Introduction

This lab is based on the house construction scheduling problem tutorial in the Cloud Pak for Data documentation. The lab shows you how to use the Decision Optimization Modeling Assistant to define, formulate and run a model for a house construction scheduling problem.

The problem

You need to plan and schedule activities and subcontractors for a house construction project. Your schedule must start on a particular date. All the activities (masonry, carpentry, plumbing and so on) must be scheduled and there is a specified order of activities that must be respected (for example windows cannot be put in until the roof is completed). Each subcontractor can perform some of the necessary activities and with differing level of skills. Your schedule must determine the best (earliest) end time for the construction project ensuring that all activities have been scheduled and decide which subcontractor to assign to each activity. In addition, you would like to know how to optimize the skill level of your subcontractors on this project.

The data

You have data for this project as shown in the following spreadsheet. For each activity you have the duration that is needed to complete it, the activities that must precede it and the possible subcontractors who are available and qualified to perform that activity.

	A	B	C	D	E
1	***Activity***	***Duration in days***	***Preceding activities***	***Possible Subcontractors***	
2	masonry	35		Joe, Jack	
3	carpentry	15	masonry	Joe,Jim	
4	plumbing	40	masonry	Jack	
5	ceiling	15	masonry	Joe,Jack	
6	roofing	5	carpentry	Joe,Jack	
7	painting	10	ceiling	Jack,Jim	
8	windows	5	roofing	Joe,Jim	
9	facade	10	roofing, plumbing	Joe,Jack	
10	garden	5	roofing, plumbing	Joe,Jack,Jim	
11	moving	5	windows, facade, garden, painting	Joe,Jim	
12					

For illustration purposes, there are just 10 activities and 3 subcontractors shown. With Decision Optimization it is easy to change your data and solve the same problem with larger data sets.

For each activity you also have data concerning the level of expertise that each subcontractor has for that activity. The higher the number, the more expertise the subcontractor has. If a subcontractor has a zero skill level, he must not be assigned to the task. The following table shows part of this spreadsheet.

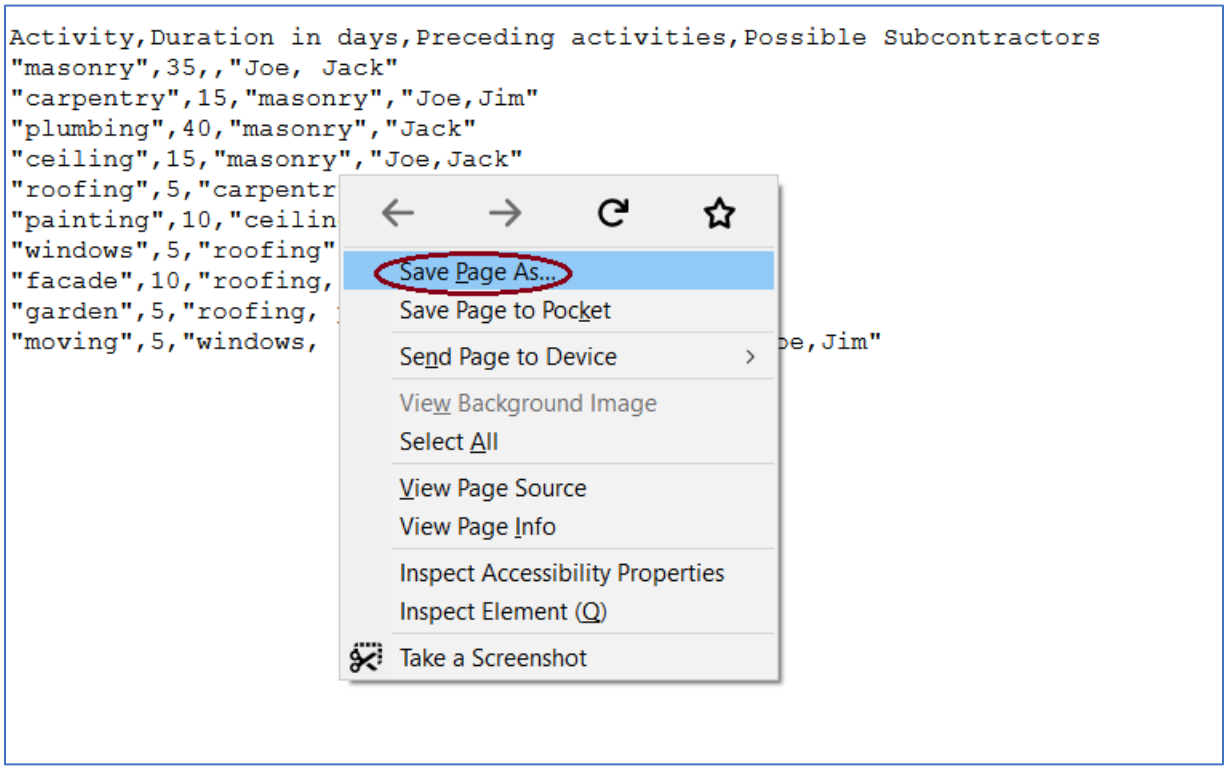
	A	B	C
1	***Activity***	***Subcontractor***	***Skill level***
2	masonry	***Joe***	9
3	carpentry	***Joe***	7
4	plumbing	***Joe***	0
5	ceiling	***Joe***	5
6	roofing	***Joe***	6
7	painting	***Joe***	0
8	windows	***Joe***	8
9	facade	***Joe***	5
10	garden	***Joe***	5
11	moving	***Joe***	6
12	masonry	***Jack***	5
13	carpentry	***Jack***	0
14	plumbing	***Jack***	7

You also have a table containing the names of the Subcontractors (Joe, Jack and so on) available for this project.

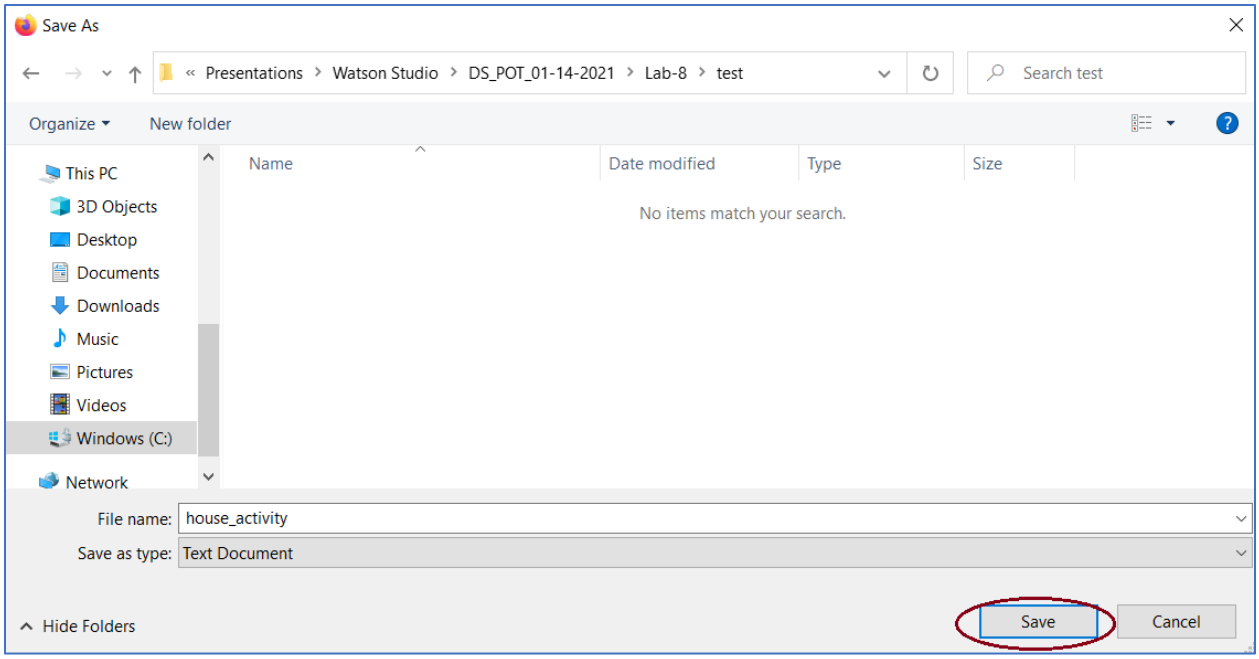
Obtain data files for this example

The data will be downloaded from the Decision Optimization Github site onto your machine.

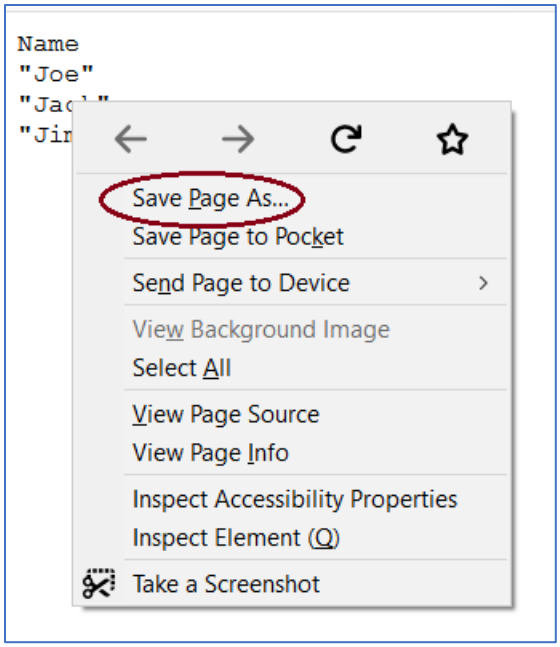
1. To download the house_activity.csv file click here.
2. Right click and then click on **Save Page As…**



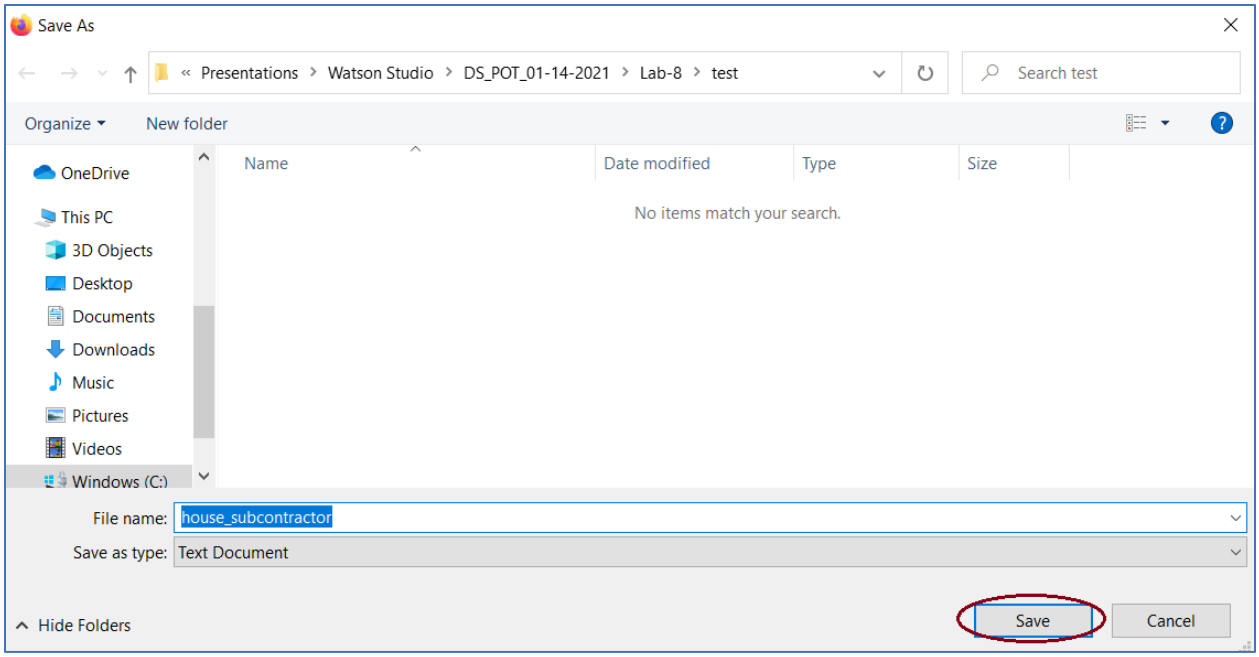
3. Navigate to the directory where you want to save the file and click **Save**.



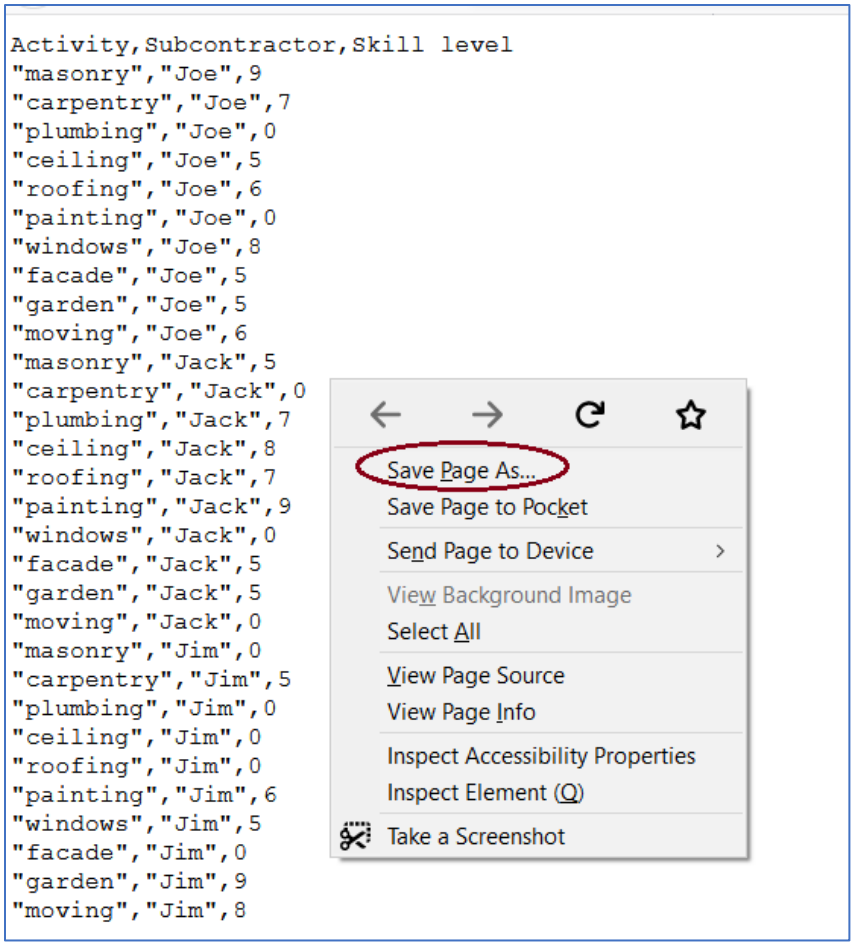
4. To download the house_subcontractor.csv file click here
5. Right click and then click on **Save Page As …**



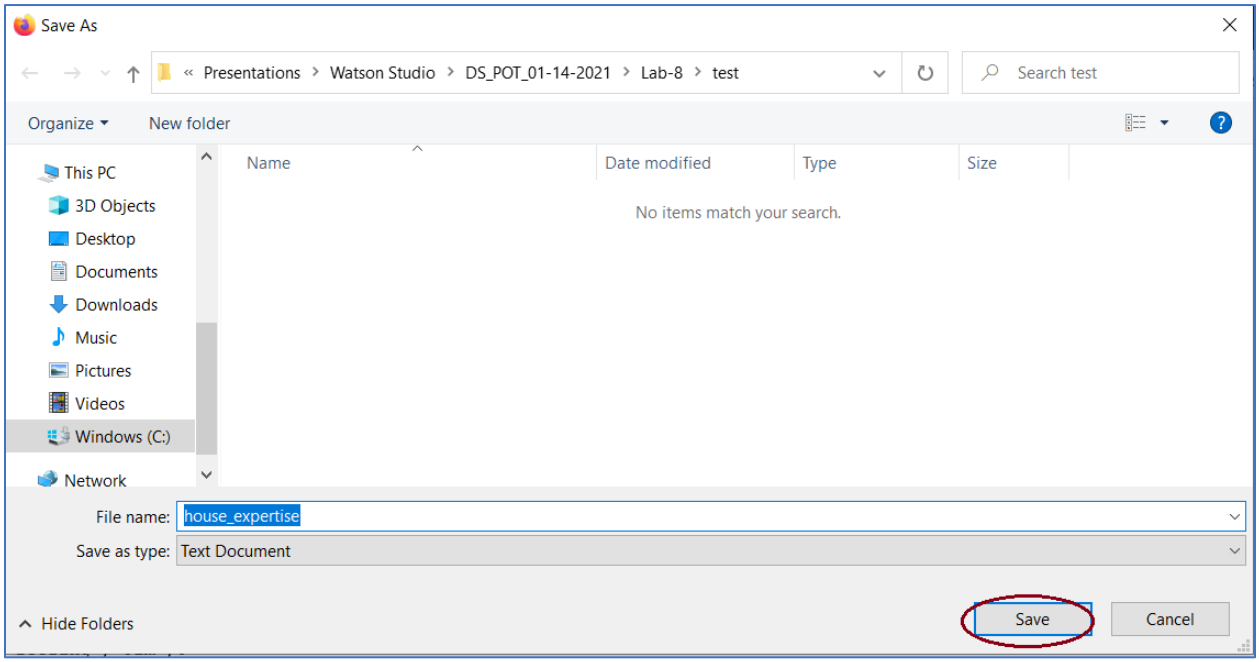
6. Navigate to the directory where you want to save the file and click **Save**.



