Trade study analysis

On this page:

A trade study or trade-off study is the activity of a multidisciplinary team to identify the most balanced technical solutions among a set of proposed viable solutions (System Engineering Manual, Federal Aviation Administration, 2006).

A trade study is used to compare with a number of alternative solutions to see whether and how well they satisfy a particular set of criteria. Each solution is characterized by a set of measures of effectiveness (often abbreviated “moe’s”) that corresponds to evaluation criteria and has a calculated value or value distribution. The moe’s for a given solution is then evaluated using an objective function (often called a cost function or utility function), and the results for each alternative are compared to select a preferred solution.

Cameo Simulation Toolkit has built-in support for trade study analysis. The **TradeStudyExamples** sample model is used as a demonstration for trade study analysis through the following steps.

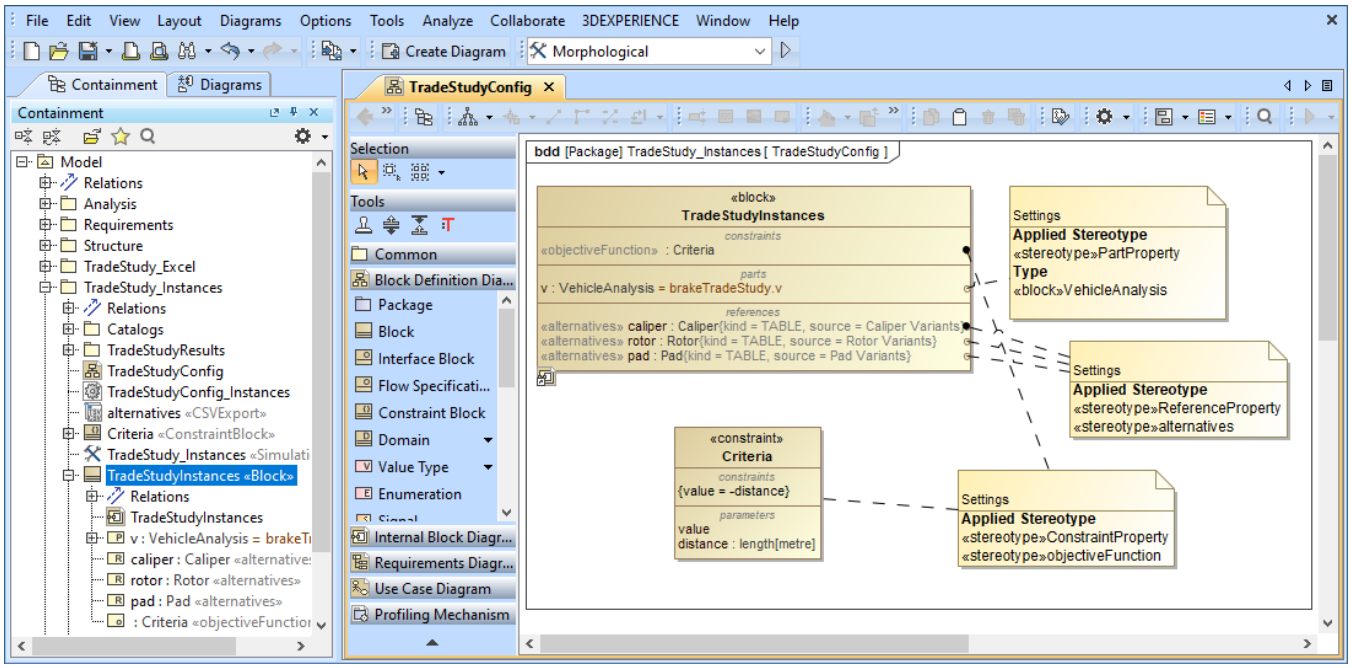
Creating a Trade Study Analysis Block

1. Create a new Analysis Block in a Block Definition diagram (BDD), e.g., *TradeStudyInstances.*
2. Add the main Block of the simulation context as the Part Property of the newly created Analysis Block, e.g., *v : VehicleAnalysis*.
3. Create a constraint Block containing a constant expression for determining the best weighted value and related constraint parameters, e.g., *C riteria*.
4. Add the newly created constraint Block as a Constraint Property in the Analysis Block then right-click the Constraint Property and select Stereotype **objectiveFunction**.

   - «objectiveFunction» is a special type of a constraint Block for determining all values of weighted alternatives in terms of weighted criteria.
   - The specification of the constraint must be an equation with LHS = RHS, where LHS contains only one parameter to bind with *TradeAnalysis::^score*, and RHS can contain multiple parameters (bound with corresponding value properties) to evaluate as **winner** criteria.
   - The output of **«objectiveFunction»** will be compared with previous weighted results. If an alternative is greater, it will be set as the **winner** (maximum value by default). However, if you want the minimum value, use a negative value, e.g., *value = -distance*.

5. Create alternatives by creating references properties typed by a Block of alternatives and apply «alternatives» to the newly created references properties, e.g., *C : Caliper*, *R : Rotor*, and *P : Pad* as shown in the figure below.

   If you intend to use the Parameter Sweep functionality to automatically generate alternatives based on the specified ranges, skip this step.



