.4
1700-1800	2485	8	2086	3.9
1800-1900	2229	7.2	1454	2.7
1900-2000	1588	5.1	1352	2.5
2000-2100	1159	3.7	1173	2.2
2100-2200	1026	3.3	1027	1.9
2200-2300	840	2.7	682	1.3
2300-2400	497	1.6	651	1.2

To complete this section of the model, specify the user costs for both passenger cars and commercial trucks. These user costs refer to the perceived value or worth of an average vehicle's time in dollars per hour. These values are often subjective and greatly depend on the specific location of your work zone, but typically the value of a passenger vehicle is less than that of a commercial vehicle. In this demonstration, the rates are based on 2007 Caltrans recommendations (11.51 $/hr for passenger cars, 27.83 $/hr for commercial trucks, transportation CPI = 177.2 in 2007).

Finally, use the checkbox specify whether you wish to include vehicle operating costs (VOCs) in the evaluation of total user costs. VOCs are costs associated with changes in driver behavior due to the presence of work zones or closures. They include price factors associated with delays due to idling, stopping, speed changes (compared to original speeds in the absence of the work zone). The cost factors used in this model are based on values presented in NCHRP Report 133 from 1970 and adjusted to present day. In this demonstration, VOC costs are included in the simulation.

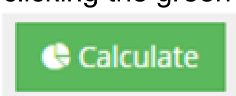


Next Steps...

Once you have filled in all fields in the Traffic Demand section of the WZT model, be sure to save your changes by clicking the blue save button on the bottom of the screen.

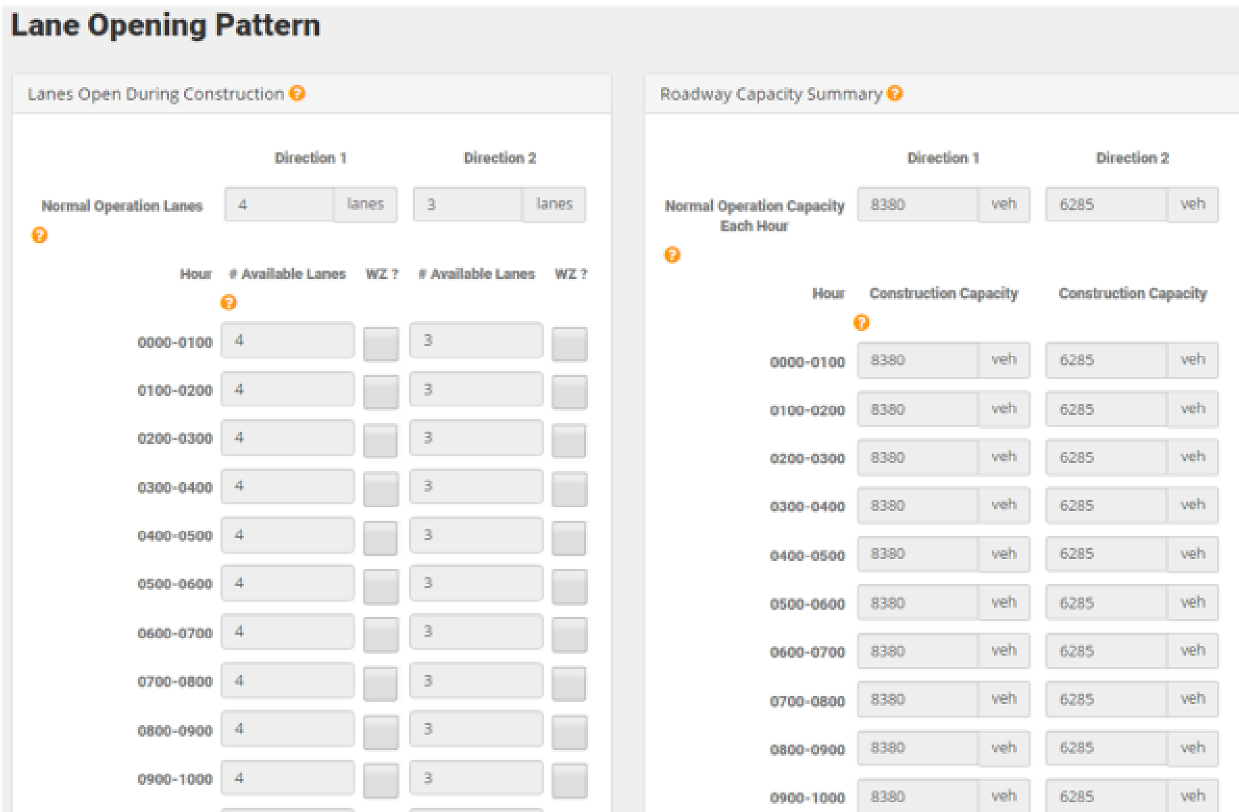
When you are ready to proceed to the next section, navigate to the Lane Opening Pattern section by clicking the corresponding node in navigation bar on the top of the browser, or using the navigation arrows on the bottom of the browser.

If you have already filled out the inputs from other sections, you can re-calculate your results by clicking the green Calculate button and skip to the Report section.



1.3.4 Lane Opening Pattern

The final section of the Work Zone Traffic (WZT) model allows you to specify the lane configuration for each hour of a typical day when construction is present. The configuration you specify will substantially impact how the model calculates traffic flow for each hour and consequently, the amount of vehicles that form queues as a result of reduced lane capacities during construction.



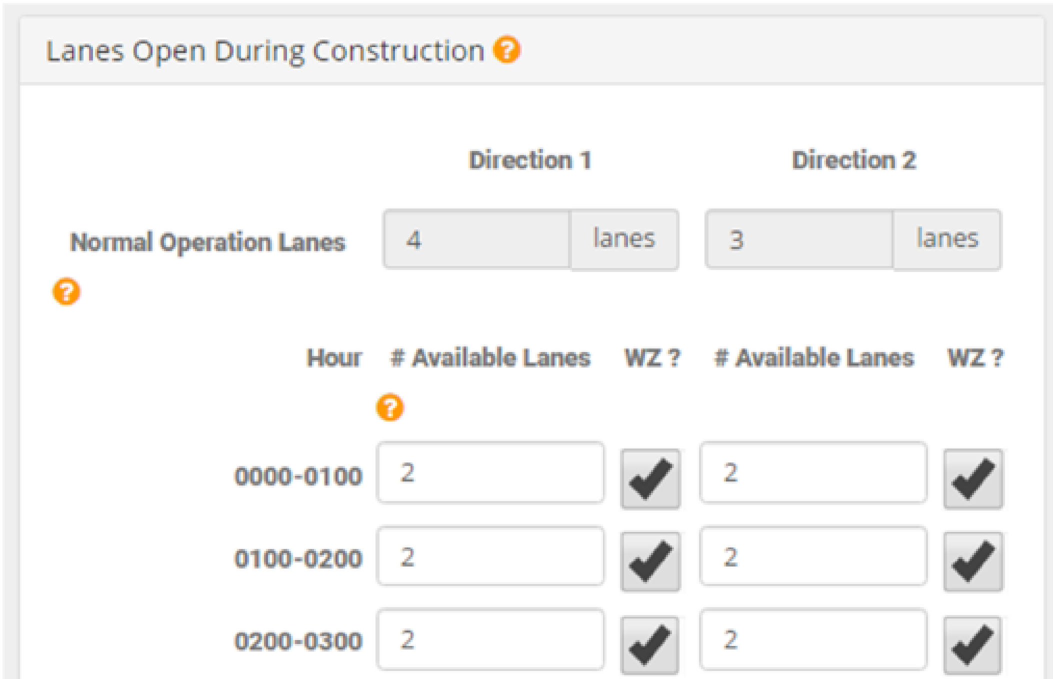
	Direction 1		Direction 2	
Normal Operation Lanes	4 lanes		3 lanes	
Hour	# Available Lanes	WZ ?	# Available Lanes	WZ ?
0000-0100	4		3	
0100-0200	4		3	
0200-0300	4		3	
0300-0400	4		3	
0400-0500	4		3	
0500-0600	4		3	
0600-0700	4		3	
0700-0800	4		3	
0800-0900	4		3	
0900-1000	4		3	

	Direction 1	Direction 2
Normal Operation Capacity Each Hour	8380 veh	6285 veh
Hour	Construction Capacity	Construction Capacity
0000-0100	8380 veh	6285 veh
0100-0200	8380 veh	6285 veh
0200-0300	8380 veh	6285 veh
0300-0400	8380 veh	6285 veh
0400-0500	8380 veh	6285 veh
0500-0600	8380 veh	6285 veh
0600-0700	8380 veh	6285 veh
0700-0800	8380 veh	6285 veh
0800-0900	8380 veh	6285 veh
0900-1000	8380 veh	6285 veh

To complete the Lanes Open During Construction table, specify the number of lanes available for traffic each hour and indicate whether the work zone is active during this hour. You will notice that this table is pre-filled with the number of lanes available before construction, which you specified in the Operating Conditions section. This is indicated by fields next to the ‘Normal Operation Lanes’ label.

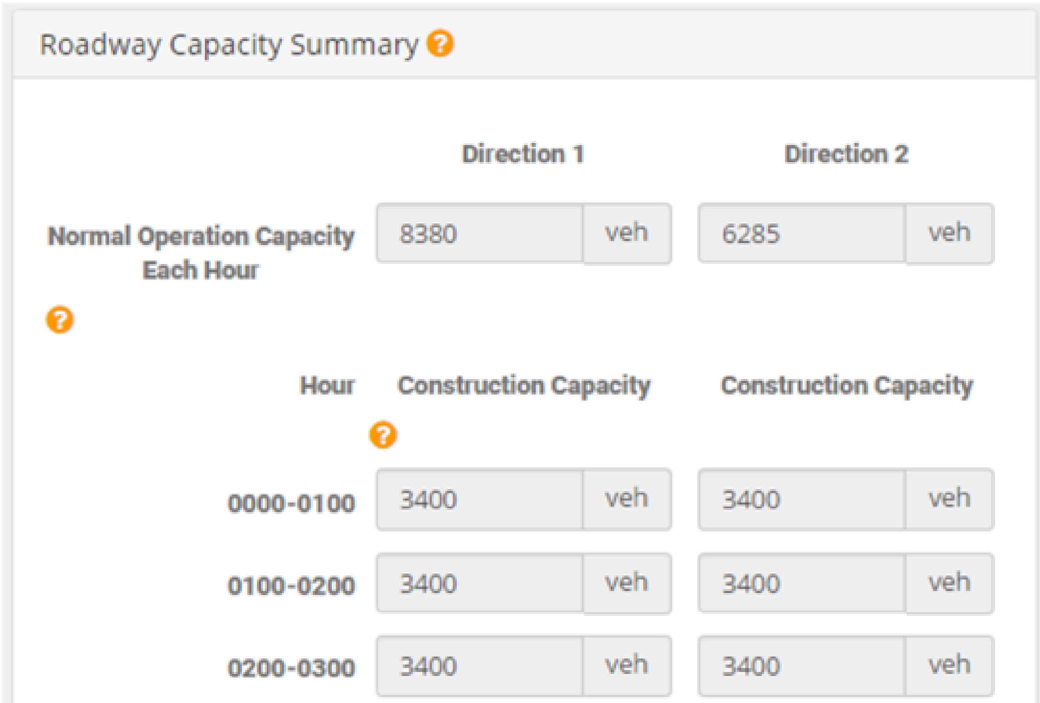
The number of lanes available for each hour may differ during construction depending on your closure strategy. For example, you may have added or reduced a lane during construction compared to pre-construction conditions. By specifying the work zone as active for a given hour, you are indicating that the lanes should exhibit the ‘during construction’ capacities specified in the Road Capacity section of the model. Leaving this option unchecked means lane capacities will be calculated using pre-construction conditions.

In this Demonstration for both directions, 2 lanes are available for traffic for each hour of the day. The work zone is active all hours during the day because it a continuous closure strategy was used with a multi-day (extended) closure. The figure below shows an example of the first three hours filled in for this demonstration.



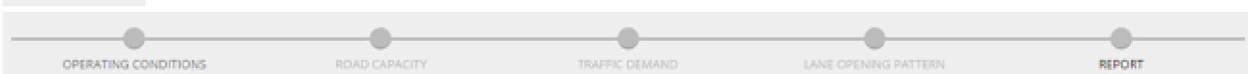
Once you have filled in the lane availability table for all hours of the day, you may notice that the Roadway Capacity Summary will be updated based on the values you have specified in the Road Capacity section as well as the Lanes Open During Construction table. This table requires no additional inputs and serves to summarize the consequences of your input choices by previewing your daily traffic capacity profile. You may notice that the first fields listed next to the 'Normal Operation Capacity Each Hour' indicates the roadway capacities prior to construction.

For each direction of traffic, two columns are shown. The first (left) column calculates your total traffic capacity prior to construction or 'operating' conditions, while the second column (right) calculates your total traffic capacity during construction by incorporating your lane configuration choices. The figure below shows the results for the first 3 hours of the demonstration.

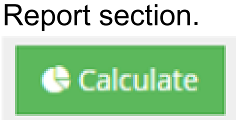


Next Steps...

When you are satisfied with the traffic capacity profile summary, you are ready to calculate your traffic impacts and road user cost. If needed, you may navigate to any previous section using the navigation bar on the top of the browser, or using the navigation arrows on the bottom of the browser.



When you are ready to calculate your results, click the green Calculate button to skip to the Report section.



2.4.0. Interpreting Work Zone Traffic Reports

The sections in this user guide provide a walkthrough of interpreting and understanding the outputs of a user cost report after running a simulation in the Work Zone Traffic module.

The report generated for a Work Zone Traffic simulation summarizes the primary results of the analysis, indicating the maximum delay, queue length, speed, and user costs for each direction of travel. Additionally, the results are visualized to provide a clearer picture of how traffic performs before and during construction as well as how each type of flow contributes to the total user cost for each direction.

Using the JPCP paving job from the Best Practice Example for the Work Zone Traffic module, the user guides in this section will address the following questions:

2.4.1 Results - What are the primary results of the work zone traffic impacts analysis?

2.4.2 Hourly Capacity and Demand - What does a daily profile for my traffic capacities and demand look like in each direction of travel?

2.4.3 User Cost Contributions - How are user costs allocated and how much do they contribute to the total user cost?

2.4.1. Results

The first section of the report tabulates the primary results of the Work Zone Traffic analysis, indicating how the presence of the work zone impacts traffic performance and the associated user costs for each direction of travel.

Workzone Traffic Report

I-15 Devore (3-Day Continuous, JPCP)

Notes

Based on Caltrans D8: 3-day Continuous Closures with Non-stop Construction (modified to demontrate functionality)

Scope=10.56 lane-mile = 2.64 mile x 2 lanes x 2 directions

Results

Item	Before Construction	Before Construction	During Construction	During Construction	Difference	Difference
Direction	Northbound	Southbound	Northbound	Southbound	Northbound	Southbound
Max Delay	0.00 min	0.00 min	0.00 min	18.92 min @ 6:00 am - 7:00 am	0.00 min	18.92 min
Max Queue Length	0.00 mi	0.00 mi	0.00 mi	3.33 mi	0.00 mi	3.33 mi
Min Speed	65 mi/hr	65 mi/hr	7.32 mi/hr	10.58 mi/hr	57.68 mi/hr	54.42 mi/hr
Daily User Cost	$0	$0	$10,204	$46,753	$10,204	$46,753
Per Closure User Cost	$0	$0	$30,612	$140,260	$30,612	$140,260
Total User Cost per Direction	$0	$0	$244,899	$1,122,082	$244,899	$1,122,082
Total User Cost	$1,366,980					

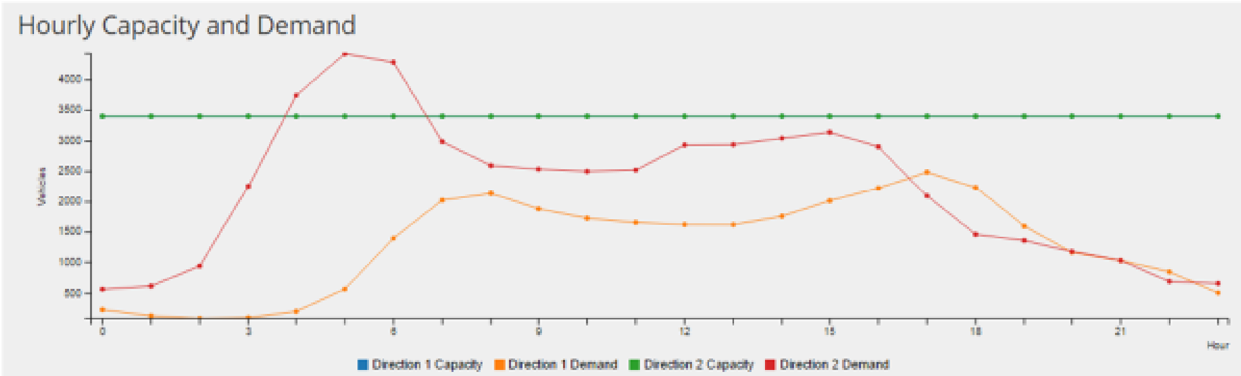
At the top of the report under the simulation name, you may notice that your notes (specified in the Operating Conditions section of the model) are included for clarity.

The table in this section includes the primary results of the traffic impacts analysis that indicate the maximum amount of delay, the hour at which this delay occurs, the resulting maximum queue length, the minimum driving speed through the workzone based on traffic conditions, the daily and per closure user costs, and finally the total user costs for both directions.

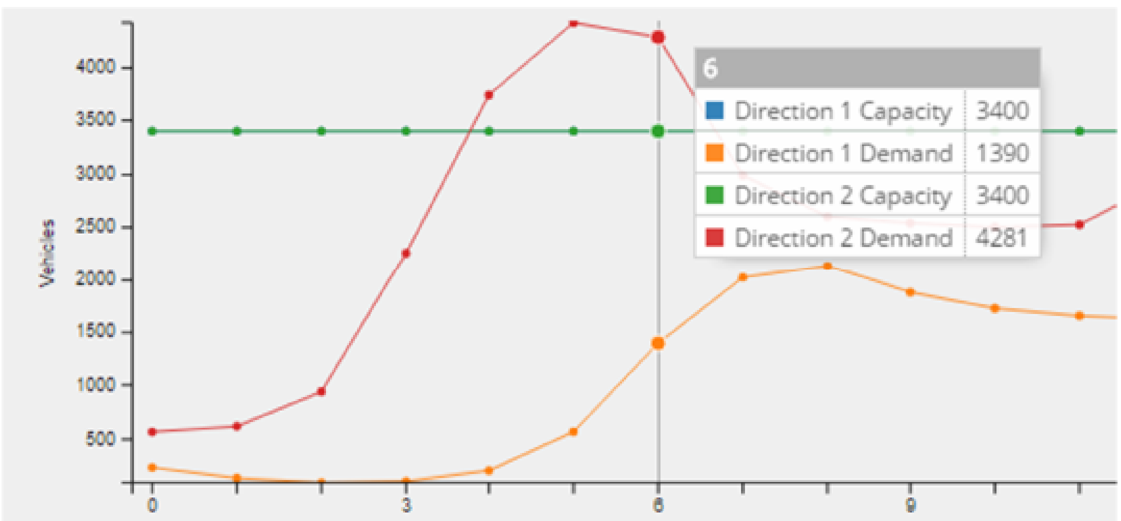
Results are shown in each direction before and after construction (first four columns), and the difference is taken to show the marginal impacts associated with the presence of a work zone (last two columns on the right). The difference is particularly important to include, as there may be some user costs already incurred under the baseline, before construction conditions.

