Experimentation User Guide

EXPERIMENTATION

Simulation Software / USER GUIDE

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Experimentation

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3 Experimentation

Experimentation is divided in:

Experiment Wizard — For defining the experiment settings, the performance measures and starting the actual simulation

Analyze Experiment Results — For defining and generating a report from an experiment

The settings of the last experiment are saved with the model when the model is saved. The results of the last experiment are saved in two text files (ExperimentResults.sim and ExperimentGroups.sim) in the same directory as the model. So it's possible to analyze the results of an experiment in a later session.

After finishing the Experiment Wizard with running the experiment, it's possible to continue with Analyze Experiment Results immediately.

3.1 Terminology

First, we will explain some common used simulation terminology. It will make the discussion about the experiment settings in Enterprise Dynamics a lot easier.

An *experiment* consists of a *number of single simulation runs*. The *observation period* of a run is the time period of a run we use for gathering data for our performance measures. These *performance measures* (PFM) or output variables are defined by us as the output we want to collect e.g. average wait time of a customer, maxcontent of a Queue or utilization of a Server. Each observation period results in exactly one outcome of a performance measure.

Often, a system has to warm up for some time before it reaches a balanced situation, also called *steady state*. This is described as the *warm-up period*. Results are gathered - as said before- during the *observation period*. An observation period starts at moment zero (the default value) or when the warm-up period has ended. Results are not recorded during the warm-up period.

> **Example 1:**
> In a factory where the average process time of a product is two weeks, it's clear that the first few weeks of a simulation run the output will be virtually nil. So this period is not representative for a performance measure like 'average week production'.

We could now define a simulation run of 15 weeks, consisting of a warm-up period of 5 weeks and an observation period of 10 weeks. The PFM 'average week production' will give for this run the number of produced items in the last ten weeks divided by 10.

When working with simulation, the representation of results in a *confidence interval* is usual. Because of the stochastic character of most models, one single outcome is not representative. Therefore, several observations are required in order to make reliable statements. The experiment has to be organized in such a way that sensible statements are possible. They are often in the shape of a confidence interval, which includes the value of an output variable. The *reliability* indicates the probability that the (unknown) value is within the range specified. Common percentages are 90%, 95% (the default) and 99%. At least 5 runs (the default) are needed to build a confidence interval.

When designing the experiment two different simulation methods are possible: the one of *separate runs* or the one of *sub runs*.

They are fundamentally different:

- The method of separate runs starts with a possible warm-up period, followed by one observation period. This is done a given number of observation periods.
  So, the number of runs or *replications* in the experiment equals the number of observation periods.
- The method of sub runs starts with a possible warm-up period, followed by a given number of consecutive observation periods. Each observation period is called a *sub run*. Here, the experiment consists of one long run.

> **Example 2:**
> Let 10 be the given number of observation periods. We take 4 weeks for a warm up period and 20 weeks for an observation period.
>
> Method of separate runs:

Run 1	Warm up 1	observation 1
Run 2	Warm up 2	observation 2
Run 10	Warm up 10	observation 10

> This gives 10 runs making together 10*(4+20)= 240 simulation weeks.
>
> Method of sub runs:

| Run | Warm up | observation 1 | observation 2 | ... | observation 10 |

> This gives one run of 4+ 10*20= 204 simulation weeks.

In case of a warm-up period the total simulation period in the method of sub runs is shorter, due to the fact that we only need one warm up period. But... the results of the observation periods are not independent: a high value for average waiting in period n, will probably result in a high value for period n+1.

Using the method of separate runs, the observation periods are by definition independent.

The method of sub runs dates from the past, where computer time was costly and running experiments was time consuming. You had to choose the length of your observation carefully, because of the correlation of the results.

The method of separate runs guarantees independent results, and is often used in practice. Therefore, this method will be default in our Experiment Wizard.

4   The Experiment Wizard

Basically there are 3 steps in the Experiment Wizard:

Step 1   **Definition of the experiment settings**

Defines experiment settings such as the number of runs, the length of the observation period and the warm-up period, etcetera

Step 2   **Definition of the performance measures**

Define the performance measures of atoms or a group of atoms

Step 3   **Experimentation**

The actual running of the experiment according to its definition. This step requires no action from the user!

4.1   Definition of the experiment settings

Picture 1 shows the screen for the definition of the experiment settings. The default settings for simulation method, observation period, number of observations and the warm-up period appear. So, without altering these settings 5 separate, independent runs from 1 hour without a warm-up period are simulated. 4DS indicates that expressions in 4DScript are allowed.

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Picture 1: Experiment settings

Simulation Method

Select either separate runs or sub-runs. Default method is separate runs.

Observation period

Enter the desired time length of your observation period (in seconds). Expressions in 4DScript are allowed. Default length is hr(1) or 3600 seconds.

Number of observations

Enter how many observations you want to use. Each observation period gives one outcome of a defined performance measure. If you increase the number of observations, the width of your confidence interval around the average of your PFM will decrease.

Default number of observations is 5.

Warm-up period

Enter the desired time length of your warm-up period (in seconds). Expressions in 4DScript are allowed. Default length is 0.

Terminating condition

Use for entering various stop conditions in 4Dscript for a simulation run. When this condition is met during the simulation run, the observation period is ended immediately.

> Example 3:
> Suppose we want to stop the simulation run when 1000 products are manufactured on Server5. This could be modeled by output(AtomByName([Server5], Model))=1000

On start of run

This option allows you to execute 4DScript code on the reset of the experiment. This will also be executed for every observation period if you use "separate runs".

On end of run

This option allows you to execute 4DScript code after each observation period.

On end of warm-up

This option allows you to execute 4DScript code after each warm-up period.

