Agilent Technologies

MBP

Statistical Modeling in Model Builder Program

Application Note

Statistical Modeling in Model Builder Program

Application Note

This application note introduces the statistical module in Model Builder Program (MBP). The module's contents, including data format, plot configuration, Monte Carlo (MC) analysis, extraction flow, and IMV plot are covered. **Note**: This document was originally released for MBP V2011.1.2 in December 2011.

1. Introduction

Incorporating process variability into models is critical for IC design. Moreover, statistical modeling is today playing an ever important role in ensuring high product yield in the design phase. MBP supports Monte Carlo simulation with statistical modeling.

In this document, we first describe the data format supported, plot configuration and Monte Carlo simulation in MBP. Additionally, the built-in flow used to run statistical model extraction with the Backward Propagation of Variance (BPV) method is elaborated. Finally, we use a demo to introduce the steps to configure and plot statistical IMV. For more information go to www.agilent.com/find/eesof or contact your local Agilent office. The complete list is available at: www.agilent.com/find/contactus.

2. Data, Plot and Simulation

2.1 Data Format

MBP supports two kinds of data formats for statistical modeling. The first is based on actual measurement data, while the second allows the user to input the mean and sigma value of the target.

2.1.1 Data Format I

Below is an example of the first format (based on measurement data) supported in MBP:

staccondition{mode=forward,type=nmos}
Page (name=Ids,target={Ids(vds=0.05,vgs=1.1)},p=vbs){w=0.18,L=0.15,T=25}
curve{0.0}
site1 1.863622E-5
site2 1.859326E-5
site3 1.826478E-5
site4 1.79857E-5
site5 1.857634E-5
site6 1.89573E-5
site7 1.831234E-5
site8 1.895472E-5
site9 1.901374E-5
site10 1.882349E-5
....

The first line of the data file begins with the keyword "*staccondition*" and contains working mode and device type information. From this example, we know that it's a NMOS device in forward working mode.

The second line defines all page related information. The information within the round bracket "*( )*" contains page name, target and P variable. The information within the brace "*{ }*" declares the page constants, including geometry and temperature.

The latter part is the data block information. For every curve block, it always begins with the keyword "*curve*" and the corresponding P value (*vbs,* in this example). All data information is listed behind it. There are two values in every line: the site number and the target value (*Ids,* in this example).

2.1.2 Data Format II

The user can also choose the other format for the statistical data, allowing the user to input the mean and sigma value of the target. An example is as follows:

condition{corner = tt,date = oct_20_02}
Datatype{statistical}
Version{1.0}
type{nmos}
Delimiter{,}
Instance{L, W, T}
Input{vds=0.05, Vgs=1, Vbs=-1,icon=1e-7}
Targets{Vth_gm,Idsat}

Data{ L, W, T, vds, vgs,vbs, ids}
0.6, 0.27 , 25 , 5.5, 5.5 , 0, 1.94e-4, 2.44e-6
0.6, 10 , 25 , 5.5, 5.5 , 0, 1.94e-4, 2.44e-6
....
Data{ L, W, T, vds,vgs,vbs, vth_gm}
0.6, 0.27 , 25 , 5.5, 5.5 , 0, 0.83, 8.95e-3
0.6, 10 , 25 , 5.5, 5.5 , 0, 0.83, 8.95e-3
....

In this format, the first part of the data file contains the general information such as corner type, time, data type, device type, instance, bias condition, and target.

The latter part of the data file is the data block information. Every block begins with the keyword "*Data*" following the variables. All data is listed from the second line of each block. Note that the last two values in every line correspond to the mean and sigma of the target. In this example, line *"0.6, 0.27, 25, 5.5, 5.5, 0, 1.94e-4, 2.44e-6"* means *"L=0.6um, W=0.27um, T=25C, Vds=5.5V, Vgs=5.5V, Vbs=0, Ids(mean)=1.94e-4A, Ids(sigma)=2.44e-6A."*

2.2 Data Plot

Depending on the number of targets, there are two kinds of plots: histogram and scatter.

2.2.1 Histogram for Single Target

Using the target *Ids* as an example, the data plot (histogram) is shown in Figure 1.