2.4.2 Hourly Capacity and Demand

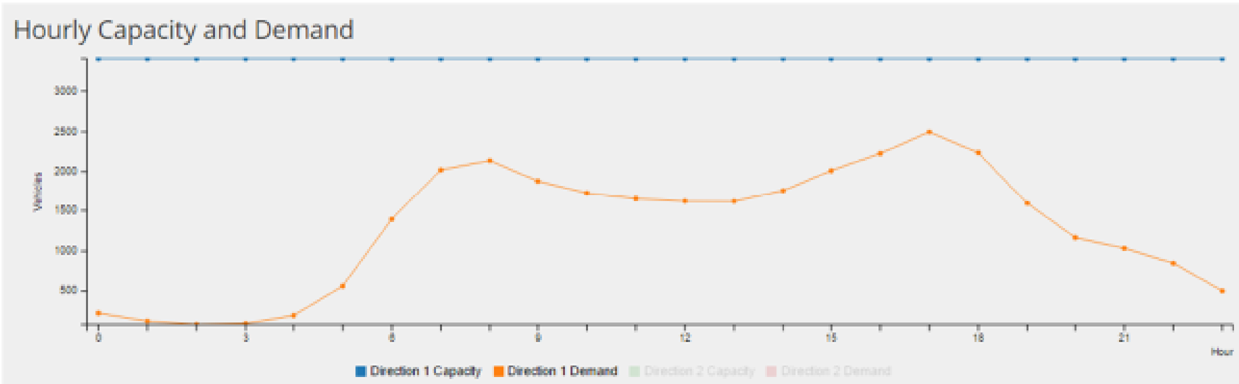
The next section of the report visualizes the daily traffic profiles for traffic capacity and demand based on the inputs you have specified in all 4 input sections of the model.



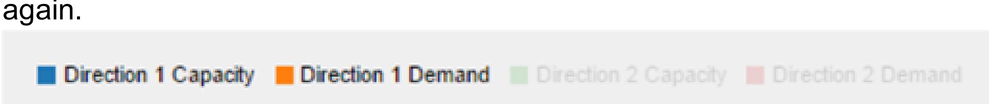
You may interact with the visualization by hovering your mouse over any point included in the figure (4 points per hour, one point for demand and capacity for each direction of travel). A small window will appear to indicate the traffic demand or capacity present at the hour you are examining.



Clicking on any of the legend items beneath the graph will toggle the associated item on or off. In this example, the demand and capacity profiles for Direction 2 have been toggled off (hidden) by clicking on the legend item for Direction 2 Capacity and Demand.

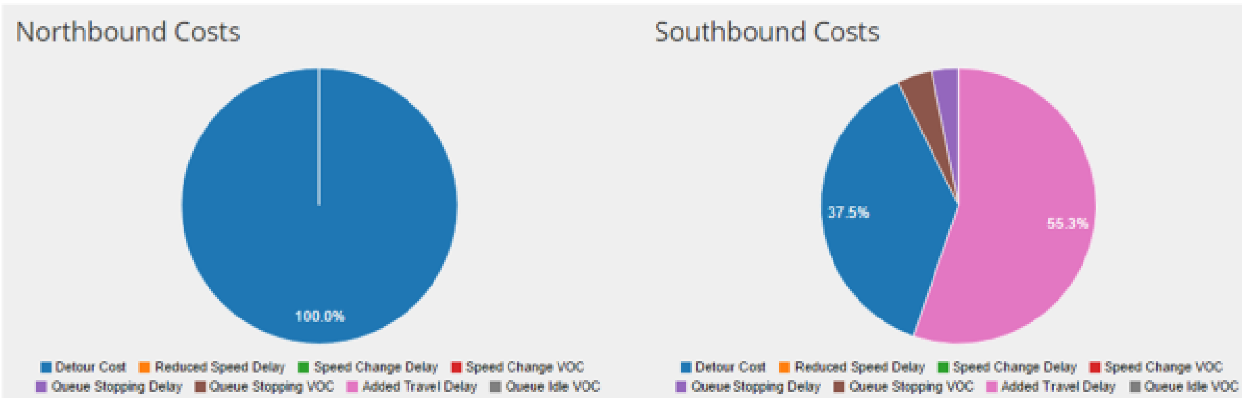


This can be useful if you are focusing on traffic performance in a particular direction or to verify that your demand and capacity profiles are producing values that you expect. You can toggle the demand and capacity profiles for Direction 2 back on by clicking the hidden legend items again.



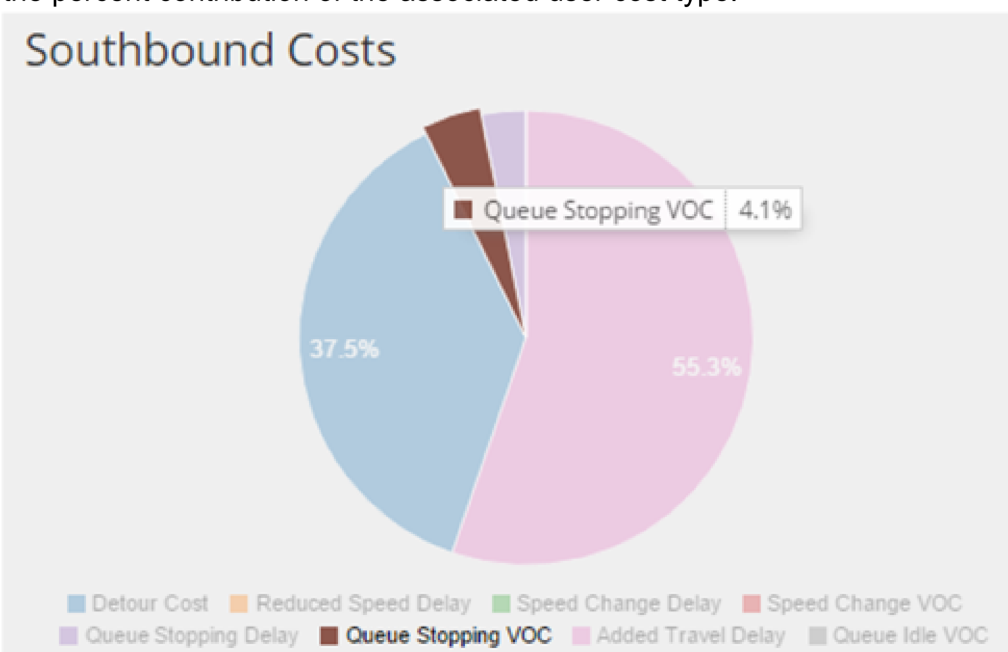
2.4.3 User Cost Contributions

This section of the report itemizes user costs associated with your work zone traffic impacts analysis for each direction of travel during construction.

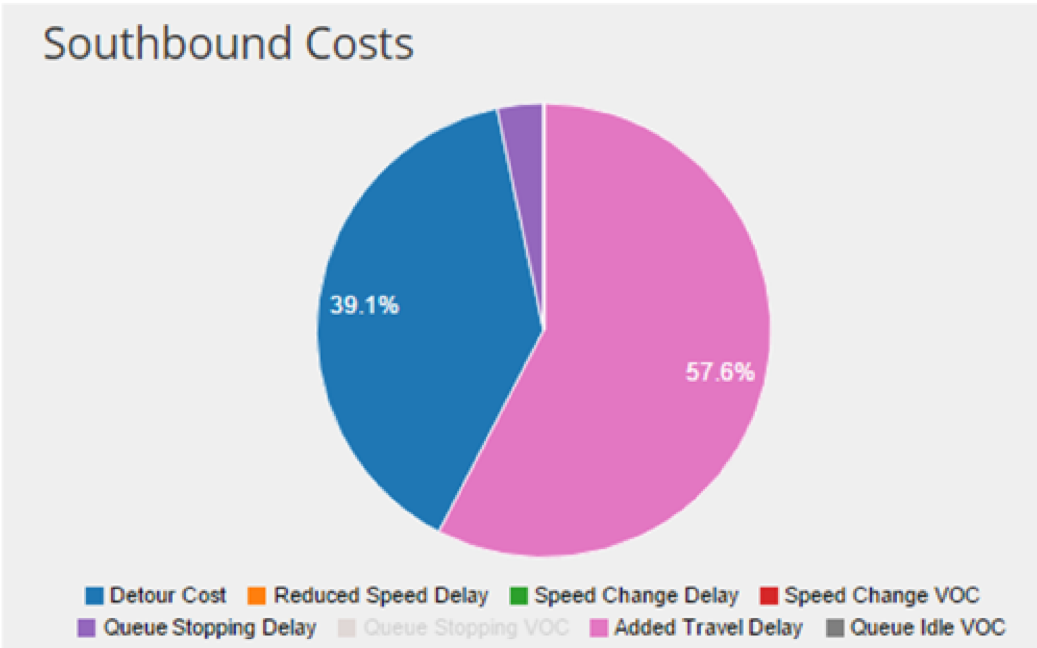


You will notice that the legends beneath each pie-chart include 8 different types of user costs, including VOC costs in this case. Based on your inputs, each of these cost categories is calculated for each hour of the day and summed both on a daily basis but also for the number of closures required to complete your paving job.

You may interact with the figure by hovering your mouse over any part of a pie-chart to reveal the percent contribution of the associated user cost type.



If you are interested in hiding a particular user cost type, click on the associated legend item you wish to hide. In this example, the Queue Stopping VOC cost is hidden so that the remaining items include only non-VOC related user costs. You may notice that the percent contribution of the remaining user cost types are re-calculated in the resulting figure. You can toggle the hidden user cost item (Queue Stopping VOC) back on by clicking the legend item again.



3.0.0. Overview of Features and Functionality

The chapter of this user guide identifies the primary purpose of the Cost Estimator and outlines the conceptual model as well as primary features included in it.

Cost Estimator is a third model in the R3 application suite that allows you to estimate the total agency cost of a paving job. Cost Estimator is designed to work in tandem with Road Scheduler and the Work Zone Traffic module, the results from which can be used as inputs in Cost Estimator. Nevertheless, Cost Estimator works independently of the other two models and can be used as a standalone application.

The application includes a total of 12 cost items grouped into 3 general cost categories, including Construction, Roadway, and total Project Costs. In general, costs can be entered as a percent of cost categories or provided directly as a lump sum cost. Additionally, some cost items can be specified with more details and calculated directly within the application (e.g. traffic costs).

Together with the results of the Road Scheduler and Work Zone Traffic Module, Cost Estimator facilitates the creation of Traffic Management Plans (TMPs) by providing economic information implied by your paving strategy and work zone configurations.

Because the data requirements to run the simulation can be complex, the overarching goal of the user guides is to provide you with a structured explanation of:

Chapter 3.0 What the application can do (current chapter)

Chapter 3.1 What conceptual knowledge is required understand and use the application

Chapter 3.2 What information must be specifically collected and what considerations should be included

Chapter 3.3 How to run a simulation with walkthrough demonstration

Chapter 3.4 How to interpret the results included in the report

In particular, the user guides in this section will address the following questions:
3.0.0: What is the intent of the Cost Estimator model?
3.0.1: What costs are included in the model and how are they organized or categorized?
3.0.2: How is information for cost items entered in Cost Estimator?
3.0.3: What unit cost information is included in Cost Estimator?

3.0.1 Cost Item Categories

What costs are included in the model and how are they organized or categorized?

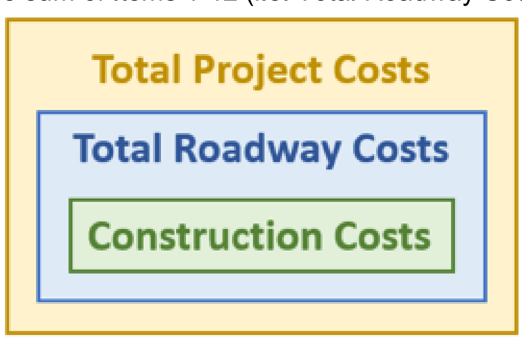
This user guide provides an overview of the 12 cost items included in Cost Estimator and grouped under 3 cost categories. The table below indicates which cost items contribute to each category but excludes information on more detailed sub-costs that a cost item includes. Please refer to the corresponding user guides in Chapter 3.1 and 3.2 for additional details regarding sub-costs included in the Cost Estimator model.

		Cost Category		
#	Cost Items	Total Construction Cost	Total Roadway Cost	Total Project Cost
1	Pavement	Y	Y	Y
2	Earthwork	Y	Y	Y
3	Drainage	Y	Y	Y
4	Specialty (SW)	Y	Y	Y
5	Traffic	Y	Y	Y
6	Minor Items		Y	Y
7	Mobilization		Y	Y
8	Supplemental		Y	Y
9	Contingency		Y	Y
10	Structure			Y
11	Right of Way			Y
12	Supporting Cost			Y

Note: The numbering used here is meant to facilitate explanation and is arbitrary

It is important to note that some cost items are included in multiple categories in the cost hierarchy - for example, mobilization is included in 2 cost categories. In short, Cost Estimator organizes the cost categories into a hierarchy as shown in the figure below:

- Total Construction Cost is the sum of Items 1-5
- Total Roadway Cost is the sum of Items 1-9 (i.e. Total Construction Costs plus Items 6-9)
- Total Project Cost is the sum of Items 1-12 (i.e. Total Roadway Costs plus Items 10-12)



For a more detailed discussion regarding the intent of these cost categories, please refer to Chapter 3.1 which covers background knowledge and definitions.

3.0.2 Data Entry Methods

How is information for cost items entered in Cost Estimator?

Cost Estimator includes 3 options for entering cost information into the model: directly as a lump sum, percentage of other cost items, or as a detailed calculation that includes sub-costs or sub-items. They are described as follows:

1. **Lump Sum** - You want to specify an exact cost for a line item (Percent contributions will be automatically calculated). This option is available for all line items.
2. **Fixed Percent** - You want to specify the cost as a fixed percent of other cost items (see right-most right-most column of the table below). This option is available for all line items except Pavement.
3. **Calculated / Detailed** - You will be prompted for additional details needed to perform the calculation such as unit costs, quantities, standard items, or adjustment factors. This option is only available for 3 items: Pavement, Traffic, and Supporting Cost. For more detailed information regarding sub-costs included in the detailed Calculation, please refer to the corresponding sections in User Guide 3.1.

As indicated in the table below, it is important to notice that some data entry methods not available to cost items, particularly detailed calculations.

		Data Entry Method			Details
	Cost Items	**Lump Sum**	***Percent**	**Detailed**	***Percent of Cost Items**
1	Pavement	Y		Y	1-5
2	Earthwork	Y	Y		1-5
3	Drainage	Y	Y		1-5
4	Specialty (SW)	Y	Y		1-5
5	Traffic	Y	Y	Y	1-5
6	Minor Items	Y	Y		1-5
7	Mobilization	Y	Y		1-6
8	Supplemental	Y	Y		1-7
9	Contingency	Y	Y		1-8
10	Structure	Y	Y		1-5
11	Right of Way	Y	Y		1-5
12	Supporting Cost	Y	Y	Y	1-5

Note: The numbering used here is meant to facilitate explanation and is arbitrary

If a cost item is specified as a percent, Cost Estimator will automatically calculate the corresponding dollar contribution (and vice versa when a cost item is specified as a lump sum). In cases where a cost item is a percent of the category to which it belongs, Cost Estimator includes logic to calculate missing information.

The information in the table generally indicates how Cost Estimator sums up cost items prior to any adjustments and depending on the entry methods you select. By understanding this table, you will gain a better general understanding of how your data entry choices will affect the computational results of the model.

3.1.0 Definitions and Background Knowledge

What background knowledge is needed to understand the Cost Estimator model?

The Cost Estimator module allows you to estimate the total agency cost of a pavement construction project based on Caltrans' Preparation Guidelines for Project Development Cost Estimates (or simply, the Cost Estimating Guidelines). Consequently, cost items and categories included in this model reflect Caltrans' guidelines and may differ from the guidelines of other DOTs or transportation agencies.

The purpose of this chapter of the Cost Estimator user guide is to clearly define which costs are included in each cost item and explain important concepts underlying the more detailed sub-calculations in the model. For additional information, please see other chapters in the Cost Estimator user guide. Chapter 3.2 elaborates on how user inputs affect results and presents important considerations when entering information into the model, while Chapter 3.3 provides a demonstration using a best practices example

More specifically, the user guides in this section will address the following questions:
3.1.0 - What background knowledge is needed to understand the Cost Estimator model?
3.1.1 - What concepts are essential to know when using Cost Estimator?

References for this Model:

California Department of Transportation. Preparation Guidelines for Project Development Cost Estimates - Cost Estimating Guidelines.
http://www.dot.ca.gov/hq/oppd/costest/Cost-Estimating-Guidance-10-10-2014.pdf

California Department of Transportation. Cost Estimating: Policies and Guidance
http://www.dot.ca.gov/hq/oppd/costest/costest.htm

3.1.1 Key Terminology and Definitions

What concepts are essential to know when using Cost Estimator?

This user guide provides you with a basic set of definitions for the 12 cost items included in the Cost Estimator model for estimating total project costs. Additionally, this section also defines terms used in detailed calculations and project adjustments. Collectively, this section aims to clarify how the Cost Estimator model categorizes considers your inputs for various construction costs.

For more detailed considerations regarding input values, please refer to Chapter 3.2, which expands on how how results are calculated and affected by input choices. For convenience, please note that much of this information can be found directly in the user interface tooltips.

12 Major Cost Items included in Cost Estimator's Calculation of Total Project Cost

#	Cost Item	Definition / Description
1	Pavement	The Pavement cost item includes the major physical material items placed during construction and are specified with unit costs (usually standard bid items from a DOT). The total pavement cost item accounts for contractor costs associated with acquiring equipment and labor using a resource cost multiplier.
2	Earthwork	This cost item refers to the costs associated with construction activities such as excavation, clearing and grubbing, cold plane, minor concrete, etc. For California, 3% of the Pavement cost is typically used.
3	Drainage	This cost item refers to the costs associated with constructing (or abandoning) drainage facilities (such as culverts), including costs related to stormwater pollution prevention planning (SWPPP). For California, this is typically 1% of the Pavement cost.
4	Specialty / Stormwater	This cost item primarily refer to expenses associated with miscellaneous construction and project coordination activities such as the installation of railing, retailing walls, or permit acquisition. This may include other roadway costs that do not otherwise have a specific category. For California, this is typically 10% of the Pavement cost
5	Traffic	The Traffic field refers to costs associated with developing and executing a traffic management plan, including wages paid for highway patrol, incident management and traffic handling during construction, public information costs, incentive/disincentive costs, or rental/equipment costs for mobile concrete barriers.
6	Minor Items	Minor items may include items such as fencing, curbs, sidewalks, or access ramps. The cost may be specified as a lump sum, or a percent of all Construction Costs (typically 5-10% for Caltrans projects)
7	Mobilization	Mobilization costs are associated with the initial staging of equipment, crew, or resources for a pavement rehabilitation operation and are

		affected heavily by the specific project attributes and locale. In Cost Estimator, this item may be specified as a percent of all Construction Costs plus Minor Items (Typically 0 to 10% for Caltrans projects). Mobilization for auxiliary (non-pavement) structures should be excluded from this item.
8	Supplemental	Supplemental Work refers to funds allocated for work that cannot be predicted in advance due to uncertainty (e.g. removal of poor material); it is considered a cost in this model. In cost estimator, this item can be specified as a percent of all Construction Costs plus Minor Items and Mobilization Costs (up to 10% for small projects, 2-3% for large)
9	Contingency	Contingency cost is money set aside for unforeseen work items as new information is obtained; it may vary widely depending on the specific project circumstances. Cost Estimator allows you to specify this cost as a percent of all Construction Costs plus Minor Items, Mobilization Costs, and Supplemental Costs (10-50%, decreasing with greater project certainty or fewer unknowns)
10	Structure	Structure costs refer to auxiliary structures that require special design (and therefore separate estimates included here), such as railroad related work, non-standard retaining walls or non-standard noise barriers. This is typically estimated as 3% for California highway projects.
11	Right of Way	Right of Way (ROW) includes items in Caltrans' Right of Way Manual, and typically include obligations or work related to land acquisition such as clearing, fencing relocation, environmental review, utility relocation, approach ramps, et. al. This is typically 0% of construction costs for rehabilitation and maintenance projects, but varies for new highway facilities depending on specific project circumstances.
12	Support Cost	Supporting costs refer to additional escalation costs to complete a pavement project, pay for supporting field engineers, or extend preparation activities. The cost may be specified as a percent of Construction Costs.