4.2   List of Performance Measures

After the experiment settings the definition of the PFM settings starts with a so-called *List of Performance Measures*. Every new defined PFM will be added to this list.
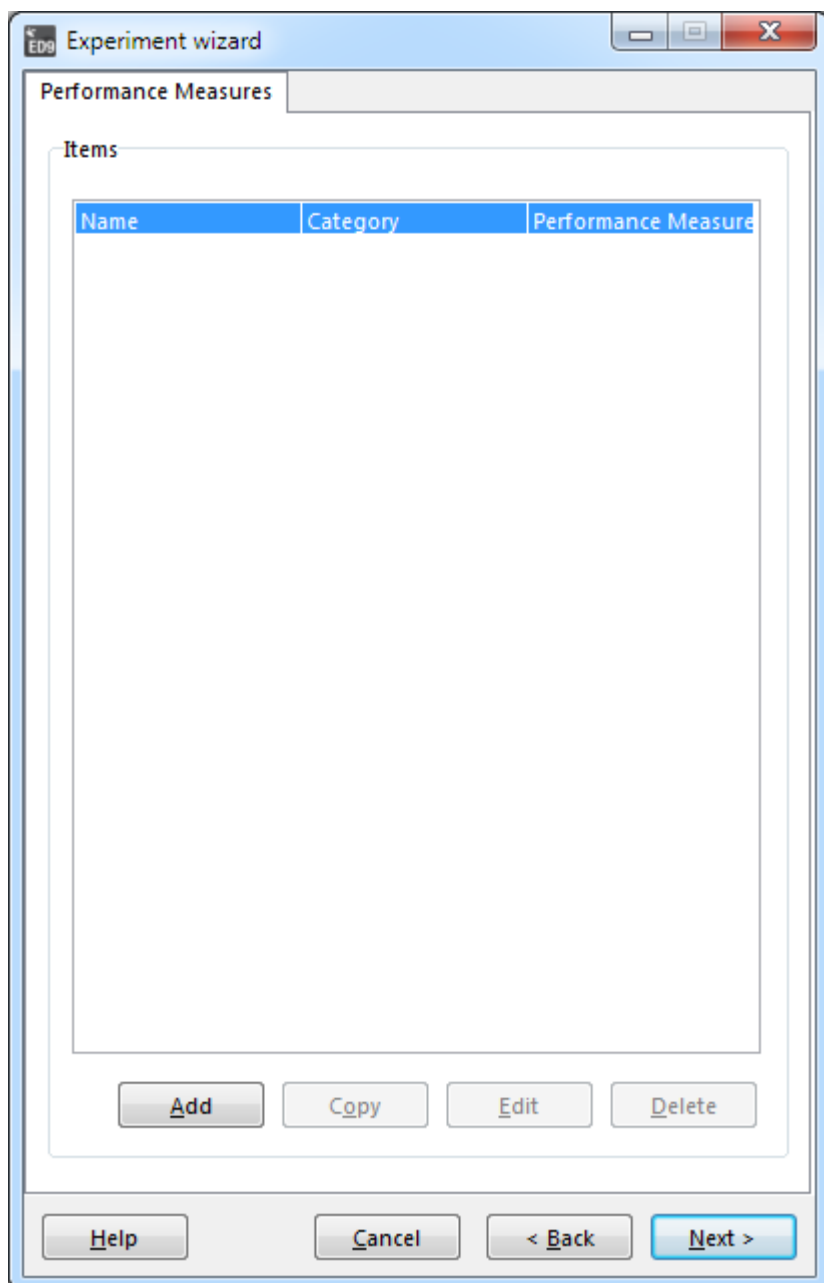
Picture 2: List of Performance Measures

It is possible to define PFM's on single atoms, on a group of (different) atoms, or on a group of atoms with the same mother atom e.g. all the queues or servers in a model. The selection of the last group is done by selecting the mother atom from the library, the selection of the others by selecting from the model tree or from a list of the atoms in the model.

Basically, we subsequently answer the following questions:

1. Is our PFM linked to a single atom or to a group with different or similar atoms? The answer gives us the category we need…
   This is done in the **selection of category**

2. Of which atom(s) in the model in this category do we want some results?
   The answer gives us the atom(s) in the model we need…
   This is done in the **selection of atom(s)**

3. What PFM do we want to measure on these atoms e.g. these atoms?
   The answer gives us the PFM on the selected atom of group
   This is done in the **selection of PFM**

The following categories exist:

|	
1. Atom	for a PFM on a single atom
2. Group	for a PFM on more than one atom
3. Atom by Mother	for a PFM on all individual atoms of the same type in the model e.g. Queues or Servers

> ⚠️ **Important!**
> Atom by Mother is nothing more than an easy way of defining PFM's on several single atoms with the same mother atom <u>at once</u>. So, defining the PFM Avgstay on ten Queue atoms in a certain model, can be done by one definition via Atom by Mother or ten times a definition via Atom.

This also means that the list of standard PFM's, which can be defined by these two categories, are the same. They are listed and explained in **Selection of category: Atom**.

The category Group defines a PFM measured over more than one atom and is therefore really different. These standard PFM's are listed and explained in **Selection of category: Group**.

Now choose Add to enter the **selection of category**. Depending on your choice of category different follow-up screens will appear. The default screen (see picture 3) is related to a PFM on a single atom.