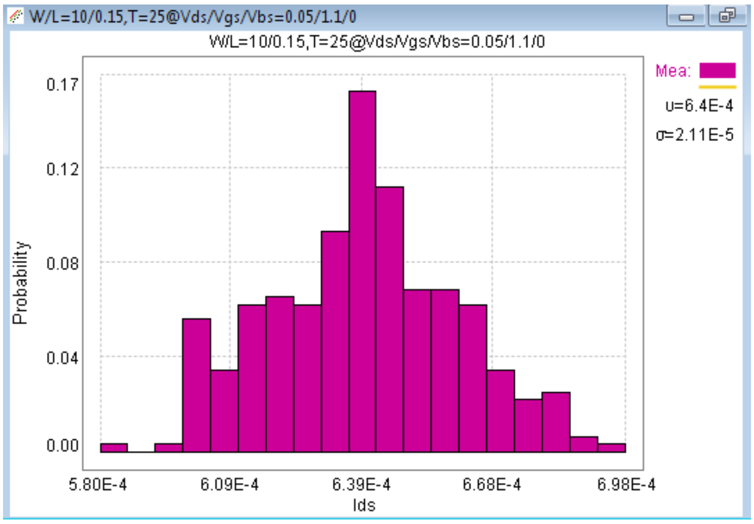


Figure 1. Histogram with fill style

Two styles are available for the histogram: the fill style as shown in Figure 1 and the bias style as shown in Figure 2. For the Bias style, simply right-click the plot and in the popup menu choose *Bar Styles -> Bias*.

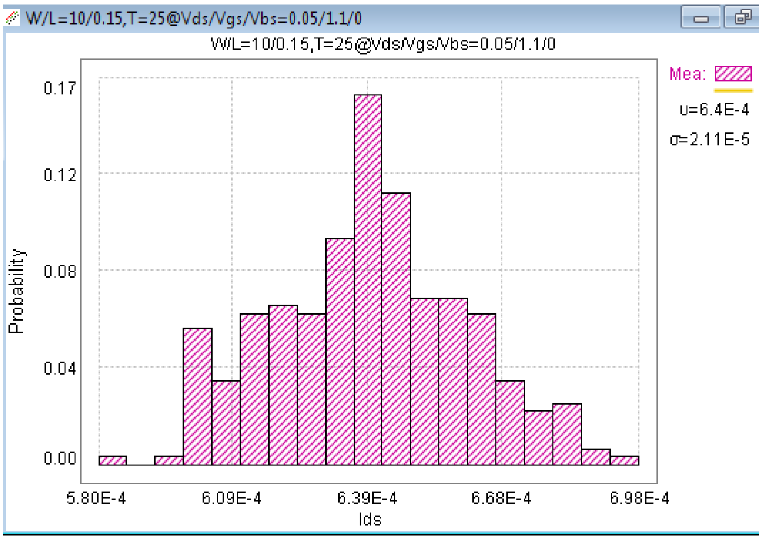


Figure 2. Histogram with Bias style

The user can also add a distribution line on the histogram. To do so, right-click on the plot and check the item *Draw Distribution* (Figure 3).

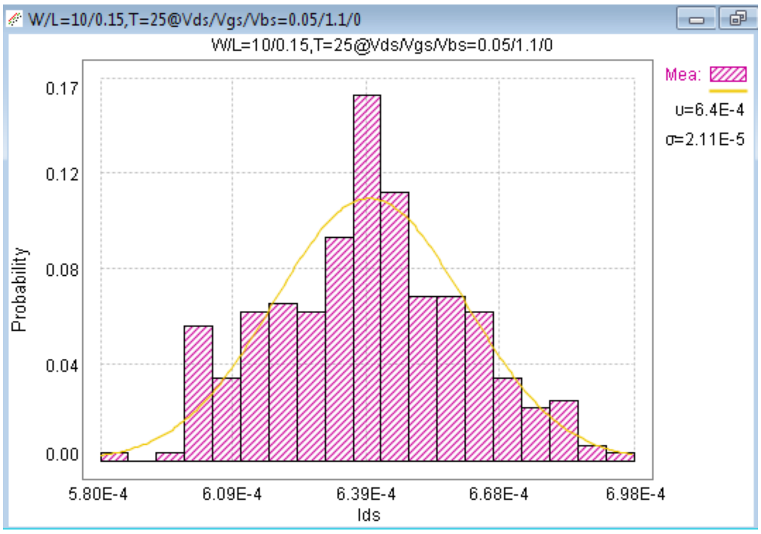


Figure 3. Histogram with distribution line

2.2.2 Scatter Plot for a Pair of Targets

The scatter plot is used for a pair of targets. In this example, the pair of targets are defined as ids and vth_con. A scatter plot can be configured by the user on MBP's graphical user interface (GUI). Simply choose *Tool -> GUI Options -> Statistical Graph Config* from the main menu to open the Statistical Graph Configuration window as shown in Figure 4.

MBP automatically parses the targets (e.g., ids, vth_con, vth_gm, Ion, and Ioff, etc.). These targets can be freely chosen as X- or Y-axis values on the scatter pages. In this example, we choose ids as X scale and vth_con as Y scale. Next, click the *Add Page* button.