Detailed Calculations - Pavement Cost

Term	Definition / Description
Contractor Resource Cost Multiplier	The contractor resource cost multiplier adjusts the total pavement costs to include contractor costs associated with acquiring equipment and labor for pavement line items. That is, the multiplier accounts for the physical construction costs associated with materials. This factor is applied after summing all line items when specifying the Pavement Cost as a detailed sub-calculation.

Detailed Calculations - Traffic Cost

Term	Definition / Description
Transportation Management Plan (TMP)	This refers to costs associated with coordinating traffic during construction. The section allows you to specify details for individual TMP-related costs, or enter the total directly as a lump sum. The TMP Cost include 4 sub items: [1] Public Information [2] Incentives/Disincentives, [3] Extra TMP Cost, and [4] COZEEP Additionally, the TMP Cost is one of 3 components of the Total Traffic Cost.
Public Information Cost	Public information refers to costs associated with raising public awareness of road closures and potential traffic impacts, including: public outreach, project website, publication, media, or other related costs. A value of $100,000 is typically recommended. (1 of 4 components of the total TMP cost)
Incentive / Disincentive Cost	Incentives or disincentives cost refer to costs incurred (or avoided) for achieving certain traffic criteria as specified by the project contract method. Incentives/disincentives can help a project encourage scheduling efficiency while maintaining a stipulated level of quality (2 of 4 components of the total TMP cost).
Extra TMP Cost	Extra TMP costs may include other components such as Highway Advisory Radio (HAR) or Freeway Service Patrol (FSP). Typical values are $100k or less for nighttime closures, and over $100k for extended closures (10+ hours). (3 of 4 components of the total TMP cost)
Construction Zone Enhanced Enforcement Program (COZEEP)	Also known as the Incident Management Cost, COZEEP refers to costs associated with improving traffic safety through the use of additional highway patrol persons to assist in traffic management. (4 of 4 components of the total TMP cost)
Moveable Concrete Barrier (MCB)	A mobile concrete barrier can be used to improve traffic safety by physically separating traffic and areas under construction, as well as guide traffic when there are changes in lane configurations. MCB costs include the physical rental costs of the barrier ($/ft/mo), rental costs for the transformer equipment to place or modify the barrier ($/mo), and any training costs. Rental costs for an MCB and a transformer may vary between the first month and additional months thereafter. The training cost is typically a uniquely occurring cost.
Traffic Handling Cost	Traffic Handling incurs expenses related to staging (and subsequent removal before reopening) equipment, lane closure signs, cones, or other safety devices for each closure. In California, Caltrans estimates

	that $2-$3k per 8-hr workday was designated for traffic handling based on 500 maintenance and rehabilitation projects over 8 years.

Detailed Calculations - Support Cost

Term	Definition / Description
Field Engineer Cost (during construction)	This refers to the costs of hiring on-site support engineers for an additional number days to prepare for a closure. This cost is calculated separately from the total man-hours for construction (product of hours per closure and the total number of closures).
Extra Preparation Days for Closure	This refers to the costs of hiring on-site support engineers for an additional number days to prepare for a closure. This cost is calculated separately from the total man-hours for construction (product of hours per closure and the total number of closures). In this case, a 'preparation day' refers specifically to an 8 man-hour work-day and so the number of engineers does not affect this calculation.
Field Engineer Rate Multiplier	The rate multiplier is used to scale up the cost of hiring on-site support engineers for a project, as part of the supporting costs included in the estimation of the project cost total. A rate multiplier of 1.1 is suggested by Caltrans.
Total Engineering Support Person Year	This refers to the costs of hiring additional support engineers at the specified annual salary rate. The value entered here will be multiplied by the engineer's annual salary and added to the total supporting cost. Caltrans suggests that a typical project will need 4-8 person-years, but may be higher or lower depending on the project. This cost may be used in lieu of estimating the costs for field engineers based on the total construction duration and extra preparation days

Total Project Cost Adjustments

Term	Definition / Description
Years After Construction	This refers to the number of years in the future that a pavement job is intended to occur. This affects the calculation of the project's present worth (based on the discount) and escalated project costs (based on the escalation rate). A positive non-zero value for Construction After (Years) indicates that the project occurs in the future; a value of zero means that the construction year is the present year.
Discount Rate	The model assumes that the pre-adjusted project total is incurred in the year of construction (future) and may therefore have a different value in the present year. The discount rate adjusts the project cost for inflation, i.e. the economic value of the project at the time of evaluation will be less than when the project is constructed in the future.

Escalation Rate	The model assumes that the pre-adjusted project total is incurred in the year of construction (future) and that the cost or valuation of goods or services may escalate with time or location (as opposed to the valuation of money itself via the discount rate).

3.2.0 Simulation Model and Data Requirements

How is information for cost items entered in Cost Estimator and what are important data considerations?

This chapter of Cost Estimator's user guide provides a detailed description of the underlying quantitative model and is intended to improve overall transparency within the R3 application suite. Additionally, this user guide presents important considerations when determining what information to collect, how to enter cost items, and how your inputs affect the overall results.

By following the recommendations in this user guide, you will be able to provide cost inputs in a meaningful way that reflects the amount of information currently available for your project. Understanding how your inputs generally will affect the results will also allow you to read the report more easily and more easily identify weaknesses in your paving strategy.

If you are not comfortable in your understanding of cost items presented in this section, please refer to Chapter 3.1, which contains background knowledge and definitions that may improve your understanding of subsequent discussions of the model.

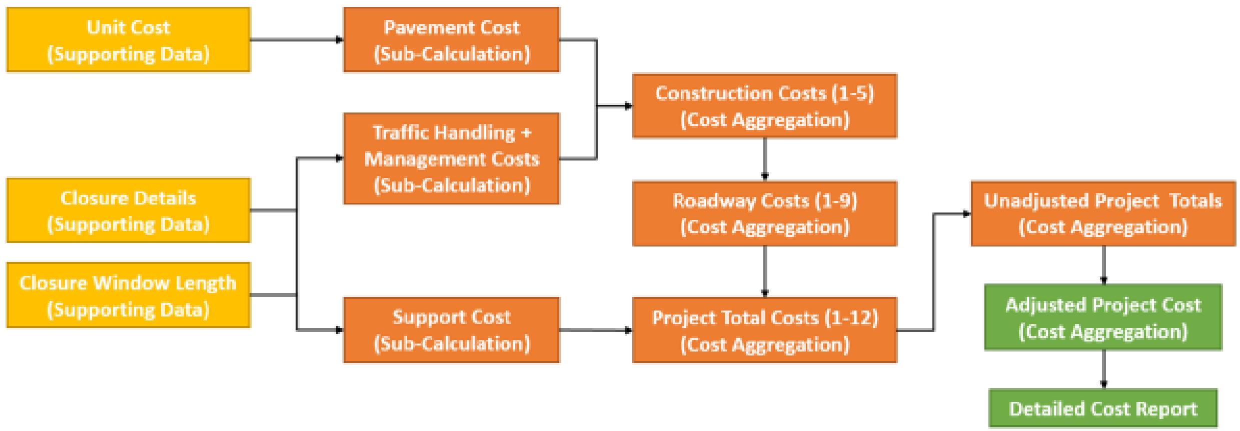
In particular, the user guides in this chapter will answer the following questions:

3.2.0: Simulation Model and Data Requirements - What concepts are included in this chapter?
3.2.1: Conceptual Simulation Model and Data Flow - How do model inputs interact with each other and affect the results?
3.2.2: Detailed Calculations: Pavement, Traffic, and Support Costs - How are detailed calculations performed for certain cost items?
3.2.3: Cost Aggregation Rules and Model Assumptions -How are cost items represented in this model?
3.2.4: Data Considerations: Closure Details - Why are closure details important to consider?
3.2.5: Data Considerations: Selecting a Data Entry Method - How do I choose an appropriate data entry method?
3.2.6: Data Considerations: Adjusted Project Cost - Why should I adjust the project cost?

3.2.1 Conceptual Simulation Model and Data Flow

How do model inputs interact with each other and affect the results?

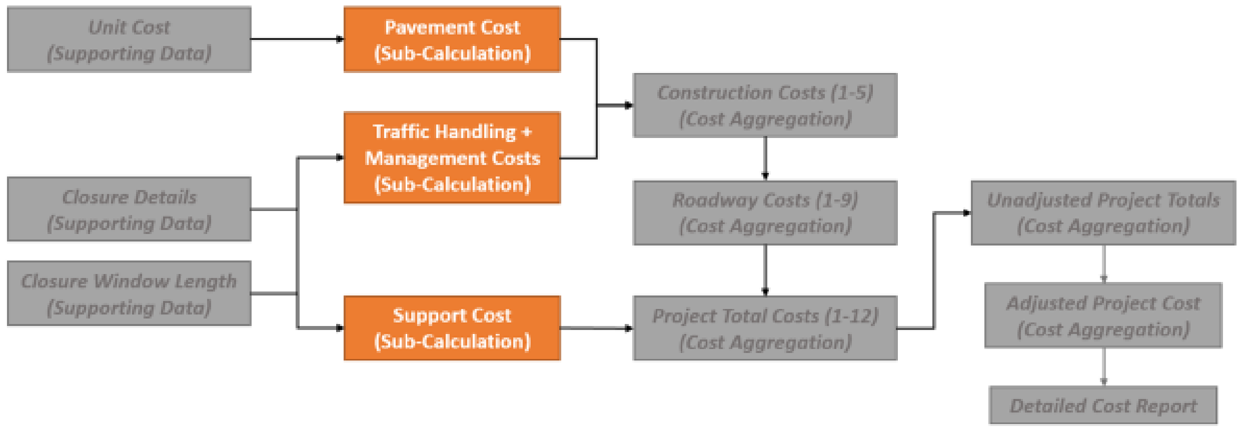
The intent of this section is to clarify the context of user inputs in the overall Cost Estimator model. The figure below indicates different groups of input parameters how individual cost items are aggregated. For example, inputs related to sub-calculations for Pavement and Traffic Handling contribute to construction costs, which in turn contribute to Roadway Costs.



It is important to note that input parameters associated with Closure Details or Closure Window Duration affect cost calculations, namely Traffic Handling and Support Costs. This is primarily because several calculations are related to wages paid, which in turn are a function of construction duration. The values for parameters related to construction duration can be generated via simulation using Road Scheduler, or you may simply provide an estimate based on your own experience.

Chapter 3.2.2 (the next chapter) expands upon the details of the sub-calculations for Pavement, Traffic, and Support Cost Items. Chapter 3.2.3 explains how the 12 main cost items are computed and aggregated in the Cost Estimator Model.

3.2.2 Detailed Calculations: Pavement, Traffic, and Support Costs

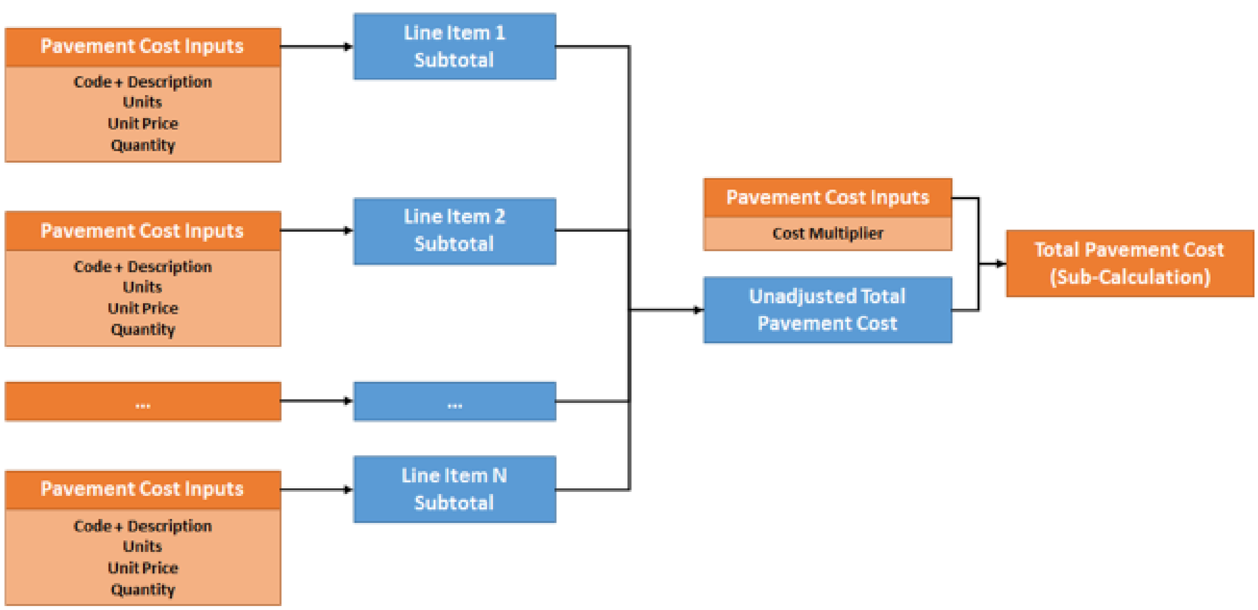


This user guide focuses on how inputs for detailed calculations are used to generate the cost items for Pavement, Traffic, and Support Cost items. Although understanding the details of this chapter are not necessary to run Cost Estimator, they may provide you with insight on the model's underlying estimation logic.

If you are unfamiliar with the terms or concepts presented here, please refer to Chapter 3.1, which presents necessary background knowledge and definitions.

Detailed Calculation for the Pavement Cost Item

A detailed sub-calculation for the Pavement Cost implies that you want to specify the cost item as a sum of line items based on unit prices and quantities.



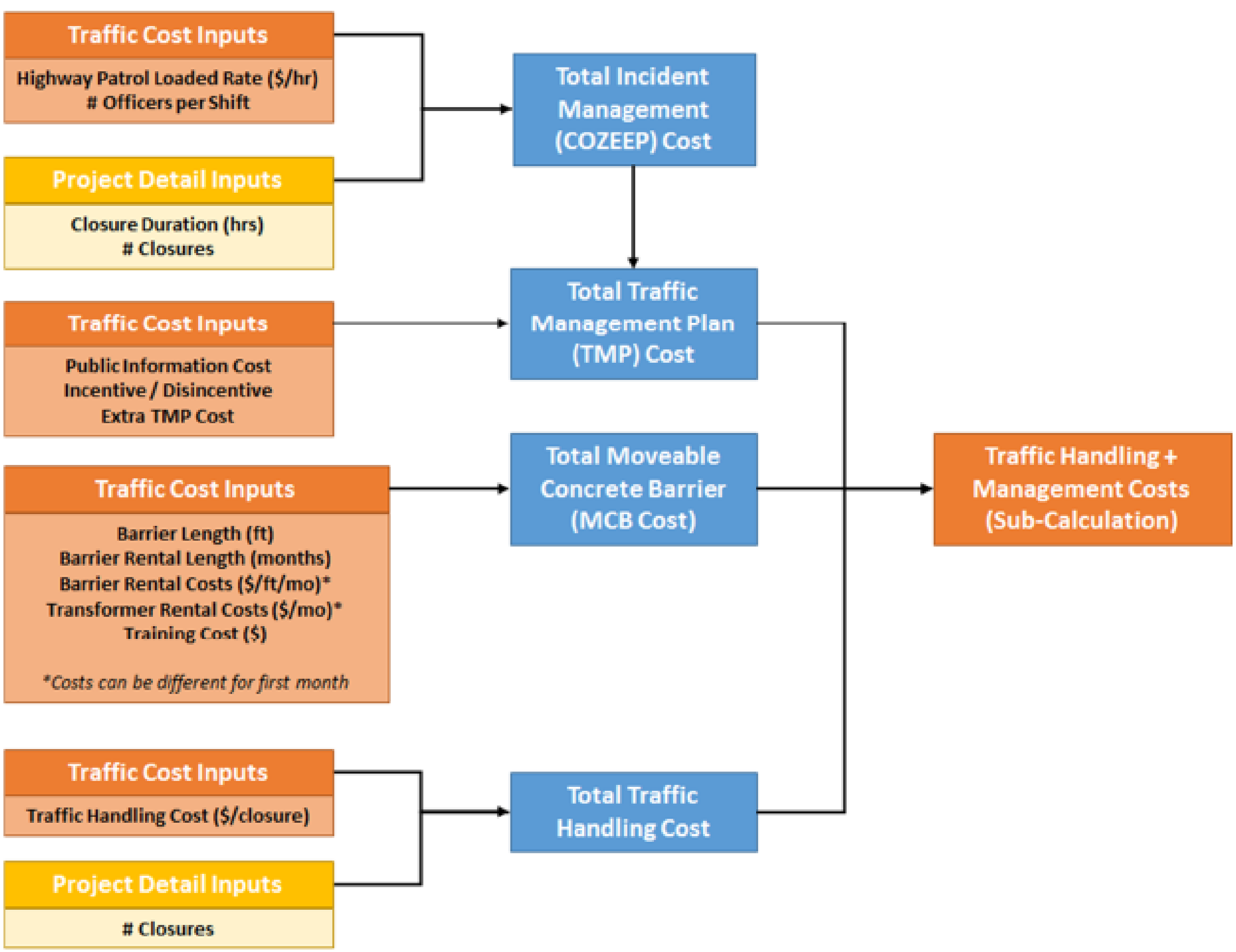
In the flow diagram below, blue boxes indicate intermediate calculations made prior to generating the total pavement cost. Orange boxes refer to inputs you will specify to complete the detailed calculation.

In this case, each line item is provided with a code and description, unit and unit price, and a total quantity. The code typically references a standard bid item from a transportation agency, but should otherwise be a unique code that identified your line item, and briefly clarified in the description.

After all line items are entered, Cost Estimator sums each line item to calculate the unadjusted total pavement cost. The contractor resource cost multiplier is then applied to this value to generate the Total Pavement Cost, one of the twelve major cost items of the total project cost.

Detailed Calculation for the Traffic Cost Item

A detailed sub-calculation for the Traffic Cost Item implies that you want to specify the cost item as a sum of other traffic-related items rather than directly as a lump sum or percentage of construction costs.



