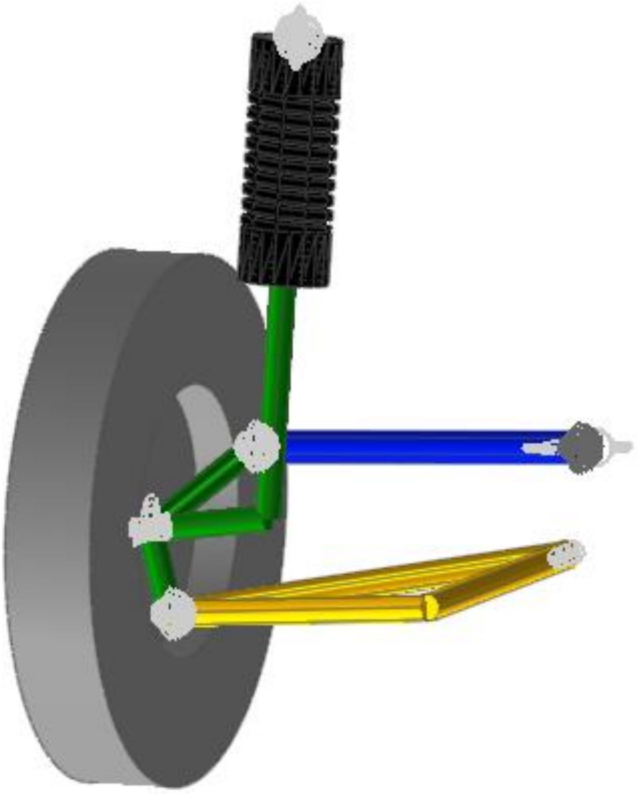
Suspension System Tutorial (AutoDesign)



FunctionBay

Edition Note

This document describes the release information of **RecurDyn V9R4**.

Table of Contents

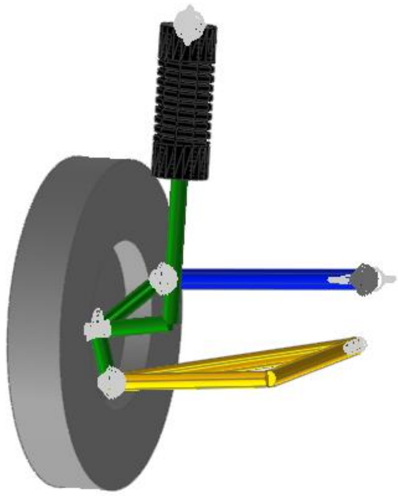
Outline of Tutorial Sample D

Model	Description
Sample D	**Suspension System Design Problem:** This design has two design objectives. Also, it has 27 design variables. The design goal is to minimize the Yaw-range and the Roll-Range of tire motion. This problem is not easy because it is a multi-objective problem and has too many design variables. In general, other design tools employ D-Optimal design or Latin Hypercube for constructing the meta model. Suppose that construct a quadratic response surface model, D-optimal design fundamentally requires 406 sampling points, which is evaluate by using 1+2*27+27*26/2. **AutoDesign** uses however only 44 evaluations to solve the problem without variable screening. **Key Point:** Study the concept of multi-objective optimization and the procedure of screening design variables.

Sample
D

Suspension System Design Problem

Let's consider the simple model of car suspension system. The system has 5 components such as arm, tie rod, knuckle, shock absorber damper and tire. When the tire moves along vertical direction, the simulation shows the damping process and kinematical motion.



All the design variables are the geometric coordinates of joints. The design objective is to minimize the first rotational Yaw-Roll of tire.

This problem has 27 design variables for 9 joints. Nevertheless, we will try to minimize the Yaw-range and the Roll- range directly. In other words, design variable screening is not used. Next, we will re-try to solve the same problem after screening the design variables. Then, the optimization results will be compared.

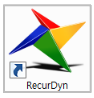
Open files related in Sample-E		
Sample	<InstallDir>\Help\Tutorial\AutoDesign\SuspensionSystem\Examples\SAMPLE_D0.rdyn	
Solution	**1**	<InstallDir>\Help\Tutorial\AutoDesign\SuspensionSystem\Solutions\SAMPLE_D0.rdyn
	2	<InstallDir>\Help\Tutorial\AutoDesign\SuspensionSystem\Solutions\SAMPLE_D1.rdyn
	3	<InstallDir>\Help\Tutorial\AutoDesign\SuspensionSystem\Solutions\SAMPLE_D2.rdyn

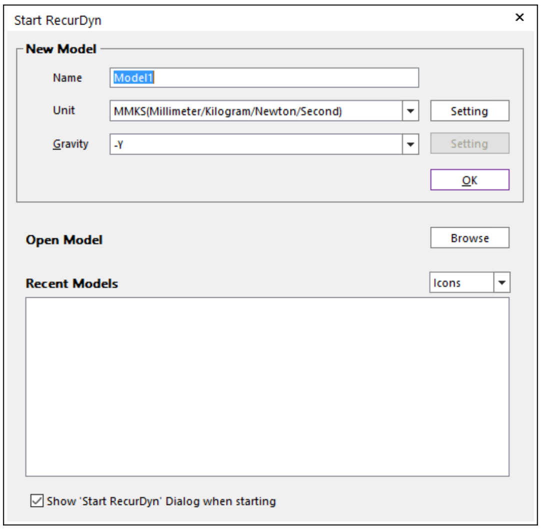
Note: If you change the file path at discretion, it can be located in any folder that you specify.

Chapter
1

Loading the Model and Viewing the Yaw & Roll ranges

To load the base model and view the animation:



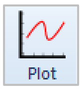


1. On your Desktop, double-click the **RecurDyn** tool.

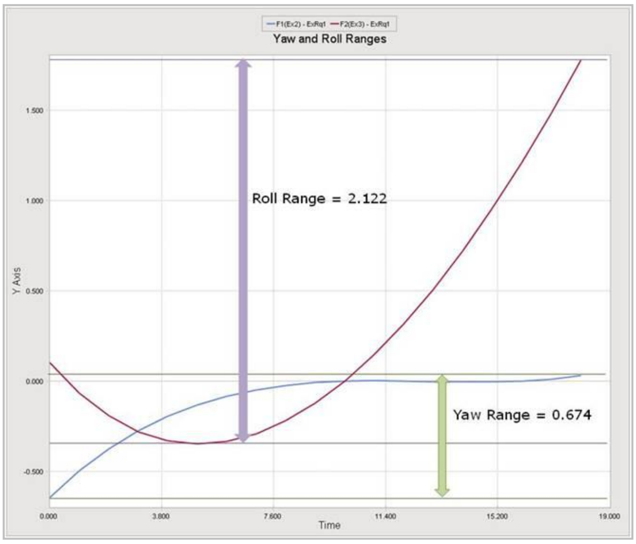
   RecurDyn starts and the **Start RecurDyn** dialog box appears.

2. Close **Start RecurDyn** dialog box. You will use an existing model.
3. In the toolbar, click the **Open** tool and select '**Sample_D0.rdyn**' from the same directory where this tutorial is located. The suspension system appears in the modeling window.

4. Click the **Dynamic/Kinematic** button.



5. Click the **Plot Result** button. Then, window is switched. In right side, you can see plot database. If it is not shown, check the database window in **View** menu. Expression 2 & 3 are Yaw and Roll angles.

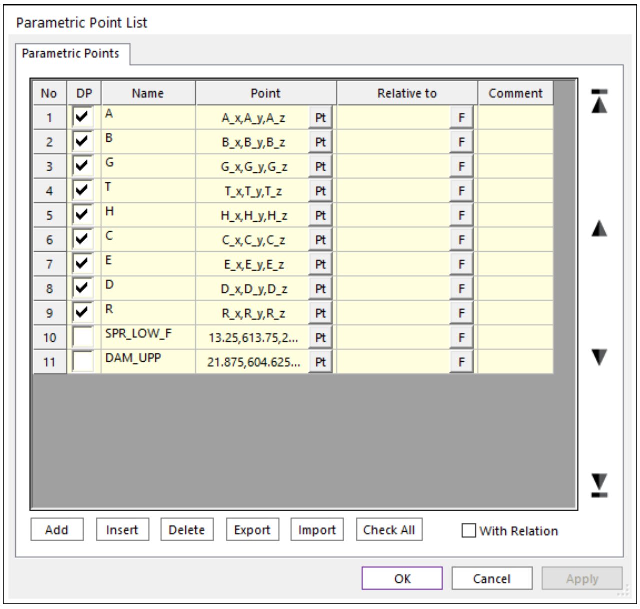


Chapter

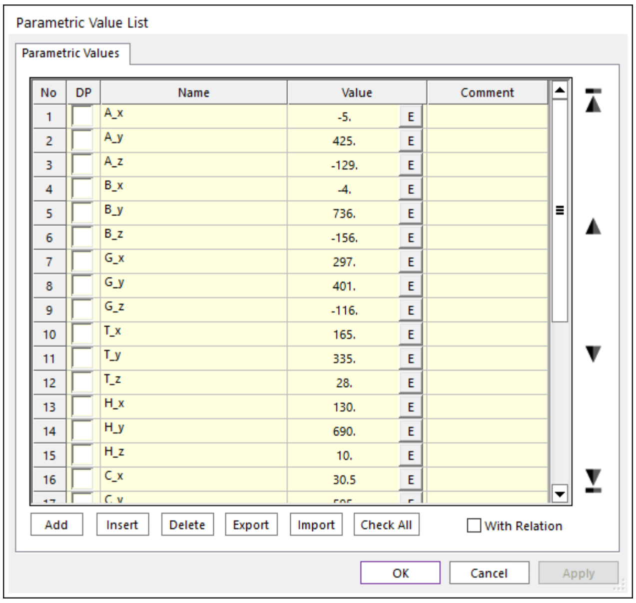
2

Defining the design variables

All geometric coordinates of joints are defined by using **Parametric Points** shown at the below figure. In Figure, they are represented as **A_x, A_y, ..., R_y** and **R_z**.