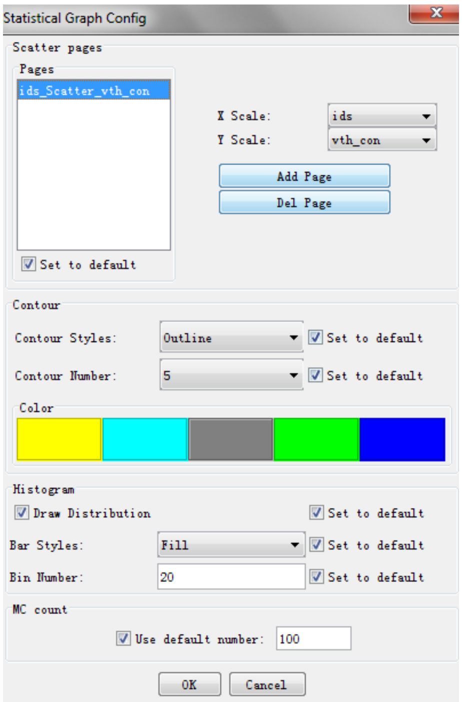


Figure 4. Statistical graph configuration

The contour of the scatter plot is also set in this window. Currently, MBP allows the user to set the contour number up to 5 (corresponding to the case of five sigma). There are three contour styles available to choose from: fill, null and outline. The corresponding scatter plots are shown in Figure 5.

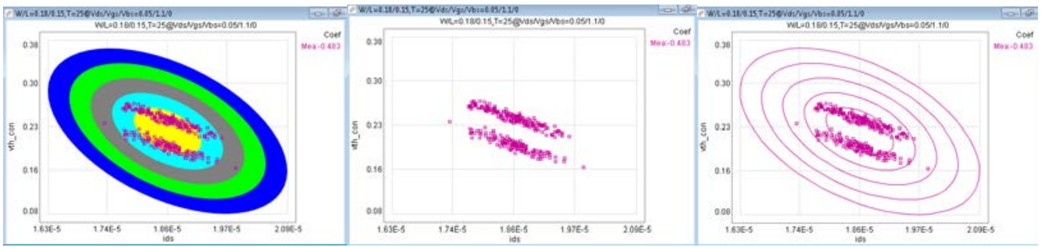


Figure 5. Scatter Plots: fill (left-most image), null (center) and outline (right-most image)

2.3 MC Simulation

MBP's internal engine is capable of performing Monte Carlo analysis. The user may also call an external simulator for verification purposes.

2.3.1 Statistical Model

To enable Monte Carlo analysis in MBP, the user first needs to build a statistical model. The model’s key parameters must be set to Gaussian distribution as follows:

.param

+p1=AGAUSS(0.37,0.01,1)

.param

+p2=GAUSS(1.21038E-1,0.03,1)

......

+vth0=p1

+u0=p2

......

To begin, the user may first load a compact model into the statistical module. Since no Monte Carlo analysis has yet been set, the user will get only one point as a simulation output on each plot.

MBP supports the ability to load the statistical model with a global or binning core model, or a macro model. It also allows the statistical model to be loaded directly from the model library using Lib Parser.

2.3.2 Set Monte Carlo Count

The user can set the Monte Carlo simulation number by right-clicking on the plot and selecting *Set Monte Count*. The user must set an appropriate number here. Note that a large number may lead to a more accurate result, but will also require a longer simulation time.

2.3.3 Fast MC Simulation

MBP provides an option to run fast MC simulation. To achieve this, choose *Simulation -> Fast-MC* from the main menu. This method speeds up the simulation using a unique methodology to deal with the statistical model.

3. BPV Extraction Flow

A demo case is used here to describe the steps required to run a statistical model extraction through the built-in flow.

3.1 Demo Files

The demo folder is *$MBPHOME\demo\Statistical\mosfet*. Here, *$MBPHOME* is the installation path of MBP. There are a total of three files in this folder:

- model_nmos.l, the initial model card;
- param.txt, the parameter list used in the BPV extraction flow; and
- sta_data.mea, the demo data.

The user can follow the steps presented below to complete the extraction process.

3.2 Set Model Type

First, the user must set the mode type. Choose *Model -> Select Model* from the main menu. In the popup Model Type window, choose *Statistical* as the project type. Then choose *mosfet* as the device type, as shown in Figure 6.