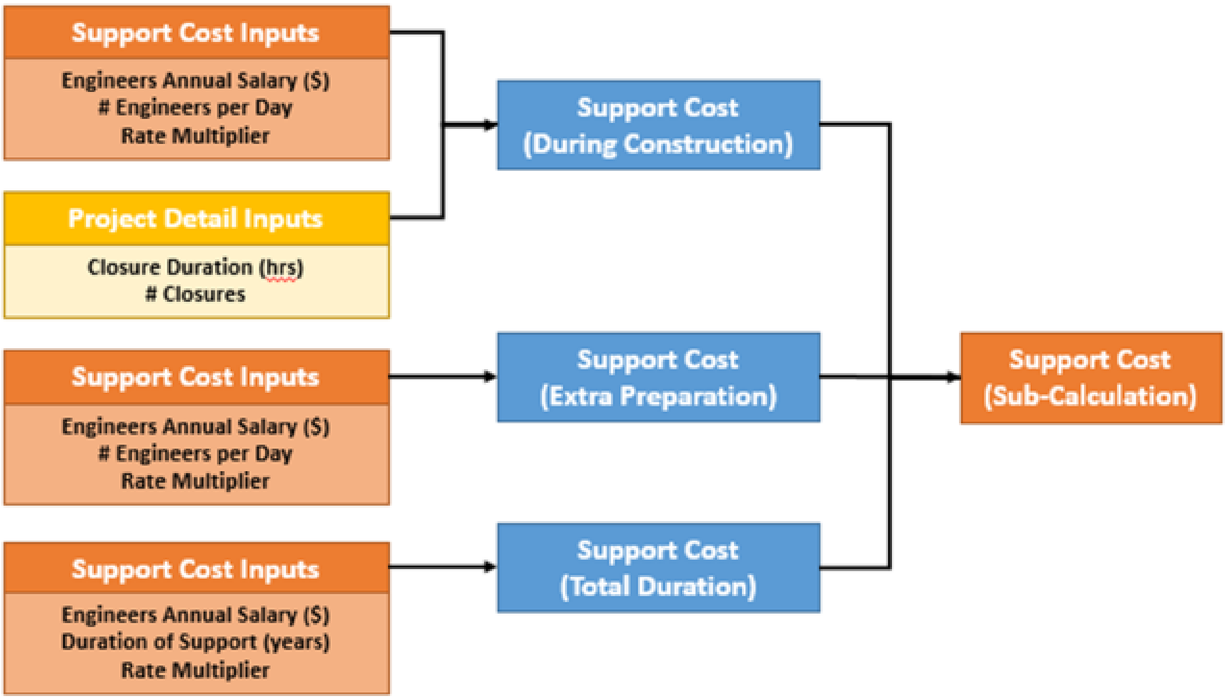
In this figure, yellow boxes refer to inputs from the project details section of the model, while orange boxes indicated inputs specific to the traffic sub-calculation. Like before, blue boxes indicate intermediate calculations made prior to the total Traffic Cost Item.

The Traffic Item Cost is essentially the sum of the three sub-items (represented by blue boxes in the figure):

Sub-Item	**Calculation**
Total TMP Cost	[COZEEP Cost] + [Public Information] + [Incentive/Disincentive] + [Extra TMP Cost] where [COZEEP] = [Officers Per Shift]*[Loaded Pay Rate]*[# Closures]*[Closure Duration]
	Note: The Total TMP Cost may also be specified directly instead of values for these sub-items.
MCB Cost	[Barrier Rental Cost] + [Transformer Rental Cost] + [Training Cost] where, [Barrier Rental Cost] = [Length]x([First Month Cost] + ([# Months] - 1)x[After First Month Cost]) and [Transformer Rental Cost] = [Transformer First Month Cost] + ([# Months] - 1)x[After First Month Cost]
	Note: The MCB Cost does not calculate the rental duration based on project details because the required rental period may differ from the total project duration. The MCB cost can also be specified as a lump sum directly, avoiding this calculation
Total Traffic Handling	[# Closures]*[Traffic Handling Costs per Closure]
	Note: The Total Traffic Handling cost may also be specified directly to skip this calculation.

Detailed Calculation for the Support Cost Item

A detailed sub-calculation for the Support Cost item indicates that you want to specify the cost of hiring field engineers directly using hourly wages and required man-hours (as opposed to directly as a lump sum or percent of construction costs).



As before, yellow boxes refer to inputs from the project details, orange boxes indicate inputs specific to the support cost sub-calculation, and blue blue boxes indicate intermediate calculations made prior to the total cost.

The total Support Cost is calculated as the sum the three sub-items (blue boxes in the figure):

Sub-Item	**Calculation**
Support Cost (During Construction)	[Hourly Rate]*[# Engineers]*[Construction Duration]*[Rate Multiplier] Where, [Hourly Rate] = [Engineer's Annual Salary]/1880, [Total Duration] = [# Closures]*[Closure Duration]
	Note: Caltrans divides the Engineer's Annual Salary by 1880 to determine an hourly pay rate.
Support Cost (Extra Preparation)	[8 man-hours]*[Extra Preparation Days]*[Rate Multiplier]
	Note: Caltrans assumes each extra preparation day is 8-man hours because this time is separate for the hours implied by the total construction duration.
Support Cost (Total Duration)	[Engineer's Annual Salary]*[Support Person-Years]*[Rate Multiplier]
	Note: In this case, Person-Years refers to the number of years multiplied by the number of engineers needed. For example, 2 engineers needed for 3 years implies

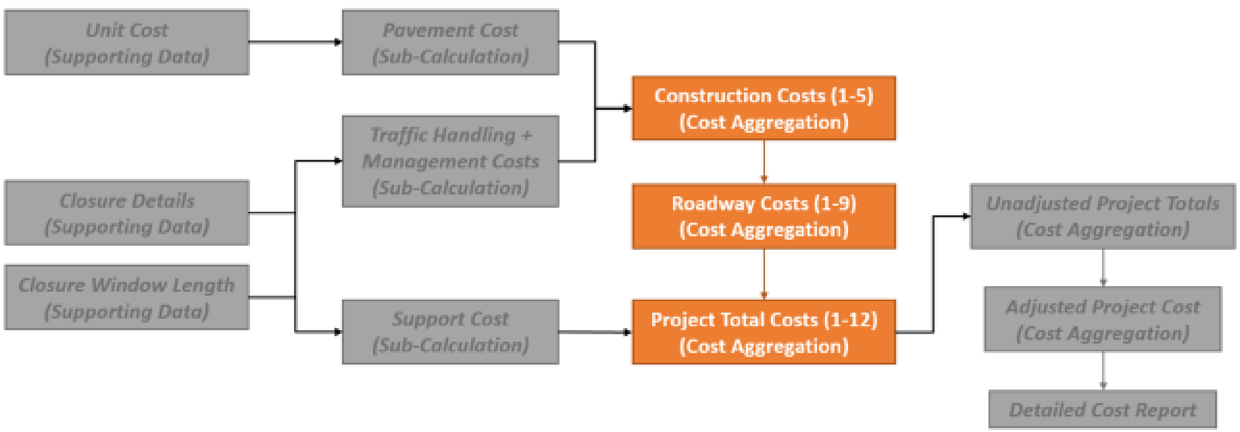
	that you should specify 6 person-years. It is important to note that this calculation is not performed automatically and must be done manually. The option is made available because you may want to specify a total number of person-years in lieu of (or in addition to) calculating costs based on hours of construction and extra preparation days.

3.2.3 Cost Aggregation Rules and Model Assumptions

This user guide elaborates on how your chosen data entry method may affect the way Cost Estimator aggregates totals, particularly when items are specified as a mix of lump sums and percentages. Additionally, this user guide explains underlying calculation assumptions within the model.

Cost Aggregation Order

Depending on the specific cost item, Cost Estimator allows you to enter cost information as a lump sum total, a percentage of other cost categories, or with more detailed sub-calculations. When you have entered appropriate values for all items within a cost category, Cost Estimator will automatically calculate a cost item's dollar value is specified as a percentage. Similarly, cost estimator will automatically calculate the percent contribution for cost item specified as a lump sum or from detailed sub-calculations.



In many cases, a cost category will consist of items specified with a mixture of entry methods. The set of rules below outlines the logic with which the model aggregates cost items. For demonstrative purposes, consider the following example of how Cost Estimator determines total construction cost:

#	Construction Items	Entry Method	Value
1	**Pavement**	Sub-calculations	$2,500,000
2	**Earthwork**	Percentage	12%
3	**Drainage**	Percentage	8%
4	**Specialty (SW)**	Lump-Sum	$200,000
5	**Traffic**	Sub-Calculations	$1,300,000

1) First add up lump sum costs and detailed sub-calculations. This value is $4 million in this example.
2) Next, sum the (percent) contribution of cost items specified as a percent and subtract this from 100%. In this case, Earthwork and Drainage comprise 20% of the cost, which

means all remaining items comprise 80% of the total construction cost (i.e. the $4 million from Step 1)

3) The total construction cost is found by dividing the results from Step 1 by the results in Step 2. In this example, if $4 million is 80% of the construction cost, then the total construction cost is $4 million/(0.80) = $5 million
4) The percent contribution of lump sum costs and detailed sub-calculations are found by dividing their contribution by the total. For example, Pavement contributes 50% of the $5 million total construction cost.
5) The dollar values of items specified as a percent are found by multiplying their percent contribution by the total construction cost. For example, Earthwork is 12% of the total construction cost or $600,000.

Cost Items and Sub-Calculations Based on Closure Duration

Some inputs are specified as dollars per unit time (e.g. wages for engineers or highway patrol, traffic handling costs). Consequently, the model requires information regarding the number and duration of each closure, which may include closures spanning a fractional number of days or include shift operations. For these items, Cost Estimator will use the number of closures and hours per closure you have specified.

Cost Adjustments

Cost adjustments for escalation or discount rates applied after the total unadjusted project cost is calculated.

Costs Calculations for Shift Operations

For shift operations, you will specify the number of hours available for construction within a 24 hour day. The hours available for construction is used to calculate cost items dependent on the duration of construction, such as wages (rather than the full 24 hours).

Hourly and Annual Wages

Converting salaries into hourly rates is necessary in the model because closures may last a partial number of days. In Cost Estimator, annual wages are converted into hourly wages by dividing the annual salary by 1880 as recommended by Caltrans. This factor is roughly 90% of the hours in a work year, assuming 8-hr days, 5 days per week, and 52 weeks per year (2080 hours total).

Field Engineers and Extra Preparation Days

When specifying the number of extra preparation days for a closure in the Supporting Cost sub-calculation, note Cost Estimator assumes that extra days are 8 man-hours each. As a result, the number of engineers does not affect this calculation. This is also important to note because the hours per closure during construction may not be 8-hours.

Rate Multiplier for Field Engineers

The rate multiplier is applied to the number of field engineers for the duration of the construction project (hours per closure multiplied by number of closures) and also to any extra preparation days excluding the closure itself. It is also applied to the total engineering support person years.

3.2.4 Data Considerations: Closure Details

This user guide explains how different construction window types will affect the calculation of cost items in the Cost Estimator model. Specifically, the construction window type provides information on how the model calculates labor hours or other time-dependent cost items.

The number of closures to complete the paving job may be specified directly or determined using Road Scheduler which performs a more detailed estimation. Additionally, Cost Estimator allows you to select one of four types of closure methods:

1. Night closure, spanning a single evening and measured in hours
2. Weekend, which includes two full days plus any additional time dictated by the start time on Friday and the ending time on Monday morning.
3. Continuous closure with continuous operation, which is specified in days (24 hours each)
4. Continuous closure with shift operation, which is also measured in 24-hour days. However, although the construction site remained closed for a full time, construction is only active for a fraction of this time (e.g. 16 hours out of 24 hours)

Based on the inputs you provide, Road Scheduler will calculate the total number of hours or days of construction. If you are performing a detailed calculation for traffic handling or support costs, this information is required to complete those estimations. For night, weekend, and continuous closure / continuous operations, Cost Estimator calculates the total construction time by simply multiplying the number of closures by the number of hours (or days) per closure. For shift operations however, the total construction time is found by multiplying the hours available for construction per day by the number of days per closure and number of closures. In other words, Cost Estimator only considers the active construction hours as billable when wages or salaries are considered.

Parameters that are affected by either the closure window type or number of closures are listed below:

- Traffic handling costs (specified as costs per closure)
- Incident Management cost (calculated from the hourly rate for highway patrols and number of officers)
- Supporting cost (calculated based on engineering annual salary, number of engineers per day, and extra prep days for closure)

3.2.5 Data Considerations: Adjusted Project Cost

This user guide explains how Cost Estimator adjusts the total project cost based on the time of construction and discount or escalation rates.

First, you will be asked to specify the ‘Construction After’ time, which refers to the number of years in the future that pavement construction is intended to occur. This value affects the calculation of the project's present worth (based on the discount rate) and escalated project costs (based on the escalation rate). A positive non-zero value for Construction After (Years) indicates that the project occurs in the future; a value of zero means the construction year is the present year. In this case however, the present value and escalated costs will be equal to the unadjusted project cost.

Discount Rate

The model assumes that the pre-adjusted project total is incurred in the year of construction (future) and may therefore have a different value in the present year. In essence, the discount rate adjusts the project cost for inflation, i.e. the economic value of the project at the time of evaluation will be less than when the project is constructed in the future.

The Present Value of your project in current year dollars is calculated as follows:

Present Value = (Pre-adjusted Project Cost)/(1 + Discount Rate)^(Years After)

Escalation Rate

The model assumes that the pre-adjusted project total is incurred in the year of construction (future) and that the cost or valuation of goods or services may escalate with time or location (as opposed to the valuation of money itself via the discount rate).

The Escalated Cost of your project in construction year dollars is calculated as follows:

Escalated Cost = (Pre-adjusted Project Cost)*(1+ Escalation Rate)^(Years After)

3.2.6 Data Considerations: Selecting a Data Entry Method

As mentioned in previous user guides for Cost Estimator, the model includes up to 3 options for entering information for cost items. This user guide provides a brief technical explanation for how changes to inputs may affect a cost item depending on how it is specified.

1. **Lump Sum** - You want to specify an exact cost for a line item (Percent contributions will be automatically calculated). This option is available for all line items. If the total project costs changes, these cost item values remain fixed but their percent contribution my change.

2. **Percent of Cost Categories** - You want to specify the cost as a fixed percent of other cost categories (from a pre-defined list). This may be because you are uncertain of the precise calculation but have some idea how much the cost item contributes to the total project cost. This option is available for all line items except Pavement. Any changes to inputs that affect the total cost will in turn affect the value of these items.

3. **Detailed Sub-Calculations** - You will be prompted for additional details needed to perform the calculation such as unit costs, quantities, standard items, or adjustment factors. This option is only available for 3 items: Pavement, Traffic, and Supporting Cost. For more information about detailed calculations, refer to the specific sections in the user guide. Changing the closure type (i.e. number of closures, closure type or duration) will affect both traffic and support costs. Changes to the total project cost will not affect the results of detailed sub-calculations.

3.3.0. Best Practice Example: Cost Estimator

The sections in this user guide provide a walkthrough of performing a cost estimate using Cost Estimator while briefly discussing best practice considerations pertaining to each step.

Each step included in the demonstration is accompanied with brief discussions of considerations and assumes that all necessary data has already been collected in advance. These discussions frequently refer to concepts presented in **User Guides for the Cost Estimator** and are intended to demonstrate how best practice considerations for inputs can influence results.

The example included in this guide is a modified version of a validated case study with several features added to demonstrate the calculator's functionality. By understanding the results of this demonstration, you will also have a better understanding of how the model calculates the results. The previous user guides are intended to explain how input parameters influence each other and the total project costs.

Using a Mill and Fill paving job as a demonstration, the user guides in this section will generally address what is included in each cost section and the options you have to specify how they are calculated or excluded. Each section is intended to answer the following questions:

3.3.1 Closure Details - What general details uniquely identify and set up my simulation?

3.3.2 Construction Costs - What costs are associated with the physical construction of my pavement?

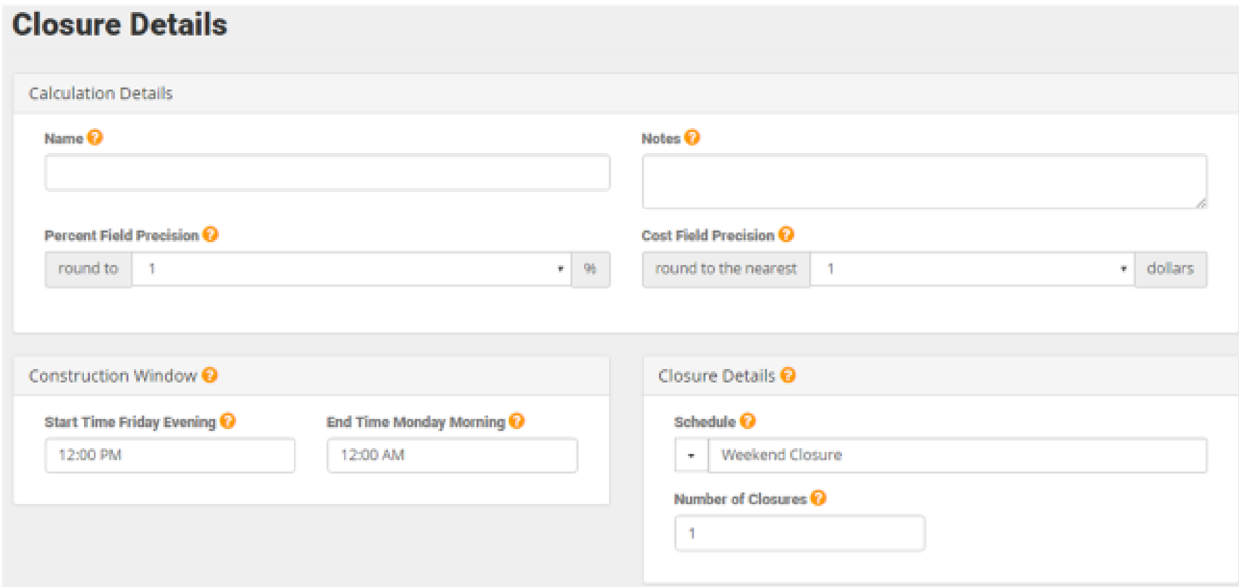
3.3.3 Roadway Cost - Aside from construction costs, what other costs are associated with the creation of the roadway?

3.3.4 Project Cost - Aside from construction and roadway costs, what other costs contribute to the total cost of the paving project?

3.3.5 Adjusted Project Cost - How can I adjust the cost of my project to account for paving performed in the future?

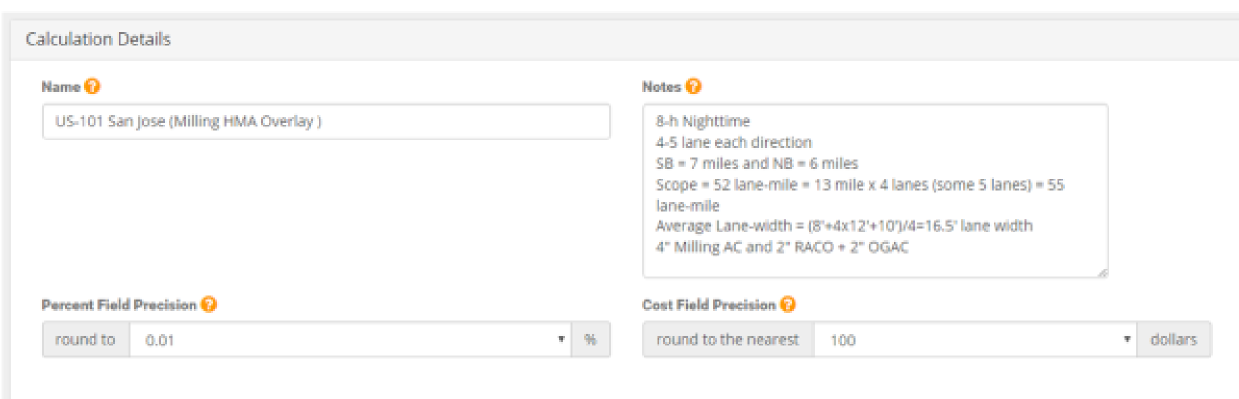
3.3.1 Closure Details

The closure details section is intended to capture basic information that identify and distinguish your calculations as well as indicate the project duration and closure strategy. This information is important to specify because they collectively determine the number construction hours and closures, which in turn are used to estimate certain cost items.