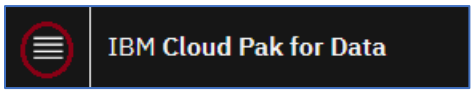
7. To download the house_expertise.csv file click here
8. Right click and then click on **Save Page As …**

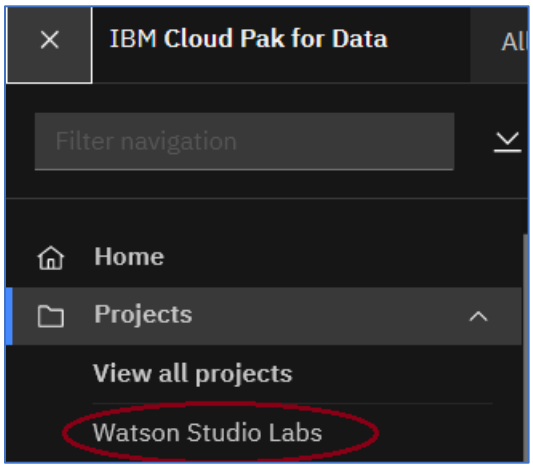


9. Navigate to the directory where you want to save the file and click **Save**.

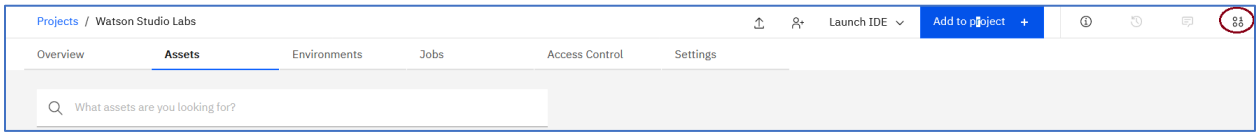


10. Go back to Cloud Pak for Data. Click on the icon, and then **Watson Studio Labs**.

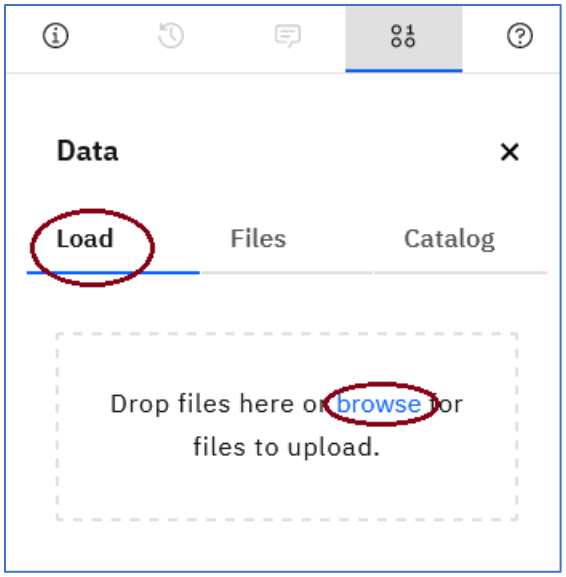




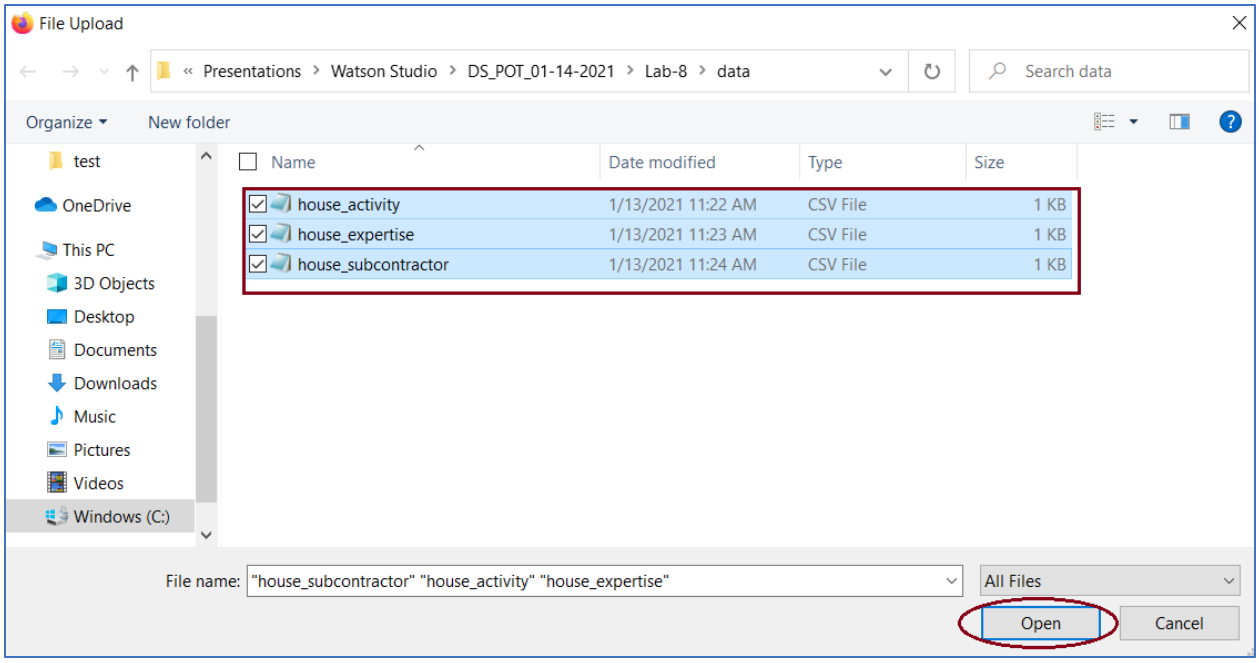
11. Click on the icon.



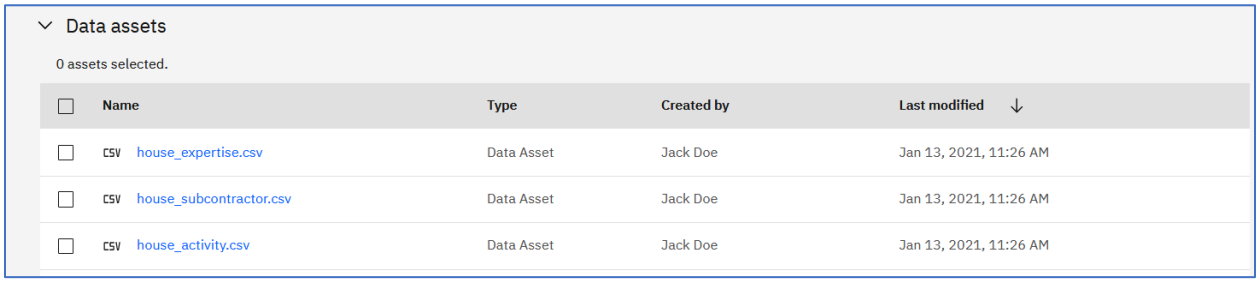
12. Click on **Load**, and then **browse**.



13. Click on the house_activity, house_subcontractor, and house_expertise files and click **Open**.



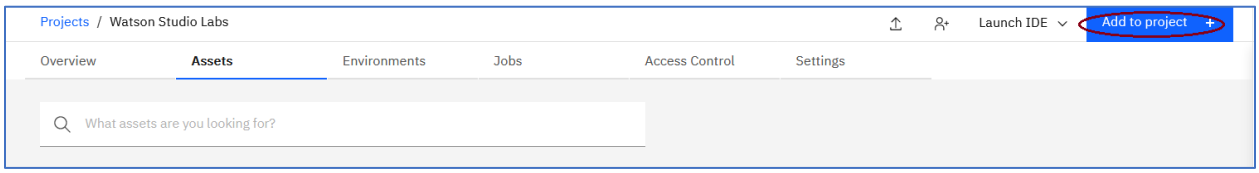
14. The data files are added as Data Assets in the project.



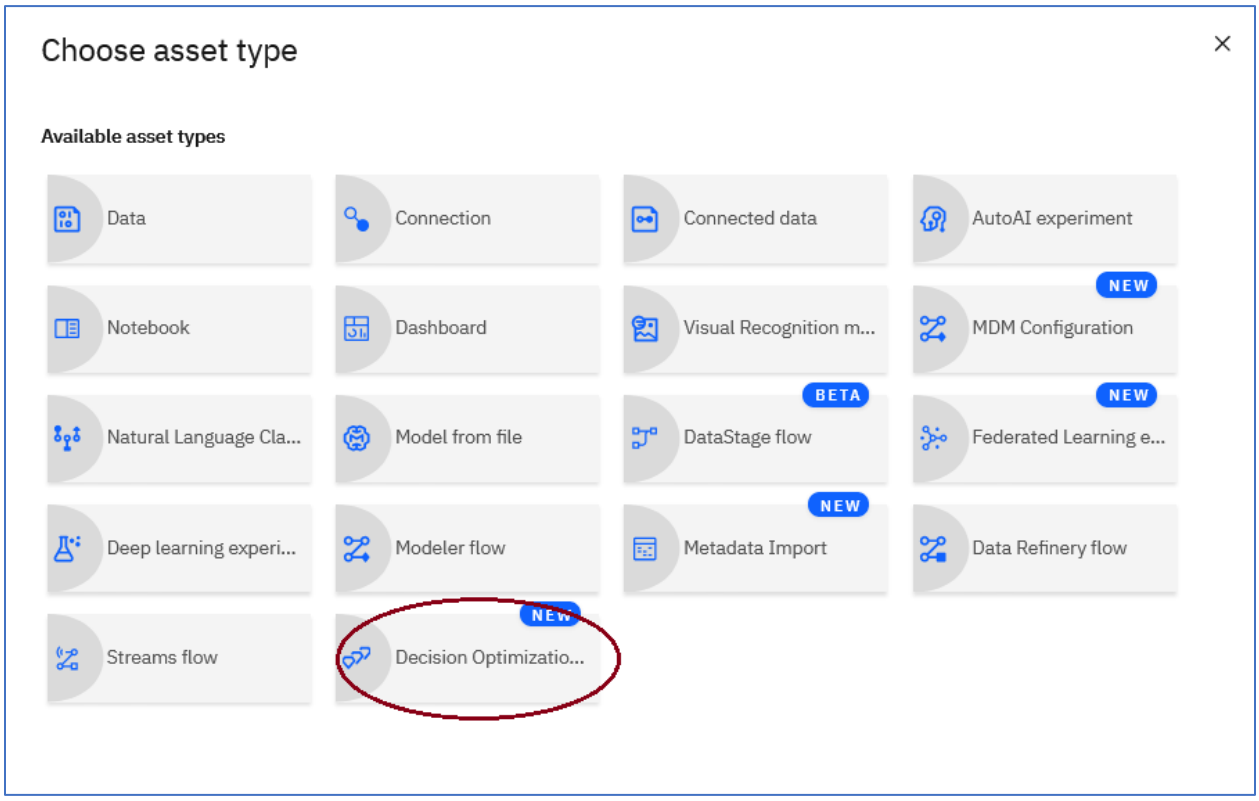
Create a Scenario

We now need to formulate the Decision Optimization problem.

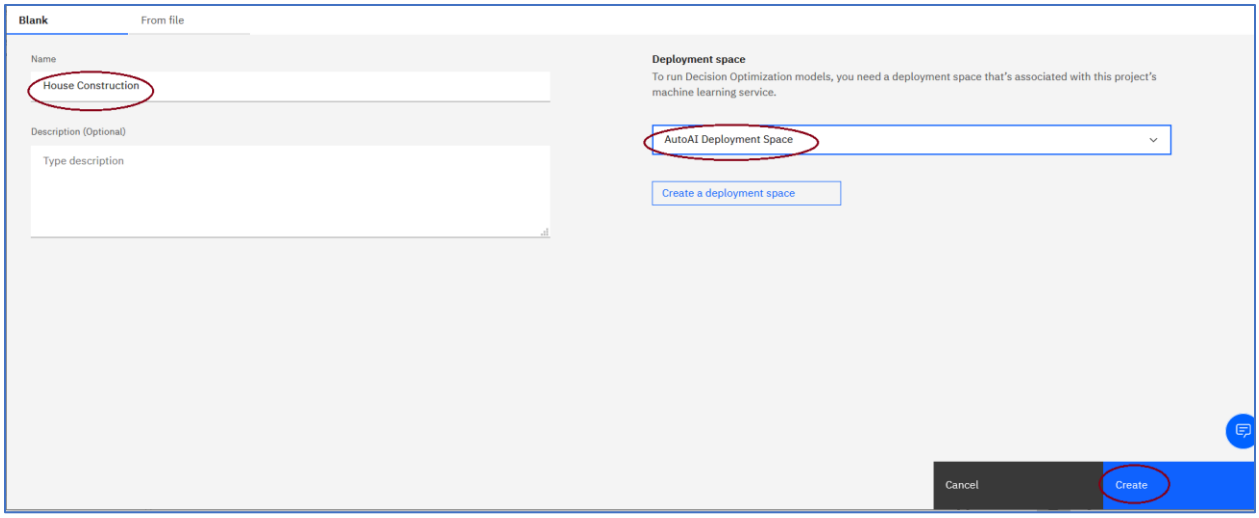
1. Click **Add to Project**



2. Click on **Decision Optimization**



3. In the **New Decision Optimization experiment** window that opens, enter **House Construction** for the **Name**, select the **AutoAI Deployment Space** and click **Create**.