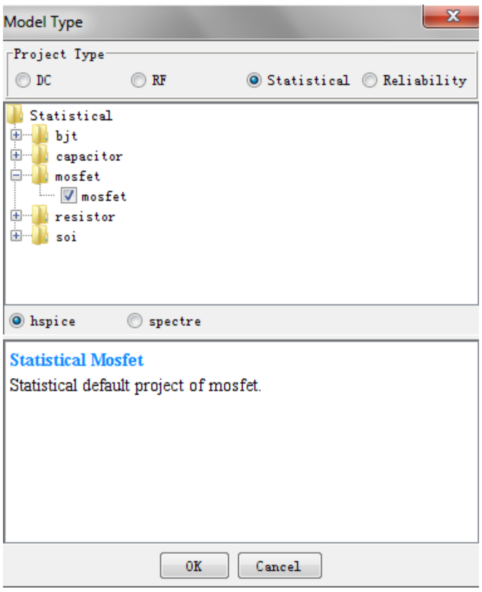


Figure 6. Model type

Click the *OK* button to close the window.

3.3 Load Data and Model

To load the data, choose *File* -> *Data* -> *Load* from the main menu. Load the data file “sta_data.mea.”

To load the model, choose *File* -> *Model* -> *Load* from the main menu. Load the model file “model_nmos.l.” Since there is no statistical information in the initial model, only one blue column indicating the simulation result is visible (Figure 7).

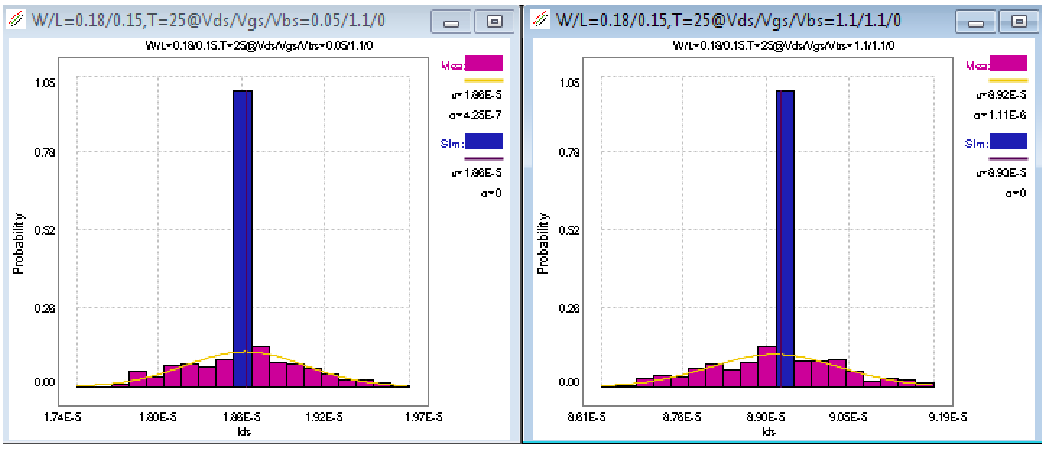


Figure 7. Initial model versus measurement data

MBP also supports the ability to load a model with existing statistical information. The user can use the flow to optimize the previously tuned model.

3.4 Run Extraction Flow

To run the extraction flow choose *Extraction -> Extraction Flow* from the main menu. The extraction panel shown in Figure 8 then becomes visible.

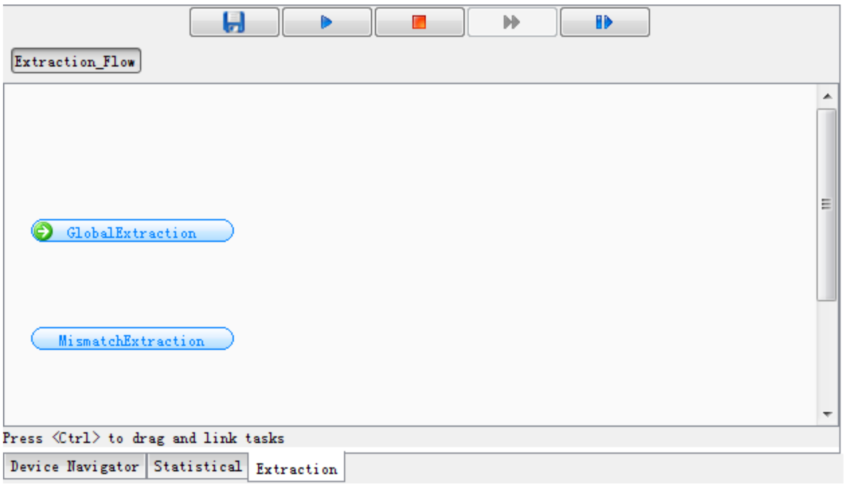


Figure 8. Extraction flow panel

Double click the *GlobalExtraction* button to expand the flow (Figure 9).

