

# **An Introduction to Jitia<sup>1</sup>: Simulation Software Designed for Developing Large System Models**

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## **Abstract**

PA Consulting Group's Business Dynamics Practice, formerly Pugh-Roberts Associates, has been developing over the past few years a new simulation software package designed specifically to support the professional model builder develop and analyse medium to large system dynamics models. Although in use at PA Consulting since mid 2000, this software will be introduced to the public for the first time during the summer of 2001.

This paper introduces many of the unique features of the software and discusses how these features support the development of large system models. These features include the introduction of a hierarchical model building construct, new navigational and editing tools, improved array handling, improved macro support, search and replace support, multiple integration methods, advance analysis tools, scenario development and management tools, and a host of other items.

## **Introduction**

PA Consulting's Business Dynamics Practice introduces Jitia, a new simulation software designed to support the development and use of medium to large system dynamics models in a graphic user environment. With their introduction in the late 1980s, graphically oriented software packages revolutionized model building<sup>2</sup>. Pictures rather than text became the model building language, and no longer were beginners required to master the rules and formats of text languages before embarking upon the modeling process. Yet, graphical packages tend to bog down as models grow from tens to hundreds and thousands of variables. Organizing and navigating through diagrams for models of several thousand variables remains a challenge with today's model building packages. From its inception, Jitia was designed for the professional model builder who creates models of hundreds to thousands of equations. Jitia's hierarchical structure, navigational tools, equation entry, editing features, macro support, output display, scenario management, advanced simulation methods and advanced analysis tools all support the professional systems modeler.

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<sup>1</sup> Proposed product name, subject to change.

<sup>2</sup> Stella, High Performance Systems, Incorporated.

## Hierarchical Model Building

The original graphical model building packages provided a large single worksheet, or page, on which to construct models diagrammatically<sup>3</sup>. Stock and flow diagrams could be grouped or clustered in any configuration but were constrained to remain on one large page. With time, some packages provided the users with the option of creating multiple pages<sup>4</sup>, and more recently the option of collapsing structure into a sub-sector diagram has emerged<sup>5</sup>.

Jitia introduces *Groups* and hierarchical model building, Figure 1. Within Jitia, model structure is organized into groups, an analogous concept to sectors and sub-sectors. At the highest level, the model is a group and may contain primary model variables such as stocks, flows, auxiliaries, and constants or other groups. Creating a cascade of groups and sub-groups within a model generates an organizational hierarchy.

From the graphical perspective, each group represents a diagram, a page on which the modeler graphically builds the model using standard tools for levels, rates, auxiliaries, constants and groups. The modeler may layout the stock and flow structure on the base model diagram and then select and group these items forming a sub-group, or the modeler may create a sub-group first and then layout the stock and flow structure on the sub-group diagram. If the modeler wishes to consolidate the structure from several groups onto one diagram, groups may be "un-grouped" or structure may simply be copied from one group and pasted into another.

Figure 1 displays a Supply Chain Management Model that has been divided into multiple groups: Manufacturer, Distributor, and Retailer at the model level. From the model level diagram, the three groups are displayed as sectors. Each of these represents an underlying diagram containing the stock and flow structures within the model along with an additional sub-group. The appropriate connections between the groups are displayed in the higher level model diagrams whereas the detailed stock and flow structures are contained within the sub-group diagrams.

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<sup>3</sup> Stella ...

<sup>4</sup> Vensim, Ventana Systems, Incorporated

<sup>5</sup> Stella ...