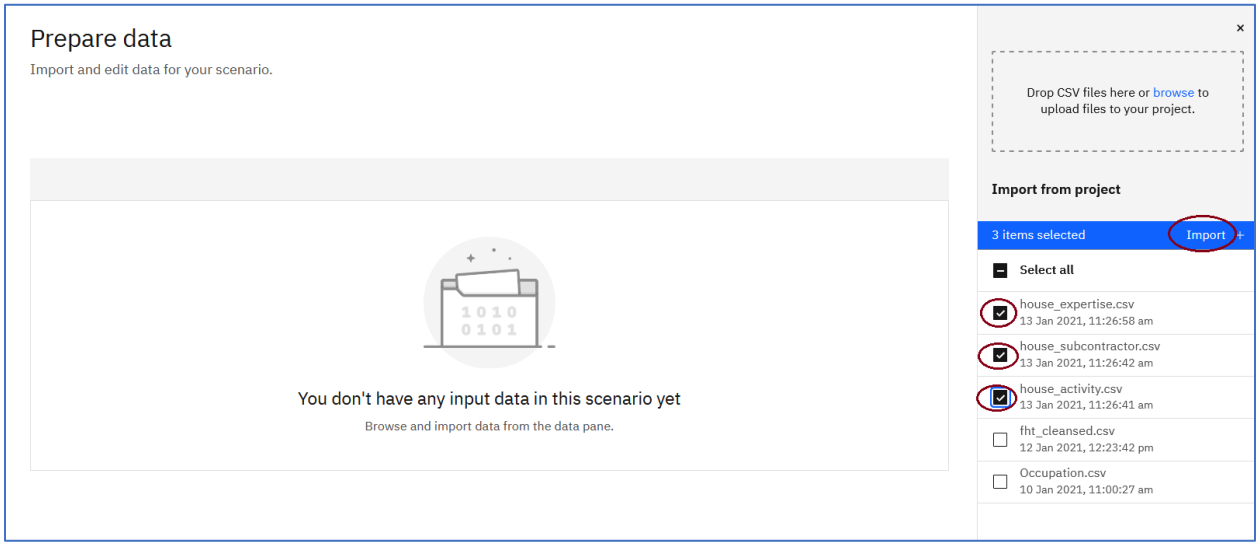


4. A new scenario is created. The scenario specifies the combination of data and the optimization model formulation that you want to solve. You can create different scenarios with different variants of data and model formulations.

Prepare data

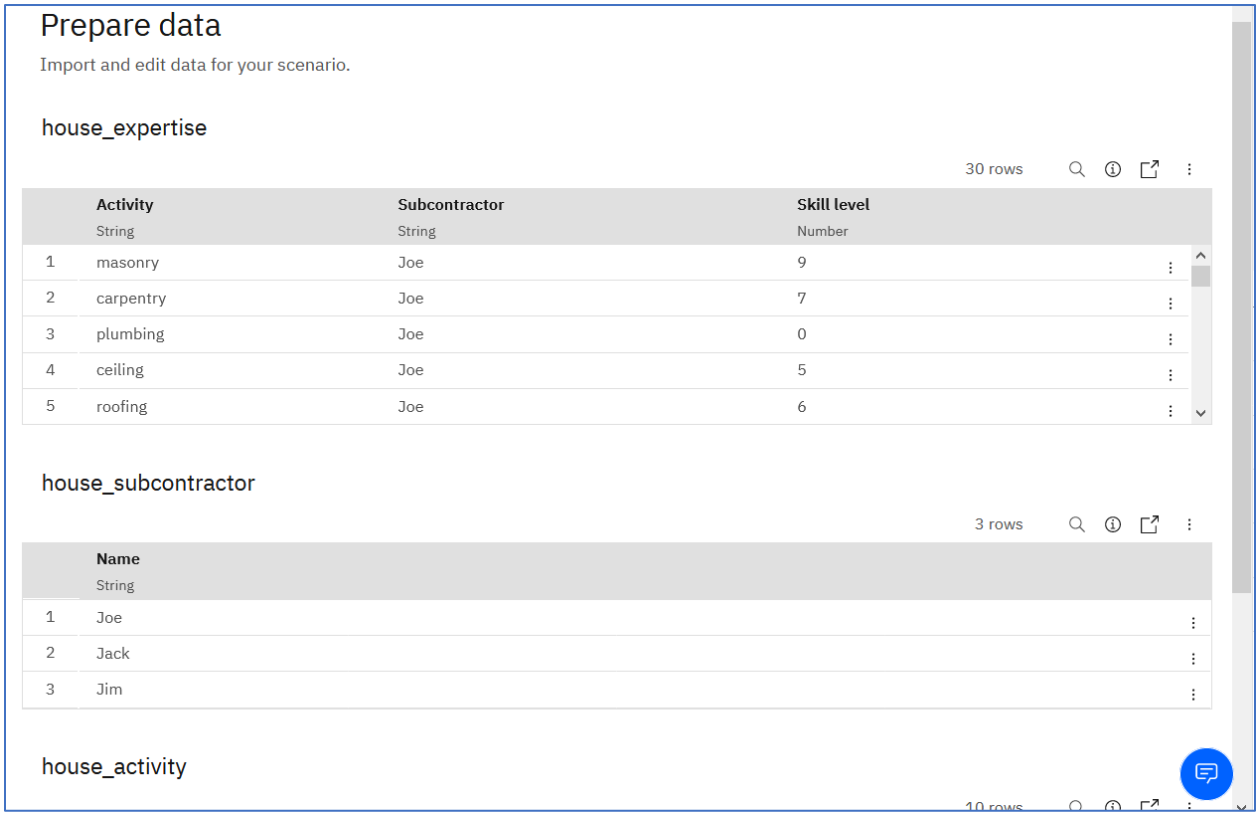
The model builder opens displaying the Prepare data view. The data files that you have in your project are displayed in the data pane. (If necessary, click  to open the data pane.)

1. Select the three house sample files and click **Import**.



2. The data files you imported are now displayed as tables in the **Prepare data** view. The following image shows the data files `house_activity.csv`, `house_expertise.csv`, and

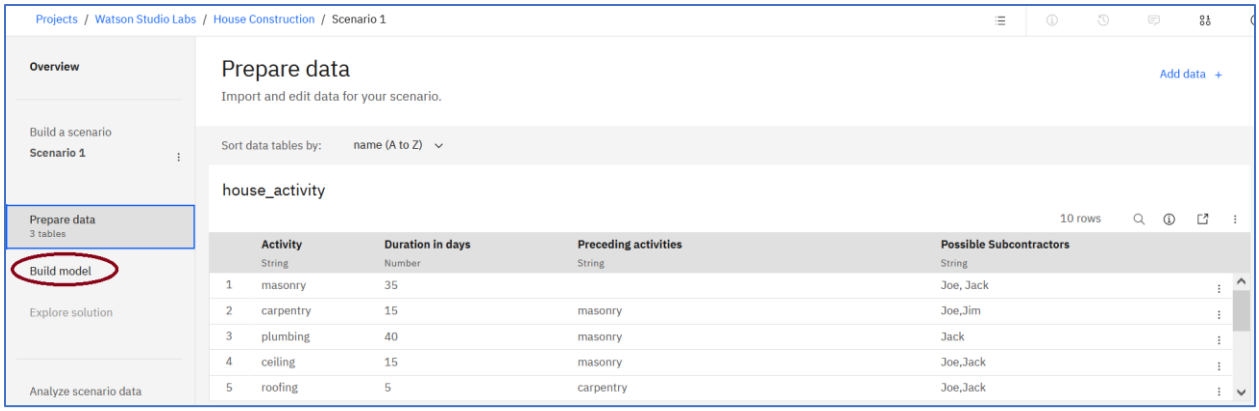
`house_subcontractor.csv` imported in Scenario 1. Note the order of the files may be different in your display.



3. You can view all the data by scrolling in a table. You can also view all the data by clicking the **Open the table in full mode** icon of a particular data table. You can edit data values directly in the table as well as in full mode.

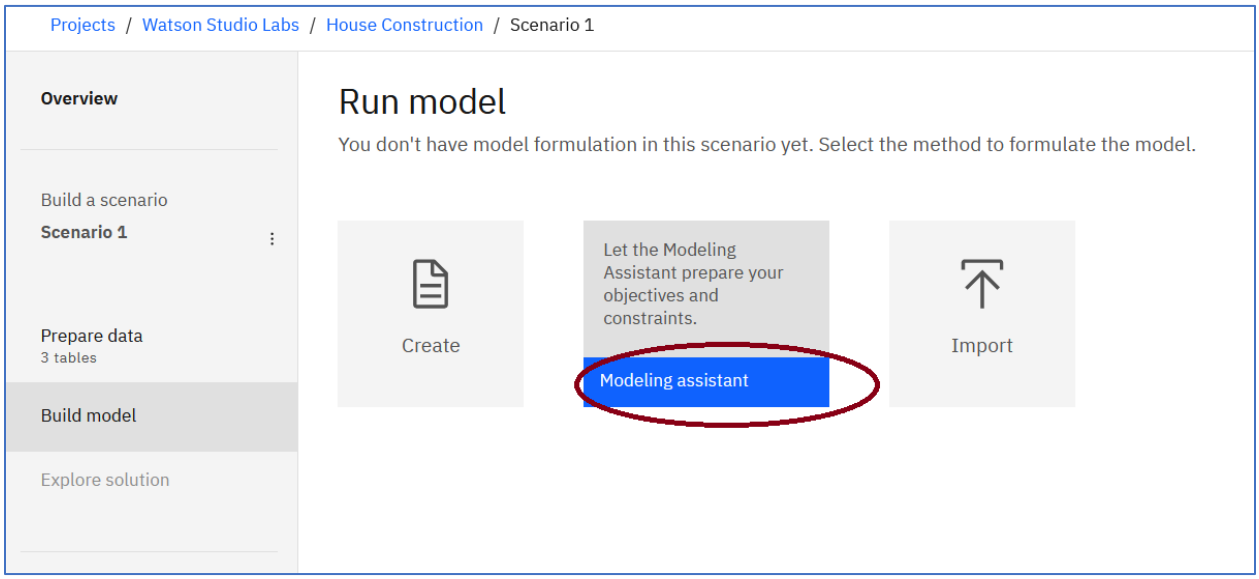
Use the Modeling Assistant

1. Click **Build model** in the sidebar and a pop-up window appears asking you how you want to formulate your model (whether you want to create or import a model with Python or OPL or use the Modeling Assistant).

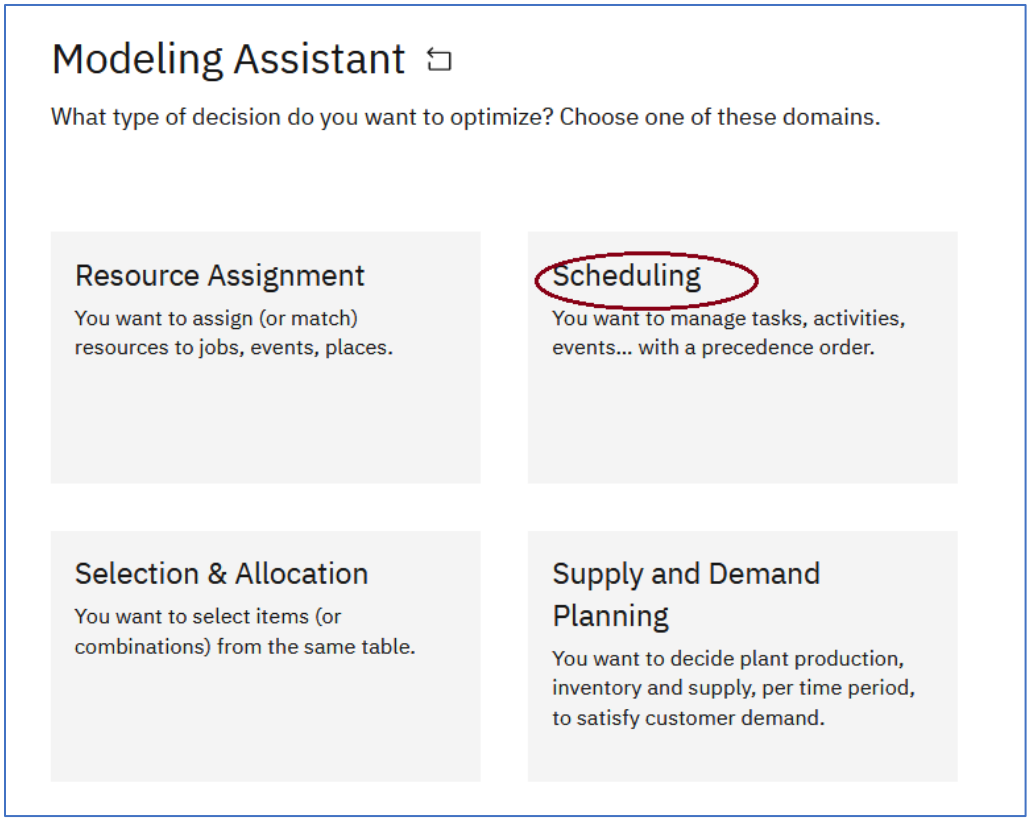


2. Click “x” to close the error message

3. Hover over the **Use modeling assistant** and then click on M**odeling assistant**.

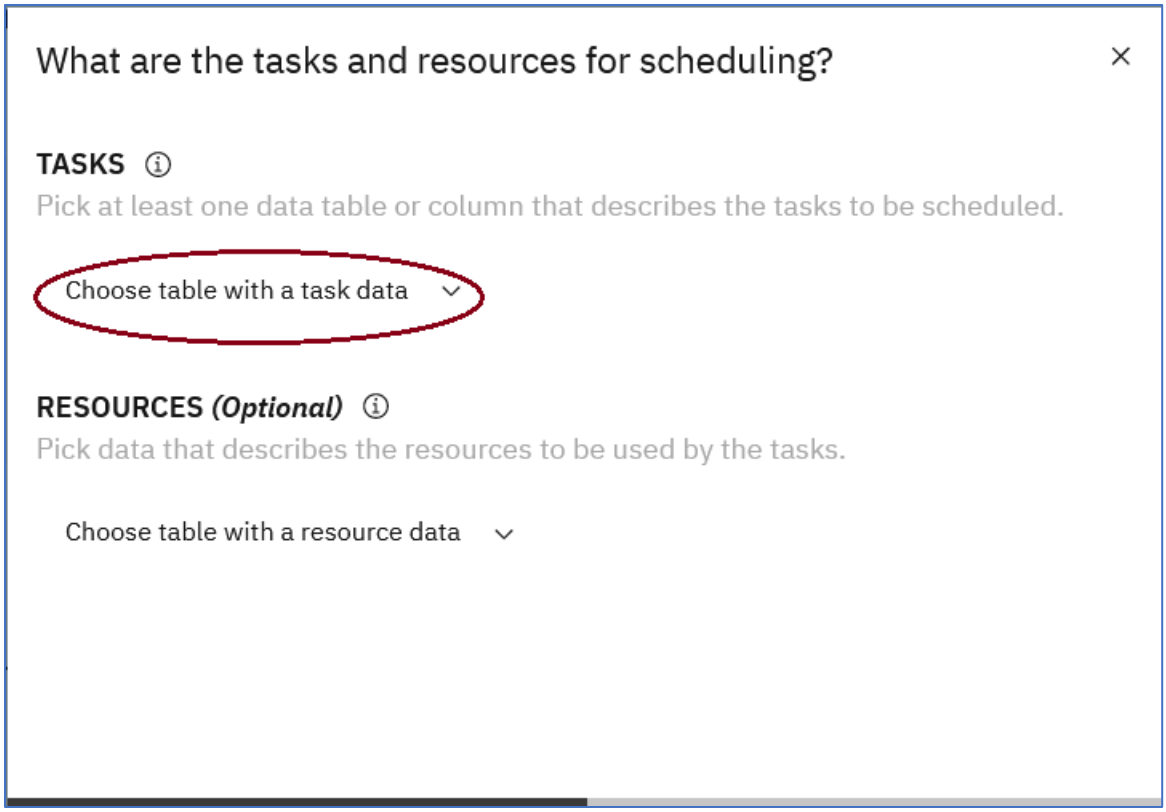


4. You need to select the decision domain for your problem. Currently, the Modeling Assistant will support four (4) domains which are **Resource Assignment**, **Scheduling**, **Selection and Allocation** and **Supply and Demand** domains. Click on **Scheduling**.