4.3   Selection of category: Atom
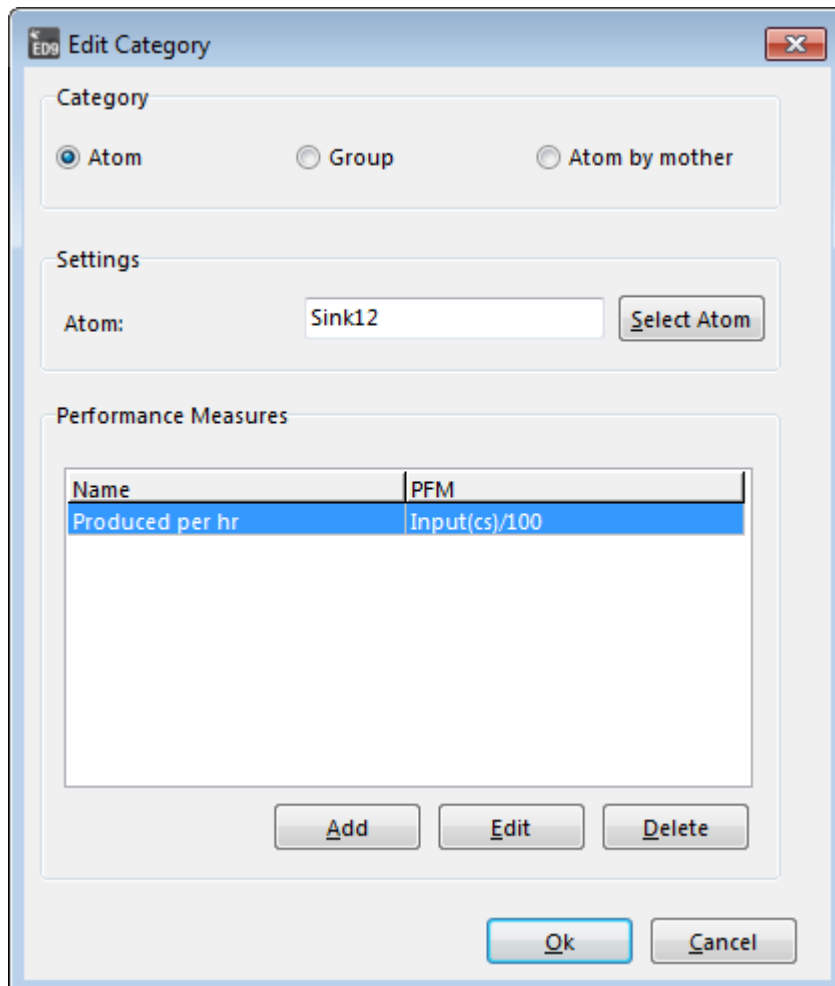
Picture 3: Selection of category (Atom)

Select Atom	A screen with the Model Tree pops up. Choose the desired atom of your model. The name of this atom will appear.
Add	A screen where you can choose from a list of predefined PFM's appears (see picture 4). You can also give your own name to the PFM of your choice.

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Edit   For editing an existing PFM on the atom

Delete   Deletes a PFM on the atom

Description of the standard PFM list (option Atom and Atom by Mother)
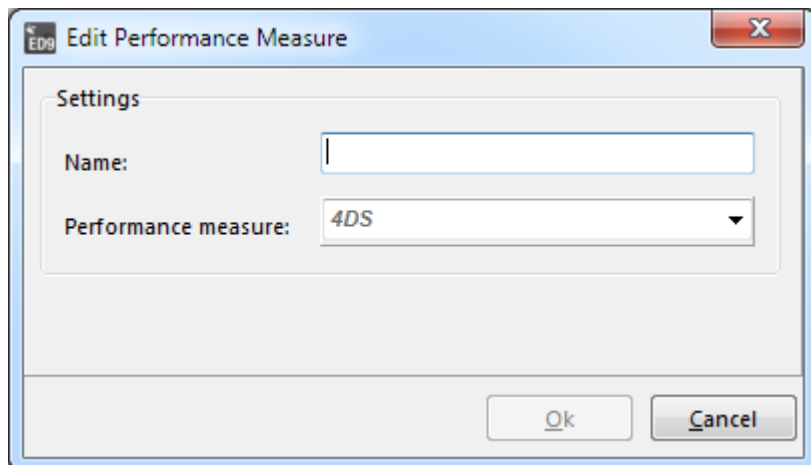
Picture 4: Selection of PFM

The dropdown list of picture 4 shows the list of all possible PFM's:

Output: the number of products that has left the atom during the observation period. This value is reset to 0 at the beginning of the observation period.

Input: the number of products that has entered the atom during the observation period. This value is reset to 0 at the beginning of the observation period.

Content: the number of products inside the atom at the end of the observation period. Not necessary to reset this value at the beginning of the observation period.

Average content: the average number of products inside the atom at the same time during the observation period. This value is reset to 0 at the beginning of the observation period.

Maximum content: the maximum number of products inside the atom at the same time during the observation period. This value is reset to the current content at the beginning of the observation period.

Average stay: the average time a product is inside the atom, measured over the number of products that has left the atom during the observation period (see our definition of output). For every product the complete stay time is used. This also applies to products already inside the atom at the beginning of the observation. This value of Average Stay is reset to 0 at the beginning of the observation period.

Maximum stay: the maximum of stay times, measured over the number of products that has left the atom during the observation period. This value is reset to 0 at the beginning of the observation period.

Table: saves a copy of the table of the atom at the end of the observation period. User has to define own reset value(s).

Status: for every status the atom has been in during the observation period, the fraction of time that the atom has actually been in this status, is returned. These values are reset to 0 at the beginning of the observation period.

Label: the value of the label on your selected atom(s) at the end of the observation period. User has to define his own reset value.

Attribute: the value of the attribute on your selected atom(s) at the end of the observation period. User has to define his own reset value.

User defined: the value of the user defined code on your selected atom(s) at the end of the observation period. User has to define his own reset value.