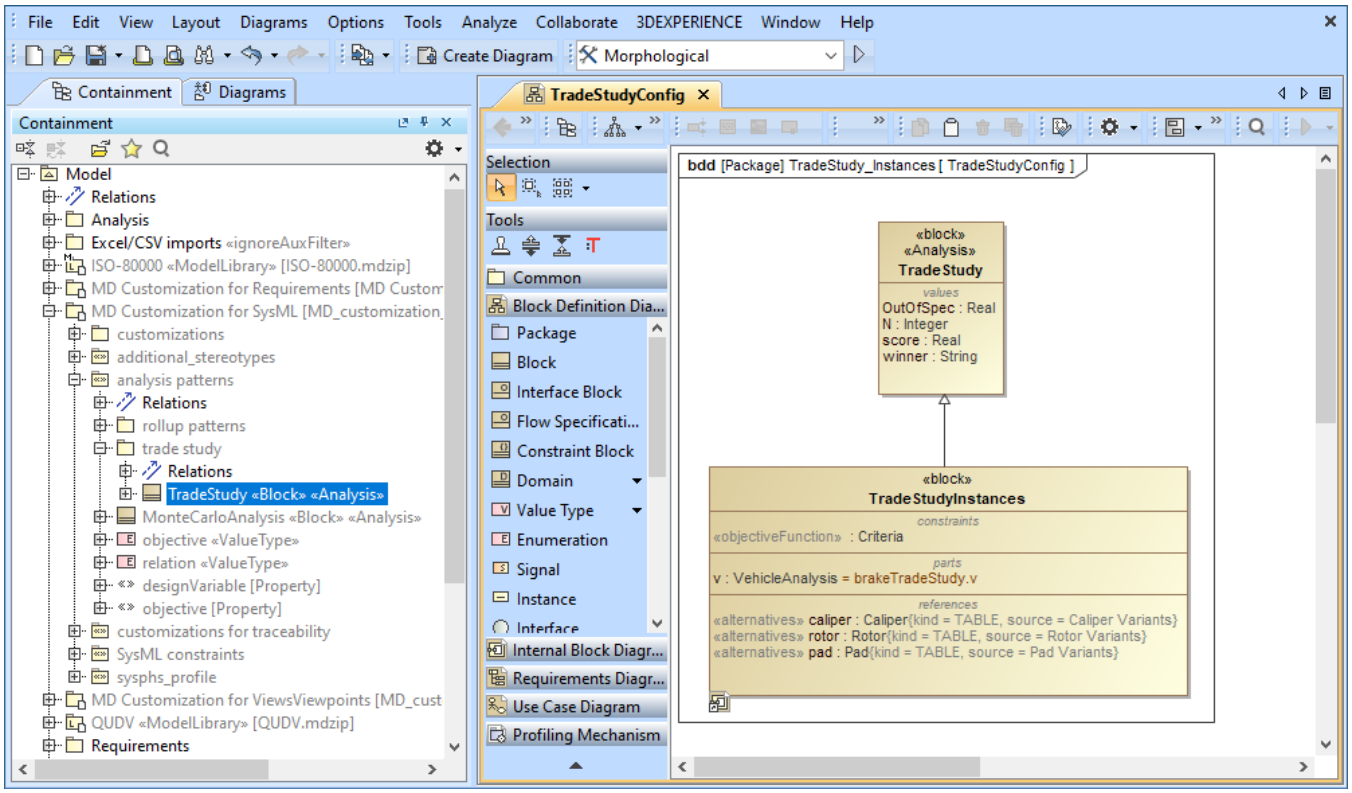
The structure of the Trade Study Analysis Block.

Inheriting the Analysis Block from the Trade Study Analysis Block

1. From the Containment tree under the **MD Customization forSysML::analysis patterns::trade study** package, drag **TradeStudy «Block» «Analysis»** into the Block Definition diagram (BDD) created in the previous section.

   > **Note**
   >
   > The **TradeStudy** package is available in all SysML projects. If the **MD Customization for SysML** package is not visible, click  in the Containment tree pane and select **Show Auxiliary Resources**.

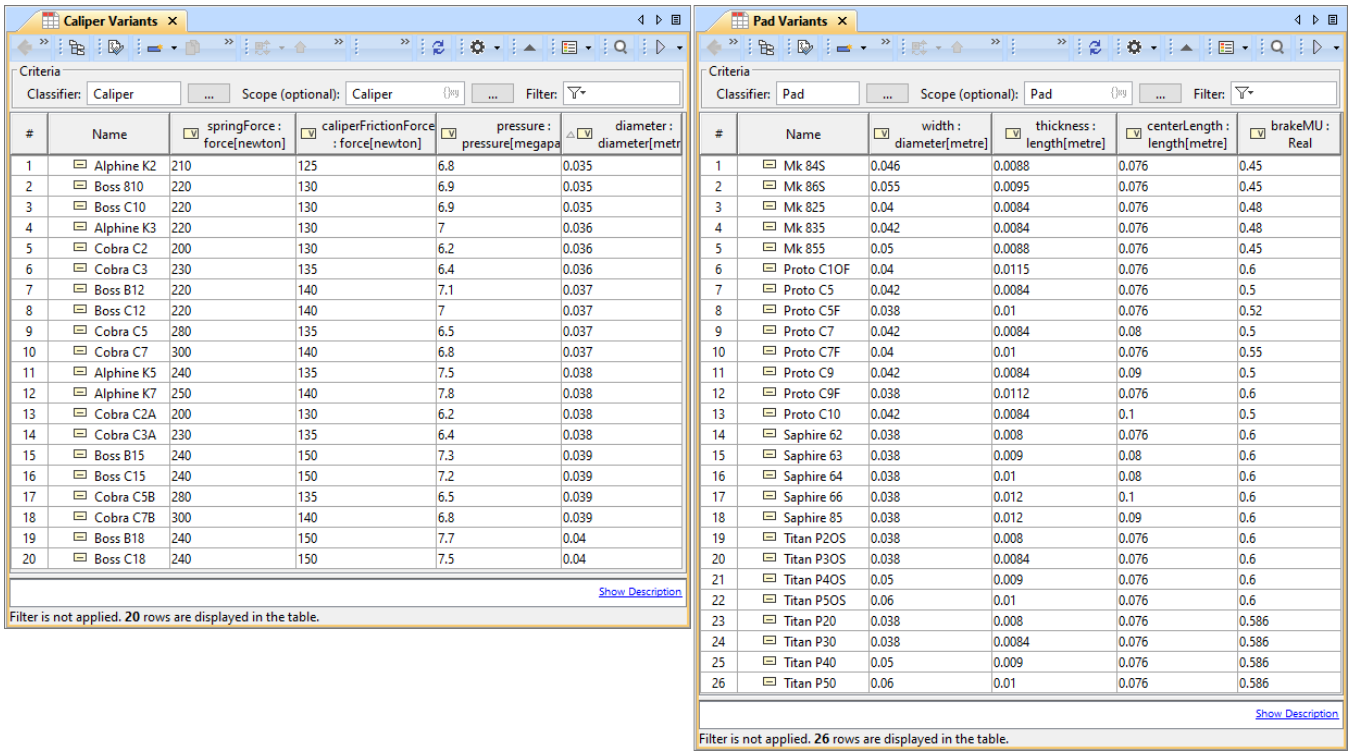
2. To inherit the TradeStudy «block» «Analysis», create a Generalization Relation from the **TradeStudyInstances** Block to **TradeStudy** «block» «Analysis» as shown in the figure below.



Inheriting the Analysis Block from the TradeStudy Block.

Creating an Internal Block diagram for alternatives kind = Instance Table

1. Create an Internal Block diagram (IBD) of the *TradeAnalysis* Block. You must select Parts which have been set as **«objectiveFunction»** and **«alternatives»** to display. You must also display *^score* (inherited property) in the diagram.
2. Bind *^score* with a Binding Connector to the LHS parameter of **«objectiveFunction»**, e.g., *^score – value*. You must also bind a value property of the main simulation context with a Binding Connector to the RHS parameter of **«objectiveFunction»**, e.g., *stoppingDistance – distance*.
3. Bind each **«alternatives»** with a Binding Connector to each Part property.
4. For each «alternatives», **source** depends on **kind** through the **Tags** settings. If **kind = TABLE**, **source** must be an instance table which must be the same Classifier as the alternative property, as shown in the two figures below. However, sorting of rows in the table is not necessary.