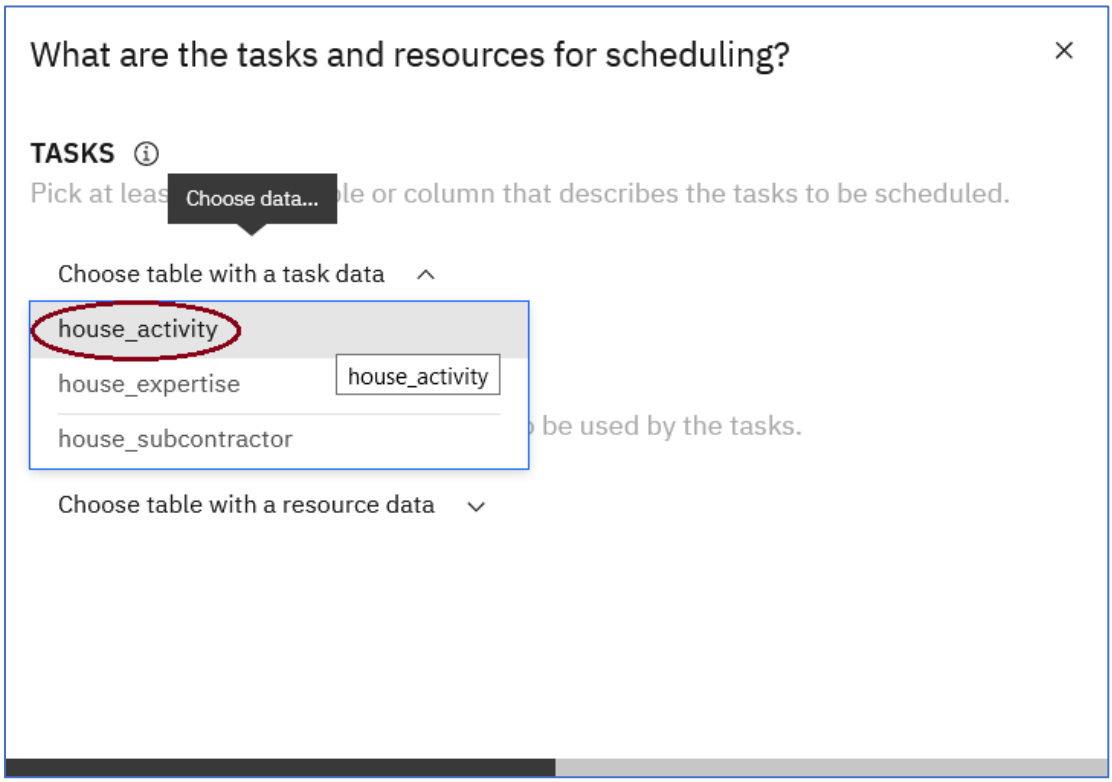


5. After selecting your domain, a pop-up window appears for you to map your data to the scheduling concepts **Tasks** and **Resources**. Tasks are whatever you want to plan and schedule over time. You must define at least one task to be scheduled. In this example, your tasks are construction activities such as masonry. Resources can be human, machine, equipment or anything you want to use for the tasks. In this case your resources are your subcontractors.

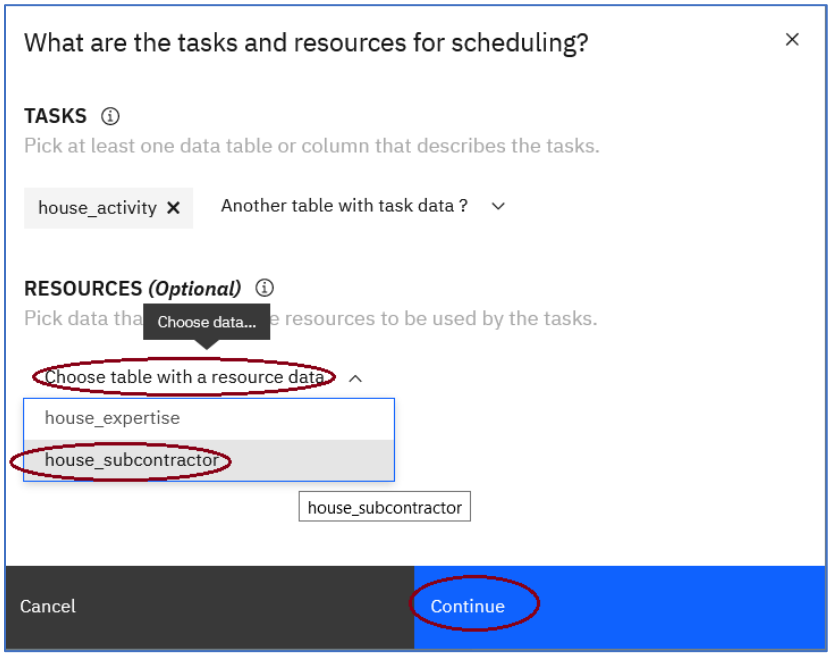
   Under **TASKS**, click **Choose table with a task data**



6. Click on house_activity from the drop-down list.



7. Under **RESOURCES** click **Choose table with a resource data** and choose `house_subcontractor`. The names of possible tasks and resources for you to choose from are taken from your imported data. For this example, you only need to map activities and subcontractors, but you could add other tasks and resource mappings if your model required it. You can remove any mapping by hovering over it and selecting the delete icon to its right. Click **Continue**.



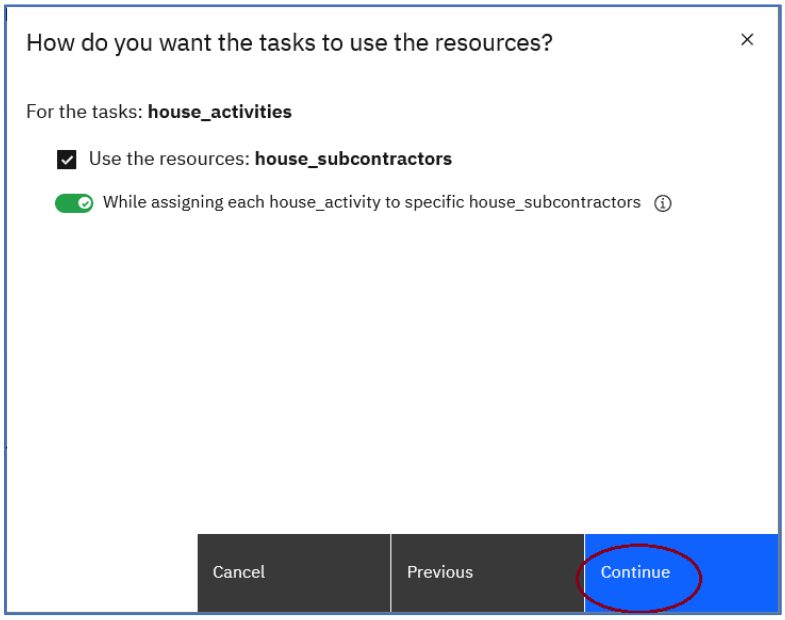
8. In the window, **How do you want the tasks to use the resources** you have three options

- **Use resources with assignment**: The default option. This means that you want to obtain a schedule for your house construction activities with the best sequence of house construction activities, taking into account the start times, durations and precedence order, and so on, and with named subcontractors assigned to the activities.
- **Use resources without assignment:** You can use resources, and clear the **While assigning...** check box to choose not to assign specific contractors to your activities. This means that you want to obtain a schedule for your house construction activities with the best sequence of house construction activities, taking into account the start times, durations and precedence order, and so on. You still want the numbers and types of subcontractors you have available to be considered in the obtained schedule (for example 3 plumbers, 2 carpenters,...), but they don't have to be assigned to specific people (for example Joe, Jack, Jim).

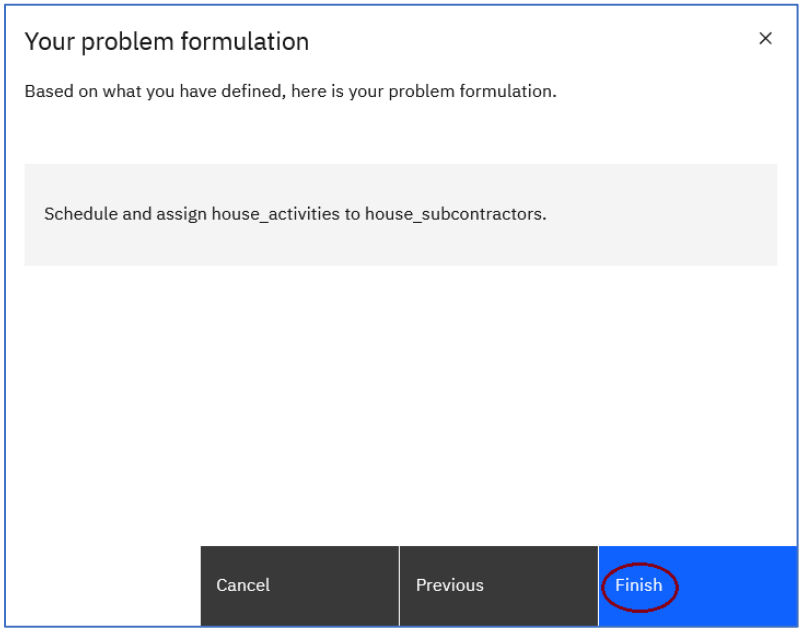
  When you use resources, with or without assignment, you can also decide to add further time-based capacity constraints to your model. For example, you can specify limits on the number of subcontractors that can be used in parallel at any given time, or individual or total subcontractor availability over a time period.

- **Continue without resources** You can clear all the options and just click **Continue** to schedule the tasks *ignoring all resource limits*. This means that you want to obtain a schedule with the best sequence of house construction activities, taking into account the start times, durations, precedence orders, and so on, but without considering your subcontractors.

  Click **Continue** (we will use the default setting)



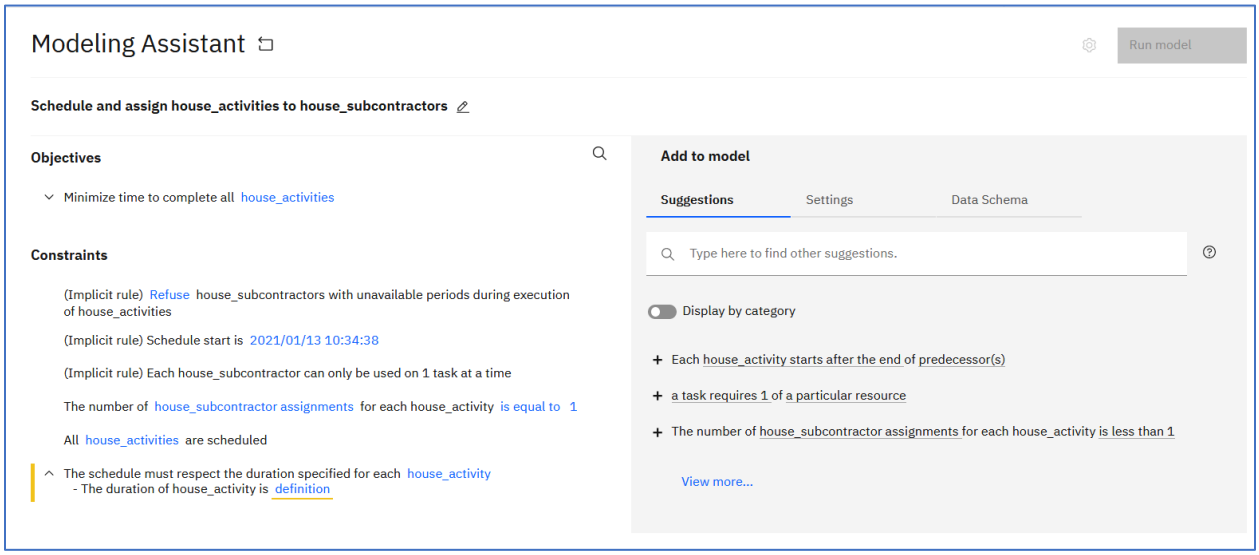
9. The problem that you want to solve is now formulated in a concise statement. Click **Finish**.



Your model formulation

Now that you have specified the problem that you want to solve, the Modeling Assistant provides you with a partially completed formulation in the Modeling Assistant view. The **Objectives** and **Constraints** pane contains the model that you will run. The **Add to model** pane displayed on the right, contains more suggestions that you can include in your model formulation. If you have re-sized your window, it is possible that the Add to model pane appears underneath the Objectives and Constraints pane.

The model consists of an objective to be attained (maximized or minimized) and some constraints that must be satisfied. For scheduling problems like this, your objective is to work out the best schedule. The best, in this case, is one in which the time to complete all the activities is minimized. (You want to complete the house construction as quickly as possible as this will reduce costs.) This objective as well as some standard scheduling constraints have been automatically added to your model. You can also use the search field above the Objectives to search the objectives and constraints.



These scheduling constraints ensure that:

- the scheduling will be performed from the start time that you define for your construction project
- each subcontractor can only be assigned to one task at a time.
- each activity has one subcontractor assigned to it
- all activities are present in the schedule, in other words, no activity can be omitted from the schedule
- the duration time for each activity is respected

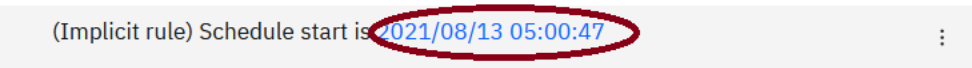
It is possible that your constraints are displayed in a different order. There is also a constraint that is automatically added to all scheduling problems with assignment. This enables you to accept or refuse to assign subcontractors who have unavailable periods during the activities that

are scheduled. In this example, unavailable periods are not considered so leave this constraint as it appears by default.

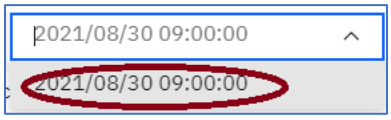
Some constraints have more details that can be displayed or hidden by clicking the arrows on each line. A bar next to the constraint  indicates that there is a value or definition that you must add. You can add items by clicking the term shown underlined and typing in or selecting from a drop-down list, and you must complete the model before running it. In the model view of your scenario, if you click the Replace arrow  next to Modeling Assistant, you will return to the screen where you choose whether you want to create your model in Python or OPL, with the Modeling Assistant or in a Python notebook or import an existing model. If you choose to replace your model at this stage, you will overwrite your current model and lose your changes. If you want to keep a copy of your current work in progress, create a new scenario before changing the model.

Complete the constraints information.

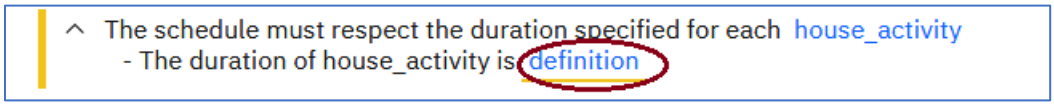
1. Set the start date. Click on the current start date.