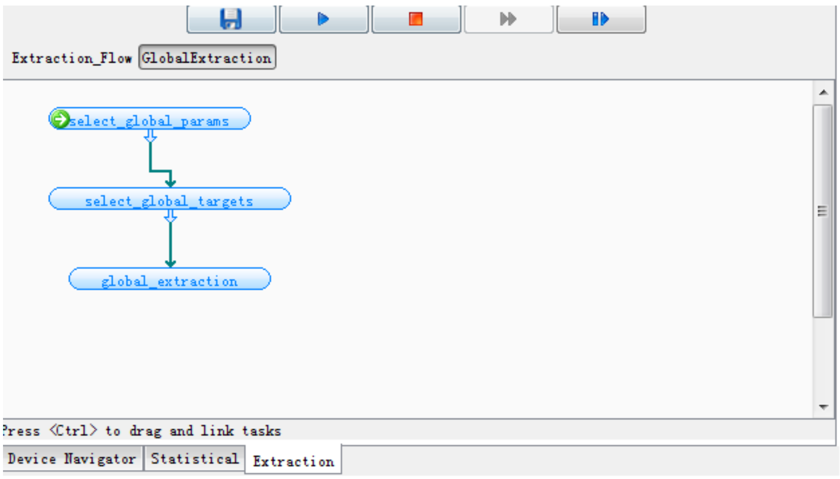
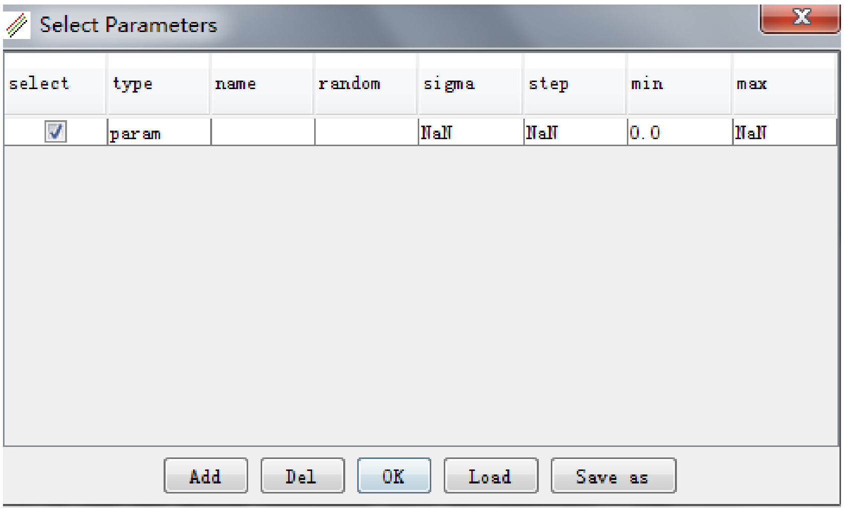


Figure 9. Global extraction flow

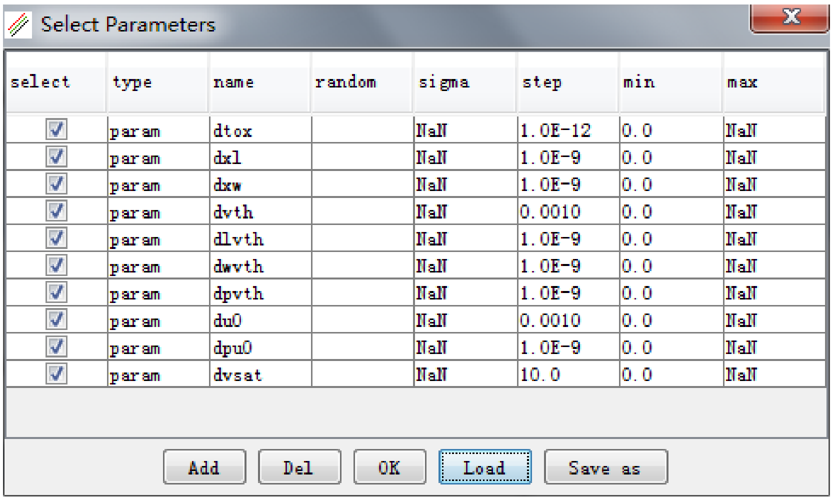
There are three steps in the flow: select_global_params, select_global_targets and global_extraction. Click the run icon ▶ to automatically run the global extraction flow. The Select Parameters window will pop up as shown in Figure 10.



select	type	name	random	sigma	step	min	max
☑	param			NaN	NaN	0.0	NaN

Figure 10. Select Parameters window

Click the *Load* button to load the parameter list file "*param.txt*." The parameters are arranged as shown in Figure 11.