Caliper Variants

Criteria

Classifier: Caliper | Scope (optional): Caliper | Filter:

#	Name	springForce : force[newton]	caliperFrictionForce : force[newton]	pressure : pressure[megapa	diameter : diameter[metr
1	Alphine K2	210	125	6.8	0.035
2	Boss 810	220	130	6.9	0.035
3	Boss C10	220	130	6.9	0.035
4	Alphine K3	220	130	7	0.036
5	Cobra C2	200	130	6.2	0.036
6	Cobra C3	230	135	6.4	0.036
7	Boss B12	220	140	7.1	0.037
8	Boss C12	220	140	7	0.037
9	Cobra C5	280	135	6.5	0.037
10	Cobra C7	300	140	6.8	0.037
11	Alphine K5	240	135	7.5	0.038
12	Alphine K7	250	140	7.8	0.038
13	Cobra C2A	200	130	6.2	0.038
14	Cobra C3A	230	135	6.4	0.038
15	Boss B15	240	150	7.3	0.039
16	Boss C15	240	150	7.2	0.039
17	Cobra C5B	280	135	6.5	0.039
18	Cobra C7B	300	140	6.8	0.039
19	Boss B18	240	150	7.7	0.04
20	Boss C18	240	150	7.5	0.04

Show Description

Filter is not applied. **20** rows are displayed in the table.

Pad Variants

Criteria

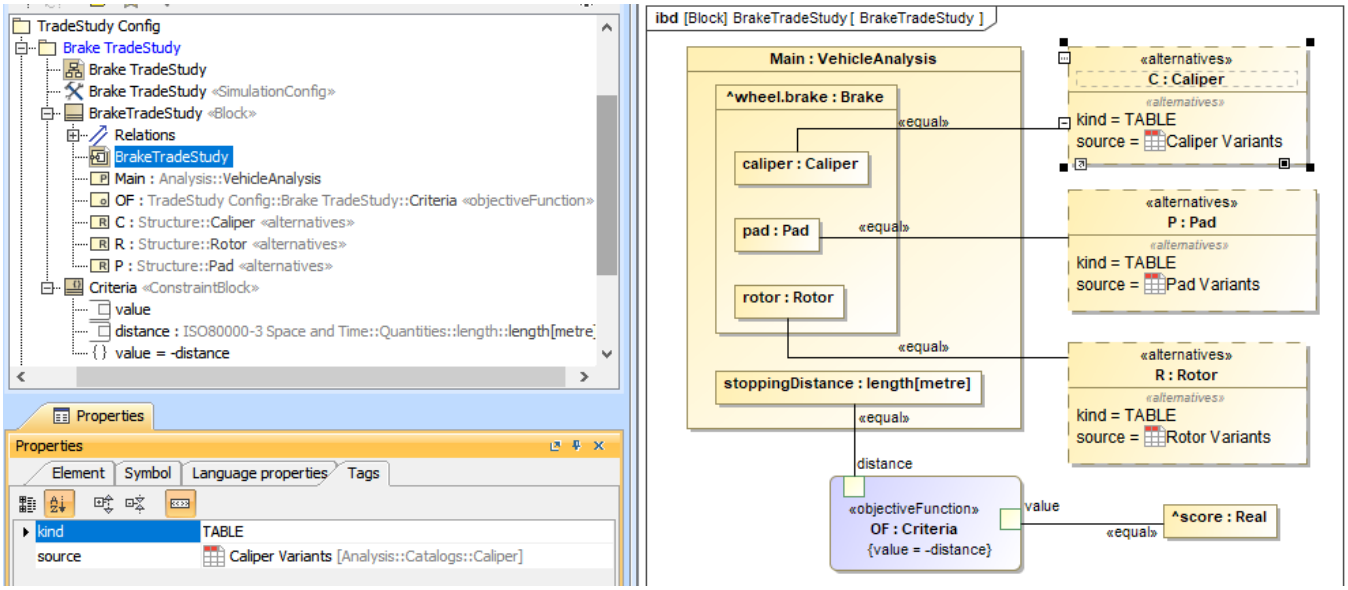
Classifier: Pad | Scope (optional): Pad | Filter:

#	Name	width : diameter[metre]	thickness : length[metre]	centerLength : length[metre]	brakeMU : Real
1	Mk 84S	0.046	0.0088	0.076	0.45
2	Mk 86S	0.055	0.0095	0.076	0.45
3	Mk 825	0.04	0.0084	0.076	0.48
4	Mk 835	0.042	0.0084	0.076	0.48
5	Mk 855	0.05	0.0088	0.076	0.45
6	Proto C1OF	0.04	0.0115	0.076	0.6
7	Proto C5	0.042	0.0084	0.076	0.5
8	Proto C5F	0.038	0.01	0.076	0.52
9	Proto C7	0.042	0.0084	0.08	0.5
10	Proto C7F	0.04	0.01	0.076	0.55
11	Proto C9	0.042	0.0084	0.09	0.5
12	Proto C9F	0.038	0.0112	0.076	0.6
13	Proto C10	0.042	0.0084	0.1	0.5
14	Saphire 62	0.038	0.008	0.076	0.6
15	Saphire 63	0.038	0.009	0.08	0.6
16	Saphire 64	0.038	0.01	0.08	0.6
17	Saphire 66	0.038	0.012	0.1	0.6
18	Saphire 85	0.038	0.012	0.09	0.6
19	Titan P2OS	0.038	0.008	0.076	0.6
20	Titan P3OS	0.038	0.0084	0.076	0.6
21	Titan P4OS	0.05	0.009	0.076	0.6
22	Titan P5OS	0.06	0.01	0.076	0.6
23	Titan P20	0.038	0.008	0.076	0.586
24	Titan P30	0.038	0.0084	0.076	0.586
25	Titan P40	0.05	0.009	0.076	0.586
26	Titan P50	0.06	0.01	0.076	0.586

Show Description

Filter is not applied. **26** rows are displayed in the table.