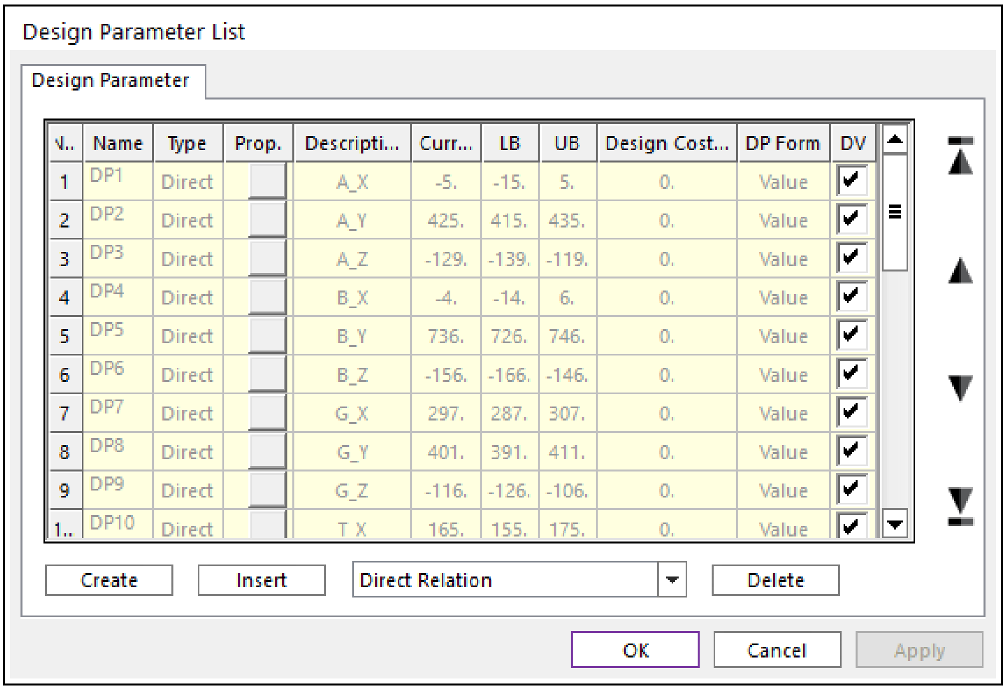
Next, the parametric values are defined in the **Parametric Value** menu in **Subentity**



All the above relations have defined in the model 'SAMPLE_D.rdyn'.

Next, select the **Design Parameter** menu.

Then, you can see that 27 parametric values are linked by design parameters as shown below.



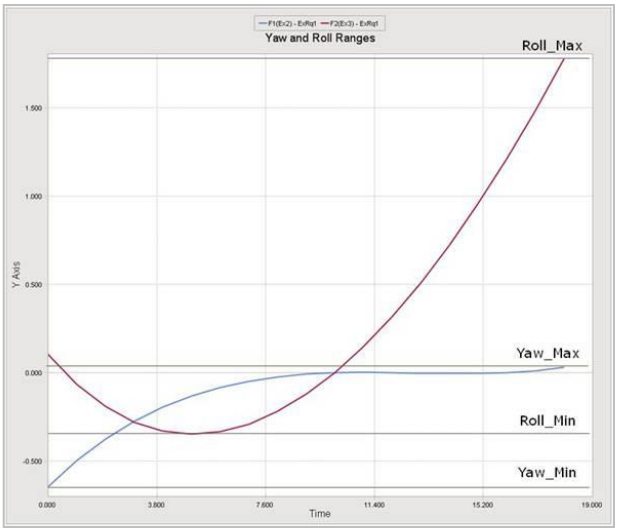
N..	Name	Type	Prop.	Descripti...	Curr...	LB	UB	Design Cost...	DP Form	DV
1	DP1	Direct		A_X	-5.	-15.	5.	0.	Value	✔
2	DP2	Direct		A_Y	425.	415.	435.	0.	Value	✔
3	DP3	Direct		A_Z	-129.	-139.	-119.	0.	Value	✔
4	DP4	Direct		B_X	-4.	-14.	6.	0.	Value	✔
5	DP5	Direct		B_Y	736.	726.	746.	0.	Value	✔
6	DP6	Direct		B_Z	-156.	-166.	-146.	0.	Value	✔
7	DP7	Direct		G_X	297.	287.	307.	0.	Value	✔
8	DP8	Direct		G_Y	401.	391.	411.	0.	Value	✔
9	DP9	Direct		G_Z	-116.	-126.	-106.	0.	Value	✔
1..	DP10	Direct		T_X	165.	155.	175.	0.	Value	✔

Chapter

3

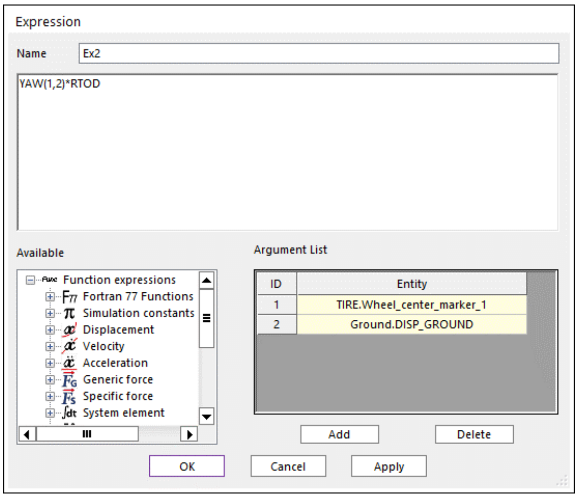
Defining the performance index

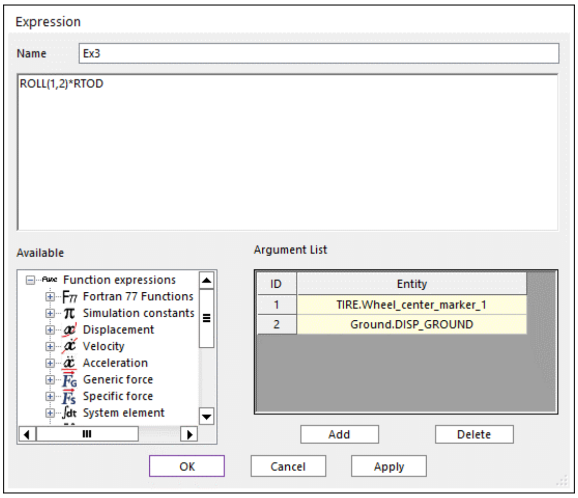
Let’s consider the performance indexes. We will minimize the Yaw and Roll ranges during tire moves vertical direction. As RD does not provide those values directly, we should evaluate them by using Expression and Variable Equation.