select	type	name	random	sigma	step	min	max
☑	param	dtox		NaN	1.0E-12	0.0	NaN
☑	param	dxl		NaN	1.0E-9	0.0	NaN
☑	param	dxw		NaN	1.0E-9	0.0	NaN
☑	param	dvth		NaN	0.0010	0.0	NaN
☑	param	dlvth		NaN	1.0E-9	0.0	NaN
☑	param	dwvth		NaN	1.0E-9	0.0	NaN
☑	param	dpvth		NaN	1.0E-9	0.0	NaN
☑	param	du0		NaN	0.0010	0.0	NaN
☑	param	dpu0		NaN	1.0E-9	0.0	NaN
☑	param	dvsat		NaN	10.0	0.0	NaN

Figure 11. Load parameter list

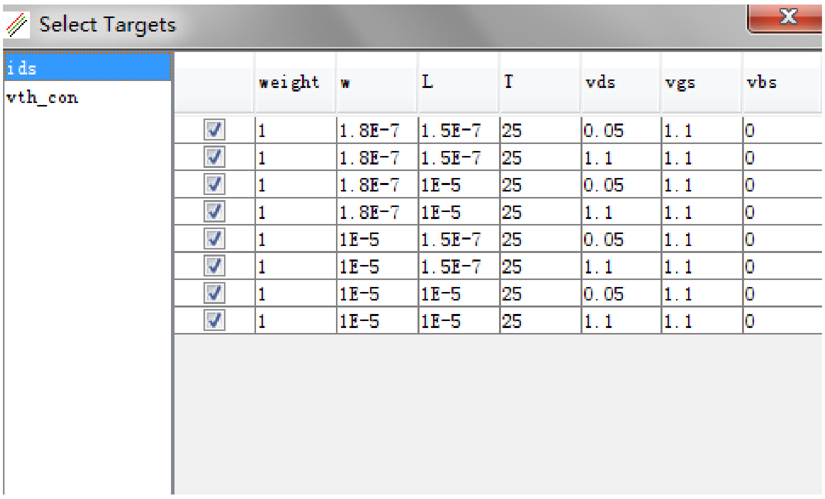
The parameter list window is now visible and can be used to select parameters for statistical calculation. Some comments on the column names are follows:

- Select. When it is checked, the parameter will be re-extracted. If it is unchecked, the parameter will depend on the sigma value. If a sigma value is given, the final value of the parameter will be the sigma value; while if a sigma value is not given, the current value of the parameter will remain as the final one.
- Name: parameter name. When "*select*" is unchecked, the parameter name may be blank. At the same time, both "*random*" and "*sigma*" must have correct values.
- Random: random variable name. If there is a random variable for the parameter in the current model file, the user must enter the name of the random variable here. If there is no random variable for the parameter in the current model file, the user may either input a new name here

or keep it blank. In the latter case, a new name will be automatically created. Note that not all names of random variables can be repeated.

- Sigma: sigma of the parameter. An example here is the *dtox* parameter. If the user knows the sigma of the TOX (normally the information can be obtained from fabrication), then the value can be input into it directly. The extraction flow then bypasses this parameter and uses the predefined value instead.
- Step: the step for BPV calculation. The step is very important for the extraction flow and is used to calculate the sensitivity of the parameter to the target. The user must input a suitable value; one that is not too big or too small. Here, the user can carefully monitor the change in IdVd or IdVg plots while adjusting the step number.

Click the *OK* button to continue. The Select Targets window will pop up as shown in Figure 12. The user must then select the targets for the BPV extraction. Normally, the user will select the targets that are important or that he/she cares most about.



	weight	w	L	T	vds	vgs	vbs
☑	1	1.8E-7	1.5E-7	25	0.05	1.1	0
☑	1	1.8E-7	1.5E-7	25	1.1	1.1	0
☑	1	1.8E-7	1E-5	25	0.05	1.1	0
☑	1	1.8E-7	1E-5	25	1.1	1.1	0
☑	1	1E-5	1.5E-7	25	0.05	1.1	0
☑	1	1E-5	1.5E-7	25	1.1	1.1	0
☑	1	1E-5	1E-5	25	0.05	1.1	0
☑	1	1E-5	1E-5	25	1.1	1.1	0

Figure 12. Select targets

Next, the user can set different weights for different targets. The default value is 1. Close the window to continue. In the last step, the Save dialog window will pop up. Here, the user inputs a name to save the model file. The user will then find that the following statistical parameters have been extracted and added into the generated model file:

```
.param
+s_dtox = 4.759276E-14          s_dxl = 2.757199E-13          s_dxw = 3.874035E-9
+s_dvth = 1.16912E-2            s_dlvth = 8.878411E-7         s_dwvth = 3.014865E-7
+s_dpvth = 3.740674E-9          s_du0 = 1.47506E-3            s_dpu0 = 2.144652E-8
+s_dvsat = 2.016329
.param
+dtox = '0.0+s_dtox*random1'     dxl = '0.0+s_dxl*random2'       dxw = '0.0+s_dxw*random3'
+dvth = '0.0+s_dvth*random4'     dlvth = '0.0+s_dlvth*random5'   dwvth = '0.0+s_dwvth*random6'
+dpvth = '0.0+s_dpvth*random7' du0 = '0.0+s_du0*random8'        dpu0 = '0.0+s_dpu0*random9'
+dvsat = '0.0+s_dvsat*random10'
.param
```