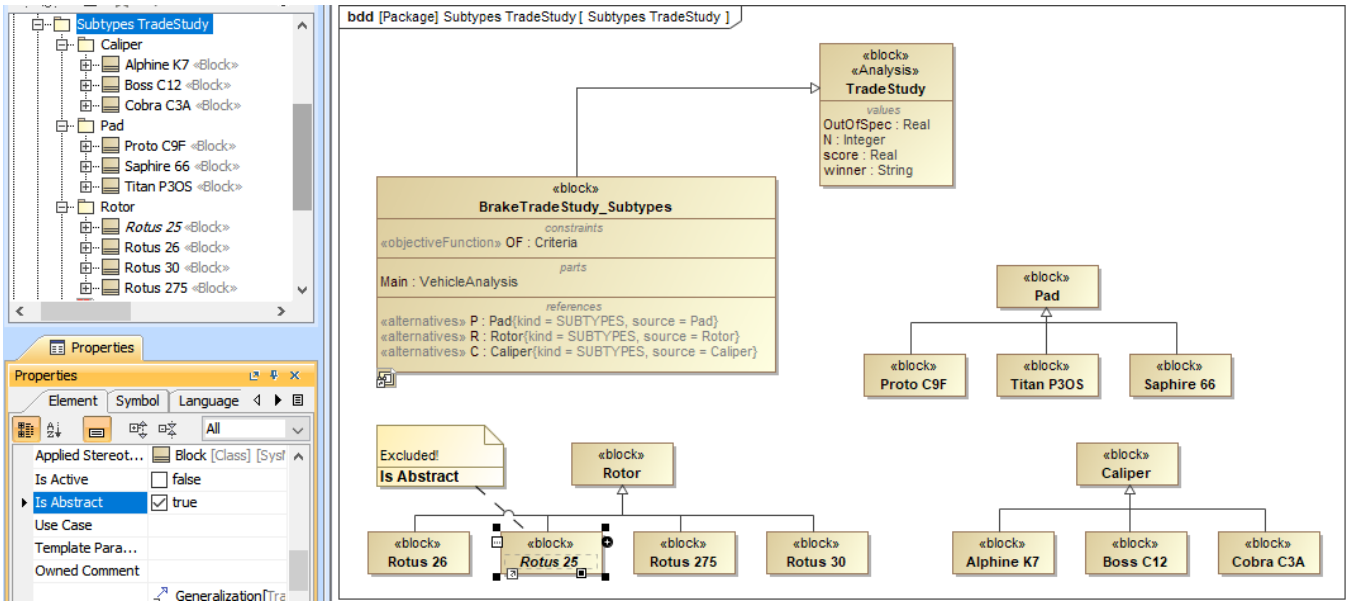
TABLE, kind of «alternatives», must be the same Classifier as the alternative property.



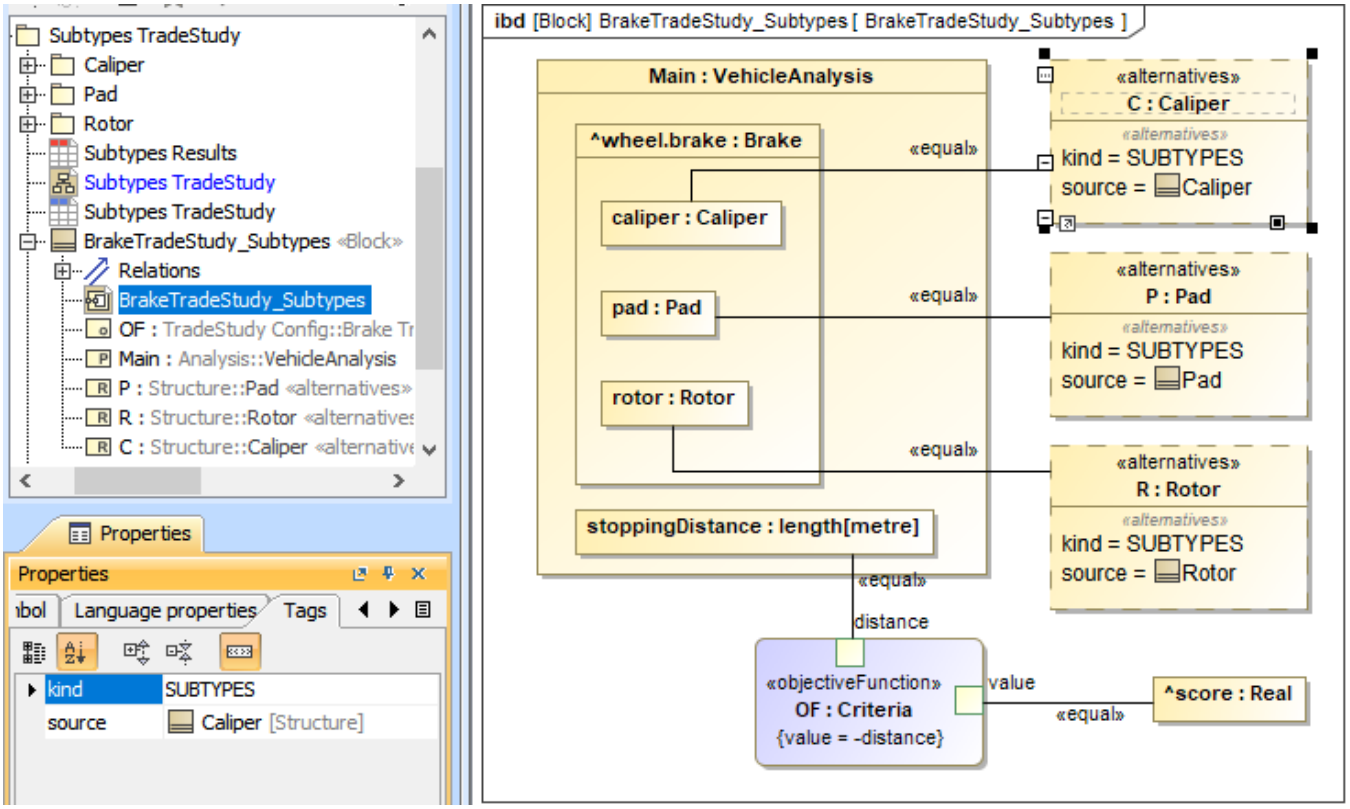
Binding of the TradeAnalysis Block in the Internal Block diagram (kind = TABLE).

Creating an Internal Block diagram for alternatives kind = Subtypes

1. Refer to Step 1-3 about creating an Internal Block diagram for alternatives kind = Instance Table.
2. For each «alternatives», **source** depends on **kind** through the **Tags** settings. If **kind = SUBTYPES**, **source** must be a parent Block of subtypes which must be the same type as the alternative property, as shown in the two figures below. Also, the parent Block will not be evaluated as well as any Blocks which have *Is Abstract* = true.