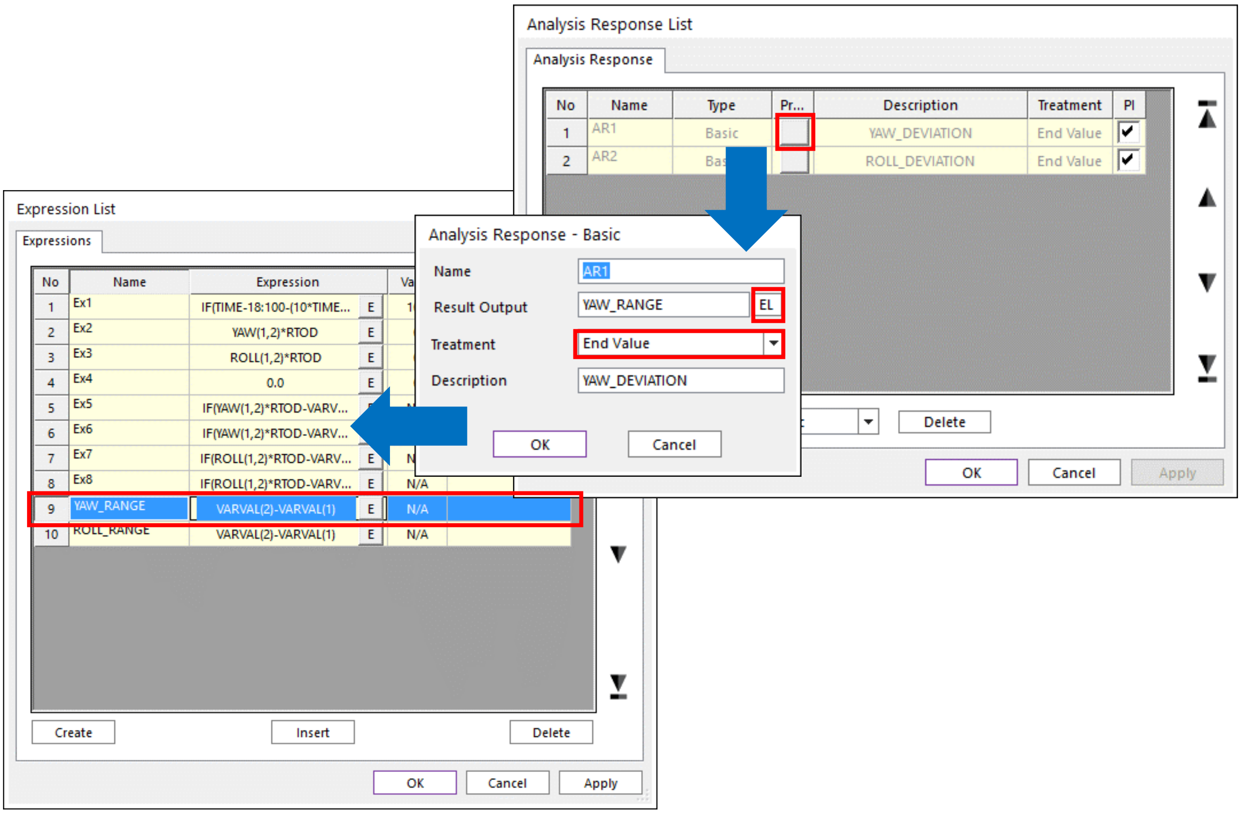
In order to evaluate them, we evaluate the minimum and the maximum values for Yaw and Roll angles. Then, the deviations between Max and Min are the ranges for them.

- **Step 1**: Create the **Expression** for **Yaw** and **Roll** angles. The following figures show the expressions to save Yaw and Roll angles.





- **Step 2**: By using **Expression**, '**YAW_DEVIATION**' and '**ROLL_DEVIATION**' are defined. Then, you can define them as analysis responses at '**Analysis Response**' in **AutoDesign**. The following figure shows this process.



Chapter

4

Running a Design Optimization

When you select the '**Design Optimization**', all the design variables, check in **DV**, will be included in the design. The performance index however will be empty. Then, you add ARs to the Performance Index.

The optimization problem is to minimize the Yaw Range and the Roll Range while satisfying those two ranges less than them of the current design. Also, we think that Yaw Range is more important than Roll Range. Thus, its' weight is twice greater than that of Roll.

Minimize Yaw_Deviation*2 & Roll_Deviation

subject to **Yaw_Deviation =< 0.67**

Roll_Deviation =< 2.12,

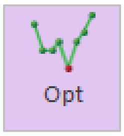
where the values of 0.67 and 2.12 are the range values for the current design. Those two inequality constraints seem to be redundant because two objectives should be minimized. It is however not guaranteed. Thus, it is difficult to solve multi-objective optimization problem. In the Part II manual: Guideline for **AutoDesign**, the chapter 5 explains the multi-objective optimization.

Let's consider the above design problem from the view of multi-objective optimization process. If necessary, let's denote $f_1 = Yaw\_Deviation$ and $f_2 = Roll\_Deviation$. When the initial samples construct the approximate functions of $f_1(\mathbf{x})$ and $f_2(\mathbf{x})$, which are called as metamodels. Then, f_1^* and f_2^* is the minimum values from the initial samples.

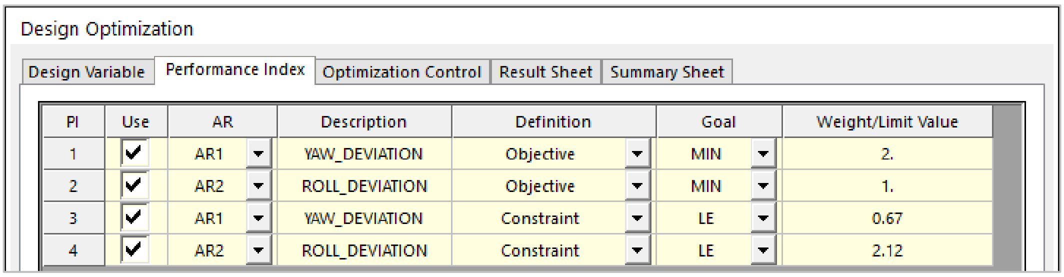
$$Min \max\left\{\left(\frac{f_1(\mathbf{x}) - f_1^*}{f_1^*}\right), \left(\frac{f_2(\mathbf{x}) - f_2^*}{f_2^*}\right)\right\}$$

Thus, the quality of multi-objectives optimization depends on the number of initial samples. Unfortunately, this problem has 27 design variables, which requires too many sample points. Those two inequality constraints can avoid the pre-mature convergence, even though the number of initial samples is minimized.

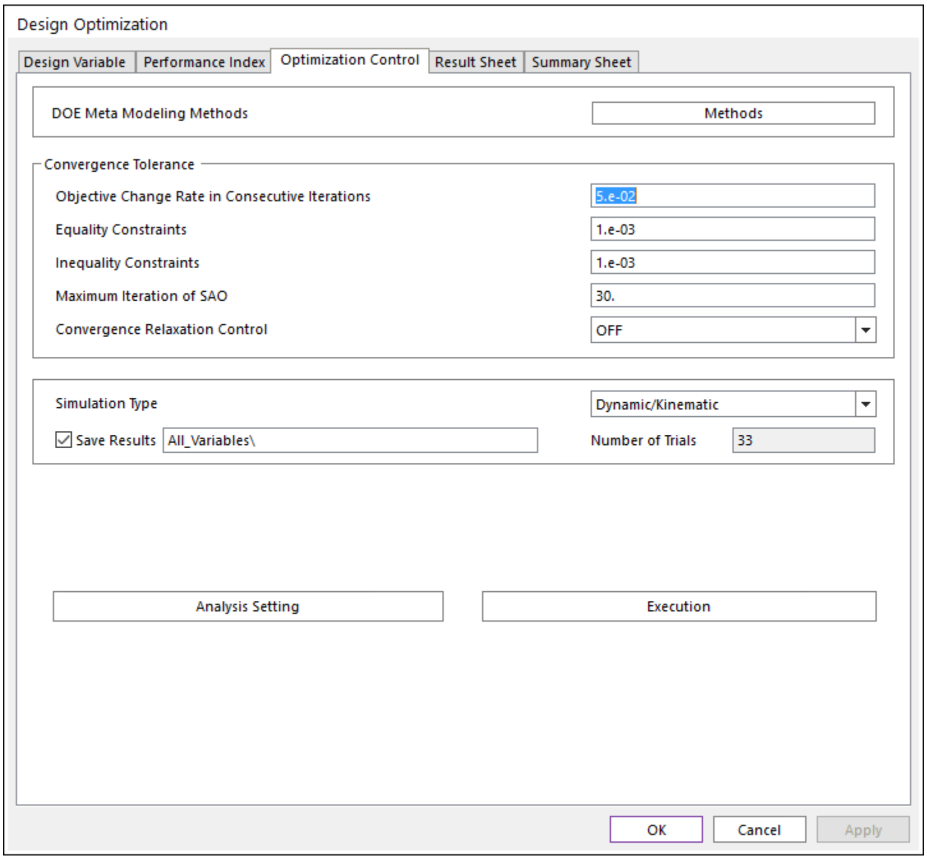
Let's start to solve the multi-objective optimization problem:



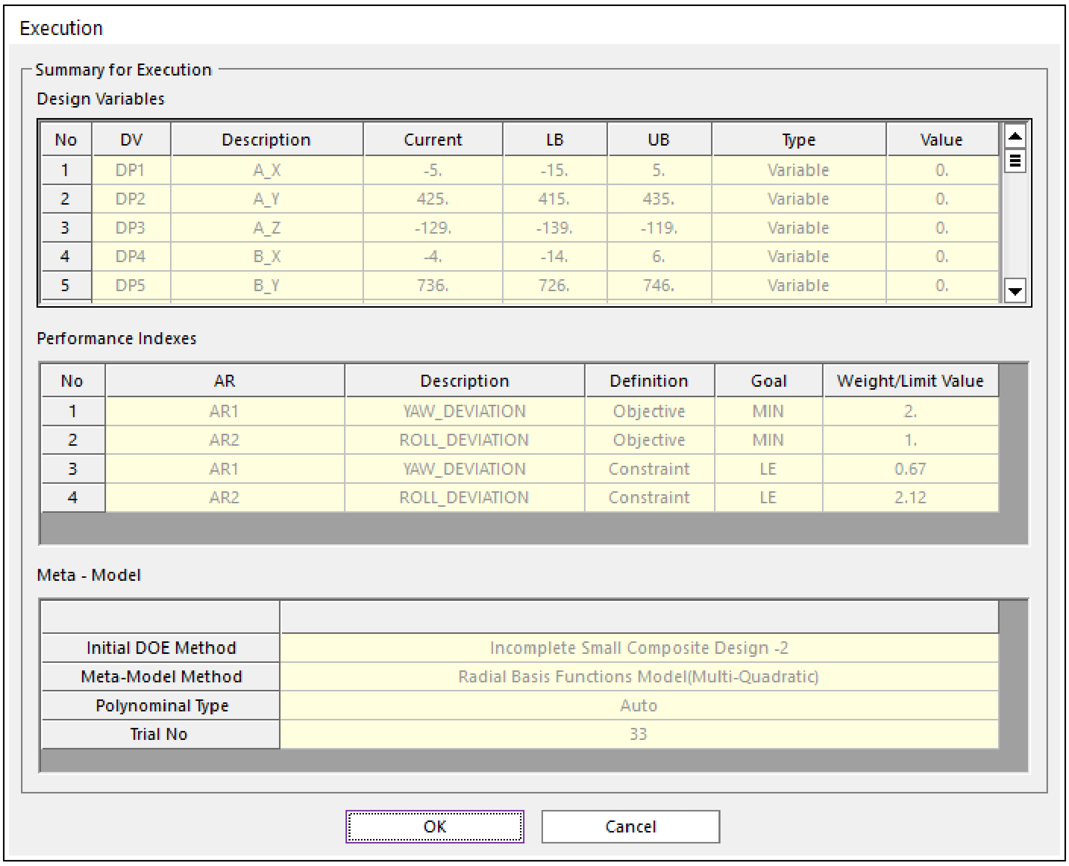
1. Click the **Performance Index** Tab. Then, define the above optimization formulation as follows:



2. Click the **Optimization Control** Tab. The default values are directly used. Then, click the **Execution** button.



Then, you can see the summary of design formulation. Check **Design Variables**, **Performance Index** and **Meta-Model information**. If all information is correct, then click the **OK** button. Then, optimization process is progressed.



Execution

Summary for Execution

Design Variables

No	DV	Description	Current	LB	UB	Type	Value
1	DP1	A_X	-5.	-15.	5.	Variable	0.
2	DP2	A_Y	425.	415.	435.	Variable	0.
3	DP3	A_Z	-129.	-139.	-119.	Variable	0.
4	DP4	B_X	-4.	-14.	6.	Variable	0.
5	DP5	B_Y	736.	726.	746.	Variable	0.

Performance Indexes

No	AR	Description	Definition	Goal	Weight/Limit Value
1	AR1	YAW_DEVIATION	Objective	MIN	2.
2	AR2	ROLL_DEVIATION	Objective	MIN	1.
3	AR1	YAW_DEVIATION	Constraint	LE	0.67
4	AR2	ROLL_DEVIATION	Constraint	LE	2.12

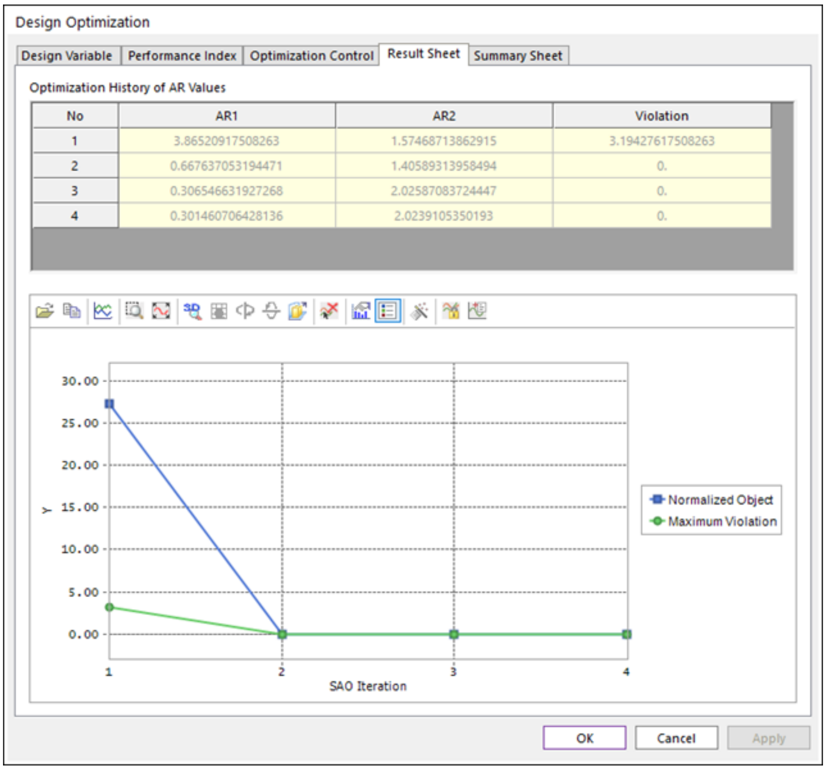
Meta - Model

Initial DOE Method	Incomplete Small Composite Design -2
Meta-Model Method	Radial Basis Functions Model(Multi-Quadratic)
Polynominal Type	Auto
Trial No	33

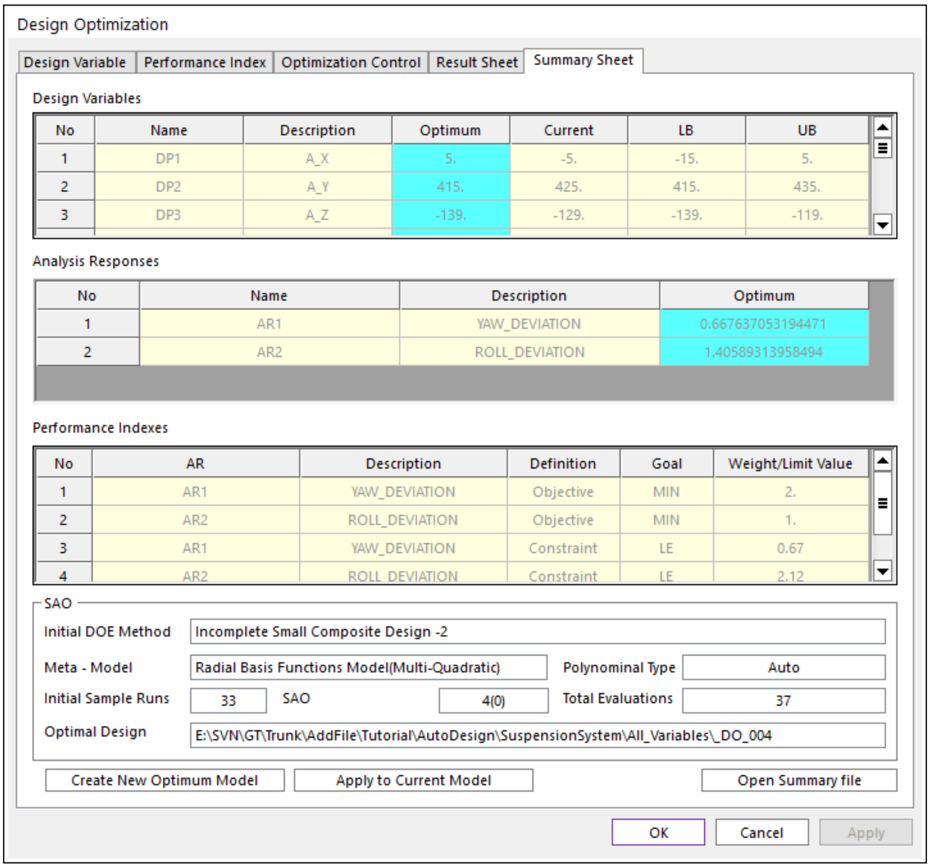
OK Cancel

3. When the optimization process is completed, the **Result Sheet** Tab is automatically shown. The optimization process is converged in 4 iterations. Thus, AutoDesign solves the suspension system design having 27 design variables only for 37 analyses that includes 33 analyses for the initial sampling points. The final design gives that AR1=0.667 and AR2=1.405, which can minimize the Yaw deviation by 0.3 % and the Roll deviation by 33.7 %.