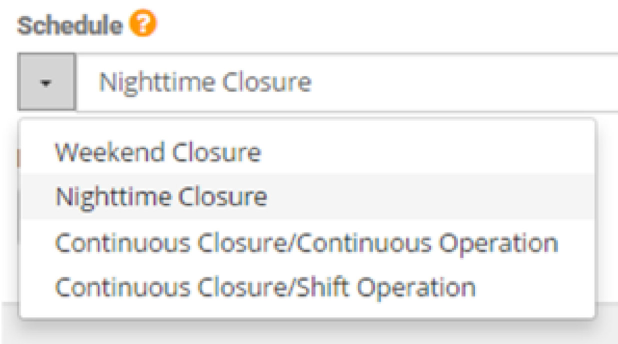


Begin by providing a name for your cost calculation and providing notes that will help you or other collaborators distinguish the intent of this simulation from other calculations associated with the same project. This may include important details that are too long to include in the project name.

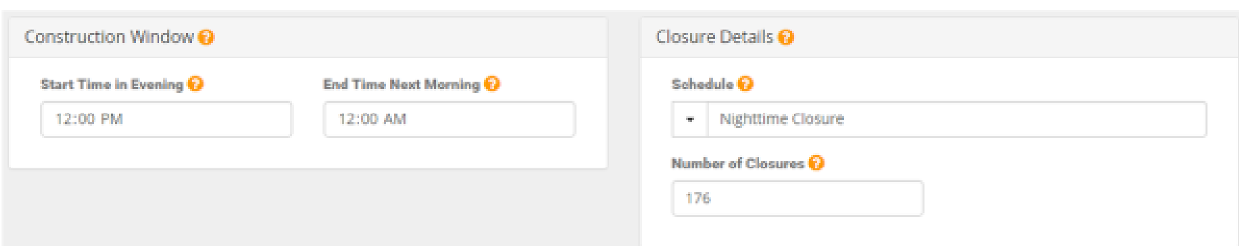
Next, specify the precision with which you would like the final results to be displayed in the simulation report. In this case, percents are set to include 2 decimal places of accuracy, and cost totals will be rounded to the nearest hundred dollars. Note that only report totals will be affected; totals displayed prior to calculating the total results will not.



In the Closure Details section, select one of the four available closure window schedules for your paving project and indicate the number of closures you expect will be required to complete your paving job. If you have already simulated your paving job's productivity using Road Scheduler, you can use the analysis results to enter these fields. In this case, the project was paved using 176 Nighttime closures.

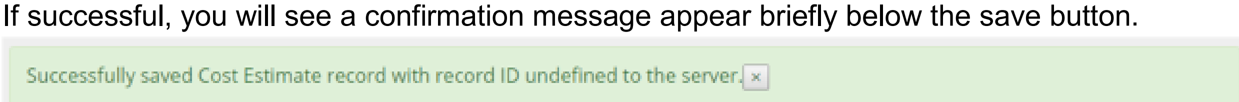


In the Construction Window, enter the details associated with the closure schedule you have selected. You may notice that the inputs in the Construction Window will change depending upon your chosen closure schedule for your paving project. For a nighttime closure, these inputs are simply the start time in the evening and end time the following morning. These details are important to specify because the difference between these times will be used to calculate the number of hours per closure. In this case, starting at 10pm and ending at 6am will yield a closure window of 8 hours.



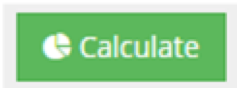
Next Steps...
Once you have filled in all fields in the Closure Details section of Cost Estimator, be sure to save your changes by clicking the blue save button on the bottom of the screen.

If successful, you will see a confirmation message appear briefly below the save button.



When you are ready to proceed to the next section, click on the right arrow to continue or skip to another section directly from the navigation bar on the top.

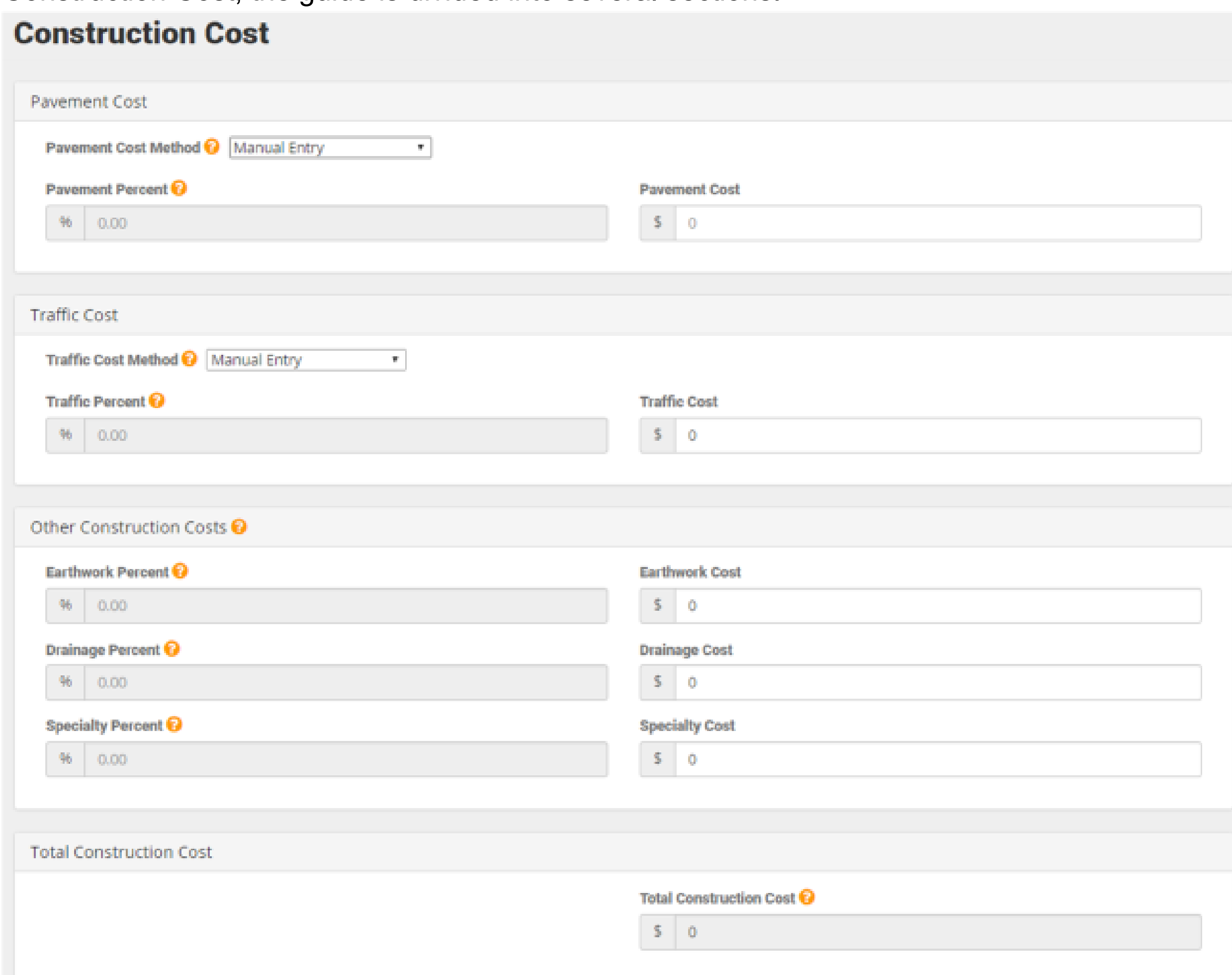
If you have already filled out the inputs from other sections, you can re-calculate your results by clicking the green Calculate button and skip to the Report section.



3.3.2 Construction Cost

Construction Cost (Part I)

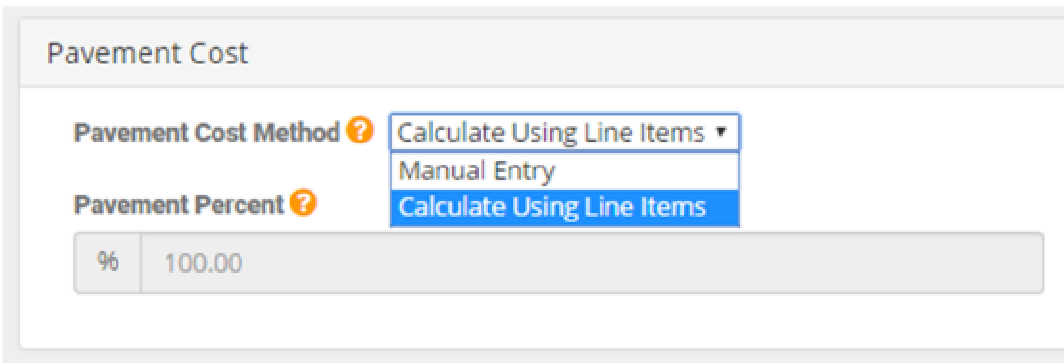
The construction cost section of Cost Estimator is intended to capture the physical costs of construction and includes 5 primary cost items: pavement, traffic, earthwork, drainage, and specialty. Because this guide involves specifying inputs in multiple sections to complete the Construction Cost, the guide is divided into several sections.

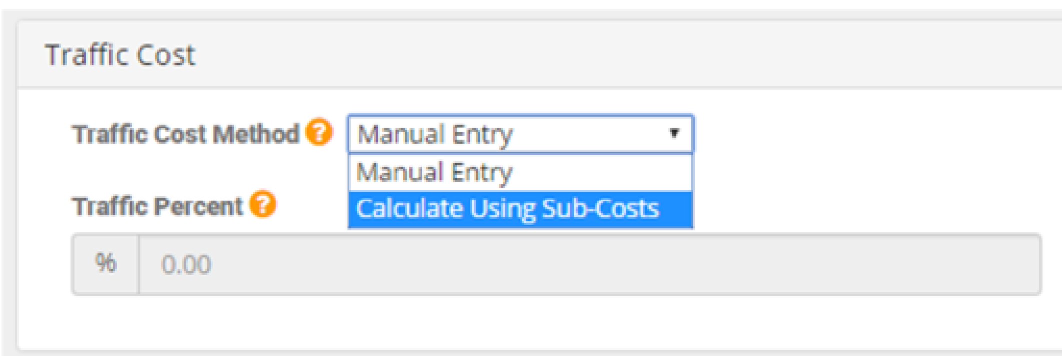


These costs are crucial to specify because many other cost items can be calculated as a percent of the total construction costs, as will be discussed in future sections. In general, all cost items have two ways of being specified:

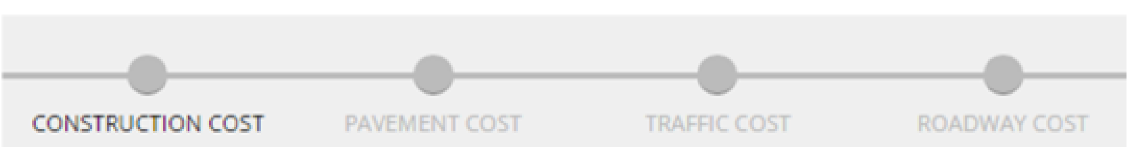
- **Lump Sum** - directly specify the total cost for the item
- **Percent** - indirectly specify the cost as a percent of other cost items. The items this percent is applied to varies, but is discussed briefly in the tooltips for each item.

Some cost items such as Pavement and Traffic costs have a third method of entry that involves a more detailed specification of how the cost item should be calculated. For this demonstration, specify the Pavement Cost Method as 'Calculate Using Line Items' and the Traffic Cost method as 'Calculate Using Sub-Costs'.





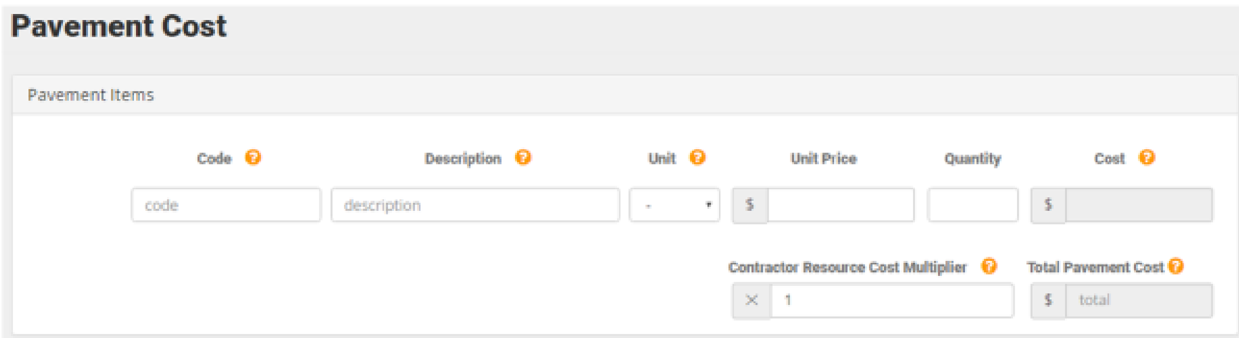
After selecting these two options, you may notice that 2 additional items appear in the navigation bar on the top of the browser, corresponding to Pavement Cost and Traffic Cost specifically. This indicates that you will be specifying additional details to calculate these items, rather than specifying them as a percent or lump sum.



Click the ‘Pavement Cost’ section in the navigation bar to continue this demonstration. You may return to the Construction Cost section at any point and will re-visit this section later in this guide.

Pavement Cost

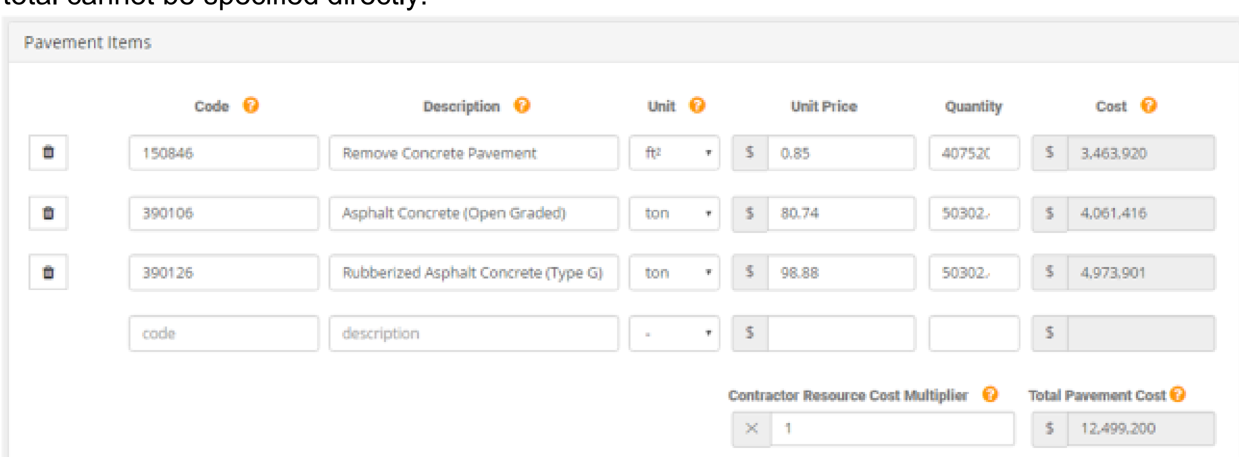
In the Pavement Cost section, you can specify the cost of the pavement with line items based on unit costs and Cost Estimator will calculate the total.



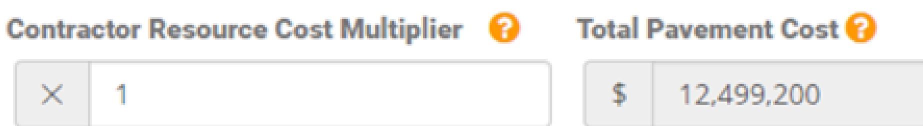
To complete this table, you must specify 5 details for each line item:

1. Code - refers to the standard code for this item, which usually specific to a DOT
2. Description - a descriptive name for the line item
3. Unit - a dropdown menu of units for the unit price of a given line item
4. Unit price - the unit price for the line item in current USD
5. Quantity - the quantity of a line item required for your paving job and based on the unit price

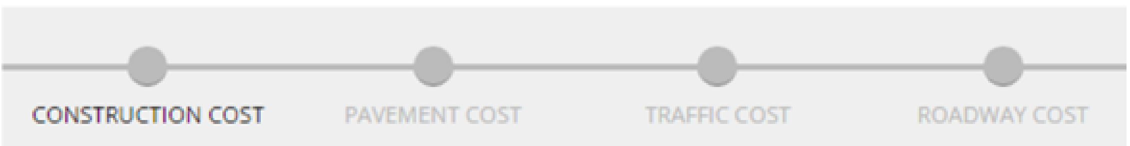
Enter these details for each line item required for your pavement. Note that failing to enter a field will cause a line item to be excluded from the total. Each line item cost is calculated by multiplying the unit price by quantity. The cost will automatically calculate for each item; this total cannot be specified directly.



Finally, specify the contractor resource cost multiplier, which will scale up the gross total of your line items. The cost multiplier is intended to capture the contractor’s overhead costs or mark-up costs that you anticipate from your contractor. These values are generally above 1.0 for closure durations less than 8 hours, and less for closure durations above 8 hours. In this example, the multiplier is set to 1.0 because there are exactly 8 hours specified per closure. The Total Pavement Cost will adjust after changing the cost multiplier.



After entering the details for Pavement Cost, proceed to the Traffic Cost section using the navigation bar on top of your browser or the arrows at the bottom. You may return to this section at any point to modify your inputs.