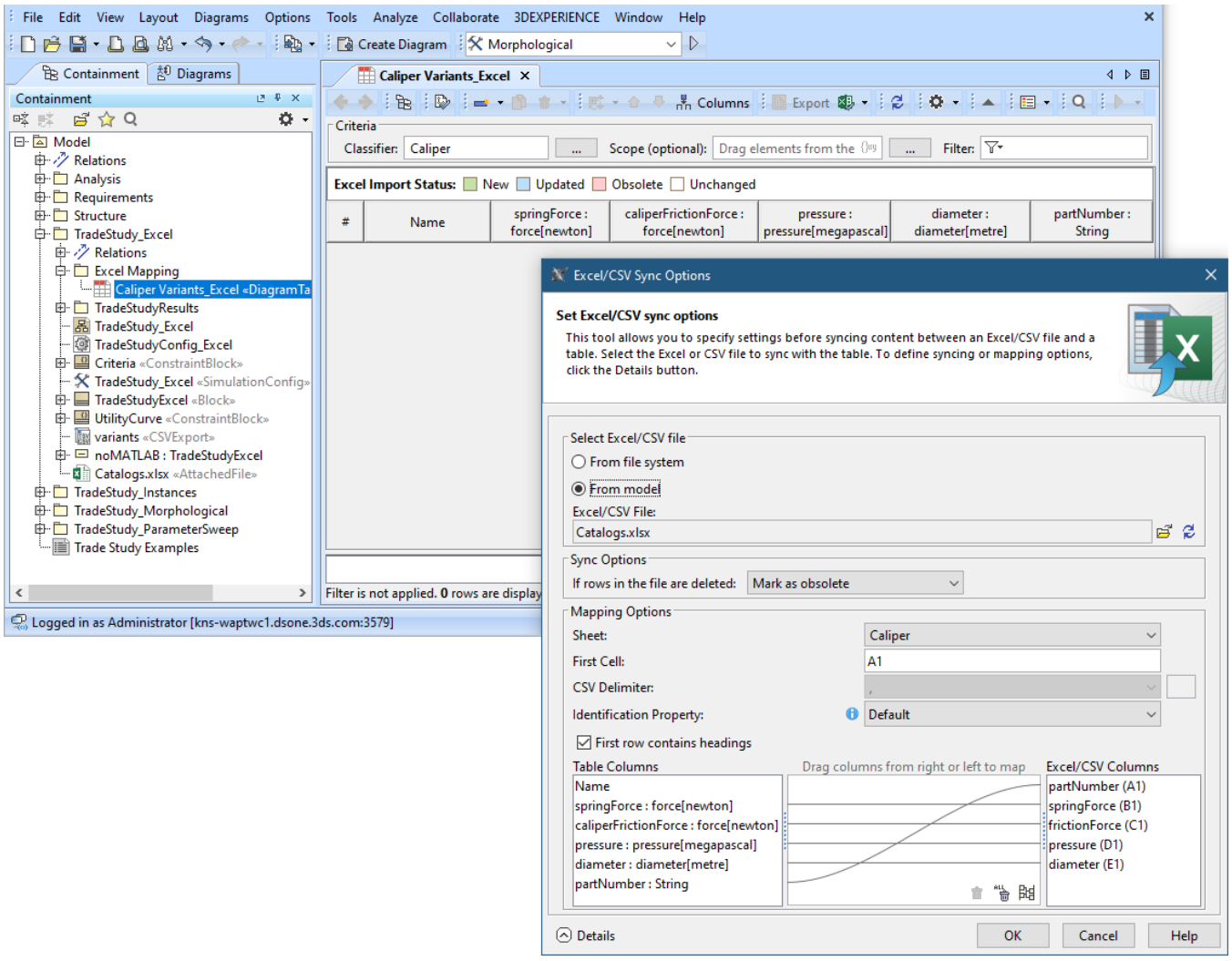
SUBTYPES, kind of «alternatives», must be the same type as the alternative property.



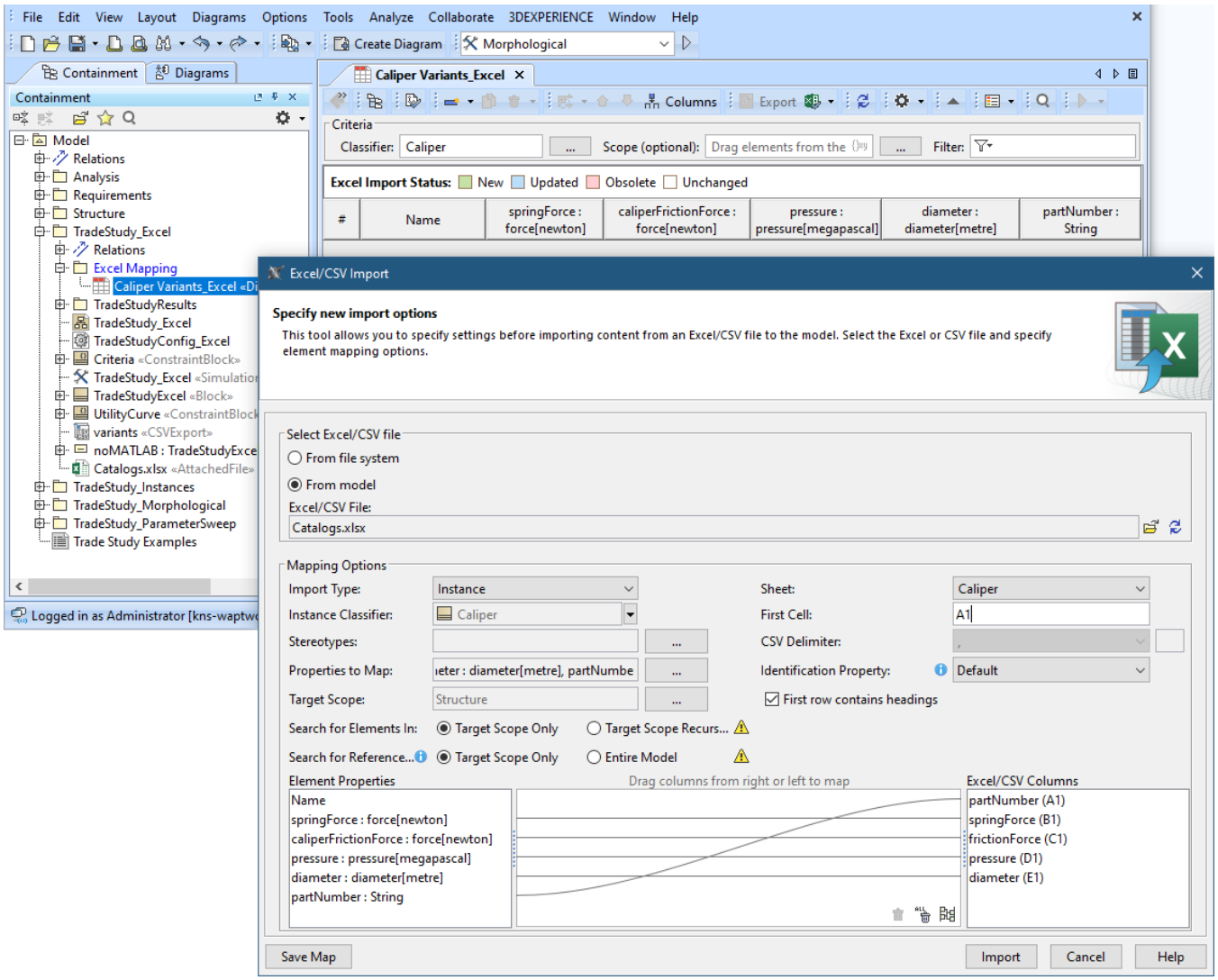
Binding of the TradeAnalysis Block in the Internal Block diagram (kind = SUBTYPES).