+random1 = agauss(0.0,1.0, 1)

+random2 = agauss(0.0,1.0, 1)

+random3 = agauss(0.0,1.0, 1)

+random4 = agauss(0.0,1.0, 1)

+random5 = agauss(0.0,1.0, 1)

+random6 = agauss(0.0,1.0, 1)

+random7 = agauss(0.0,1.0, 1)

+random8 = agauss(0.0,1.0, 1)

+random9 = agauss(0.0,1.0, 1)

+random10 = agauss(0.0,1.0, 1)

The fitting result is shown in Figure 13.

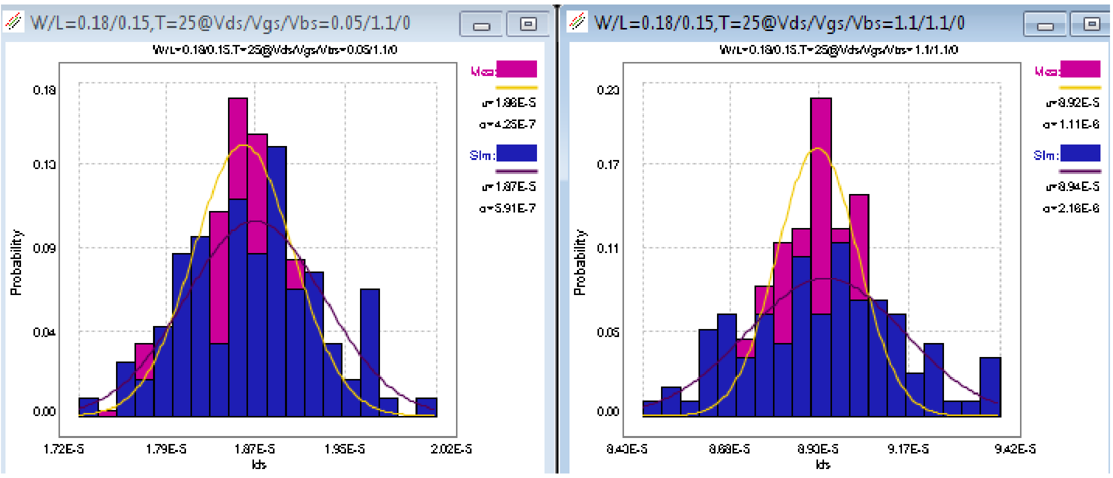


Figure 13. Fitting result

The user may continue to fine tune the parameters manually, or simply modify the step number as previously mentioned and rerun the flow until a satisfactory result is obtained.

4. Statistical IMV

Finally, we use a demo to illuminate how to customize statistical IMV and plot it in MBP. After loading the demo data, choose *Script* -> *Script Project* from the main menu to pop up the MBP Script interface. In the left Project tab window, click *default* -> *imv* -> *imv* -> *statistical* to expand the file structure, as shown in Figure 14.

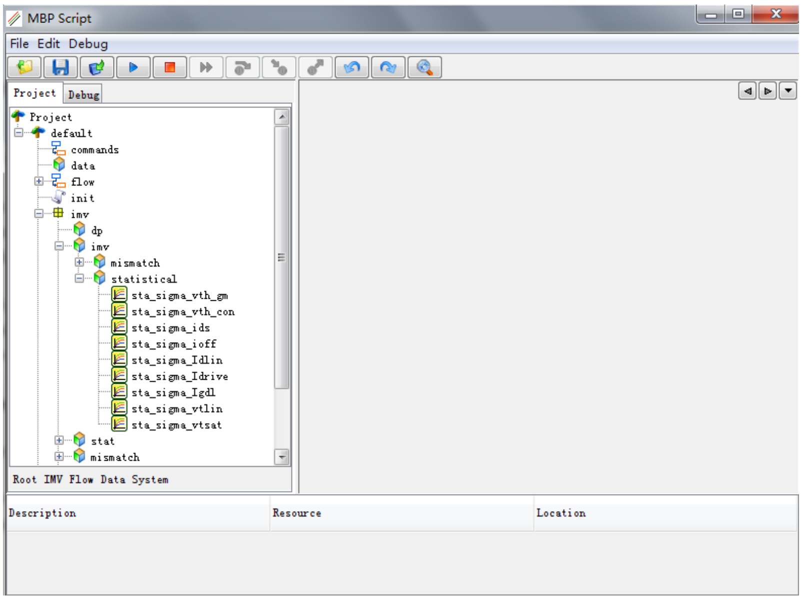


Figure 14. MBP Script

Right click the IMV "*sta_sigma_ids*" and choose *New* -> *Graph* (Figure 15).