- ## Convergence History



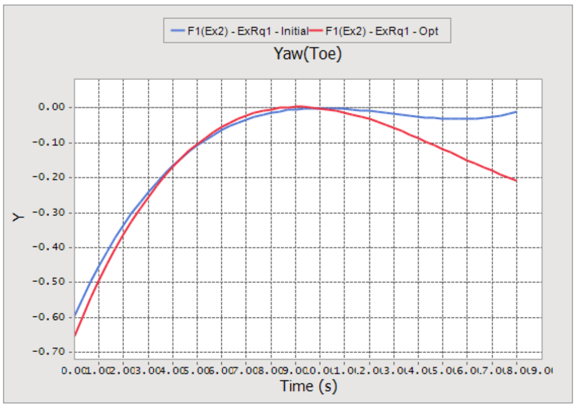
- ## Summary Sheet

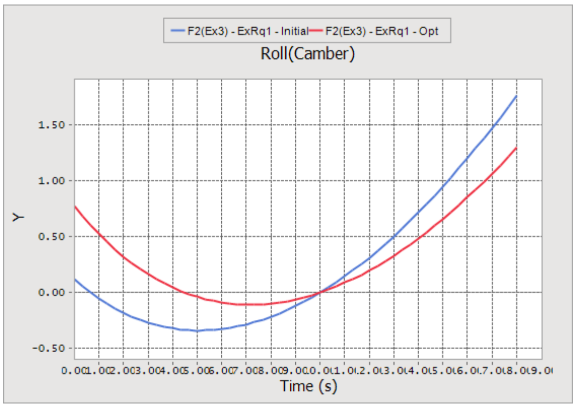


In the summary sheet, shown in the above, is newly provided. The optimization results are summarized in the design variables and analysis responses lists. Also, the SAO information is summarized, which shows that SAO requires 4 iterations. Thus, the number of total evaluations is 37. And the analysis result of optimal design is 'DO_004'.

4. Finally, let's compare the yaw and roll ranges for the initial design and the final design. DO_004 is the final design. Also, DOE33 is the initial design. The following figures show those comparisons. When the ISCD-1 and ISCD-2 compose the initial samples, the final one of the initial samples is the current design. In the following figures, the red color line is an optimum result.

Yaw(Toe) **Roll(Camber)**



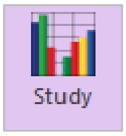


Chapter 5

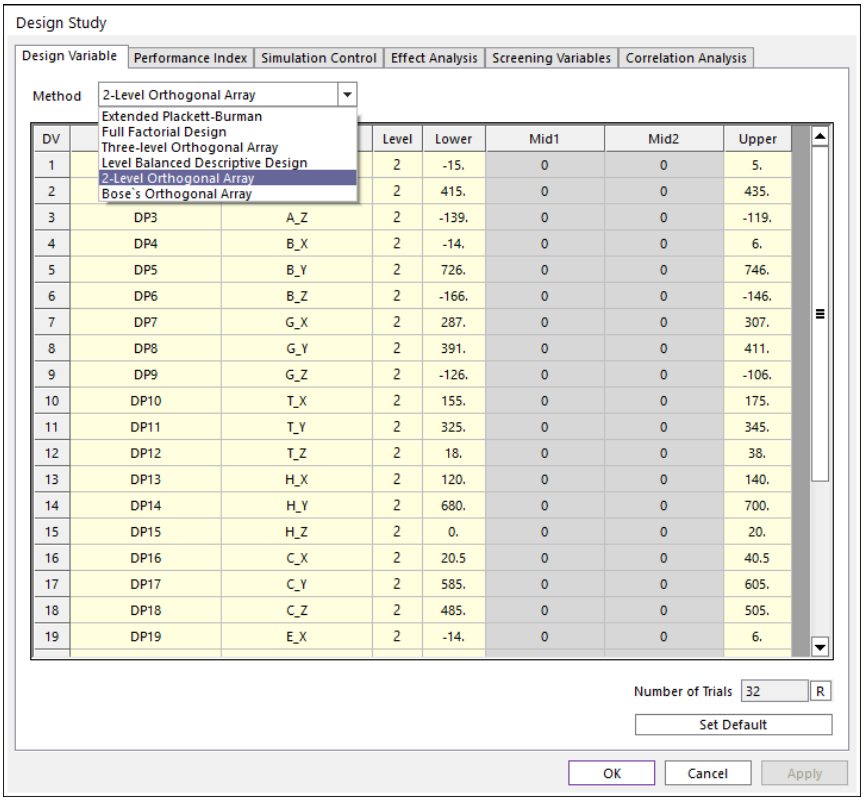
Design Optimization with Screening Variables

Now, let's compare the optimization results for considering all design variables and the screened design variables. Thus, save the model file **'Sample_D0.rdyn' as 'Sample_D1.rdyn' and delete all the results in the Simulation History.**

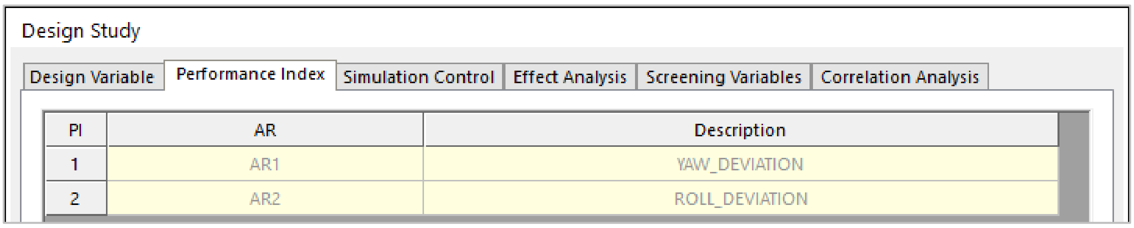
First, let's try to screen the design variables. As screening is based on the effect analysis results, you select the design study in **AutoDesign**. Following steps explain the screening process:



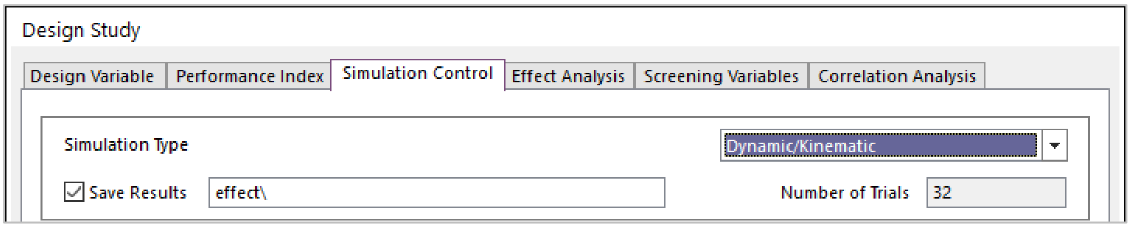
1. Enter the **Design Study** menu.
2. Then, you can see the list of design variables in the **Design Variable** tab. As the number of design variables is 27, we select the **2-Level Orthogonal Array** to reduce the number of trials. If 3-Level Orthogonal Array is selected, the number of trials is 81.