4.4 Selection of category: Group

This selection can be used to calculate performance metrics over a group of atoms as a whole. For example, if you have a waiting area with three queues, you can create a group containing the three queues and obtain the number of arrivals and departures, and for example the average waiting time of the waiting area. In many cases the combined PFM is simply the sum of the constituent PFMs, for example with the arrivals and departures, but in some cases the precise formula is more complicated, see Section *Description of the standard PFM list below*.
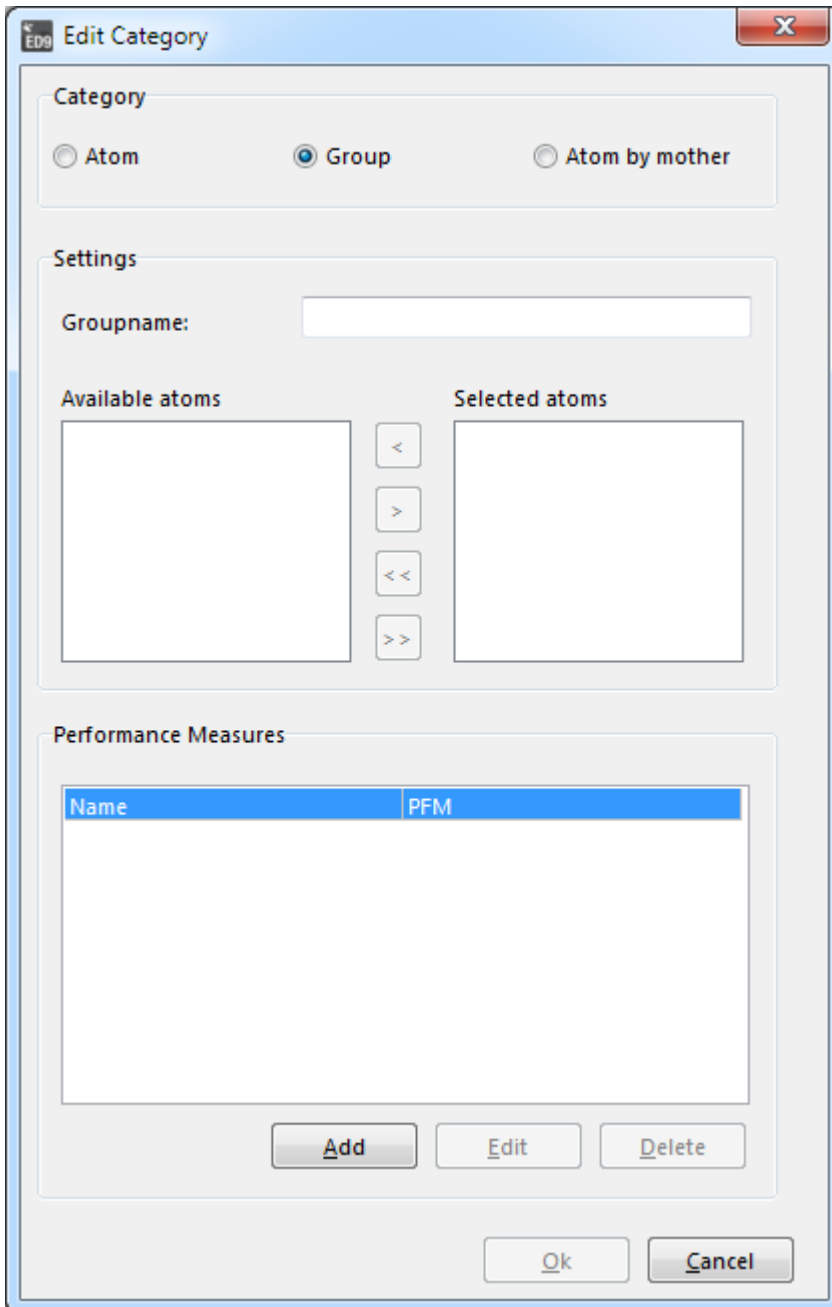
Picture 5: Selection of category (Group)

Groupname
Here you have to enter the name of the group

Available Atoms
List of atoms in your model that are not included in the definition of the group

Selected Atoms

List of atoms in your model that are included in the definition of the group

>   moves one selected atom in the list from left to right

<   moves one selected atom in the list from right to left

>>   moves all the atoms in the list from left to right

<<   moves all the atoms in the list from right to left

The options Add, Edit and Delete are described in **Selection of category: Atom**. Choose Add New to continue…

Description of the standard PFM list (option Group)

The same dropdown list as in picture 4 shows us a list of eight possible PFM's for a group:

|	
Output:	Sum of the output of all atoms of the group
Input:	Sum of the input of all atoms of the group.
Content:	Sum of the content of all atoms of the group.
Average content:	Sum of the average content of all atoms of the group.
Average stay:	Weighted average of the elements of the group, divided by sum of the output of the elements k of the group.

$$\frac{\sum_{k} avgstay(k) * output(k)}{\sum_{k} output(k)}$$

Maximum content:	The maximum of the maximum content of the elements of the group.
Maximum stay:	The maximum of the maximum stay of the elements of the group.
Status:	For each status, first the fraction of time that an atom in the group has actually been in this status is calculated. Then the sum off all fractions for this particular status is taken and divided by the number of the group.

> ⚠️ **Warning:** this PFM measure will make sense only if all group members have the same mother.

> 📝 It may seem confusing that *Average content* computes the sum of the average content of the atoms in the group. The reason is that *Average content* means the average over time. For example, in the example with the waiting area consisting of three queues, the average content of the waiting area during a run of 1 hour is the sum of the contents of the individual queues over that time span.