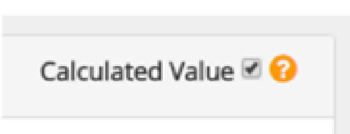


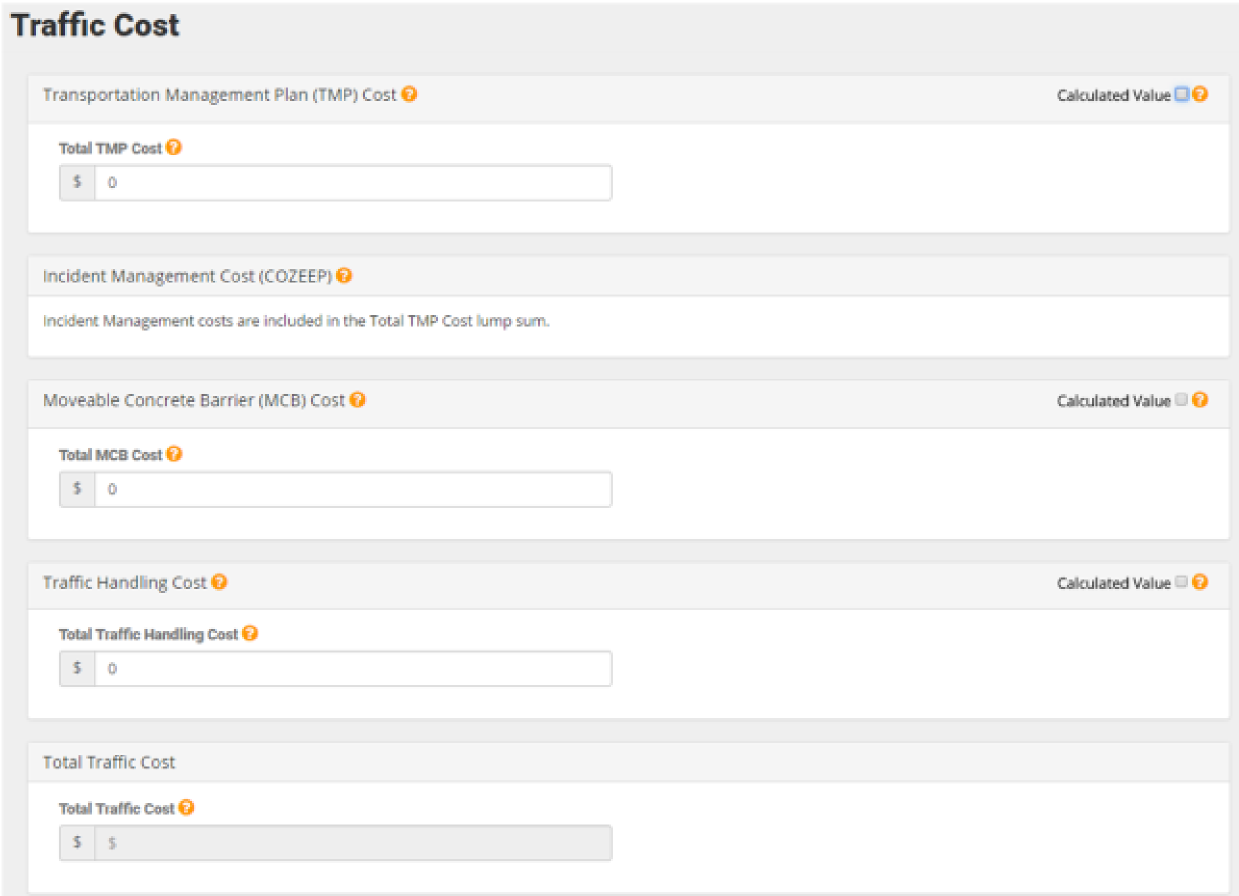
Traffic Cost

In the Traffic Cost section, the total cost of traffic control for your project is calculated from a set of sub-costs that include:

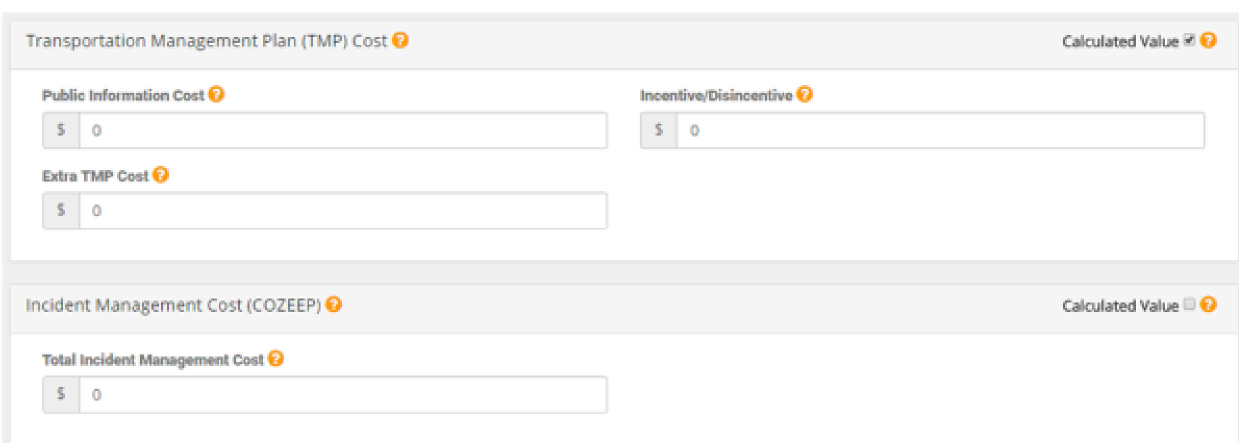
1. Transportation Management Costs
2. Incident Management Cost (aka COZEEP or Construction Zone Enhanced Enforcement Program)
3. Moveable Concrete Barrier (MCB) Cost
4. Traffic Handling Cost

Each of these items may be specified as a lump sum total or based on a more detailed calculation by selecting the ‘Calculated Value’ checkbox located in the top right corner of each sub-cost box.

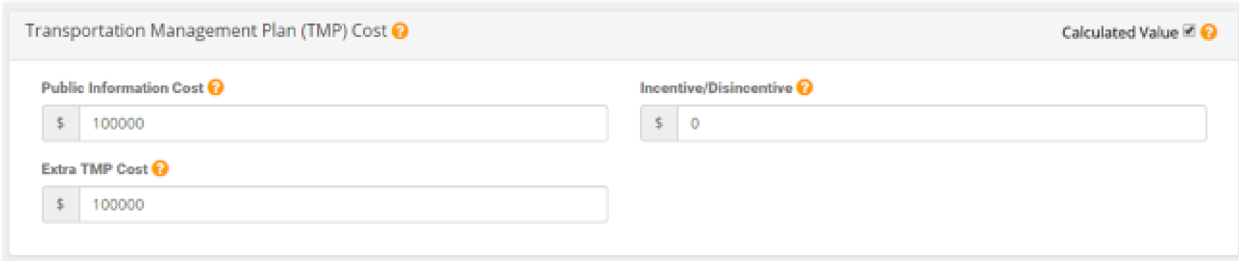




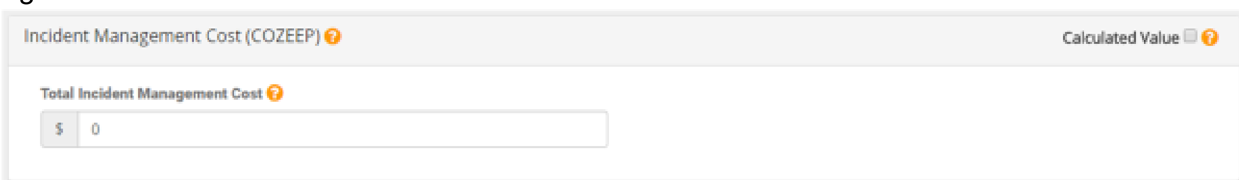
The first item, Transportation Management Plan (TMP) Cost, may be specified as a lump sum total or can be specified as a detailed calculation by selecting the 'Calculated Value' checkbox. Select this checkbox for this demonstration for the TMP Cost. You will notice that the input fields will change for both the TMP Cost and COZEEP. Since COZEEP is included in the TMP Cost, you will notice that this field can now be entered as a lump sum.



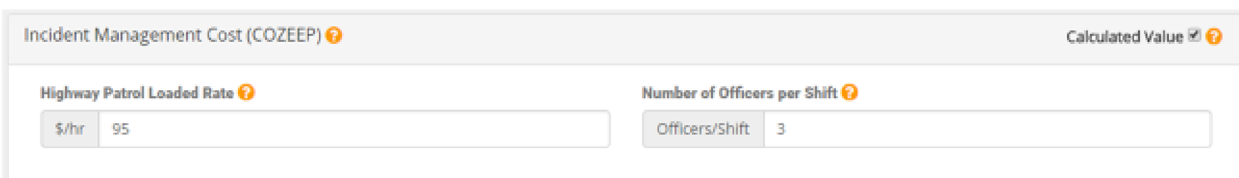
Enter lump sum totals for Public Information, Incentive/Disincentive, and any Extra TMP Costs such as those shown in the figure below.



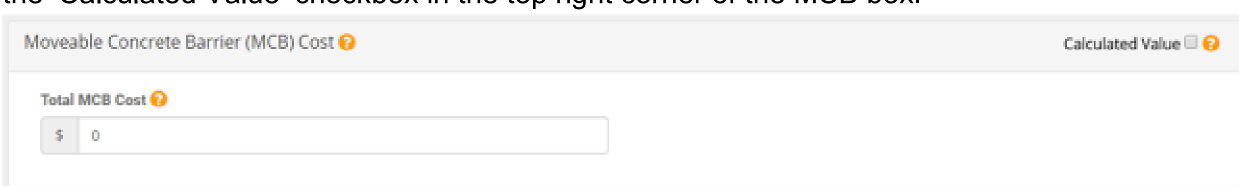
You may calculate COZEEP by specifying a lump sum total directly, or by specifying the number of highway patrol officers and their salary by selected the ‘Calculated Value’ checkbox in the top right corner of the COZEEP box.



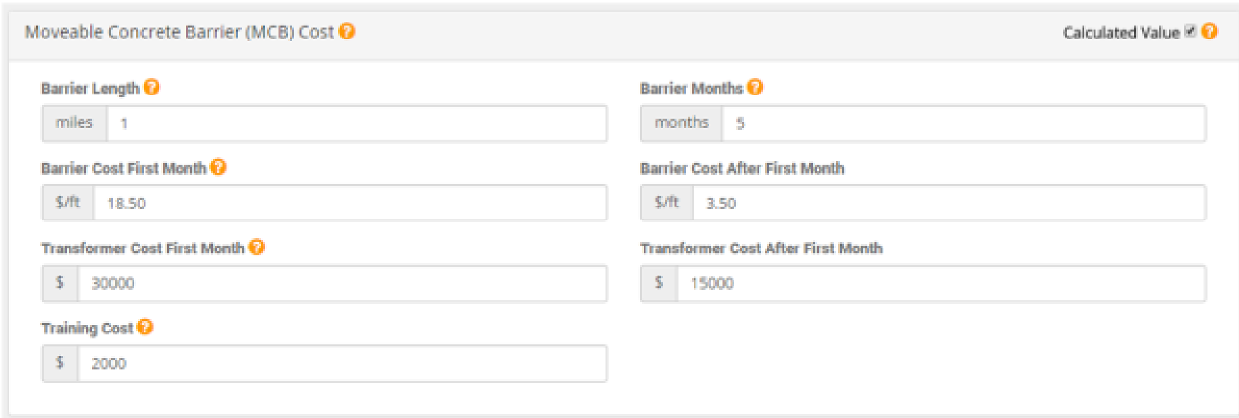
Select this checkbox for COZEEP for this demonstration. You will notice that the inputs for COZEEP will change. Enter the number of highway officers required per shift (closure) and an appropriate hourly wage, such as those shown in the example below. If you chose to specify COZEEP as a calculated value, Cost Estimator will incorporate the number of closures and closure duration into this determination.



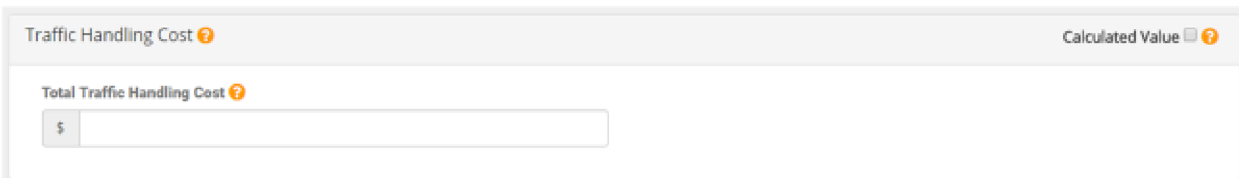
Similarly, you may specify the MCB cost directly as a lump sum or with unit costs by selecting the ‘Calculated Value’ checkbox in the top right corner of the MCB box.



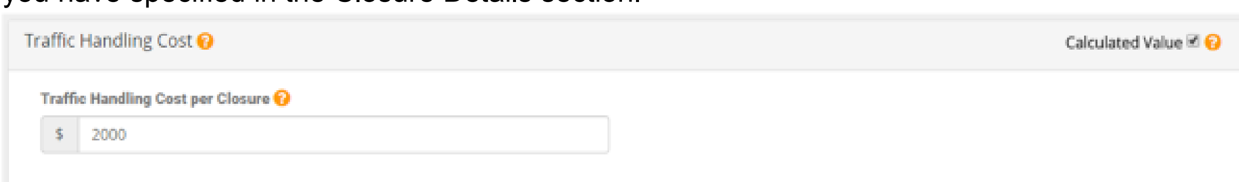
Select this checkbox for this demonstration for the TMP Cost. You will notice that the additional fields will appear for the MCB sub-cost. Enter values for the length of MCB needed, as well as the rental length (in months), unit rental costs for both the barrier itself and the transformer equipment needed to place it, as well as any additional training costs.



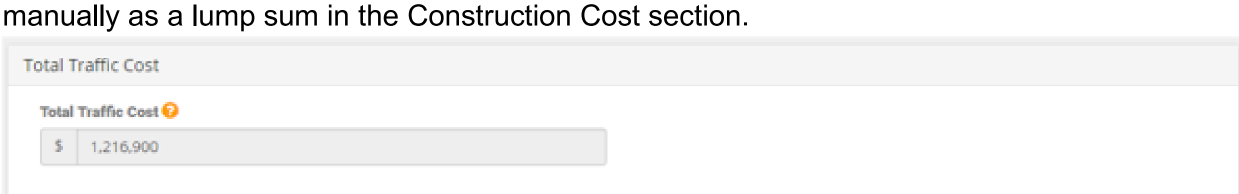
Finally, specify Traffic Handling costs as a lump sum by leaving the ‘Calculated Value’ option unchecked.



For this demonstration, select the ‘Calculated Value’ option and notice that the input field will change from a lump cost to a cost per closure. Enter a cost per closure similarly as shown below. In this case, the total traffic handling cost will be calculated using the number of closures you have specified in the Closure Details section.

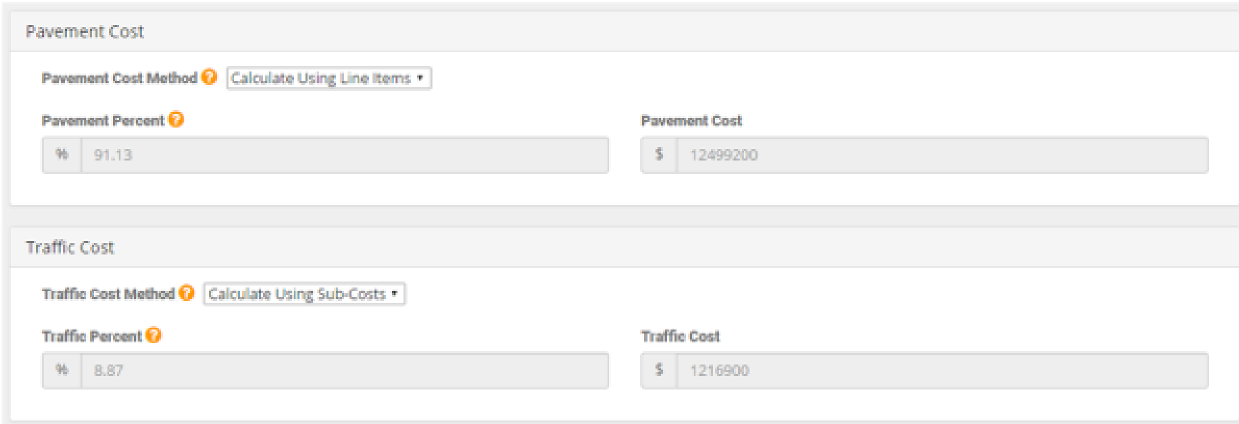


Having completed all inputs for the Traffic Cost item, you may notice that the total is calculated at the bottom of the browser. This value cannot be overridden unless you specify Traffic Cost manually as a lump sum in the Construction Cost section.

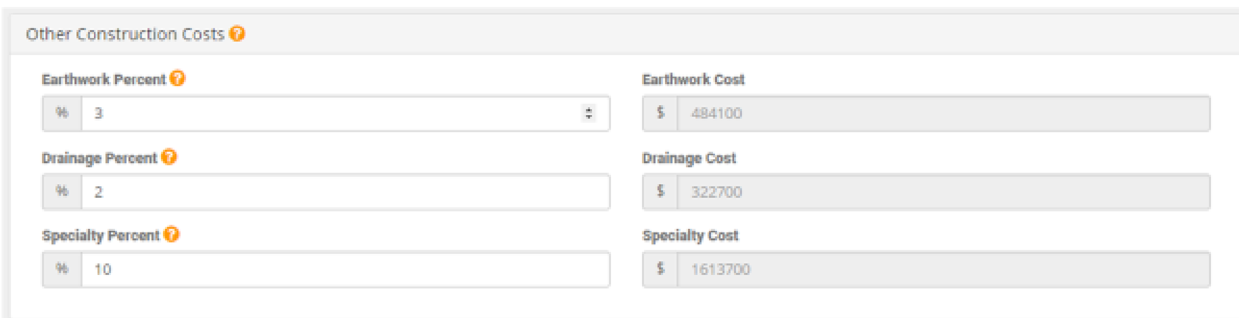


Return to the Construction Cost Section of Cost Estimator using the navigation bar or navigation arrows. You may notice that the totals for both Pavement Cost and Traffic Cost items are now imported to update the appropriate fields in the Construction Cost section.

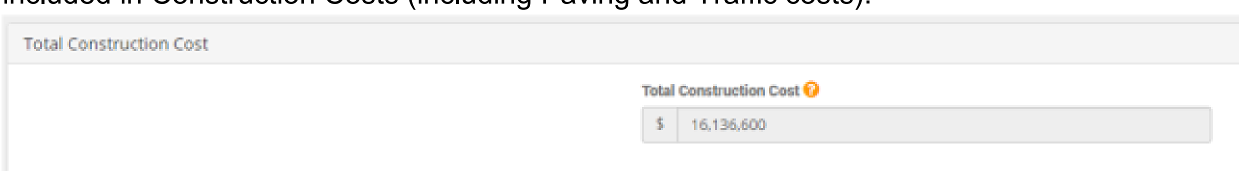
Construction Cost, revisited (Part II)



To complete this section, specify the Earthwork, Drainage, and Specialty costs individually as a percent of total construction costs or directly lump sums, such as those shown below. If you choose to enter these cost items as percents, the percent contribution of the Pavement and Traffic Costs will automatically update.

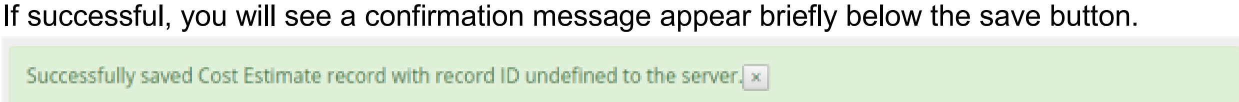


Notice that the Total Construction Cost is updated by summing the total of all cost items included in Construction Costs (including Paving and Traffic costs).

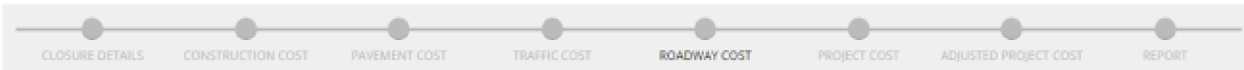


Next Steps...
Once you have filled in all fields in the Construction Cost section of Cost Estimator, be sure to save your changes by clicking the blue save button on the bottom of the screen.

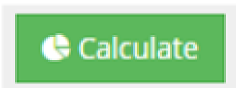
If successful, you will see a confirmation message appear briefly below the save button.



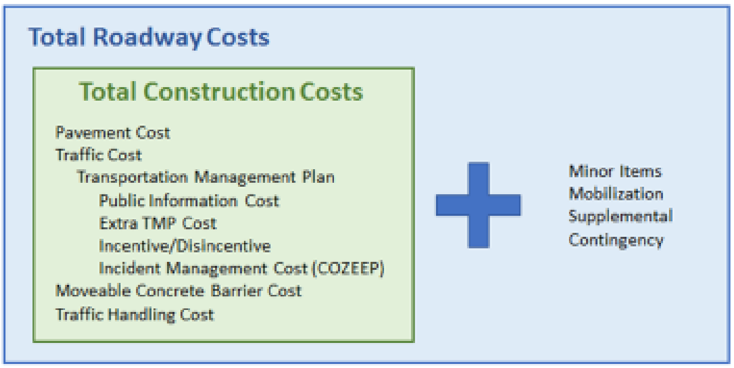
When you are ready to proceed to the next section, click on the right arrow to continue or skip to the Roadway Cost section directly from the navigation bar on the top.



If you have already filled out the inputs from other sections, you can re-calculate your results by clicking the green Calculate button and skip to the Report section.