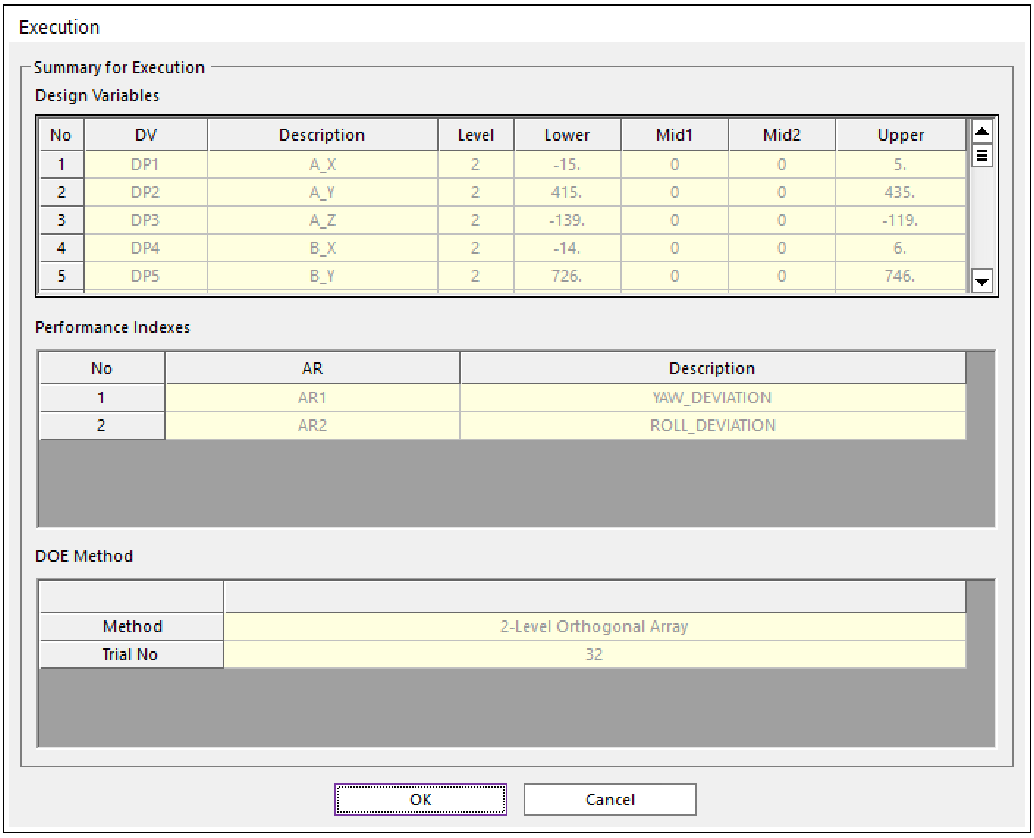


3. Next, in the Performance Index tab, two analysis responses such as AR1 and AR2 will be shown. If they are not, you retry to make '**Sample_D1.rdyn**' from '**Sample_D0.rdyn**'.

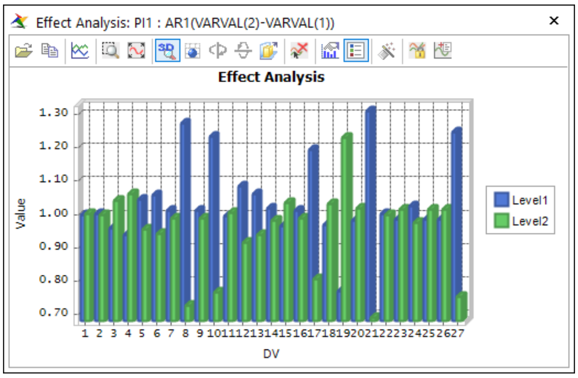


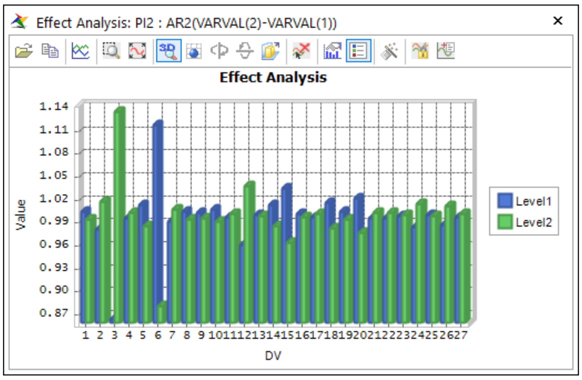
4. Next, click the **Simulation Control** tab. If you save the analysis results each trial, check the **Save Results** and enter the **Folder name**. Then, click the **Execution** button.





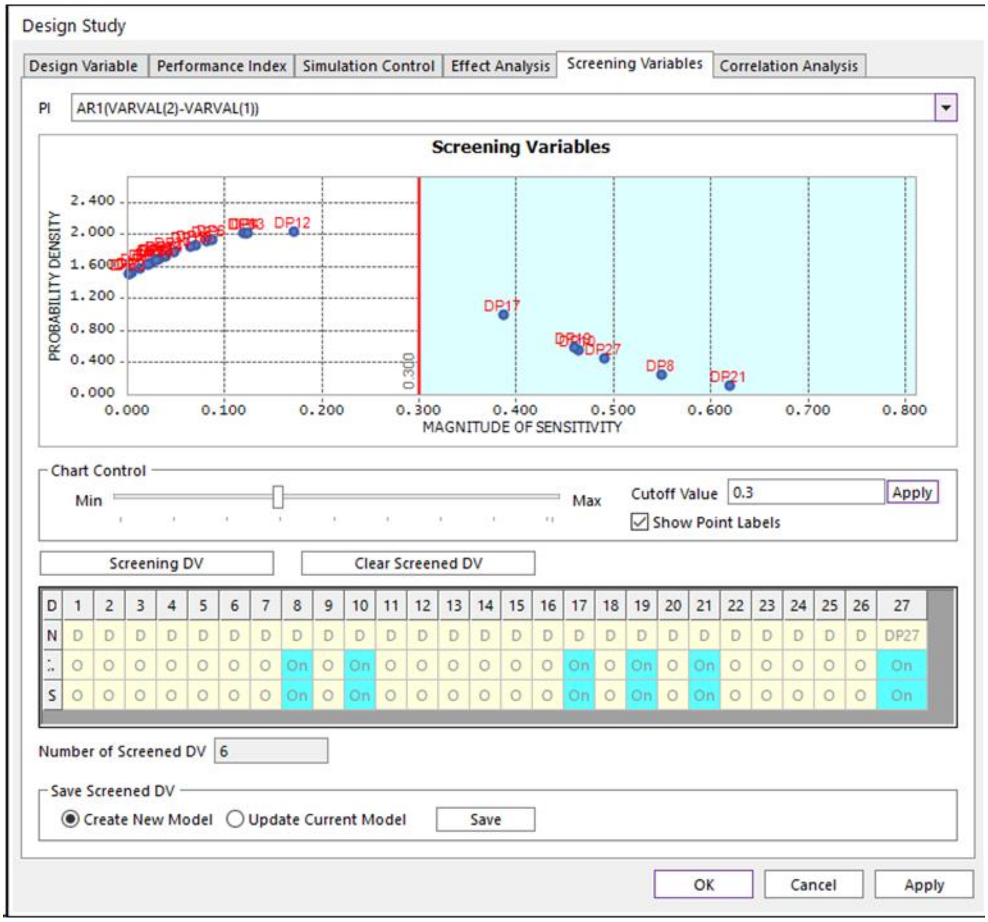
5. After all analyses have been completed, the design study window is activated. Then, click the **Effect Analysis** tab. Then, you can see the effect analysis chart by checking the check boxes in the **Effect Values** column and clicking the **Draw** button. The effect analysis results are shown as follows:





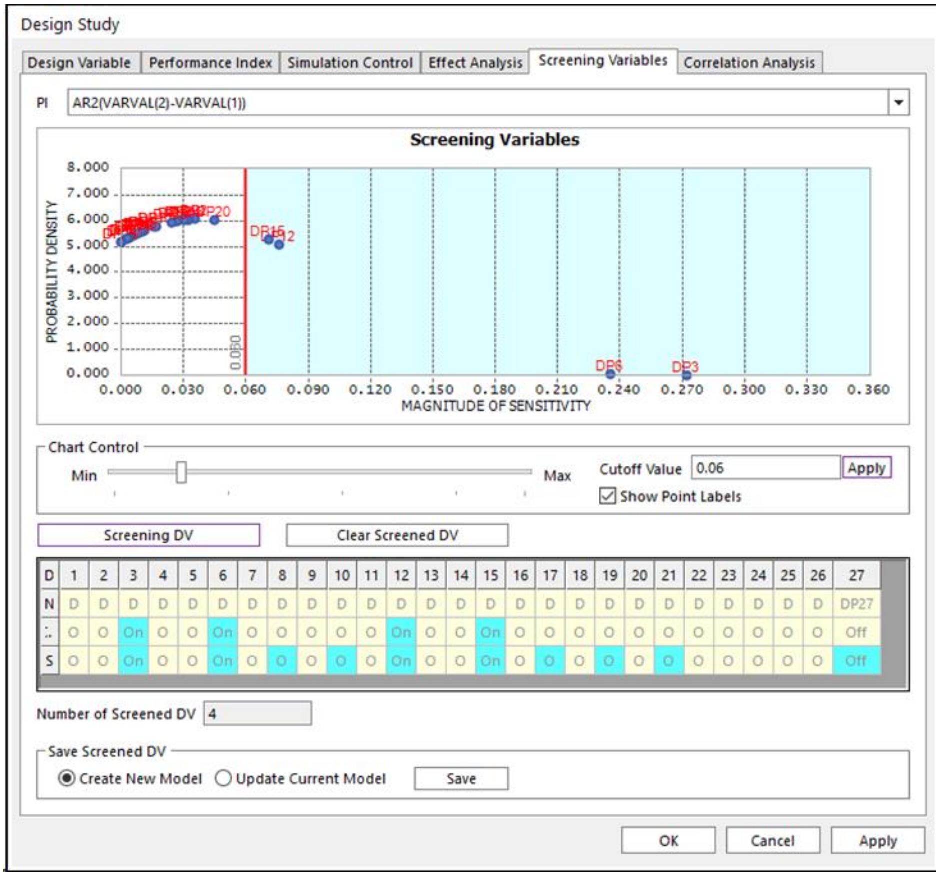
Two figures show that the different variables are sensitive to PI_1 and PI_2. Generally, users select the sensitive variables from the above charts. It is however not easy. Thus, **AutoDesign** provides a statistical guideline for screening variables.