Creating an Internal Block diagram for alternatives kind = Excel

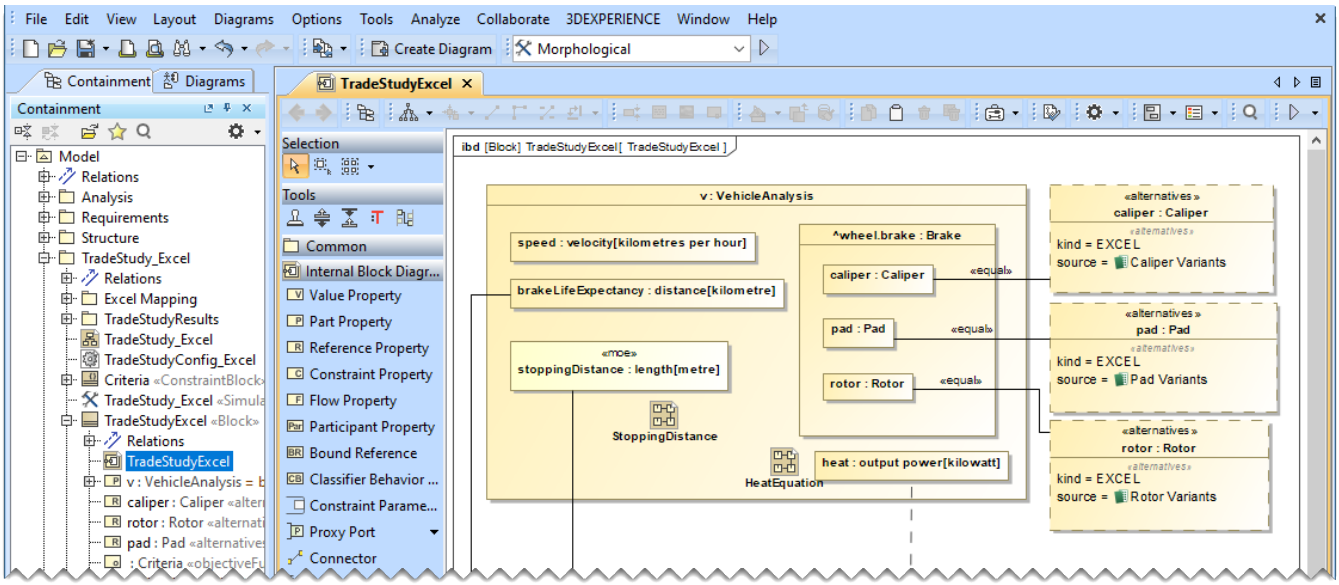
1. Refer to Step 1-3 about creating an Internal Block diagram for alternatives kind = Instance Table.
2. For each «alternatives», **source** depends on **kind** through the **Tags** settings. If **kind = EXCEL**, **source** must be either an Instance table linked to an Excel file («DiagramTableMapToDataSource» applied) or using an «ImportMap». Table columns or element properties must be correctly mapped to Excel/CSV columns as shown in the two figures below (see also Sync with Excel or CSV files). However, you do not need to use the **Read from File** command from the **Publish** Excel toolbar to load data into the table.



EXCEL, kind of «alternatives» with an Instance table linked to Excel file («DiagramTableMapToDataSource» applied) settings.



EXCEL, kind of «alternatives» with Import Map settings.



Binding of the TradeAnalysis Block in the Internal Block diagram (kind = EXCEL, source = Import Map).

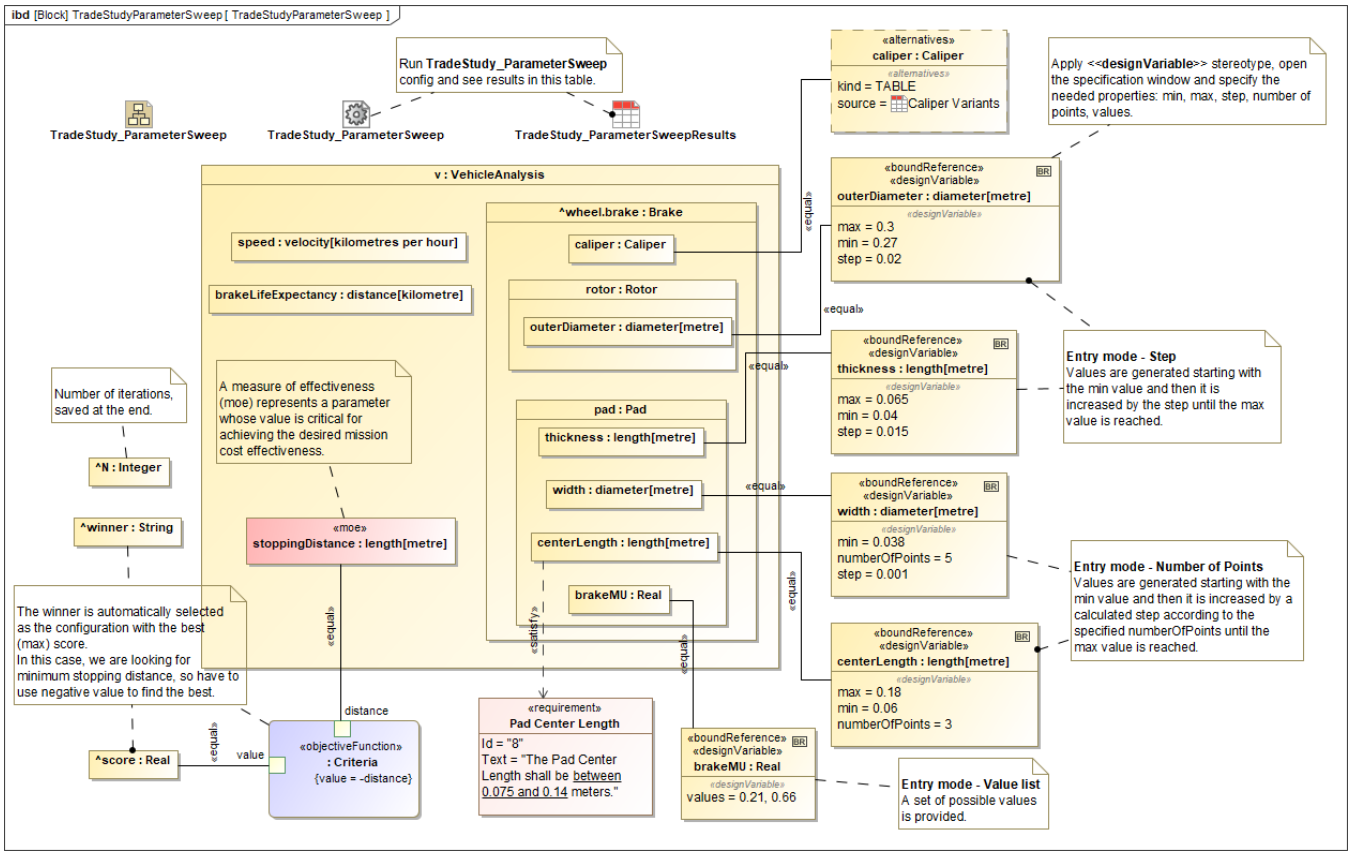
Creating an Internal Block diagram for alternatives kind = Parameter Sweep

Parameter Sweep generates alternatives automatically based on the specified parameters. Once you create the Analysis Block, follow the steps below to model an Internal Block Diagram for using Parameter Sweep.