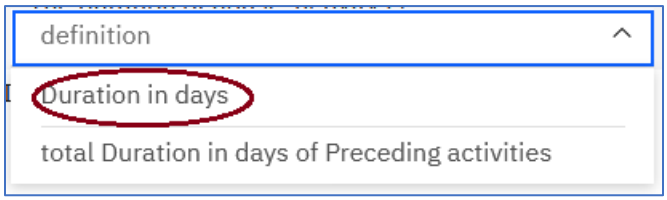
2. Type 2021/08/30 9:00:00 and the press the <Enter> key. Click on the entry in the drop down list.



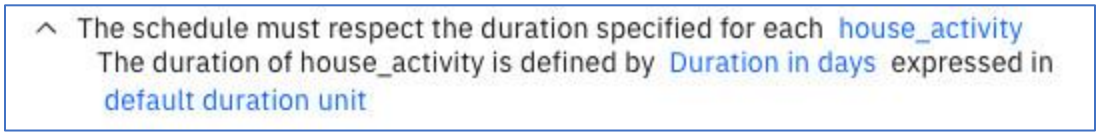
3. Set the housing task durations. Click on **definition**



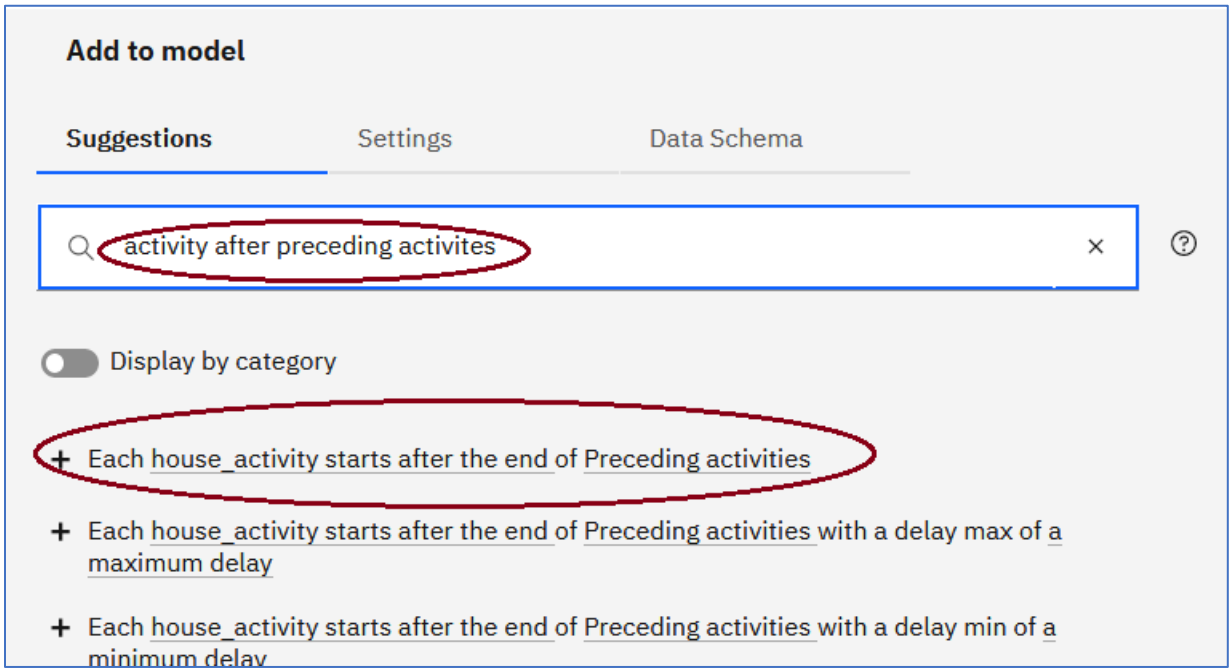
4. Click on **Duration in days**



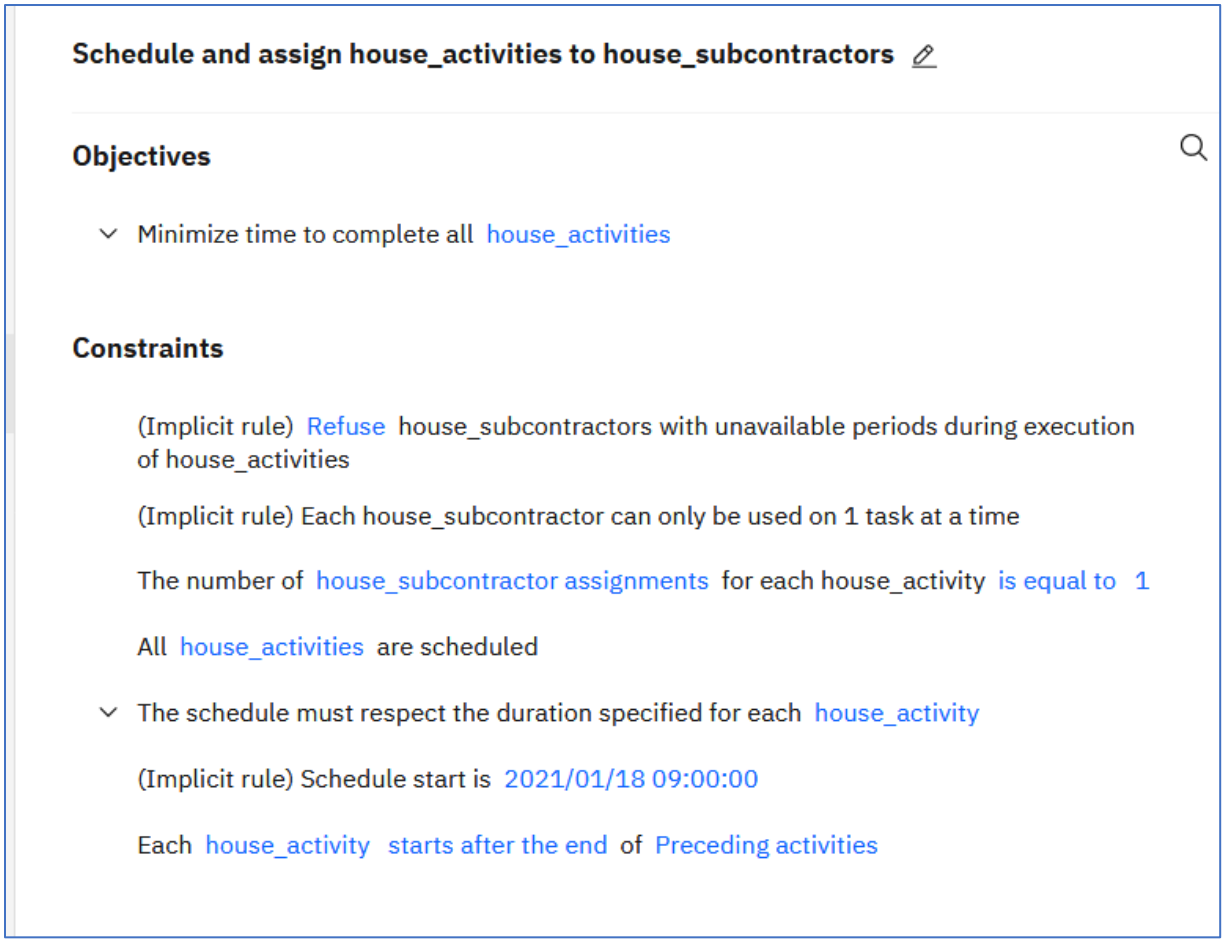
5. The default duration unit **expressed in default duration unit** is added to the end of the constraint. You might modify this by clicking **default duration unit** and selecting **days**, but the default unit is already days. You can also modify the default duration unit and customize how dates and times are defined, in the **Settings** panel. Once you have completed the duration constraint, the row is no longer highlighted.



6. The constraints are no longer highlighted once you have entered values. The model, however, isn't quite complete. You might want to make sure that your schedule considers the order of precedence of tasks so that each activity can only start after those that must precede it. Type in **activity after preceding activities** in the **Suggestion** pane and then press the <Enter> key. Select the **Each house_activity starts at the end of preceding activities.**

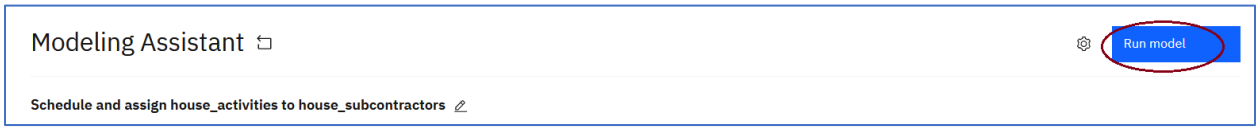


7. The new precedence constraint appears in your model formulation.

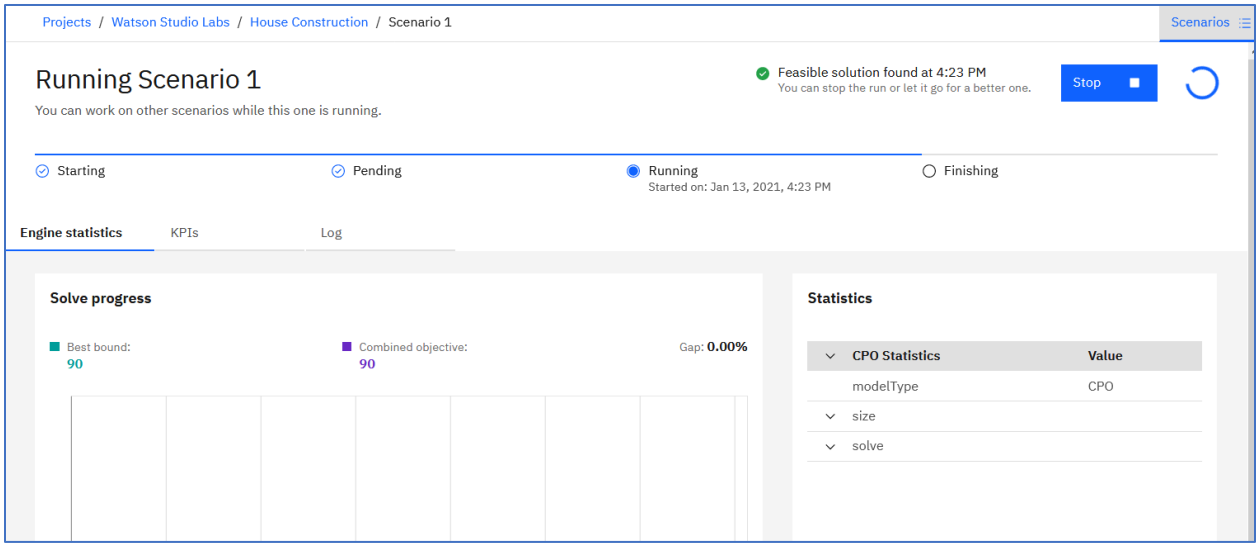


Run the Model

1. When you have completed your model and there are no objectives or constraints still highlighted, you can run it to find a solution that will decide the best optimal schedule based on your model objectives and constraints. Click the **Run model**.

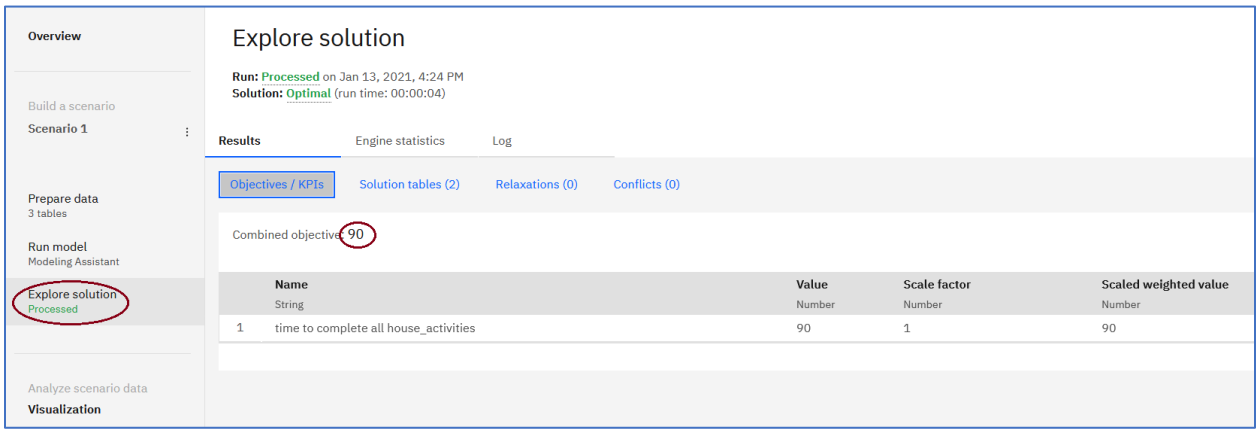


2. A pop-up window appears to show you the progress of this run and while this is showing, you cannot edit the model. If you want to end this run before the optimal solution is obtained, you can quit by clicking **Stop** . When the optimal solution has been found the pop-up window closes.



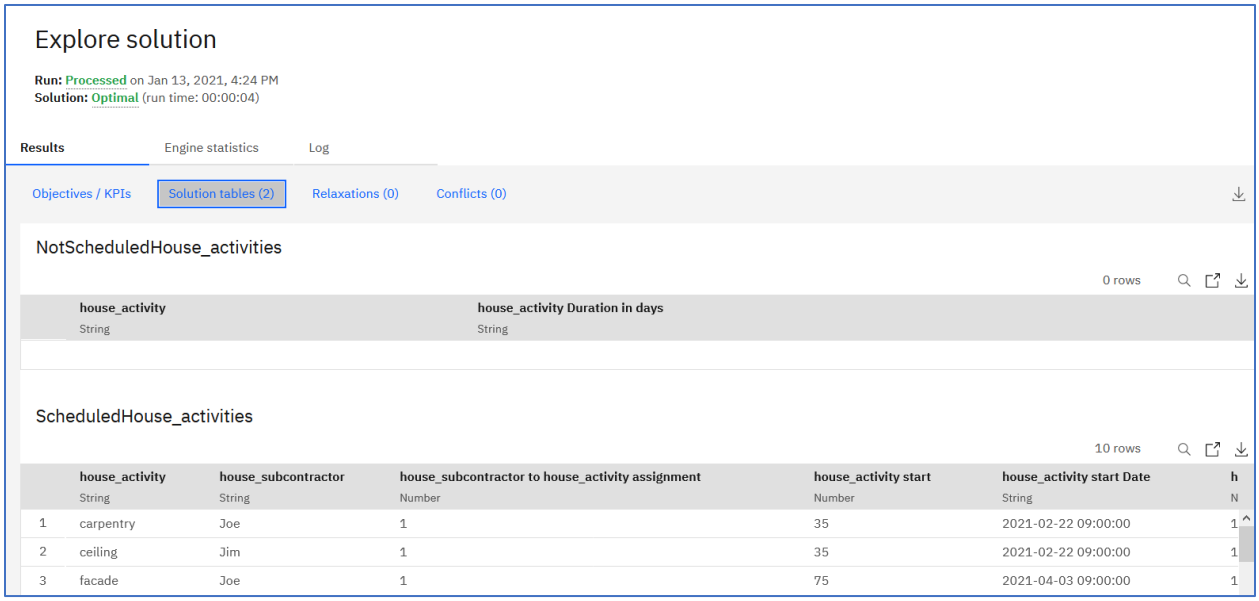
3. When the run is completed, you can see the results in the **Explore solution** view. Click on **Explore solution** if it is not already selected. The first tab in the Explore solution view shows the objective (or objectives if you have several) with its values and weights. We can see that the objective function is 90 days.

   You can also click Engine statistics or Log to see the solution chart and inspect the solver engine log files.