4.5   Selection of category: Atom by Mother
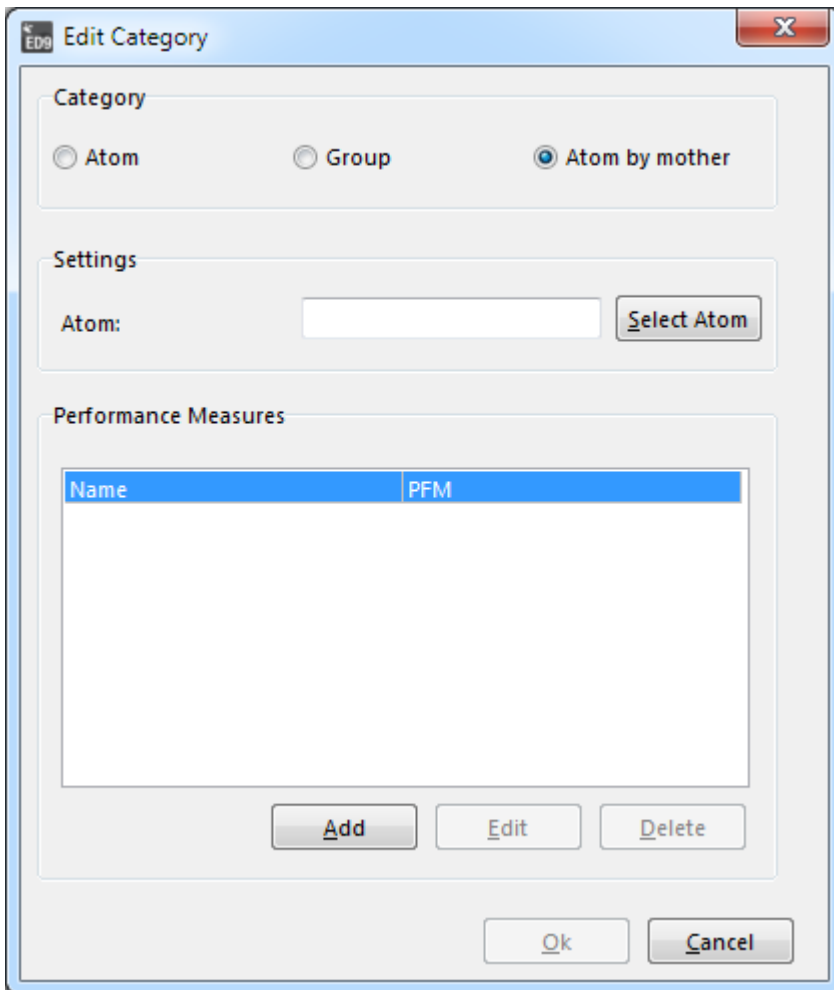
Picture 6: Selection of category (Atom by Mother)

When you select the option Select Mother Atom a selector for an atom from the library appears. Select the desired mother atom from the library. Now all atoms in your model with this mother atom are selected. Define your PFM as shown before.

The options Add, Edit and Delete are the same as described in **Selection of category: Atom**.

Description of the standard PFM list (Atom by Mother)

See **Description of the standard PFM list (option Atom and Atom by Mother)**: the same list applies.

This concludes the description of the PFM definitions. Continue from the List of Performances Measures to Run Experiment and push the Start Experiment button. If you have checked the option Automatically open the Analyze Experiment Results window, you will continue with the results when the experiment has finished.
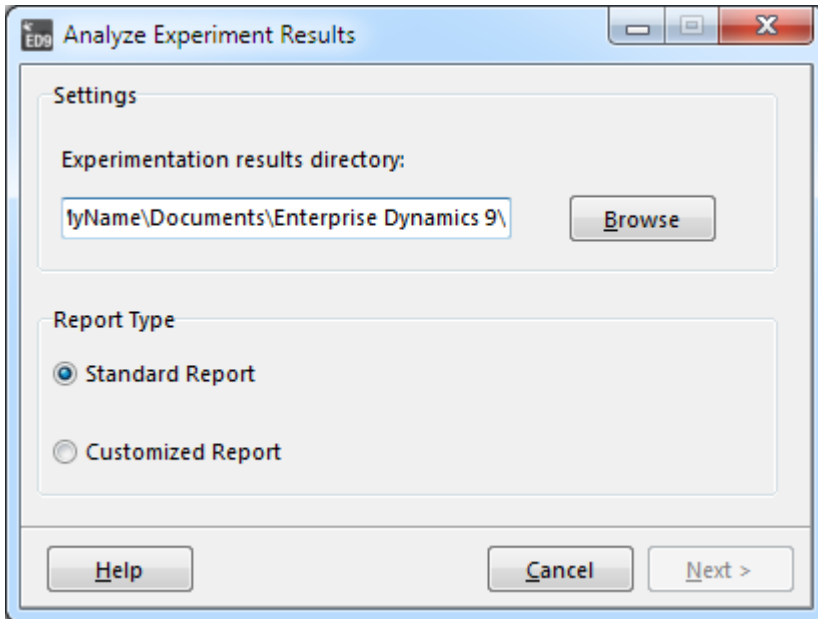
5   Analyze Experiment Results

The settings of the last experiment are saved with the model when the model is saved. The results of the last experiment are saved in two text files (ExperimentResults.sim and ExperimentGroups.sim) in the same directory as the model. So it's possible to analyze the results of an experiment in a later session.

Reports can be generated in different formats, including the well-known .csv format. Results will be shown with confidence intervals and can be displayed with or without graphical information.

We have two ways to enter the results screen of picture 7:

1. Via the menu: Experimentation| Analyze Experiment Results or
2. Directly after running an experiment via Automatically open the Analyze Experiment Results window

Picture 7: Analyze Experiment Results screen

Output directory

You can browse for the directory where your result files are located; the .csv reports will be saved in this directory as well. When a model is opened, the model directory will be used as the default output directory. Otherwise the work directory (set in File| Preferences| General) will be used as default output directory.