> In this workflow, the *TradeStudyExamples* model is used as an example. You can find it in the <*install_root*>*samples**simulation* directory.

To create an Internal Block Diagram for using Parameter Sweep

1. Create an Internal Block diagram (IBD) for the Analysis Block (e.g, *TradeStudyParameterSweep*).
2. In the diagram, display the Constraint Property of the Analysis Block with the «objectiveFunction» stereotype.
3. In the diagram, display the *^score* Value Property (inherited from the *TradeStudy* Block in the *MD Customization for SysML* profile).
4. Connect the *^score* Value Property to the LHS parameter of the Constraint Property (e.g., *value*) using a Binding Connector.
5. Connect a Value Property of the main simulation context (e.g., *stoppingDistance*) to the RHS parameter of the Constraint Property (e.g., *distance*) using a Binding Connector.
6. Create Bound References and use Binding Connectors to connect them to specific properties whose alternatives you want to generate in the specified ranges, e.g., *outerDiameter : diameter[meter]*, *thickness : length[meter], etc.*
7. Apply the «designVariable» stereotype to the newly created Bound References.
8. Specify ranges for design variables using any of the four methods described in Parameter sweep.



The Internal Block Diagram for the Analysis Block illustrating how to use different methods of Parameter Sweep.

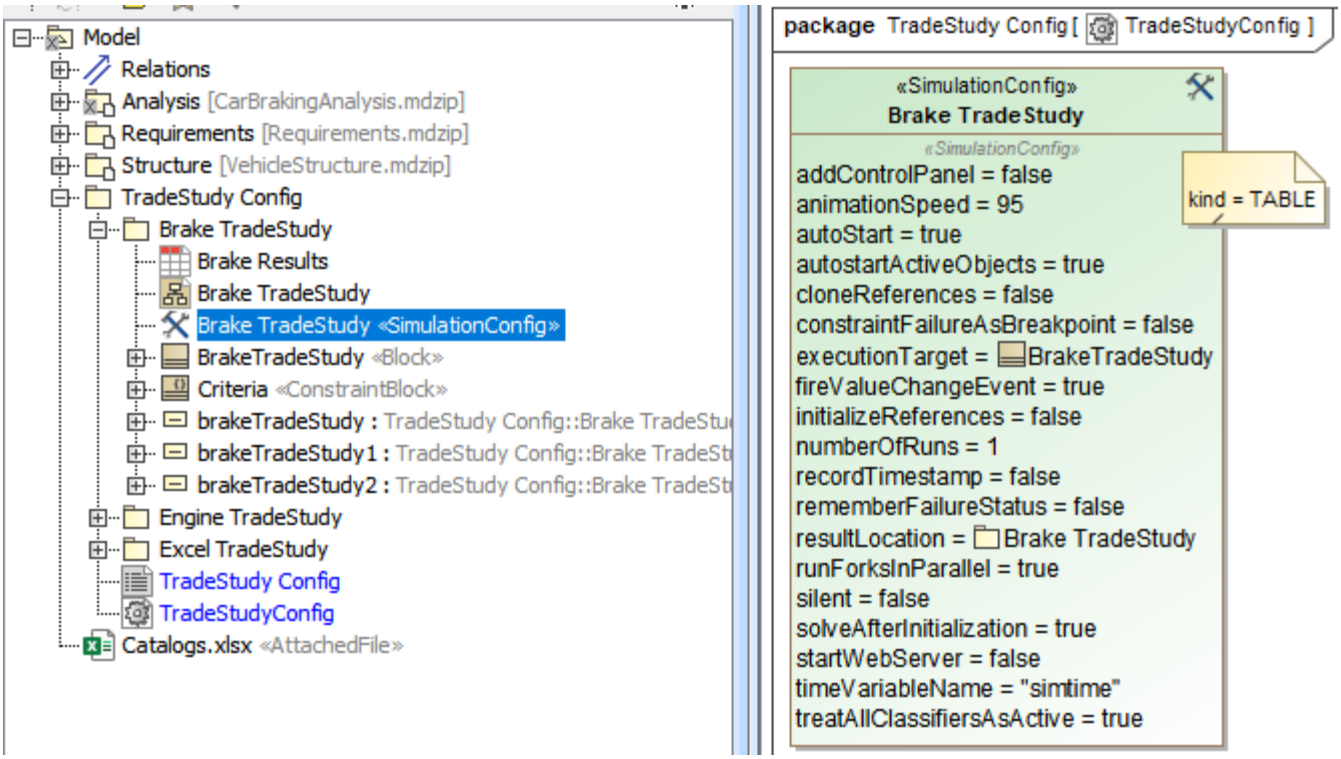
Creating a Simulation Configuration diagram and configuring other settings

Create a Simulation Configuration diagram, add a SimulationConfig to the newly created diagram, and set the following tags:

- **executionTarget**: set to the *TradeAnalysis* Block, e.g., *BrakeTradeStudy* in the sample. *executionTarget* can be an instance of the *TradeAnalysis* Block so that the instance can be reconfigured.
- **resultLocation**: a package/instance table must be specified so an instance with related information will be saved after running the simulation. The information includes **N**, **OutOfSpec**, **score**, **winner**, and other elements.

> **Note**
>
> - If you do not create a SimulationConfig and run the *TradeAnalysis* Block directly, **TradeStudy** will not be triggered, but the *TradeAnalysis* Block will be run as normal .
> - If the **executionTarget** of a SimulationConfig is the *TradeAnalysis* Block, **TradeStudy** execution will override other executions, so Monte Carlo simulation will not be triggered even if **numberOfRuns** is more than 1.

- **silent**: set the **silent** tag accordingly to see the animation.
- **rememberFailureStatus**: use *rememberFailureStatus* when evaluating those weighted alternatives. Any alternatives violating any of the attached constraints/Requirements will not be considered as the **winner**, but they will be used in the calculation of **OutOfSpec**.
- **Tags neglected**: to neglect **animationSpeed**, **constraintFailureAsBreakpoint**, **UI**, and **autoStart**.