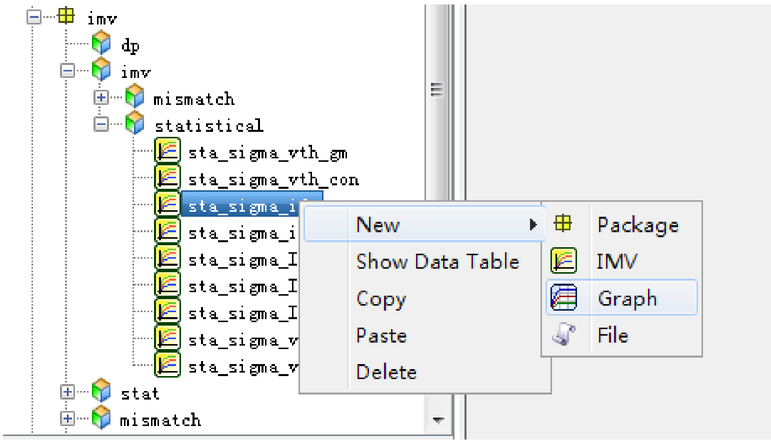


Figure 15. Create new graph

Input "*sta_sigma_ids_w_l*" as the code name. In the GRAPH_PROP tab, choose "w" as "Axis[x]," "sta_sigma_ids" as "Axis[x]" and "l" as "Axis[x],"as shown in Figure 16.

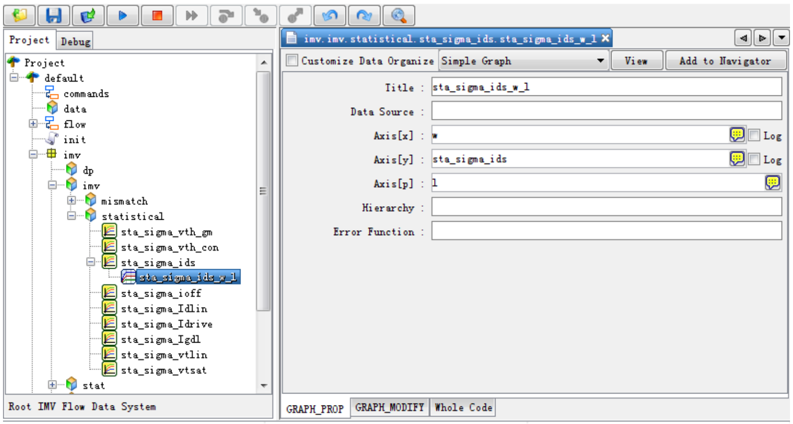


Figure 16. Configure graph

Click the icon  to save the current code. In the main menu of MBP, choose *Extraction -> IMV -> IMV Pages* to open the IMV page. Click the icon  to refresh. Then, the user can view the customized IMV page (sta_sigma_ids_w_l) as shown in Figure 17.

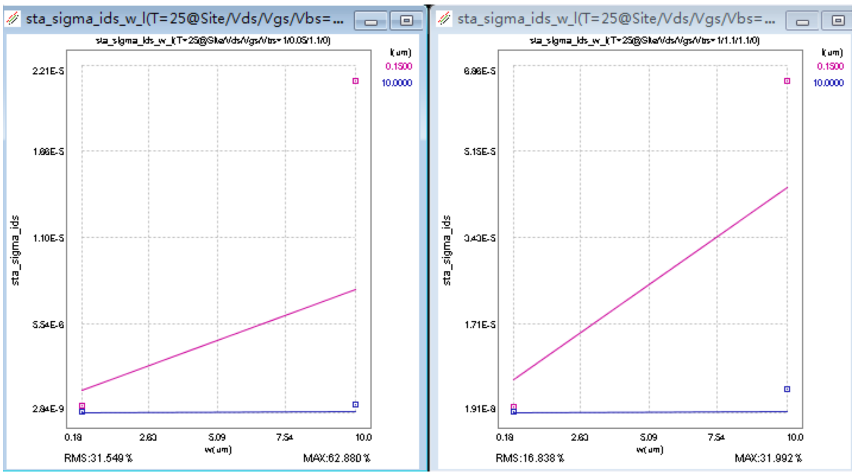


Figure 17. IMV pages