Standard report

Generates a predefined report with confidence intervals on the PFM's (default)
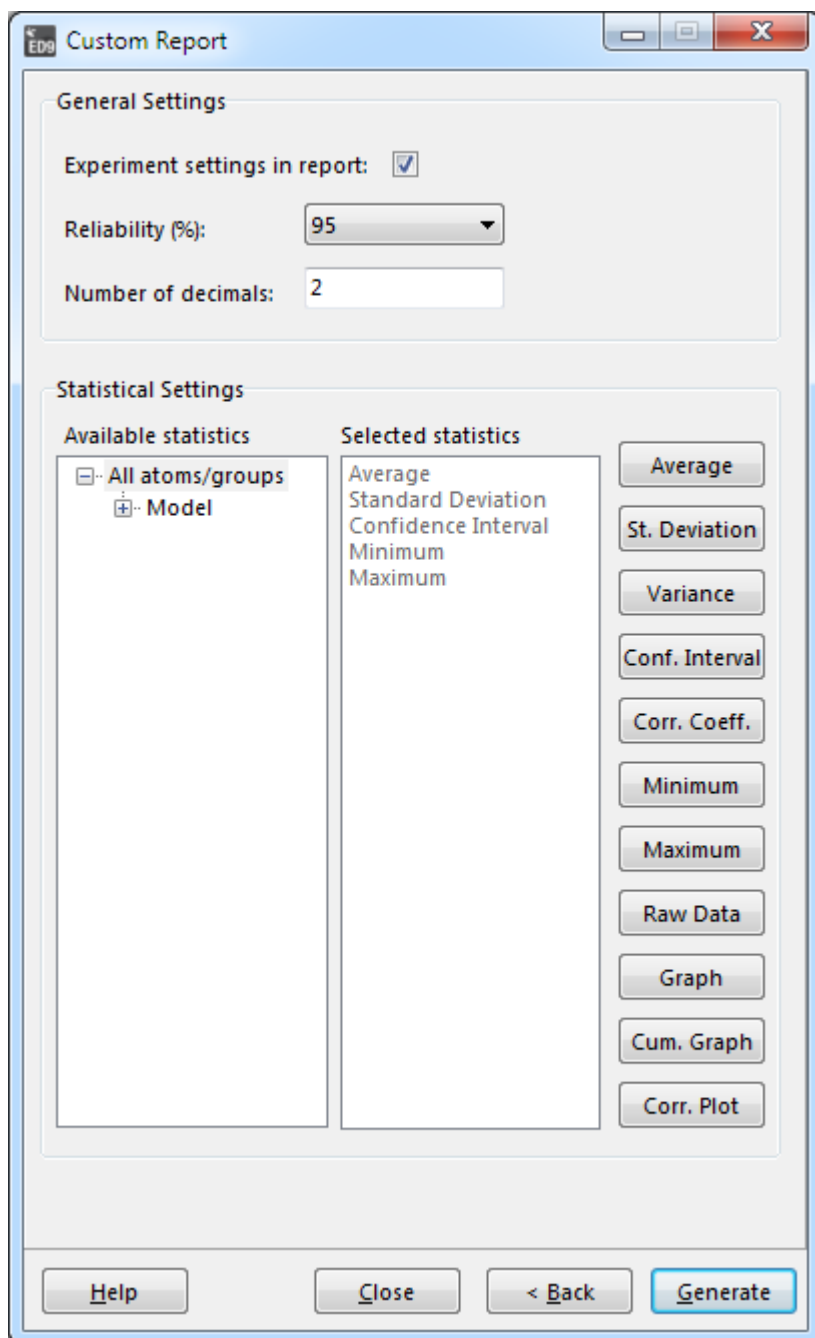
Customized

For designing a report with your own choice of statistics and graphics
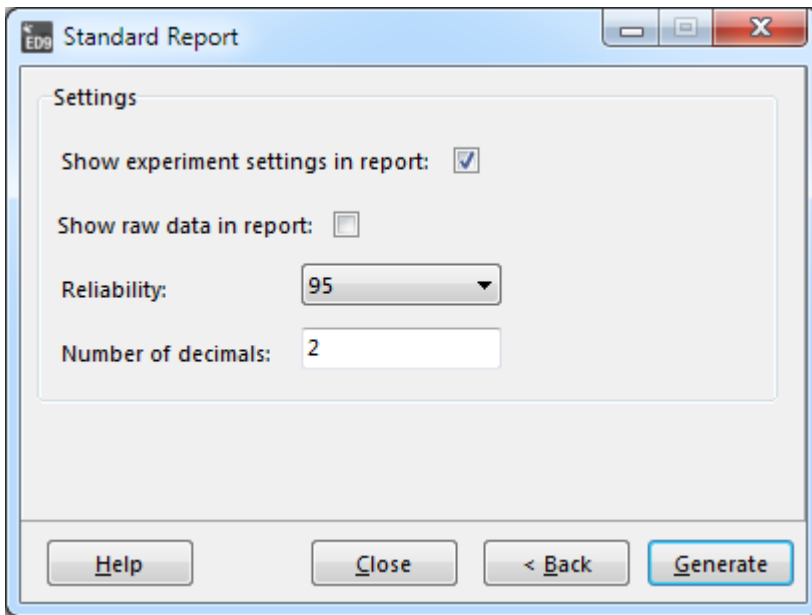
Picture 8: Settings of a standard report

5.1   Generating a report

You can generate a standard report (picture 8) with a predefined list of statistics or a customized report (picture 9), where you have more choice to include or exclude certain statistics:

Picture 9: Settings of a customized report

We describe the settings of the <u>customized report</u> only, because both settings include a number of similar items and customized report also includes the statistics of the standard report.