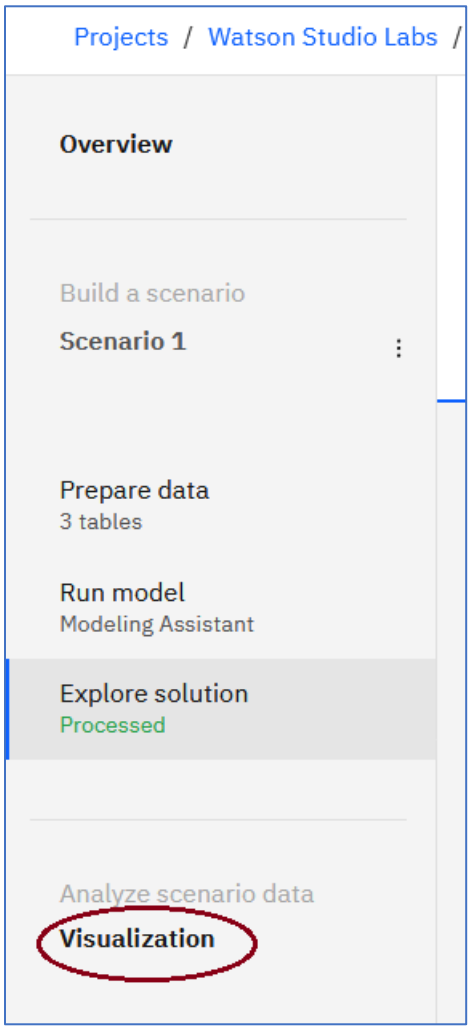


4. Click on **Solution tables**. The Solution tables tab provides you with the best schedule with the assignment of activities to subcontractors. You can also download the solution tables as `csv` files.

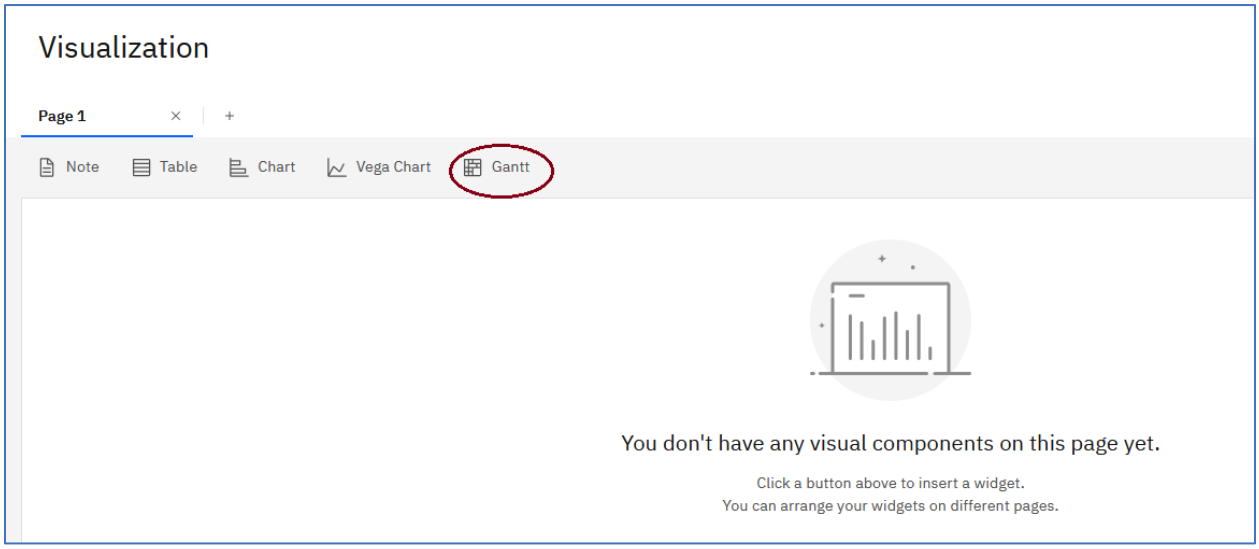
   If your model had any conflicting constraints, these would be shown in the Conflicts tab with the Relaxations necessary to solve the model.



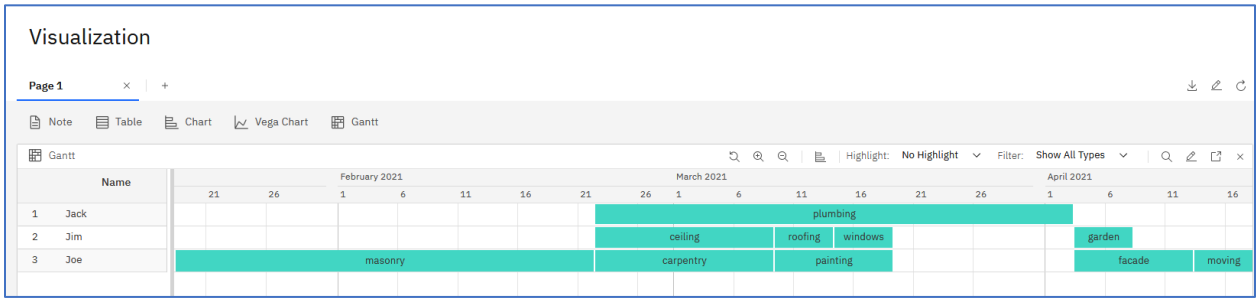
5. Click on **Visualization**



6. Click on **Gantt**.



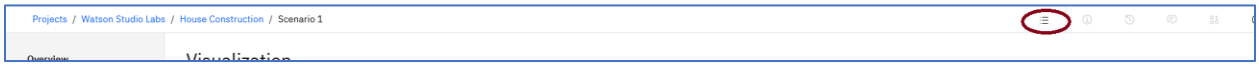
7. A Gantt chart is displayed showing the scheduled activities.



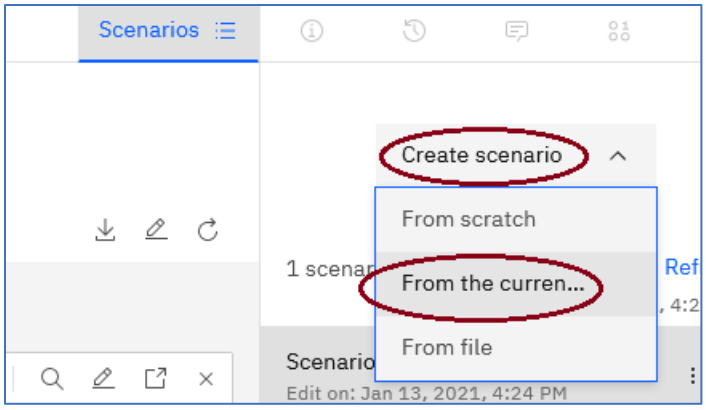
Create Scenario 2

If you look at the schedule that was created, we can note that Jim is slated to do the ceiling, but in the house_activity table, only Joe and Jack are the possible subcontractors. The reason is that we didn't add the constraint on subcontractor assignments. We could go back and fix this in Scenario 1, or create another scenario. Let's create another scenario based on Scenario 1.

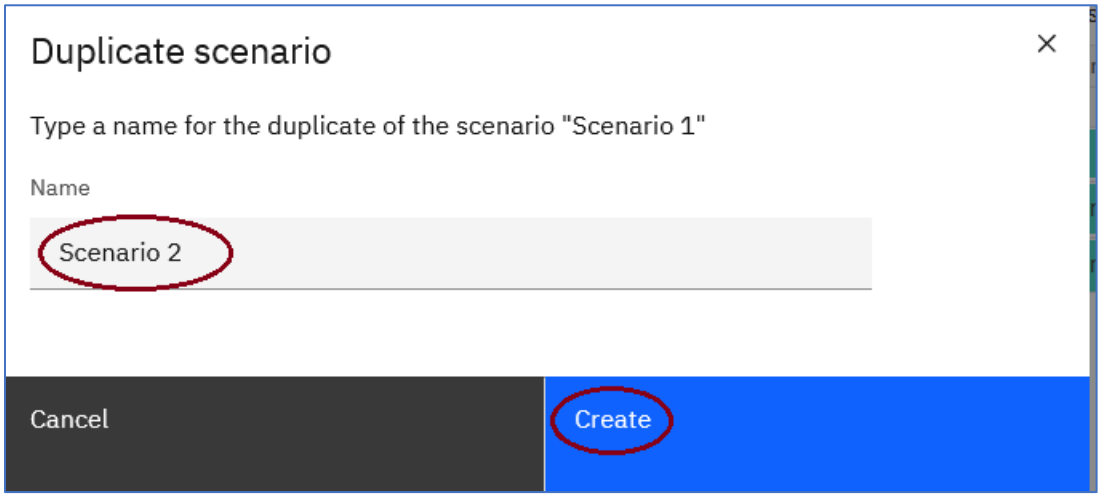
1. Click on the Scenarios icon 



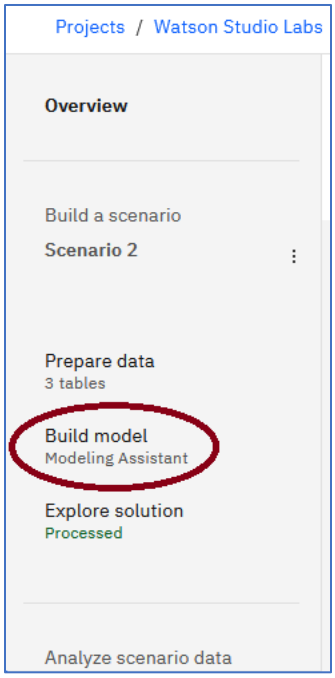
2. Click on **Create scenario**, and **From the current**.



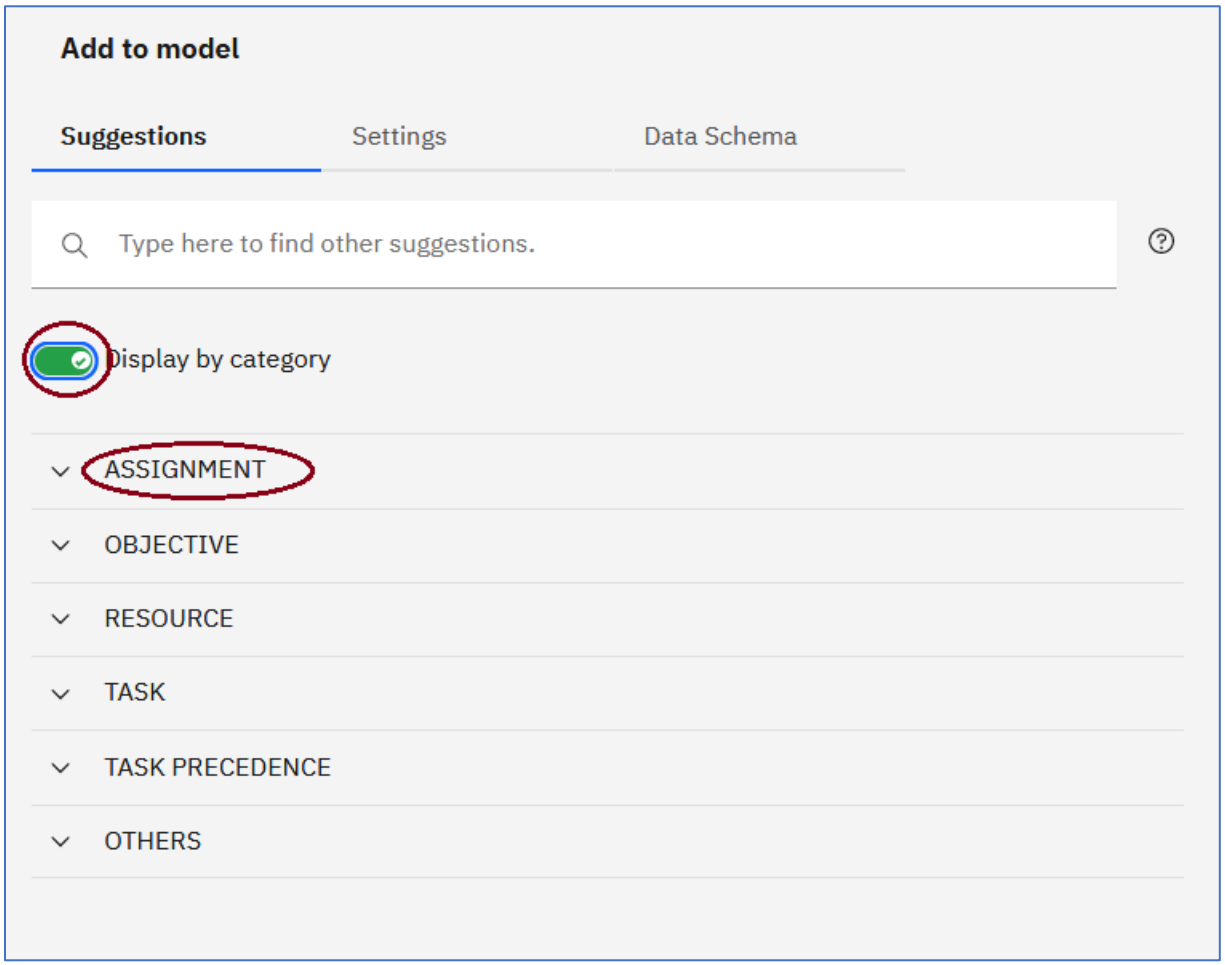
3. Enter **Scenario 2** for the **Name** and click Create.