6. Click the **Screening Variables** tab. Then, select **AR_1** in the **PI** box. Then, you can see the scatter points. The right positioned points are more sensitive to the left ones. Move the controller to divide design variable groups. Then, the **Cutoff Value** as **0.3** and click the **Screening DV** button.



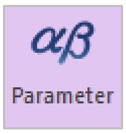
Then, the red line divides the scatter points into two groups. The right group is the remaining variables. Then, the screened variables are marked as '**On**'. Others are done as '**Off**'.

Next, select **AR2** in the **PI** box and do the same process similarly except defining **Cutoff Value** as **0.06**. Then, the screened variables are summarized as follows:

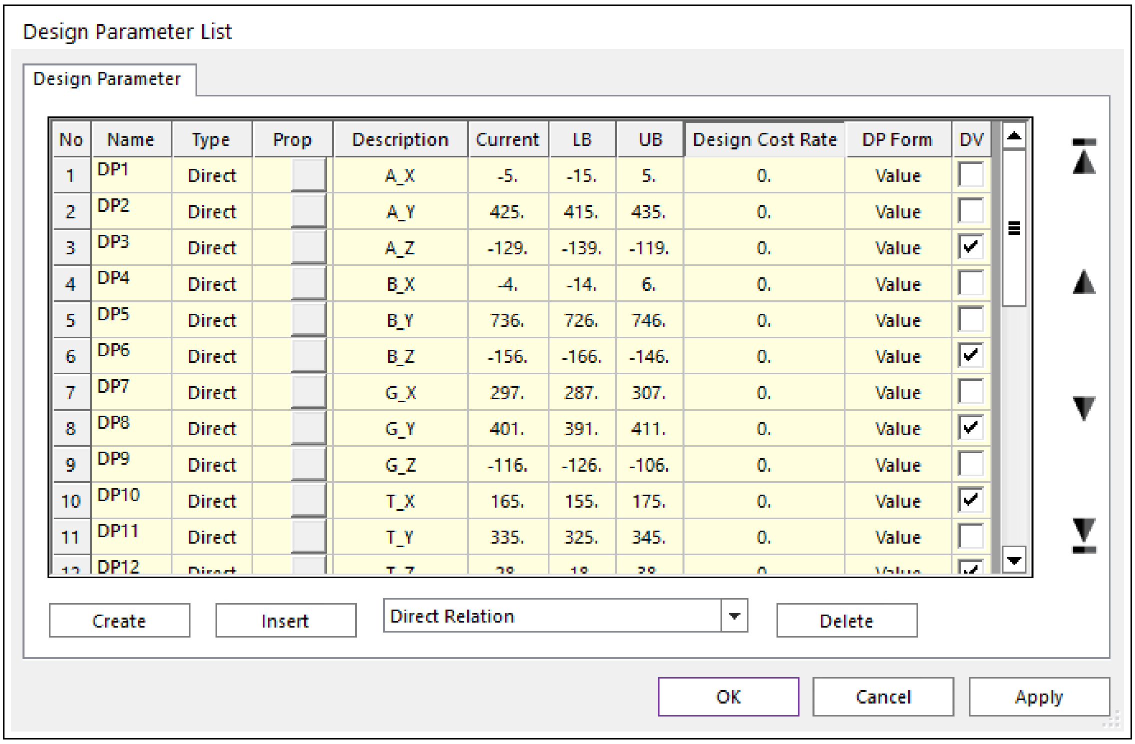


The screening DV gives that the active design variables (DV) are DP3, DP6, DP8, DP10, DP12, DP15, DP17, DP19, DP21, and DP27.

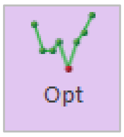
Now, create the new model by clicking the **Save** button with checking **Create New Model**. The new model file name is '**Sample_D2.rdyn**'.



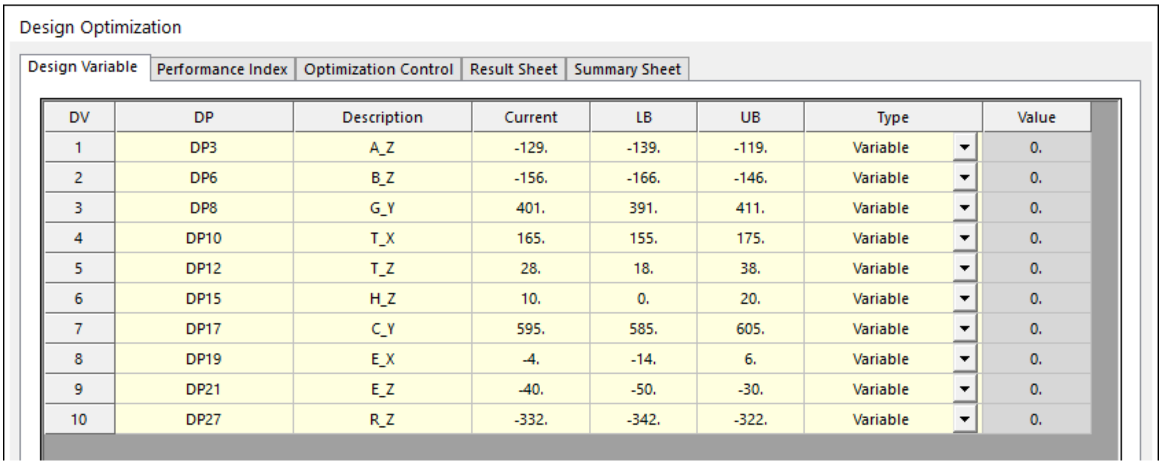
7. Now, you can see that the model file is changed as '**Sample_D2.rdyn**'. Click the **Design Parameter** icon in **AutoDesign**. Unlike the model **'Sample_D1.rdyn'**, the screened variables are only checked in DV column. This represents that DV1=DP3, DV2=DP6, DV3=DP8, DV4=DP10, DV5=DP12, DV6=DP15, DV7=DP17, DV8=DP19, DV9=DP21, and DV10=DP27. Most of the active design parameters are z-coordinate values.



No	Name	Type	Prop	Description	Current	LB	UB	Design Cost Rate	DP Form	DV
1	DP1	Direct		A_X	-5.	-15.	5.	0.	Value	☐
2	DP2	Direct		A_Y	425.	415.	435.	0.	Value	☐
3	DP3	Direct		A_Z	-129.	-139.	-119.	0.	Value	☑
4	DP4	Direct		B_X	-4.	-14.	6.	0.	Value	☐
5	DP5	Direct		B_Y	736.	726.	746.	0.	Value	☐
6	DP6	Direct		B_Z	-156.	-166.	-146.	0.	Value	☑
7	DP7	Direct		G_X	297.	287.	307.	0.	Value	☐
8	DP8	Direct		G_Y	401.	391.	411.	0.	Value	☑
9	DP9	Direct		G_Z	-116.	-126.	-106.	0.	Value	☐
10	DP10	Direct		T_X	165.	155.	175.	0.	Value	☑
11	DP11	Direct		T_Y	335.	325.	345.	0.	Value	☐
12	DP12									