<u>PFM Tree view and Statistics list</u>

When you select a PFM in the tree, the statistics list will show you which statistics will be included in the report for that specific PFM. It's possible to add extra statistics to the list or remove statistics from the list for the selected PFM through the buttons in the right half of the screen.

If you have selected an atom or groupname or the 'All atoms/groups' item in the tree view, all changes on the statistics list will be executed on all PFM's below the selected item.

<u>Show experiment settings in report</u>

Adds a header to your report with information about the length of the observation period, warm-up period, number of runs, run method and the experiment description.

<u>Reliability (%)</u>

Here you choose a percentage for the reliability you desire for your confidence interval. The predefined list

contains the values 80, 85, 90, 95 (default) and 99 (see also paragraph 1 for an explanation of a confidence interval)

<u>Nr. of decimals</u>

Sets the number of decimals used in the statistics of the PFM.

<u>Generate report</u>

Generates first a table in Enterprise Dynamics with all the information you included in your report definition. In a second step this information can be shown in a Report Preview, but also exported to a .csv (=comma separated file) file, which can be imported in Excel.

<u>Statistics buttons</u>

For every PFM an observation w_i is recorded after each observation period i. In picture 10 you can see how every statistic is calculated based on the data $w_1, w_2, ... w_n$, where n is the number of observation periods.

Statistics	Formula
Average	$\overline{w} = \sum\limits_{i=1}^{n} \dfrac{w_i}{n}$
Standard deviation	$s = \sqrt{\mathrm{var}\,iance}$
Variance	$s^2 = \dfrac{\sum\limits_{i=1}^{n}(w_i - \overline{w})}{(n-1)}$
Precision (Absolute)	$= \begin{cases} t_{\left(n-1, 1-\frac{1}{2}\alpha\right)} \cdot \dfrac{s}{\sqrt{n}} & \text{for } n \leq 30 \\[2ex] \mu_{1-\frac{1}{2}\alpha} \cdot \dfrac{s}{\sqrt{n}} & \text{for } n > 30 \end{cases}$
Confidence interval	$= \begin{cases} \overline{w} \pm t_{\left(n-1, 1-\frac{1}{2}\alpha\right)} \cdot \dfrac{s}{\sqrt{n}} & \text{for } n \leq 30 \\[2ex] \overline{w} \pm \mu_{1-\frac{1}{2}\alpha} \cdot \dfrac{s}{\sqrt{n}} & \text{for } n > 30 \end{cases}$
Correlation coefficient	$r = \dfrac{\sum\limits_{i=1}^{n-1}\left((w_{i+1} - \overline{w}) \cdot (w_i - \overline{w})\right)}{(n-1) \cdot s^2}$ with $-1 \leq r \leq 1$
Minimum	$\min = \min\limits_{i \in \{1, n\}}(w_i)$
Maximum	$\max = \max\limits_{i \in \{1, n\}}(w_i)$
Raw data	$\{w_1, w_2, w_3, ..., w_n\}$

Picture 10: Mathematical background of the list of statistics

The lower bound and upper bound of the confidence interval are obtained from the formulas in picture 10: average $\pm$ precision. The values $t_{n-1, 1-\frac{1}{2}a}$ and $\mu_{1-\frac{1}{2}a}$, where a= 1-Reliability, are obtained from a table of t-values which can be found in every book about statistics.
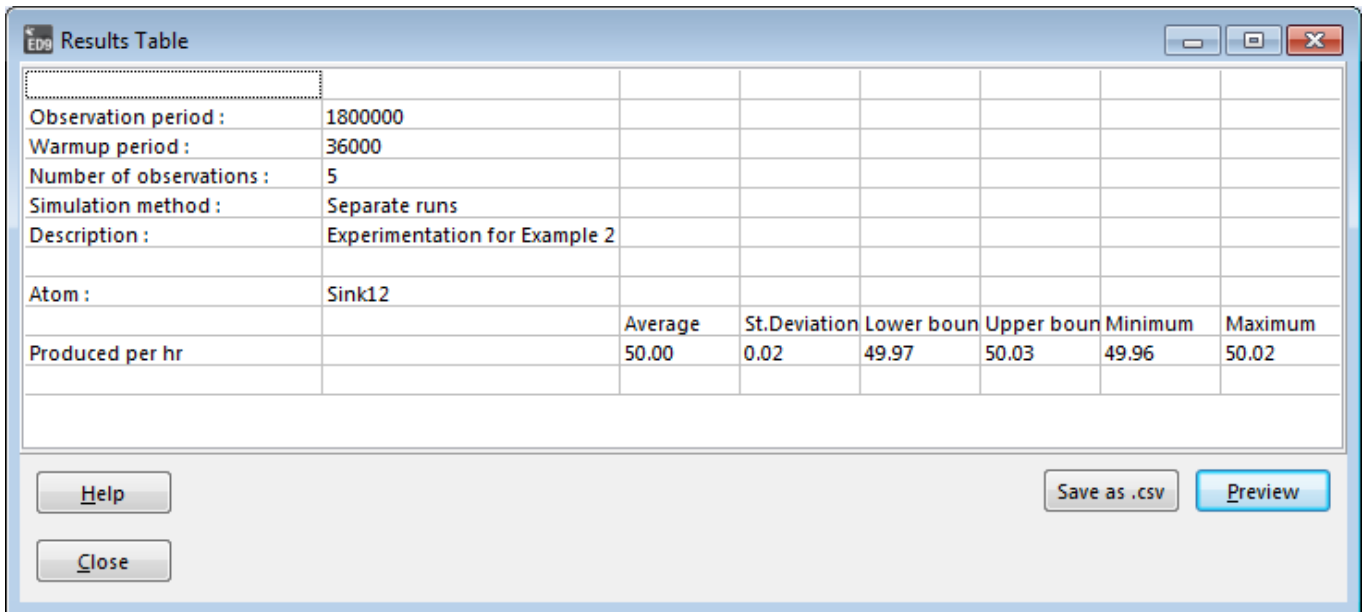
If you click on the name of the statistic, the statistic is added to the statistics list. It is included in your report. Clicking the button again removes the statistic.