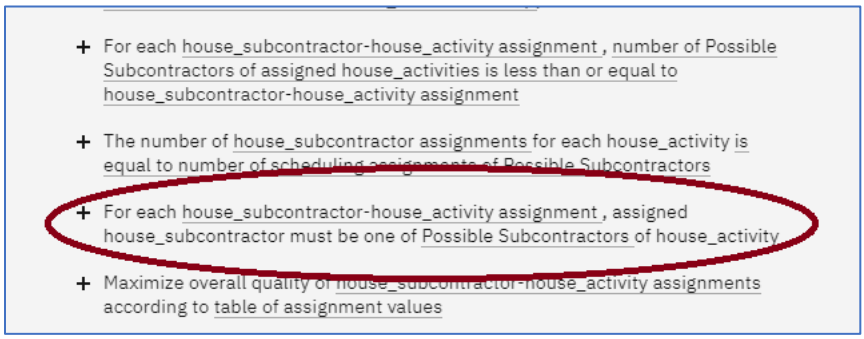
4. Click on **Run Model**



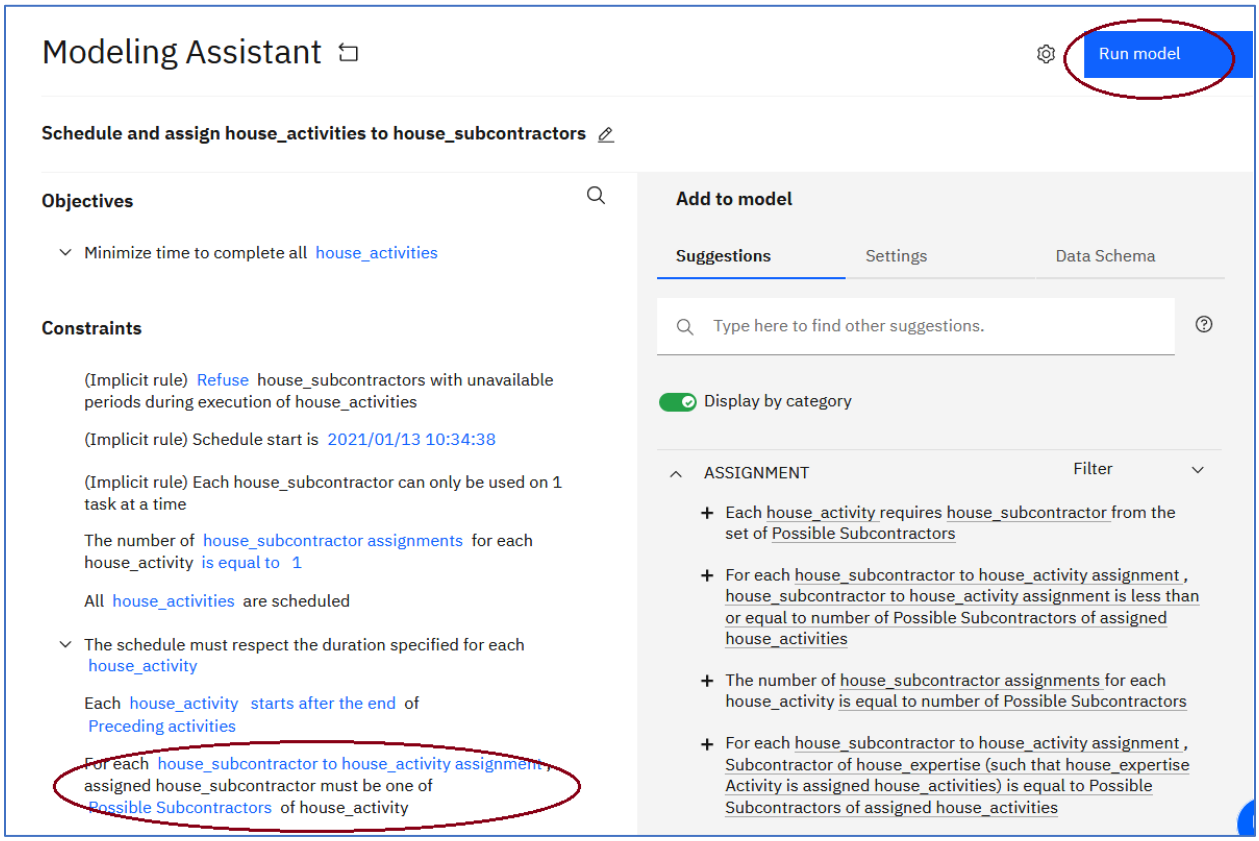
5. Toggle **Display by category** in the **Suggestion** pane, and then click **ASSIGNMENT**.



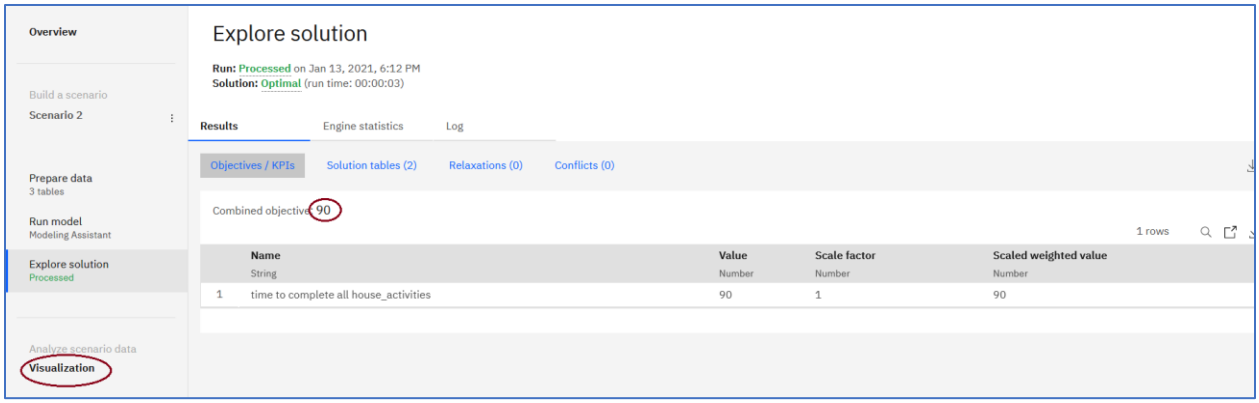
6. Scroll down and click on **For each house_subcontractor - house_activity assignment, assigned house_subcontractor must be one of Possible Subcontractors of house_activity.**



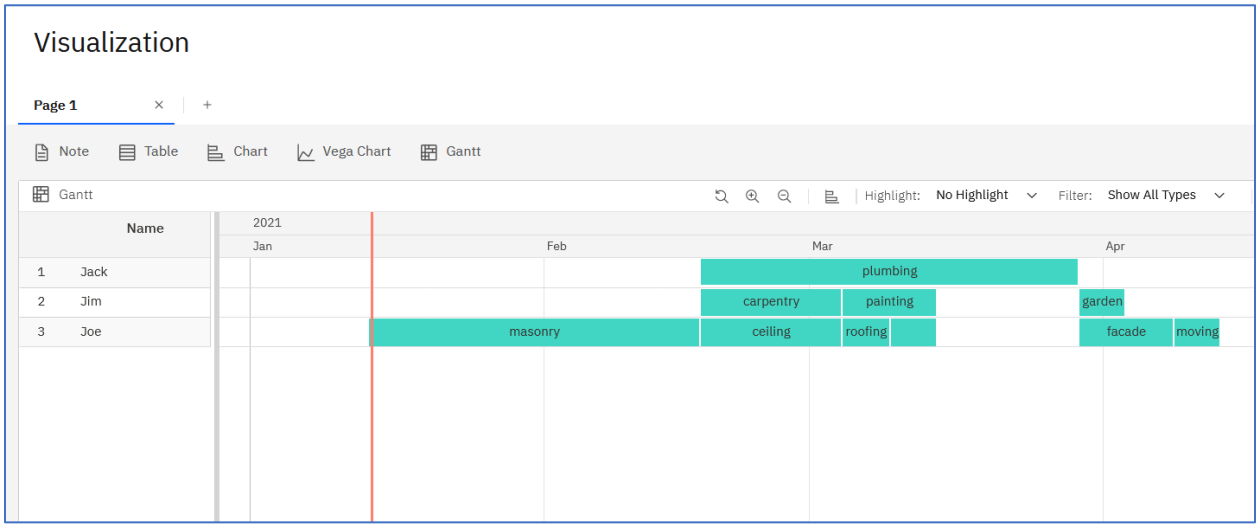
7. The suggestion is added to the constraints. Click on **Run Model**



8. The objective is computed to be the same as before – 90 days. Click on **Visualization**.



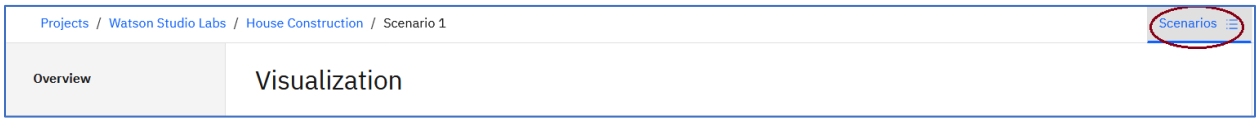
9. Click on Gantt.



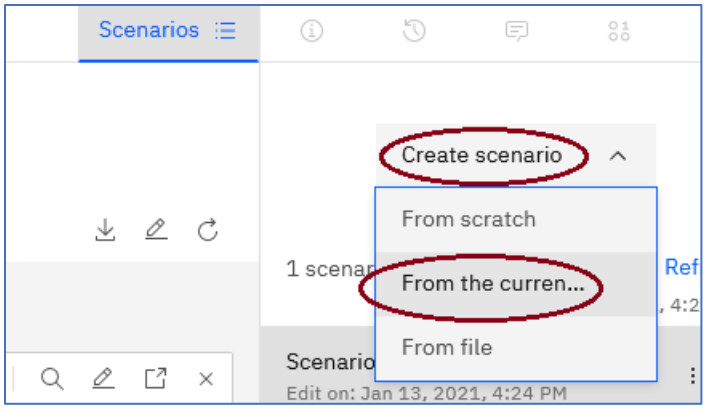
Create Scenario 3

We now have satisfied the required constrains. But, we haven't considered the skill levels of the subcontractors.

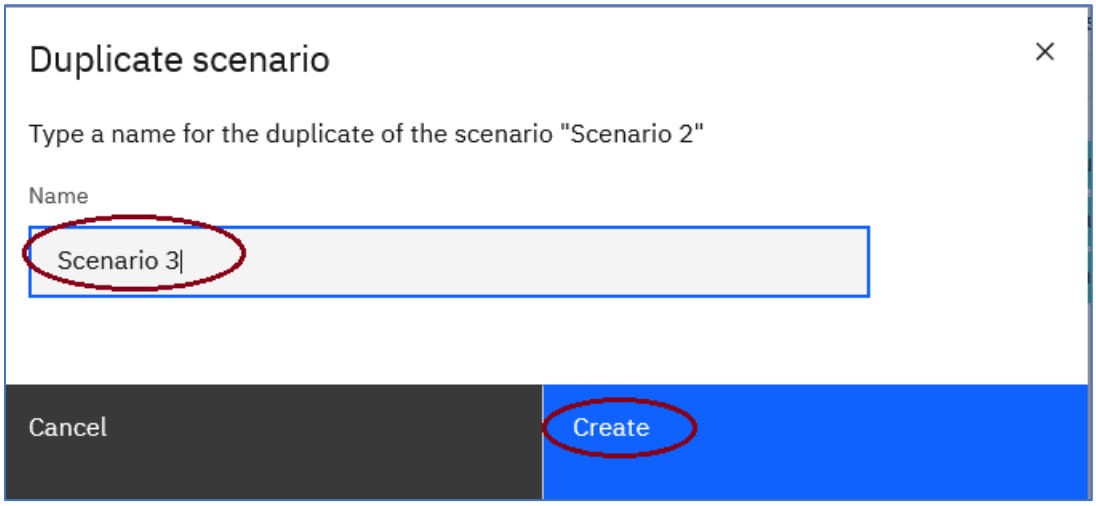
1. Click on **Scenarios** at the top of the panel.



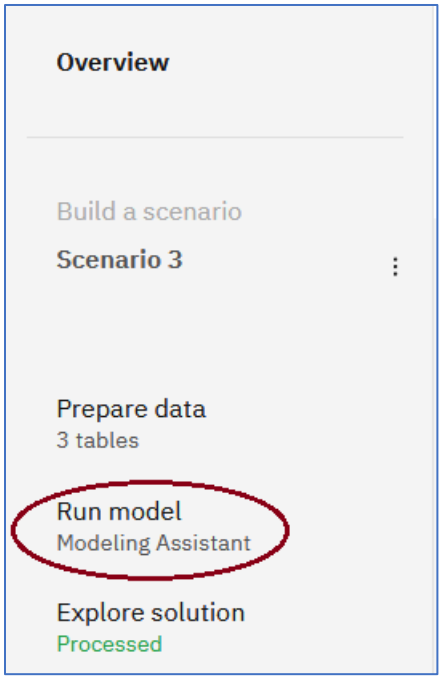
2. Click on **Create scenario**, and **From the current**.



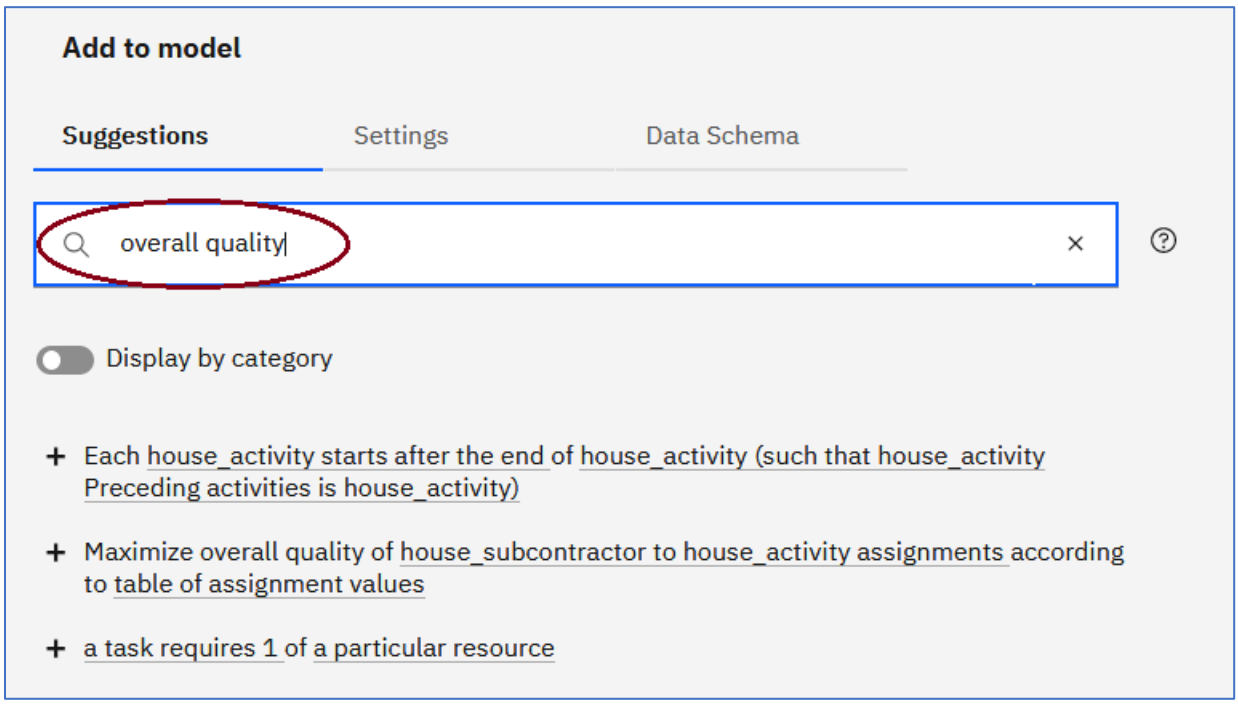
3. Enter **Scenario 3** for the **Name** and click Create.