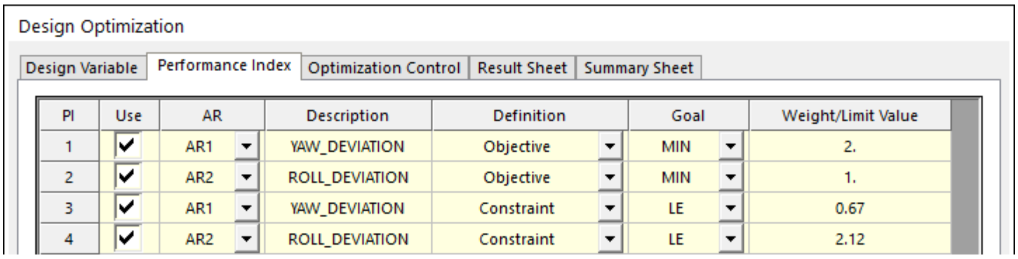


8. Next, Click the **Design Optimization** icon. Then, the screened variables are shown as follows:



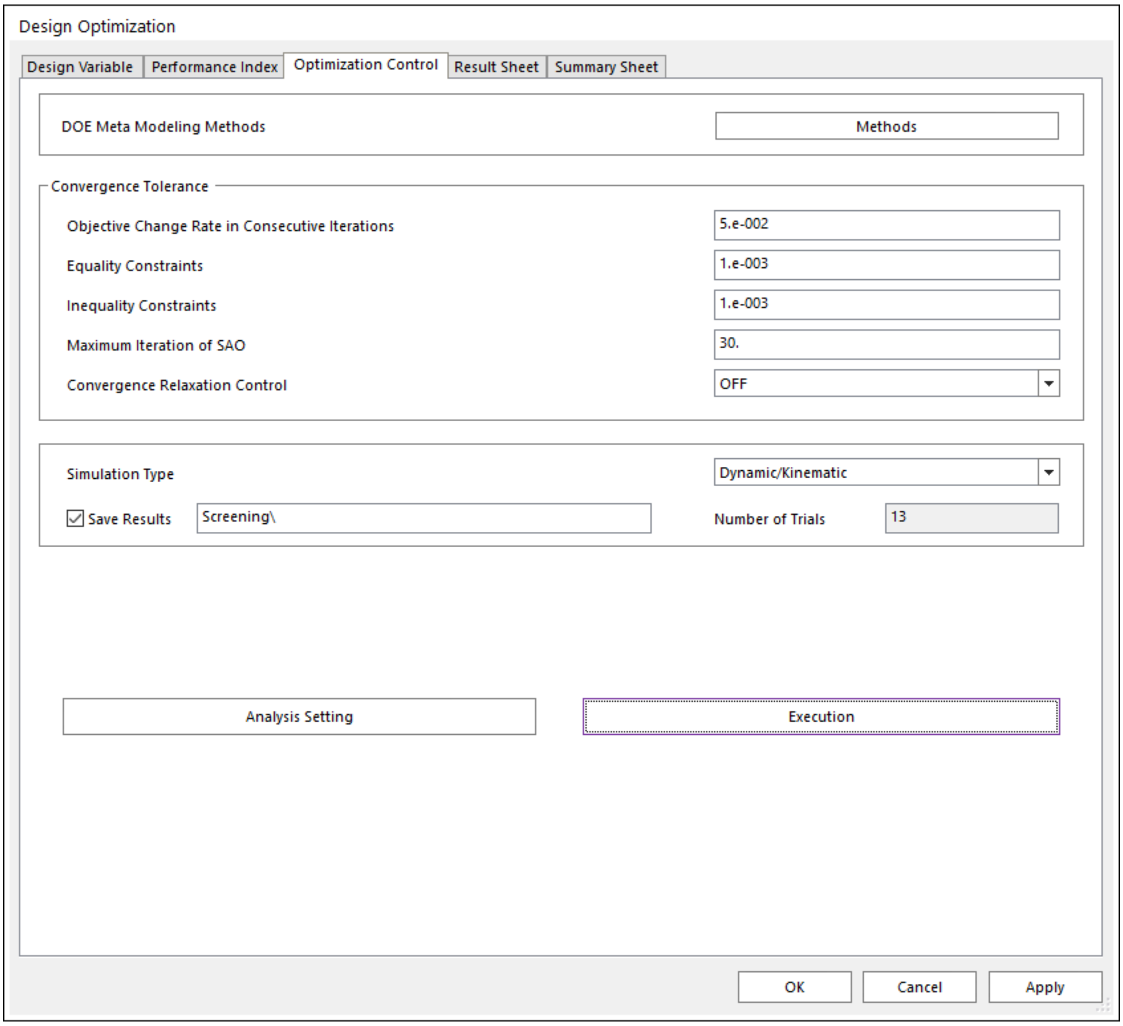
DV	DP	Description	Current	LB	UB	Type	Value
1	DP3	A_Z	-129.	-139.	-119.	Variable	0.
2	DP6	B_Z	-156.	-166.	-146.	Variable	0.
3	DP8	G_Y	401.	391.	411.	Variable	0.
4	DP10	T_X	165.	155.	175.	Variable	0.
5	DP12	T_Z	28.	18.	38.	Variable	0.
6	DP15	H_Z	10.	0.	20.	Variable	0.
7	DP17	C_Y	595.	585.	605.	Variable	0.
8	DP19	E_X	-4.	-14.	6.	Variable	0.
9	DP21	E_Z	-40.	-50.	-30.	Variable	0.
10	DP27	R_Z	-332.	-342.	-322.	Variable	0.

9. Click the **Performance Index** tab. The optimization formulation will be the same as that of '**Sample_D1.rdyn**'. Let's use the same formulation.



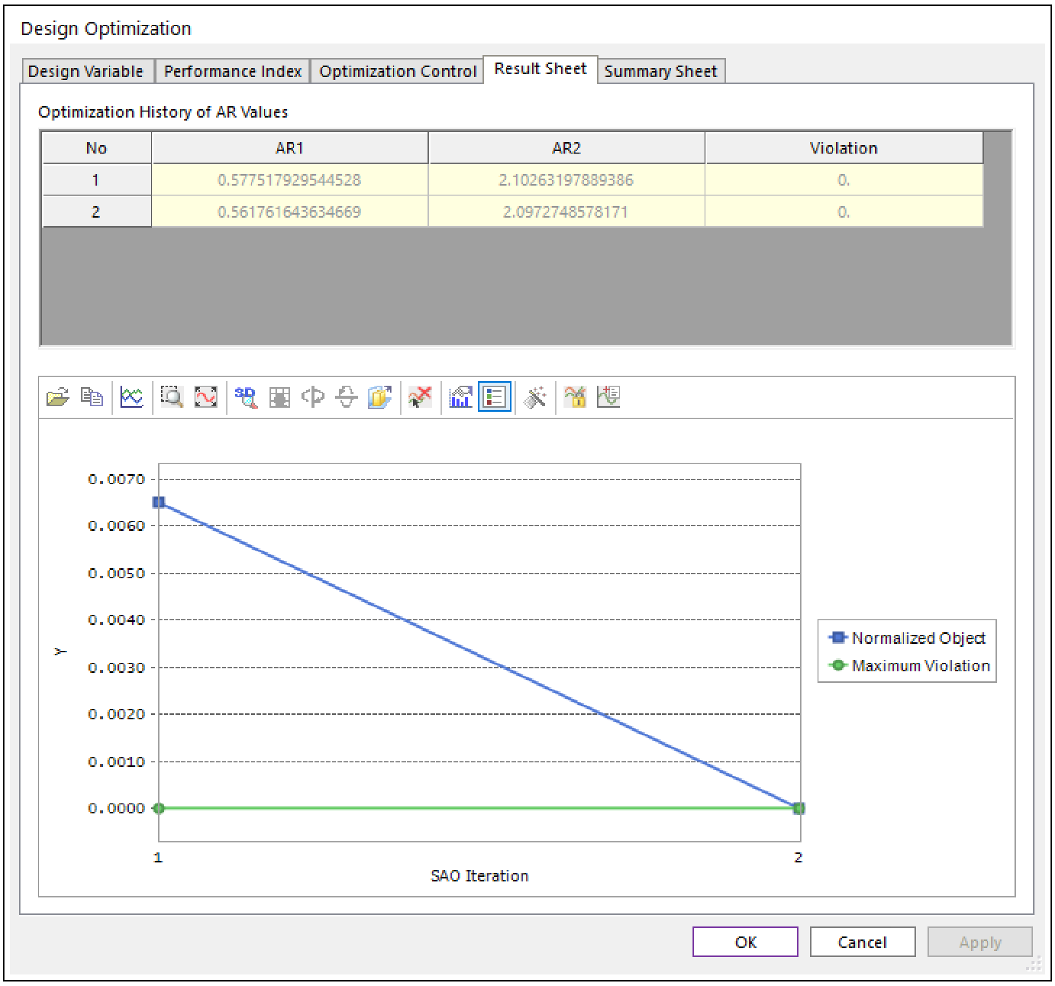
PI	Use	AR	Description	Definition	Goal	Weight/Limit Value
1	☑	AR1	YAW_DEVIATION	Objective	MIN	2.
2	☑	AR2	ROLL_DEVIATION	Objective	MIN	1.
3	☑	AR1	YAW_DEVIATION	Constraint	LE	0.67
4	☑	AR2	ROLL_DEVIATION	Constraint	LE	2.12

10. In the **Optimization Control** tab, all the convergence tolerances use the default values. The result files are saved in the folder '**Screening**'.



11. After the optimization is completed, let's see the result sheet. **AutoDesign** is converged in 3 iterations. The optimized AR1 and AR2 are 0.657 and 2.087, respectively. AR1 and AR2 are similar to those of the design without screening.

- **Convergence History**



Unlike the convergence history for the design problem without screening, the above convergence history simply decreased. Let's compare the summary of two optimization problems.

	With Screening	Without Screening
Number of design variables	10	27
Initial samples	13	33
Number of SAO runs	2	4
Samples for screening	32	-
Optimum response	0.657, 2.087	0.667, 1.405

Thanks for participating in this tutorial!