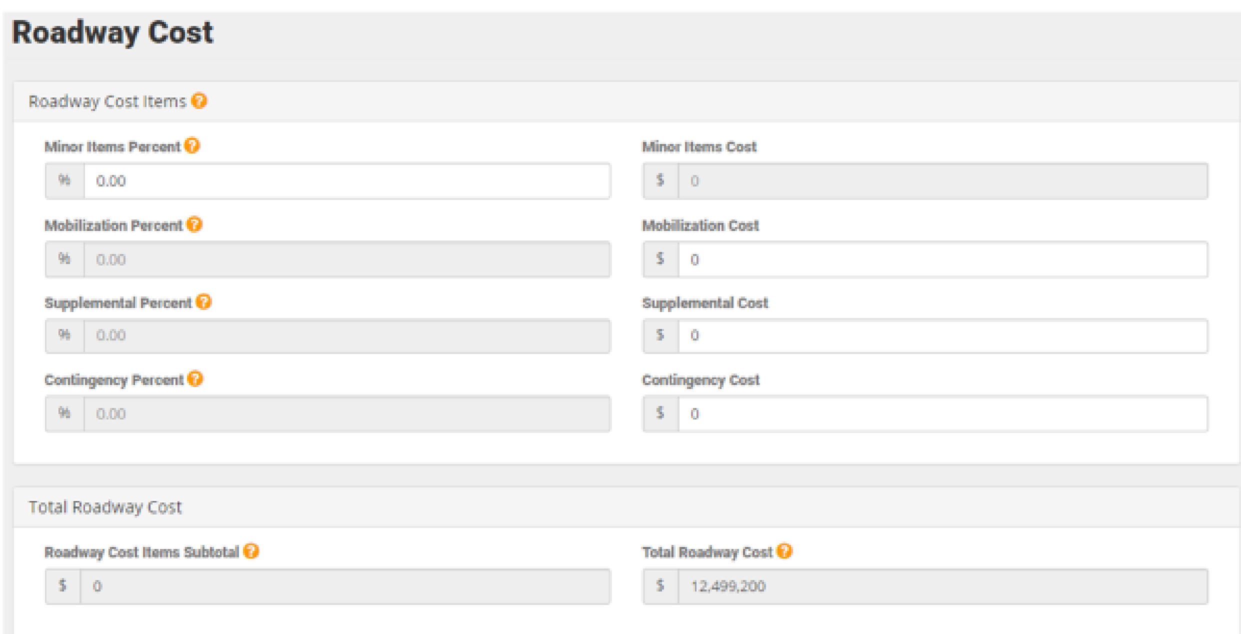
3.3.3 Roadway Cost



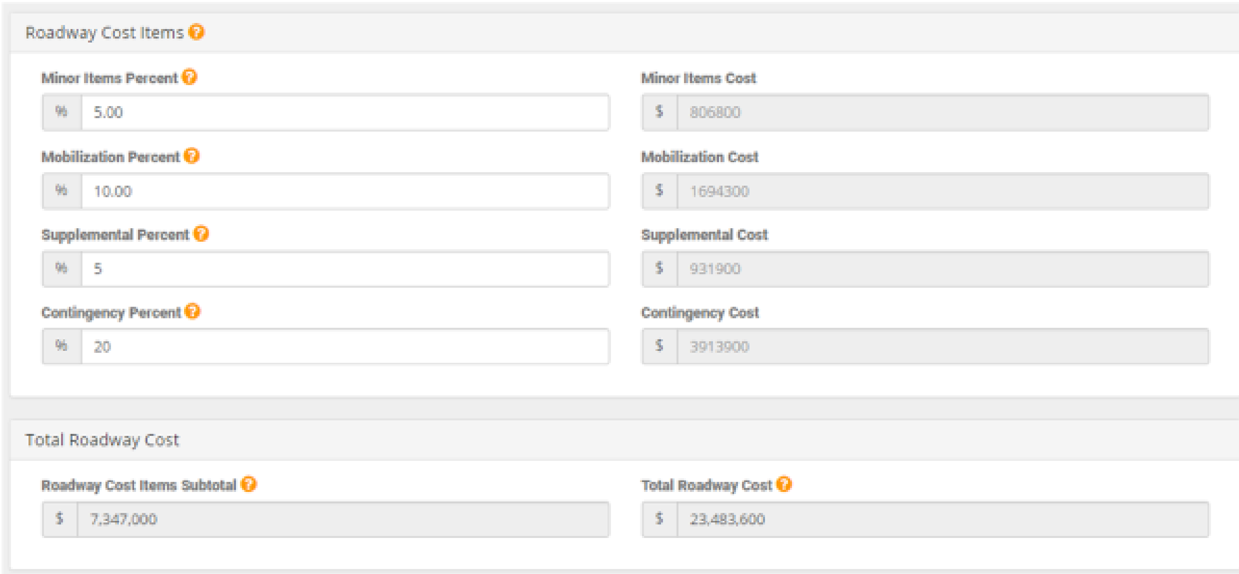
The Roadway Costs section is intended to capture costs associated with completing the roadway in addition to the physical construction costs. In this version of Cost Estimator, cost items in this section may only be specified as a lump sum or percentage (no detailed calculations).

The Roadway Cost section includes four additional cost items:

1. Minor Items (LS or % of Total Construction Cost)
2. Mobilization (LS or % of Total Construction Cost + Minor Items)
3. Supplemental (LS or % of Total Construction Cost + Minor Items + Mobilization)
4. Contingency (LS or % of Total Construction Cost + Minor Items + Mobilization + Supplemental)



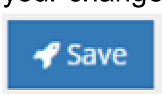
Enter the details for each cost item as a percentage or directly as a lump sum total. In this demonstration, each of these items are entered as a percent as shown below:



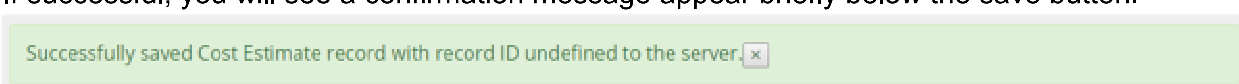
You may notice that the Total Roadway Cost contains two automatically calculated fields. The Roadway Cost Items Subtotal (left field) includes total Roadway Cost minus the Construction Costs (effectively, only the cost items shown in this section). The Total Roadway Cost includes Construction Costs plus the 4 cost items in this section (i.e. Roadway Cost Items Subtotal).

Next Steps...

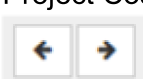
Once you have filled in all fields in the Roadway Cost section of Cost Estimator, be sure to save your changes by clicking the blue save button on the bottom of the screen.

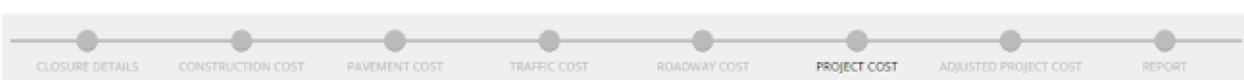


If successful, you will see a confirmation message appear briefly below the save button.

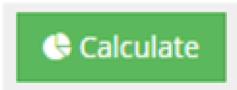


When you are ready to proceed to the next section, click on the right arrow to continue to the Project Cost section or skip another section directly from the navigation bar on the top.

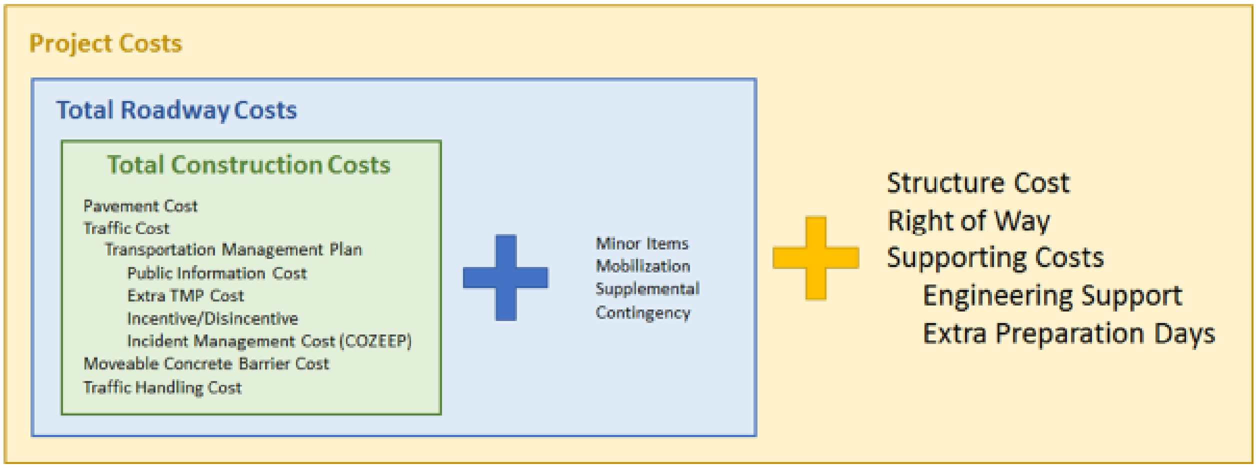




If you have already filled out the inputs from other sections, you can re-calculate your results by clicking the green Calculate button and skip to the Report section.


Calculate

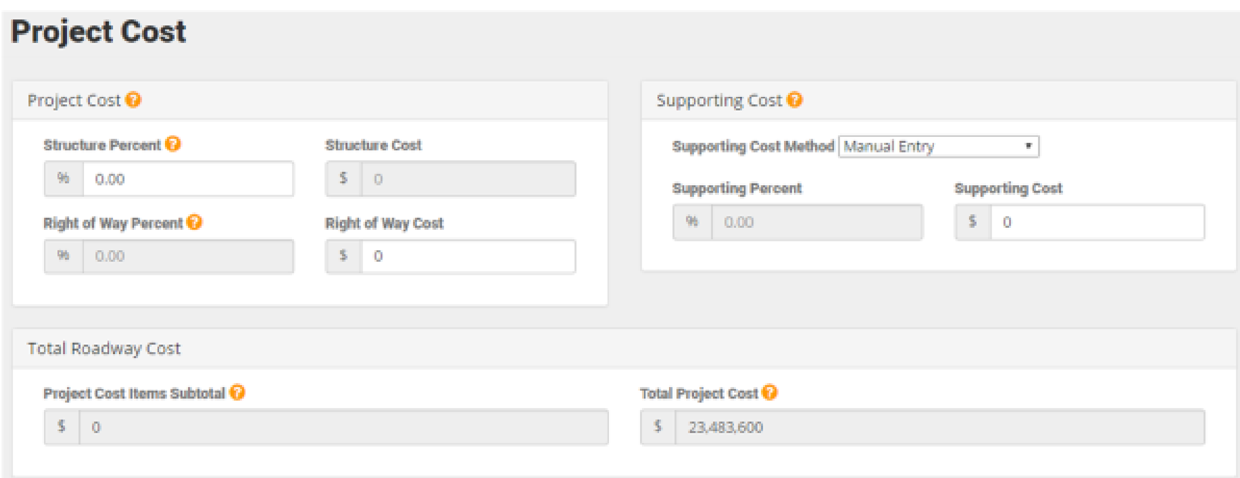
3.3.4 Project Cost



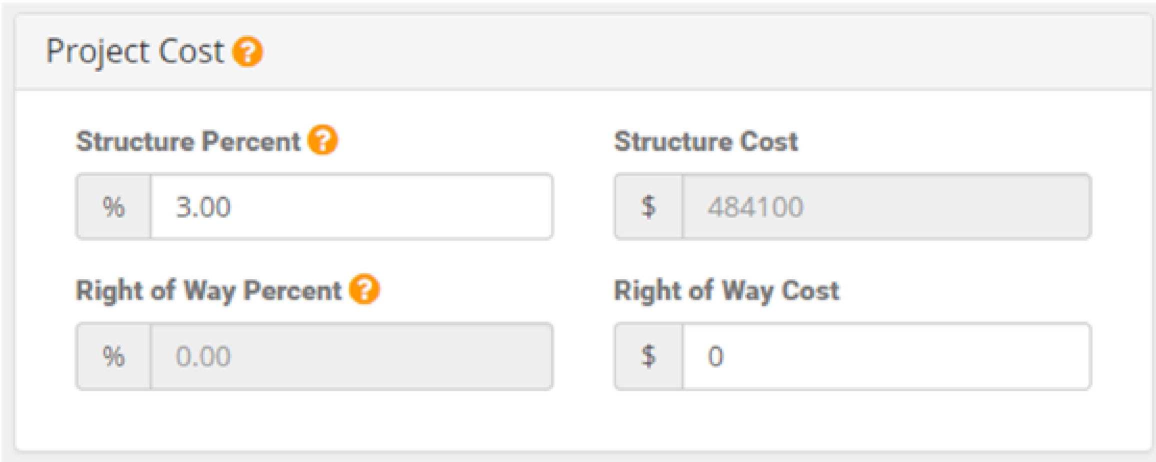
The Project Cost section is the last category of the Cost Estimator calculator and includes Total Roadway Costs plus 3 additional cost items: structure, right of way, and supporting costs. Recall that Total Roadway Costs also includes Total Construction Costs.

The additional items in the Project Cost section can be specified as follows:

- Structure Cost (LS or % of Total Construction Cost)
- Right of Way Cost (LS or % of Total Construction Cost)
- Supporting Cost (LS, % of Total Construction Cost, or calculated using Sub-Costs)

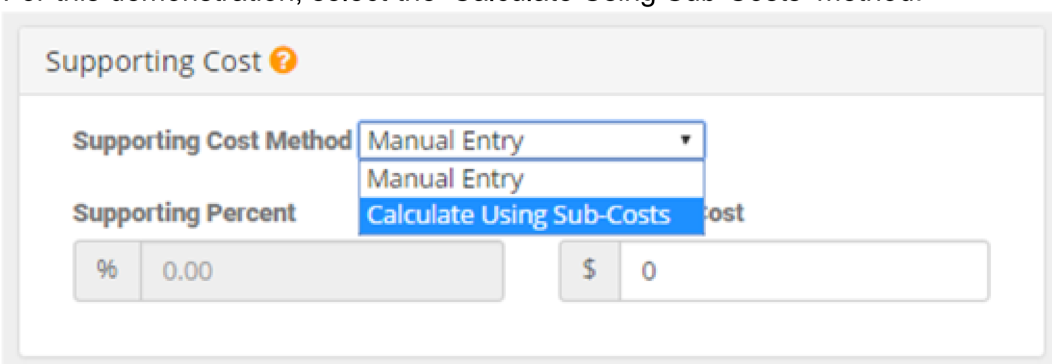


Begin by specifying the Structure and Right of Way costs as a percentage of Total Construction Costs or directly as lump sums. In this demonstration, Structure cost is specified as a percentage while Right of Way Costs are specified as a lump sum of zero.

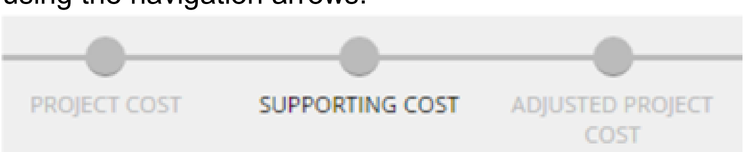


Supporting Cost can be specified in 3 ways. Using the dropdown menu for Supporting Cost method, you may select ‘Manual Entry’ to enter the cost as a percentage or lump sum, or ‘Calculate Using Sub-Costs’ to reveal an additional section of Cost Estimator to perform a detailed calculation for this cost item. This is similar to the options available for the Pavement and Traffic cost items.

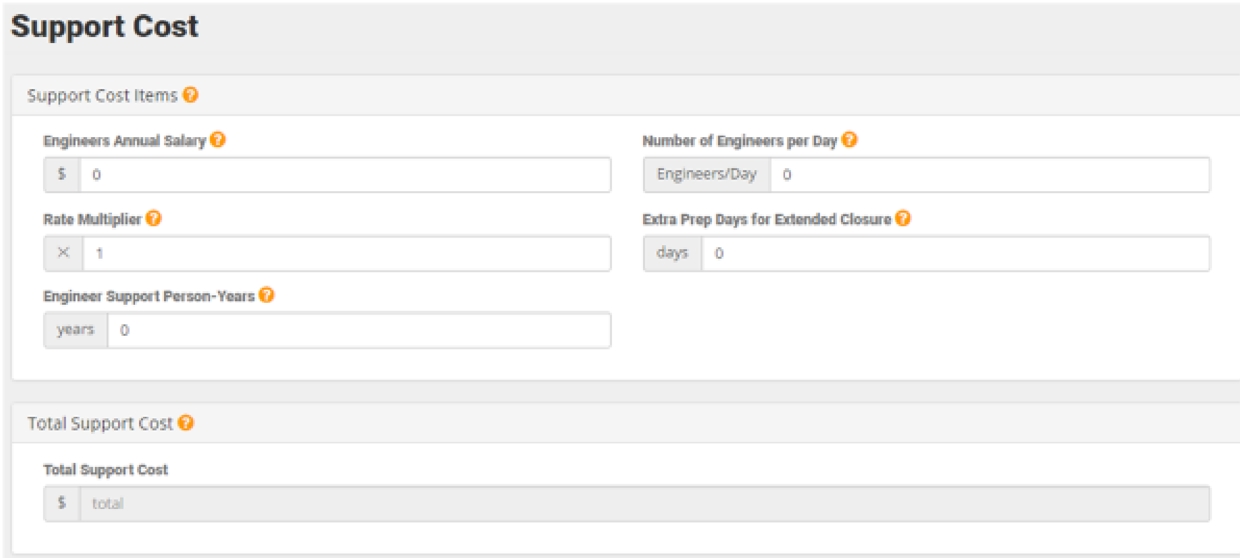
For this demonstration, select the ‘Calculate Using Sub-Costs’ method.



Navigate to the Supporting Cost section of the model by selecting it from the navigation bar or using the navigation arrows.



In the Supporting Cost section, you will calculate this cost item based on the additional amount of on-site engineering support hired to facilitate construction.