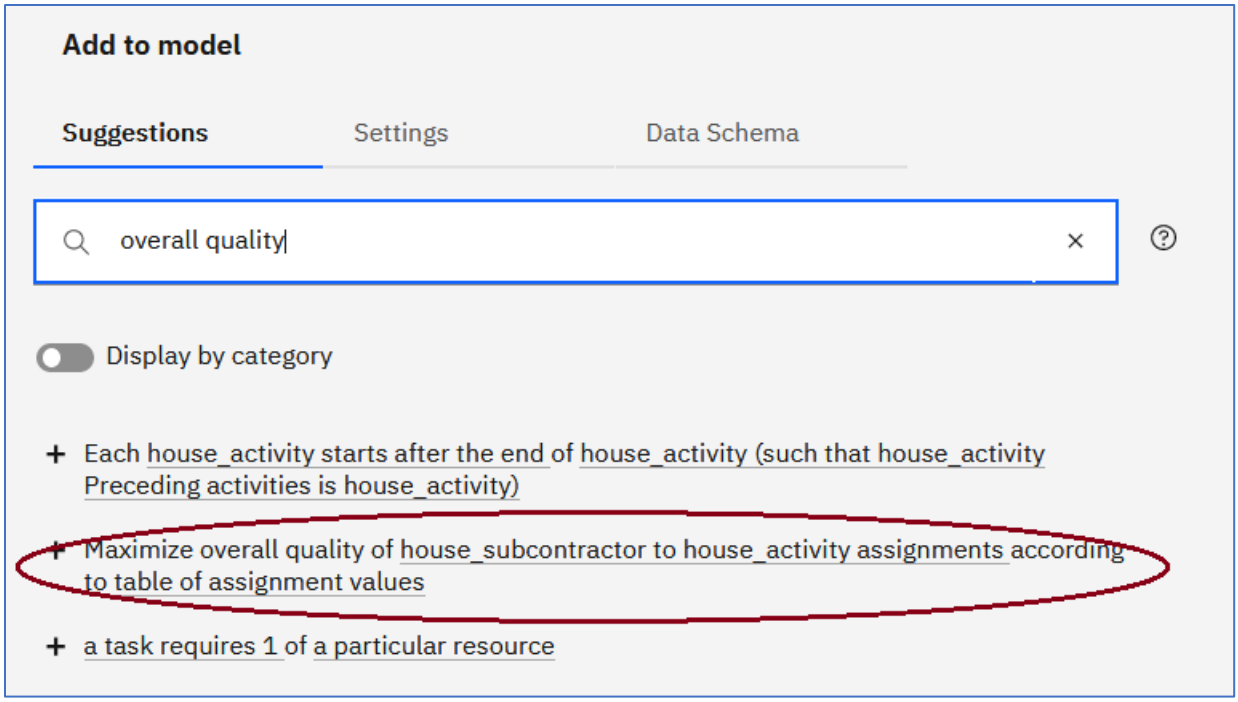
4. Click **Run Model**



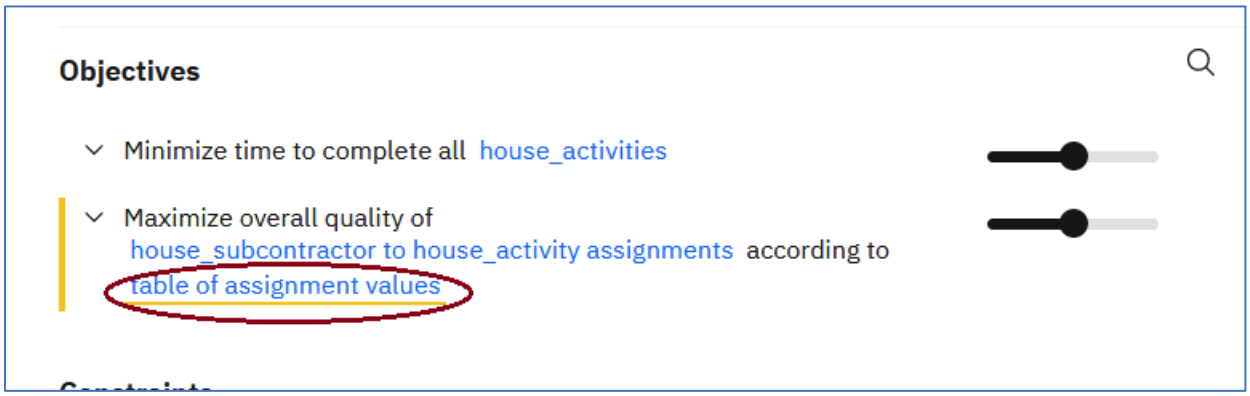
5. Enter **overall quality** in the **Suggestion** pane (Toggle the Display by Category off if necessary) Then press <Enter>



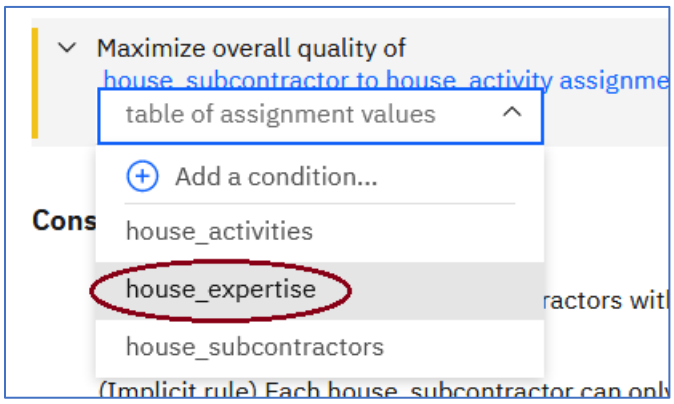
6. Click on **Maximize overall quality of house_subcontractor- house_activity assignments according to table of assignment values**



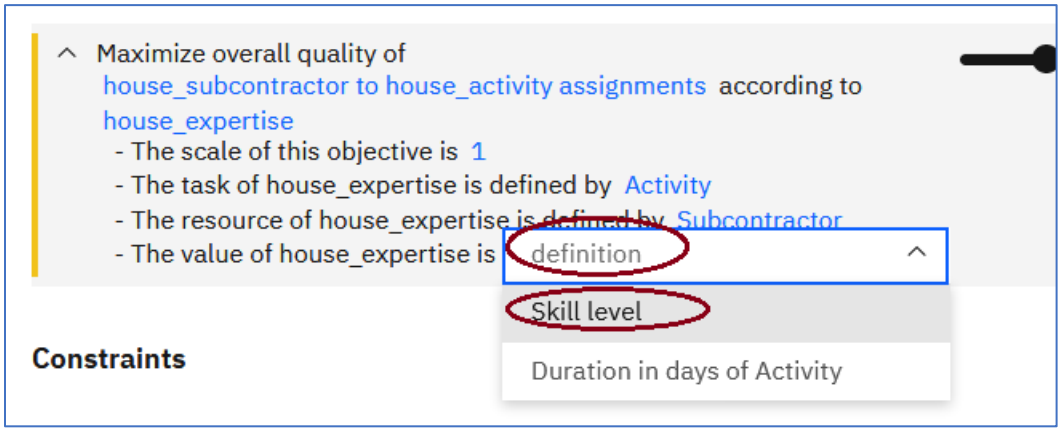
7. Click on **table of assignment values**



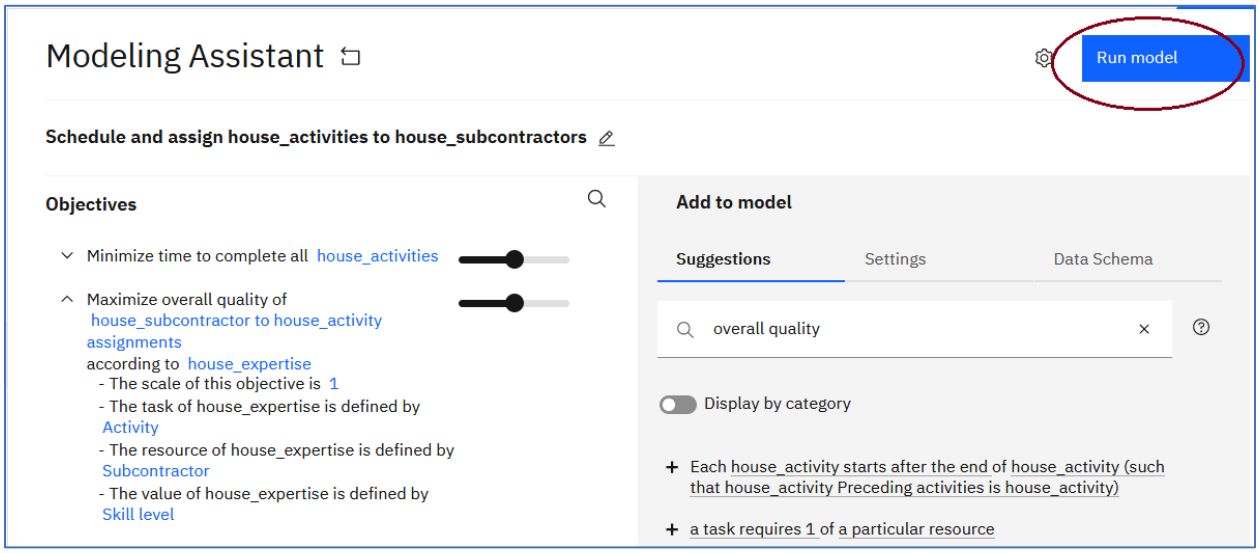
8. Click **house_expertise**



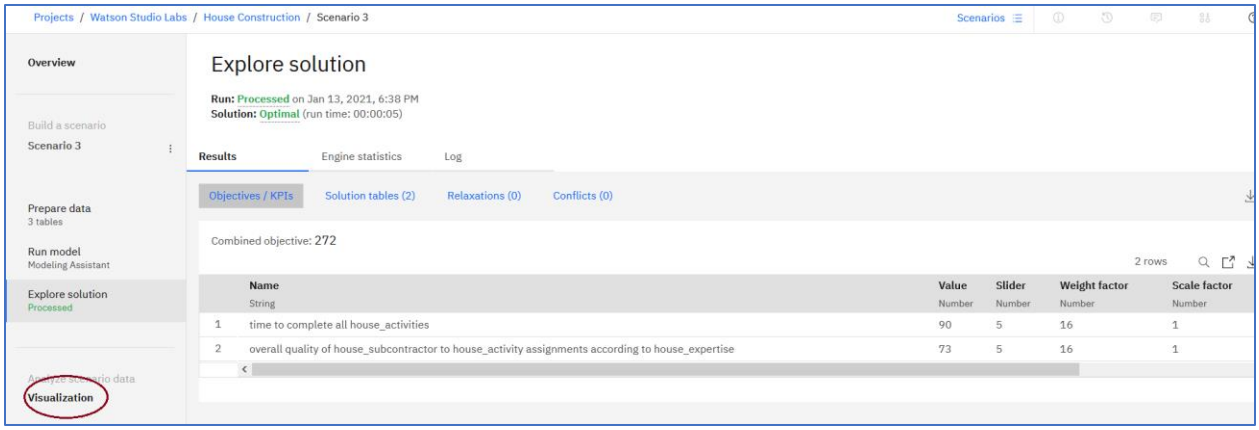
9. Click definition



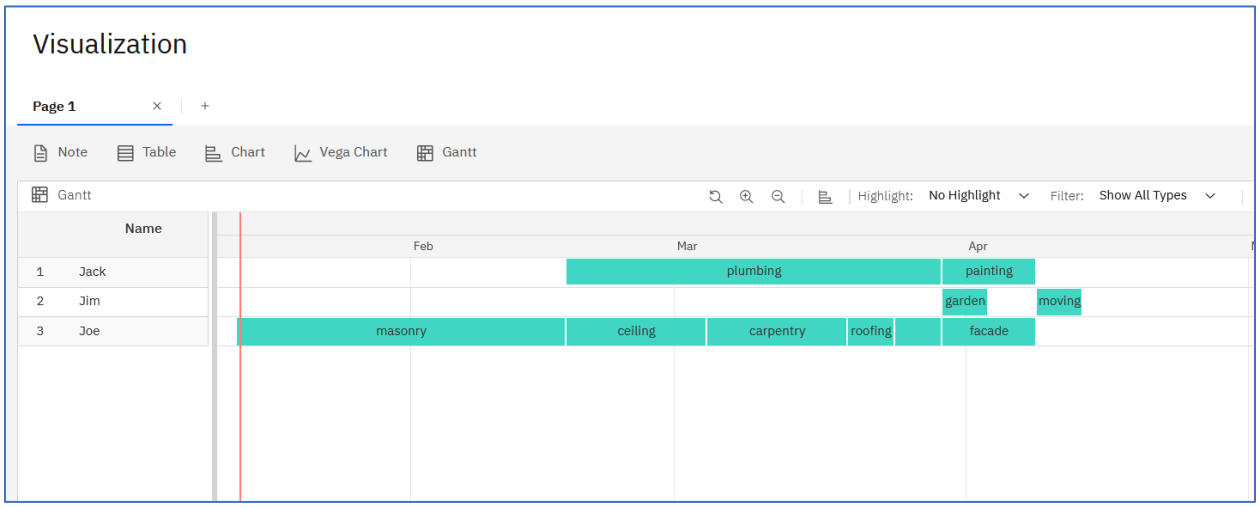
10. You now have two objectives. You can decide whether the objectives are to be considered equally or with **different weightings**. You can increase and decrease the weights on each objective by using the adjacent slider. Leave the two sliders at 5 so that your two objectives are equally weighted. You can also add scale factors for the objectives. For this example, leave the scale factors as 1. Click **Run model**.



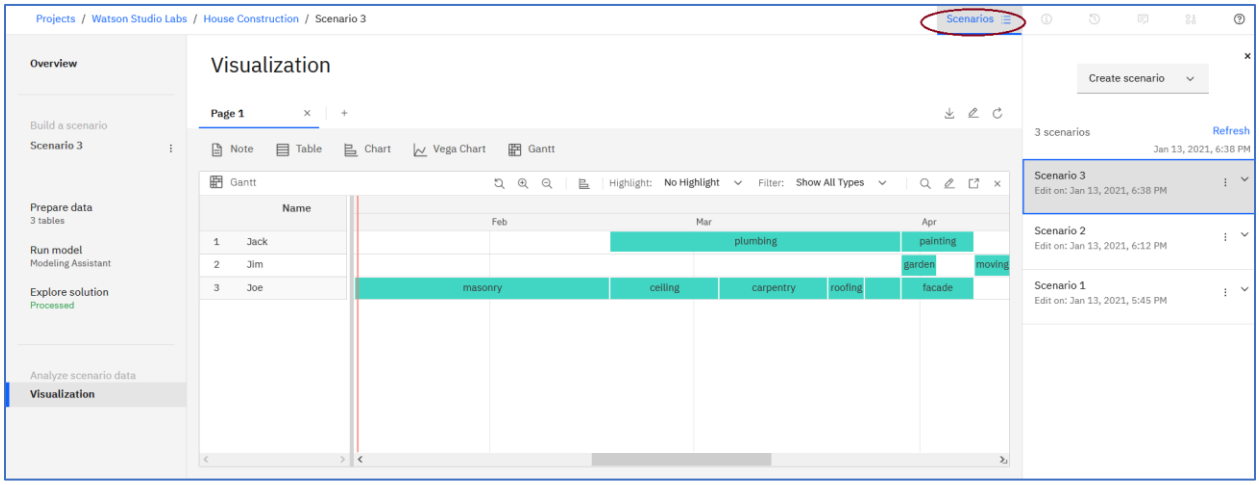
11. The results are displayed. You now have two objective functions. The schedule time is still 90 days. Click **Visualization**.



12. The Gantt chart is shown for Scenario 3.



13. Note, to compare solutions, open the Open scenario pane and click a scenario.



Other Notes

You can change the solve time limit for your model in the Run model view by clicking the **Settings** tab next to the suggestions. Other parameters can also be set using run configuration parameters

The **Suggestions** filter

You can also filter the suggestions to find objectives and constraints. Set **Display by category** to **on** (a tick is displayed on the switch) which opens a pane for you to select various categories of interest and apply filters to the list of suggestions. The filters enable you to see fewer suggestions. If you click the question mark icon next to the search field, you can see all possible expressions for the scheduling domain including those that are disabled. Hovering over the information icon for each expression provides you with a description. For disabled terms hovering over the expression itself also gives you an explanation for why it is disabled for this model.

The **Settings** tab

The Settings tab in the model view lists different scheduling and optimization parameters that can be edited. You can specify here a customized date/time format to suit your data.

The **Data Schema** tab

The Data Schema tab view lists, table by table, all information that the Modeling Assistant has imported and deduced from the input data that is necessary for the scheduling problem to be solved. You can edit certain entries in the schema which will update your model and prompt you to accept the implied model changes or cancel your edits. This can be useful for expert users for data debugging purposes. For example if a column containing an ID has been deduced as numerical, it might be useful to change this to nominal so that it can be used as a primary key.

If you want to generate a Python notebook from your model created with the Modeling Assistant:

1. If the scenario pane is not open, click the Scenarios icon.
2. Click the three dots next to one of your scenarios and select **Generate notebook**.
3. Enter a name for your notebook and click **Generate**.

A Python notebook for this model is created in your Project.