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The last three options generate a plot in your report:

Graph — shows the sample observation w_i for every observation i.

Cumulative Graph — shows the moving average of w_1, w_2,.....w_n. This gives a visual indication how fast the average $\overline{w}$ is reached.

Correlation Plot — plots sample observation w_i against w_{i+1} for i =1,2,...n-1. If these results are not correlated, these points will be scattered in the area.

5.2   The results table

Picture 11: The results table

The Results table includes all the information based on your report definition. Right-click your mouse in the first row to set the width of a column. To copy a selected area from the table you can right-click and use the Copy option from the pop-up menu. (see picture 11).

This report is a table in Enterprise Dynamics and can have many rows and columns. It's easy to copy data from the table and paste it in Excel but many times it won't be fit for printing.

Report preview

Generates a report on screen in .qrp format. You can print, save or reload these reports. Qrp stands for Quick Report File and gives a nice first impression of the results -especially if you add graphical information with the Customized Report option- without too much work. Raw data is not included in these reports.
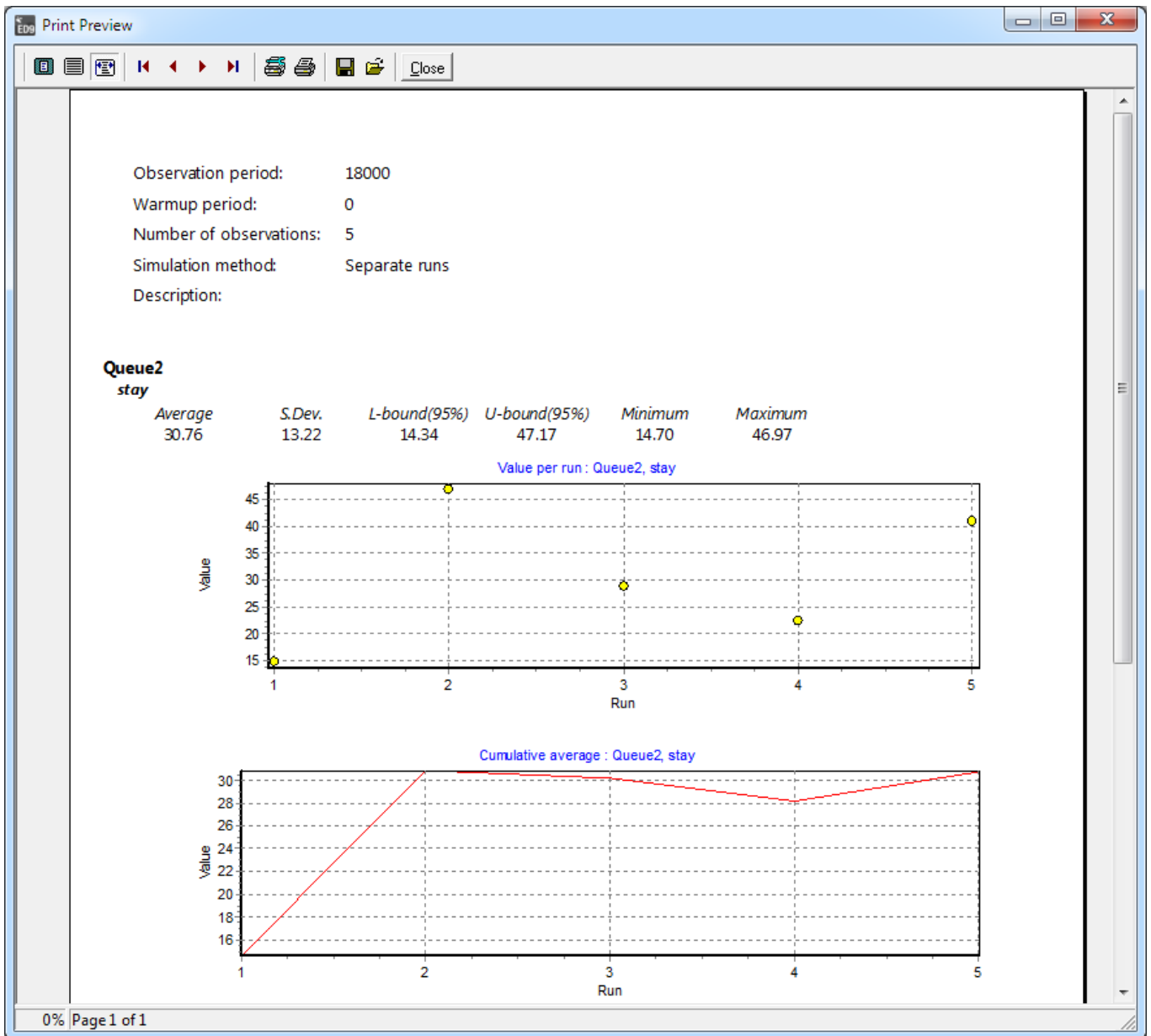
Picture 12: Example of a report in qrp-format

<u>Save Table as .csv</u>

Generates a report named report.csv in the directory in which your output files are located. You can import this comma-separated file in Excel for further analysis.

This concludes the description of the Experiment Wizard and how to generate reports of your results.