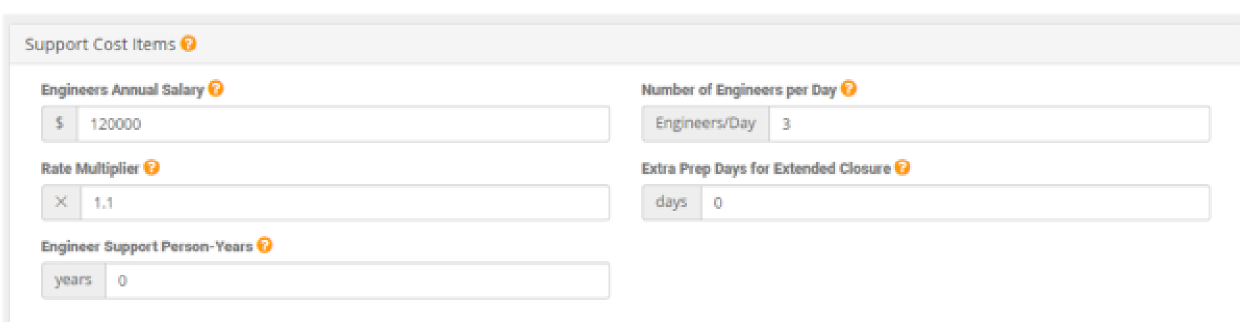


First, specify the annual salary of an on-site support engineer, the number of engineers required, and a rate multiplier. It is important to note that the engineering salary is converted into an hourly rate by dividing by 1880. The number of hours billed for each engineer is calculated directly from the number of closures and the closure duration specified earlier in the Closure Details section. In short, total salaries associated with closure hours is as follows:

(Engineering Salary/1880) * (Rate Multiplier) * (Number of Closures) * (Hours Per Closure)

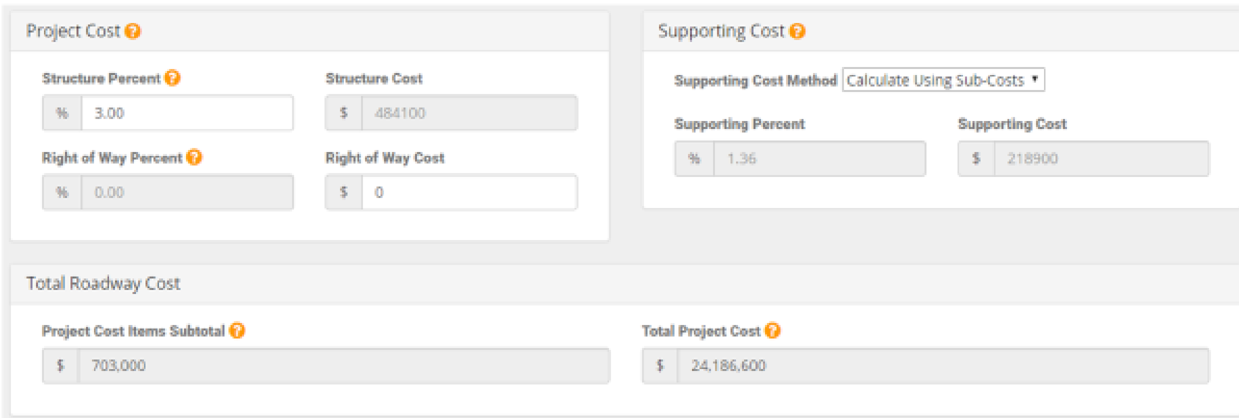
Specify the number of extra pre-days for an extended closure, which refers specifically to the extra number of workdays the engineers should be hired outside of the hours implied by your inputs in the Closure Details section. In this case, ‘days’ refers specifically to an 8-hour workday regardless of how you specified the closure window.

Additionally, you may also specify the additional number of engineer person-years that should be billed to the project. For example, specifying 2 engineer support person-years could imply 2 engineers hired for half a year or a single engineer hired for a year. The marginal added cost to the Support Cost is equivalent to the product of the annual salary, rate multiplier, and the number of person-years. In this example however, both Extra Pre Days and additional Engineer Support Person-Years are specified as zero.



After entering values for these five inputs, you will notice that the Total Support Cost will be updated in accordance to your inputs.

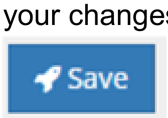
Return to the Project Cost section of Cost Estimator using the navigation bar or arrows.



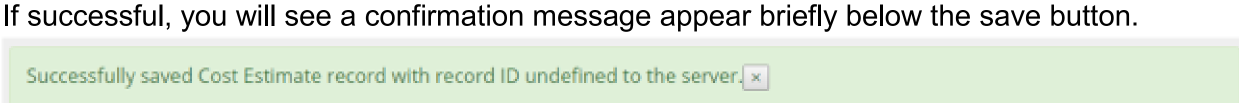
You may notice that the fields in the Supporting Cost box have been grayed out and updated with your totals from the Supporting Cost section. Additionally, the Total Roadway Cost fields are updated with the two totals. The Project Cost Items Subtotal (left) includes the sum of Structure, Right of Way, and Supporting Costs (i.e. the Total Project Cost excluding Roadway Costs). The Total Project Cost includes the 3 cost items included in this section plus Roadway Costs. The Total Project Cost is also the gross grand total for your paving project and includes all cost items from all sections prior to any adjustments for discount or escalation rates.

Next Steps...

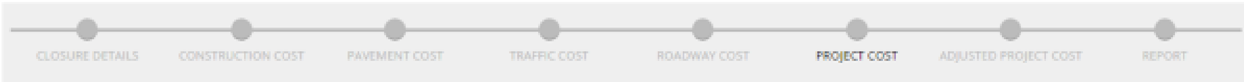
Once you have filled in all fields in the Project Cost section of Cost Estimator, be sure to save your changes by clicking the blue save button on the bottom of the screen.



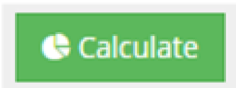
If successful, you will see a confirmation message appear briefly below the save button.



When you are ready to proceed to the next section, click on the right arrow to continue to the Adjusted Project Cost section or skip another section directly from the navigation bar on the top.

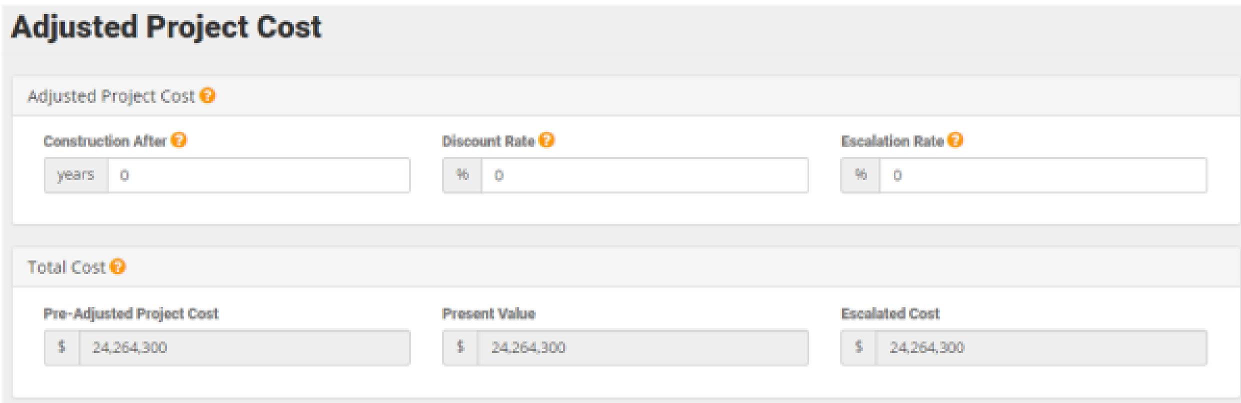


If you have already filled out the inputs from other sections, you can re-calculate your results by clicking the green Calculate button and skip to the Report section.



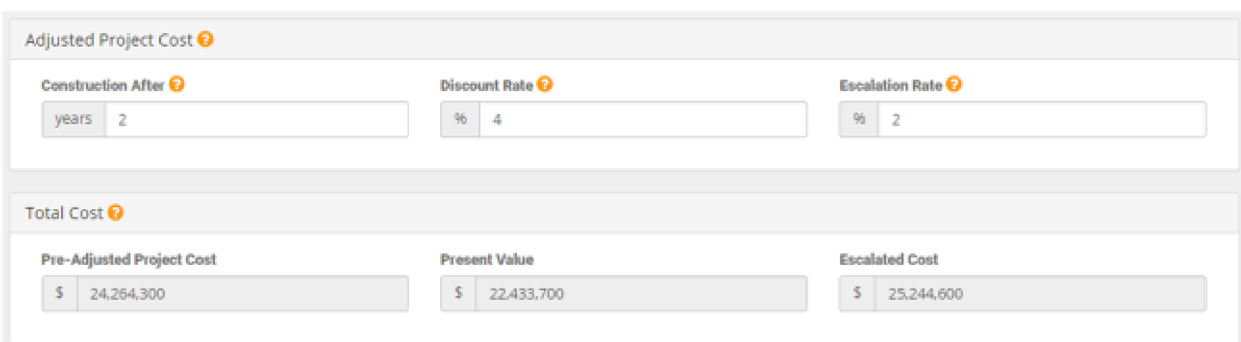
3.3.5 Adjusted Project Cost

The Adjusted Project Cost section allows you to adjust your Total Project Cost for discount and escalation rates based on the number of years in the future your project will occur. Notice that the Pre-Adjusted Project Cost is equal to your Total Project Cost since no adjustments have been made.



In the 'Construction After' field, enter the number of years in the future your project will be constructed. Specify a discount rate to reflect the notion that the value of currency may change by the time of construction. Specify an escalation rate to reflect the notion that the price of cost items may also change with time.

Note that if your 'Construction After' is specified as zero, your present value and escalated project costs will be equal to your Pre-Adjusted Project cost regardless of whether a discount or escalation rate was specified. In this demonstration, the pavement is intended to be built in 2 years based on a 4% discount rate and 2% escalation rate.



The Present Value of your project in current year dollars is calculated as follows:

Present Value = (Pre-adjusted Project Cost)/(1 + Discount Rate)^(Years After)

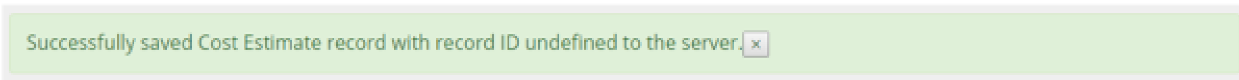
The Escalated Cost of your project in construction year dollars is calculated as follows:

Escalated Cost = (Pre-adjusted Project Cost)*(1+ Escalation Rate)^(Years After)

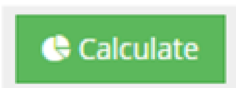
Next Steps...

At this point, you have successfully completed entering all necessary inputs to calculate the results of your simulation. Be sure to save your changes by clicking the blue save button on the bottom of the screen.

If successful, you will see a confirmation message appear briefly below the save button.



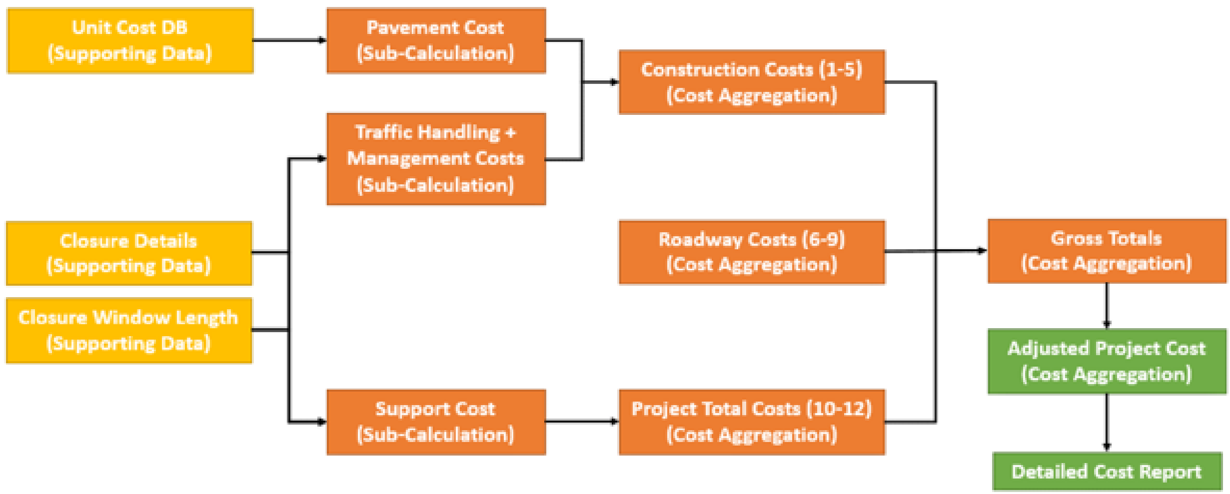
When you are ready to review the results of your calculation, click the green Calculate button, which will automatically navigate you to the Report section of Cost Estimator.



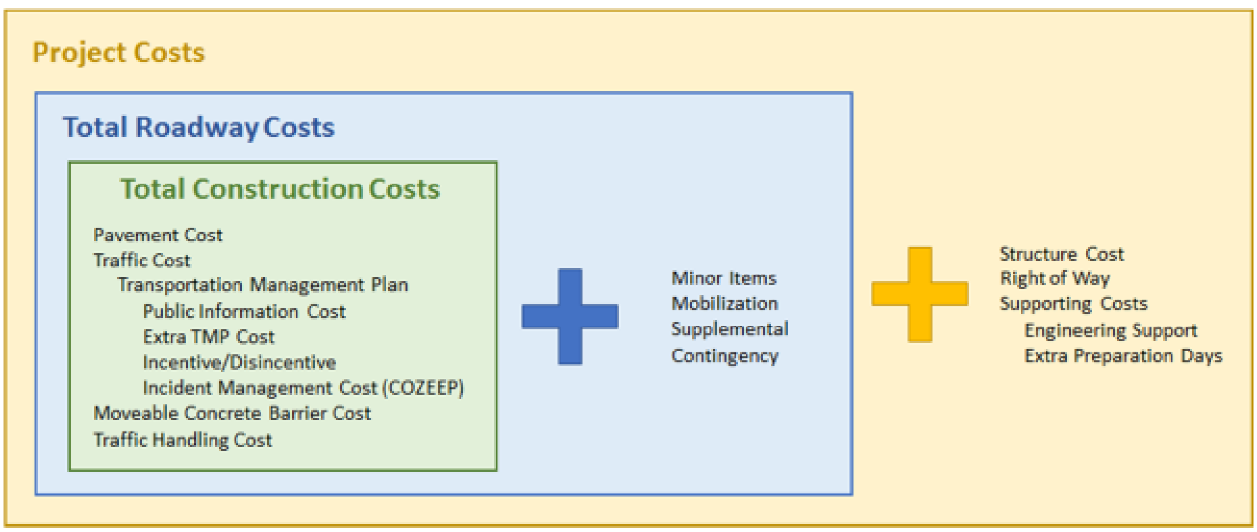
3.4.0. Interpreting Agency Cost Reports

This user guide is intended to provide a walkthrough of interpreting and understanding the outputs of a detailed productivity report after running a simulation in Cost Estimator.

Cost Estimator reports summarize the total project costs of your pavements and details any cost calculations based on the options you selected. The figure below outlines how your inputs in Cost Estimator are aggregated and combined to generate the total adjusted project costs.



More specifically, recall that your Pre-adjusted Total Project Cost include Total Roadway Costs, which in turn include Construction Costs and other items.



The report demonstrated in this user guide is a continuation of the Mill and Fill example used in the detailed walkthrough of the Cost Estimator calculator.

Agency Cost Estimate Report

US-101 San Jose (Milling HMA Overlay)

Notes

8-h Nighttime

4-5 lane each direction

SB = 7 miles and NB = 6 miles

Scope = 52 lane-mile = 13 mile x 4 lanes (some 5 lanes) = 55 lane-mile

Average Lane-width = (8'+4x12'+10')/4=16.5' lane width

4" Milling AC and 2" RACO + 2" OGAC

Results

Construciton After	2 yr
Discount Rate	4%
Escalation Rate	2%
Pre-Adjusted Project Cost	**$24,264,300**
Present Value	**$22,433,700**
Escalated Cost	**$25,244,600**

Construction Window

Schedule	Nighttime Closure
Start Time	10:00 pm
End Time	6:00 am
Hours per Closure	8
Number of Closures	176

Agency Cost Summary

Cost Item	Percentage (%)	Cost ($)
(1) Pavement	77.46% (of 1-5)	$12,499,200
(2) Traffic	7.54% (of 1-5)	$1,216,900
(3) Earthwork	3.00% (of 1-5)	$484,100
(4) Drainage	2.00% (of 1-5)	$322,700
(5) Specialty (SW)	10.00% (of 1-5)	$1,613,700
Construction Cost (1-5)		**$16,136,600**

The report begins by displaying your notes that distinguish your Cost Estimator simulation. Following this, the gross and adjusted totals are presented in the 'Results' column (left) as well as the Construction Window details specified in the Closure Details of your simulation.

Results

Construciton After	2 yr
Discount Rate	4%
Escalation Rate	2%
Pre-Adjusted Project Cost	**$24,264,300**
Present Value	**$22,433,700**
Escalated Cost	**$25,244,600**

Construction Window

Schedule	Nighttime Closure
Start Time	10:00 pm
End Time	6:00 am
Hours per Closure	8
Number of Closures	176

The Agency Cost Summary table provides additional details for each cost item, displaying only the main totals for each of the 12 major cost items from the Construction, Roadway, and Project Cost sections of the model.

Agency Cost Summary

Cost Item	Percentage (%)	Cost ($)
(1) Pavement	77.46% (of 1-5)	$12,499,200
(2) Traffic	7.54% (of 1-5)	$1,216,900
(3) Earthwork	3.00% (of 1-5)	$484,100
(4) Drainage	2.00% (of 1-5)	$322,700
(5) Specialty (SW)	10.00% (of 1-5)	$1,613,700
Construction Cost (1-5)		**$16,136,600**
(6) Minor Items	5.00% (of 1-5)	$806,800
(7) Mobilization	10.00% (of 1-6)	$1,694,300
(8) Supplemental	5.00% (of 1-7)	$931,900
(9) Contingency	20.00% (of 1-8)	$3,913,900
Roadway Cost (1-9)		**$23,483,600**
(10) Structure	3.00% (of 1-5)	$484,100
(11) Right of Way	0.00% (of 1-5)	$0
(12) Supporting Cost	1.84% (of 1-5)	$296,600
Project Cost (1-12)		**$24,264,300**

If your simulation included detailed calculations for the Pavement, Traffic, or Supporting Cost items, the details of each cost item calculation are also summarized. In this demonstration, all three items were specified as detailed calculations.

The first section includes a summary of your Pavement Cost, which was entered as a set of line items and unit costs.

Pavement, Traffic, and Support Cost Details

Pavement Cost Items

Code	Description	Unit	Quantity	Cost
150846	Remove Concrete Pavement	ft²	4,075,200	$3,463,900
390106	Asphalt Concrete (Open Graded)	ton	50,302.4	$4,061,400
390126	Rubberized Asphalt Concrete (Type G)	ton	50,302.4	$4,973,900

Contractor Resource Cost Multiplier: 1
Pavement Cost Total: $12,499,200

Next, the details of your Traffic Cost are displayed, including any further detail eWd calculations you may have specified in your simulation. In this demonstration, Incident Management (COZEEP), Transportation Management Plan, Moveable Concrete Barrier, and Traffic Handling costs were all specified with detailed calculations.

Traffic Cost

Incident Management (COZEEP) Cost	
Highway Patrol Loaded Rate	$95 per hr
Number of Offiers per Shift	3
Total Incident Management Cost	$401,280
Transportation Management Plan (TMP) Cost	
Public Information Cost	$100,000
Incentive/Disincentive	$0
Extra TMP Cost	$100,000
Total TMP Cost	$601,280
Moveable Concrete Barrier (MCB) Cost	
Barrier Length	1 miles
Barrier Months	5
Barrier Cost for First Month	$18.5 per ft
Barrier Cost for Each Additional Month	$3.5 per ft
Transformer Cost for First Month	$30,000
Transformer Cost for Each Additional Month	$15,000
Training Cost	$ 2,000
Total MCB Cost	$ 263,600
Traffic Handling Cost	
Traffic Handling Cost	$2,000 per closure
Total Traffic Handling Cost	$352,000

Traffic Cost Total $1,216,900

Finally, the last section available in the Cost Estimator report are the details for your Support Cost Calculations. In this demonstration, the Support Cost was specified as a detailed calculation rather than as a percent or lump sum total.

Support Cost

Engineers Annual Salary	$ 120,000
Number of Engineers per Day	3
Rate Multiplier	1.1
Extra Prep Days for Extended Closure	0
Total Engineering Support Person-Years	0

Support Cost Total: $296,600

The agency cost report includes all necessary details for another user to independently reproduce the results of your simulation. All inputs used in your simulation are included in this report.

At this point, you may revisit and update any section of the model as needed. However, it is important to note that no changes will be saved unless you click the save button on the bottom of the screen (even if you make changes and re-calculate your results).

Save

If successful, you will see a confirmation message appear briefly below the save button.

Successfully saved Cost Estimate record with record ID undefined to the server. ×