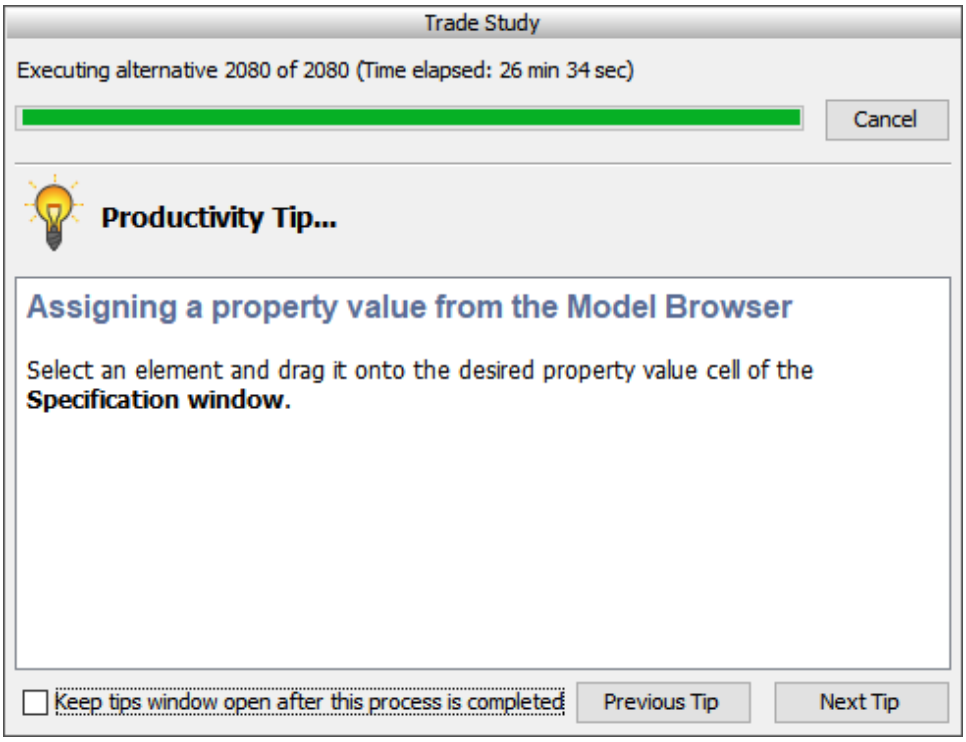


SimulationConfig created for other settings, e.g., executionTarget and resultLocation.

Running the SimulationConfig and reviewing results

1. Run the SimulationConfig created in the previous section.
2. When running the SimulationConfig, the information of TradeStudy will be printed in the **Console** pane. The Simulation pane will be disabled, but all warning/errors will be printed.
3. There is a progress bar shown with the description of **Executing alternative [n] of [total iterations] (Time elapsed: [time])**, and the **Cancel** button that allows canceling Trade Study as shown in the figure below.
4. Simulation automatically iterates all variants and instantiates all possible configurations in memory. For example, *Brake* which contains the combinations of *Pad* (26 instances), *Caliper* (20 instances), and *Rotor* (4 instances) will have 26 x 20 x 4 = 2,080 configurations.
5. The **winner** value on each iteration will be compared directly with the **score** value property.

> **Note**
>
> - The **Starting Math Engine** progress bar will be shown in this sample because MATLAB is used as the external evaluator. See also Integration with MATLAB.
> - Any alternatives violating any of the attached constraints/Requirements will not be considered as the **winner**. They will be used in the calculation of **OutOfSpec**.
> - The **rememberFailureStatus** of a SimulationConfig will be used when evaluating those alternatives.
> - When more than one alternative has the same winning score of a Trade Study, a warning message is printed.
> - In some cases, you can click **Unlock** in the **Simulation** pane to see execution details during the execution.



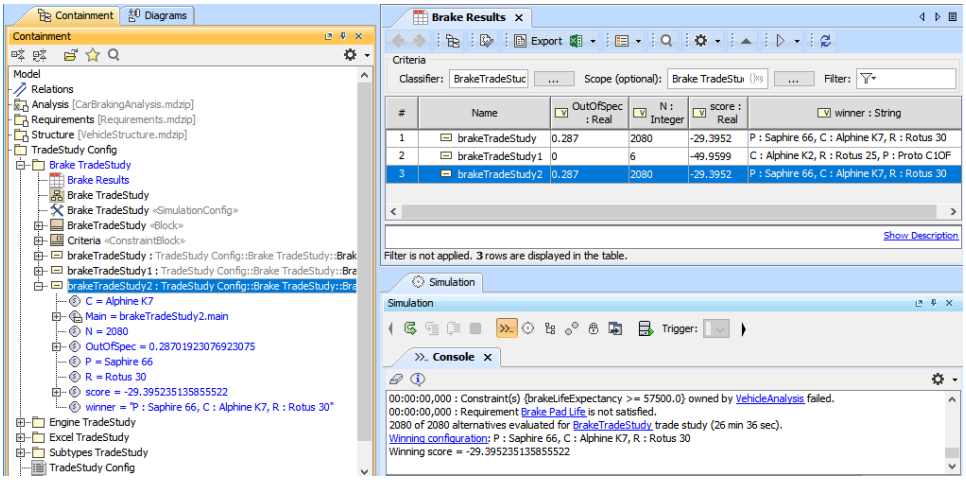
A progress bar shown with description and the Cancel button during the simulation.

6. When the simulation is either completed or canceled, **winning** information will be printed on the **Console** pane in the following three lines as shown in the figure below.

    - The first line shows the number of iterations (completed/canceled) of all alternatives for ***executionTarget*** with elapsed time.
    - The second line displays the *winning* configuration from the **winner** string.
    - The third line is the **winningscore** from the ^*score*.

    > **Note**
    >
    > The **winner** string is printed with the formats as follows:
    > *AlternativeProperty.Name1 : StringKind [, AlternativeProperty.Name2 : StringKind, AlternativeProperty.Name3 : StringKind, …]*
    >
    > where *StringKind* will apply the following rules, depending on **kind** of alternative:
    >
    > - *kind=TABLE*: then *StringKind*=InstanceName, e.g., P : Saphire 66, C : Alphine K7, R : Rotus 30.
    > - *kind=SUBTYPES*: then *StringKind*=subtypesName, e.g., power : Diesel, support : Wheels, stopping : Brakes.
    > - *kind=EXCEL*: then *StringKind*=#Row, e.g., R : #5, P : #21, C : #21, where *Row* is the number of Excel rows.
    > - *kind=Parameter Sweep:* then *StringKind*=GeneratedValue, e.g., brakeMU : 0.66, centerLength : 0.12, outerDiameter : 0.29, thickness : 0.04, width : 0.038.

The result instance will be saved at the location as specified in **resultLocation** of SimulationConfig. You can create an instance table, set a Classifier to the *TradeAnalysis* Block, and set *Scope* to the package of the results.



The TradeAnalysis result (in the last 3 lines) is printed on the Console pane, and the result instance is saved into a package and presented in the instance table.