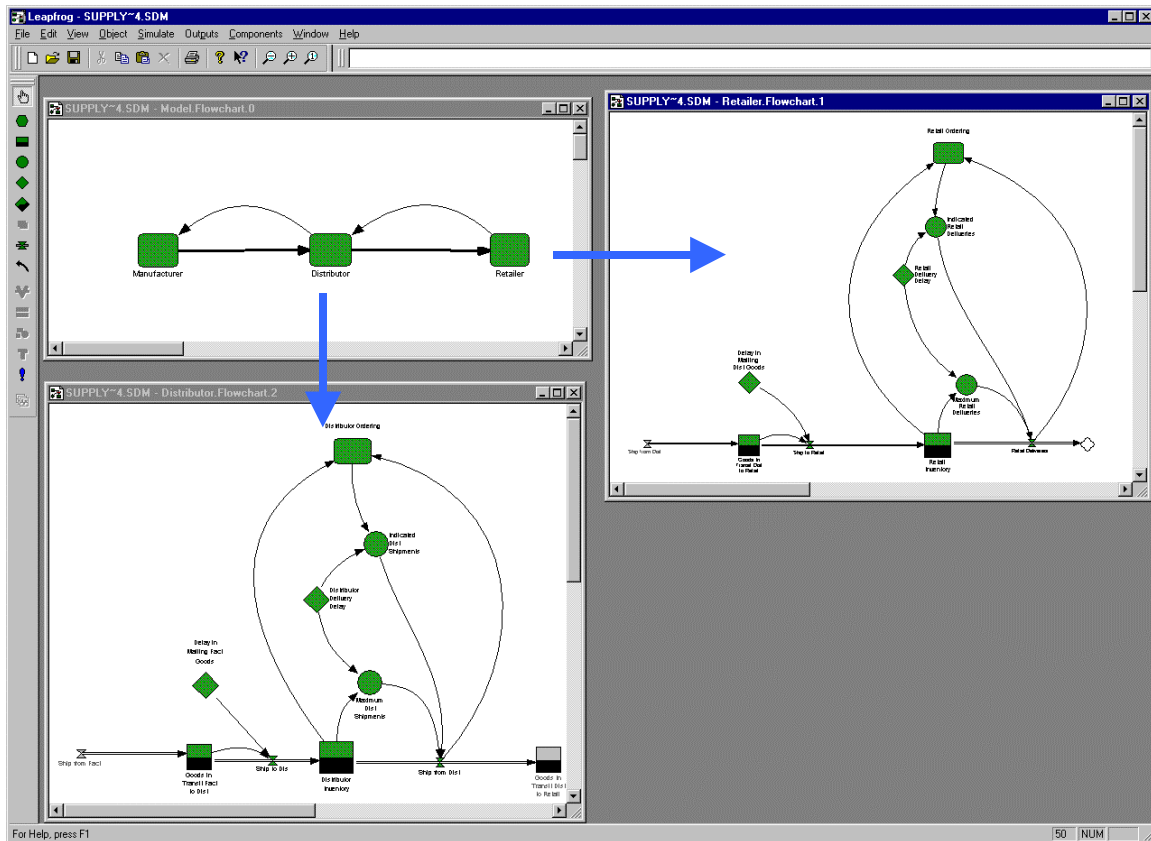


Figure 1

Jitia organizes model diagrams into a hierarchical structure rather than a simple list. Groups are used to represent major sectors and sub-sectors of a model. Groups may also be used to collapse small collections of intermediate equations into subgroups. This allows the model builder to simplify higher level diagrams. Furthermore, groups provide a mechanism for editing large blocks of equations. Models can be re-organized simply by moving groups from one location to another within the model hierarchy. Groups can be copied to replicate structure or deleted when cutting out large blocks of equations. Dimensions can be added to an entire group or collection of groups when subscripting. Groups can be copied or moved from one model to another. This can enable the modeler to build a model from a library of modules or to easily replace current structures with alternative formulations. Of course the group concept does not prevent modelers from working with smaller chunks; primary model variables (stocks, flows, auxiliaries and constants) or selections of primary variables may also be moved, copied, pasted or deleted within a model or across models.

Groups are a powerful construct, and Jitia provides a variety of means for viewing and interacting with them. Models may be built and exercised entirely through the model diagrams. Graphical tools support the creation and placement of model variables and connections. Dialog boxes provide a means for equation entry and view. "Group" and "ungroup" commands support the grouping process; drag and drop capabilities along with standard copy, cut, paste, and delete commands support the model building and editing processes; and menu commands enable the modeler to navigate up and down the model hierarchy within the diagrams. However, the modeler is not limited to the

diagrams. A text view provides an alternative means for reading or editing a model, and Jitia provides a Navigator tool specifically design for navigating and manipulating group structures.

## Navigator

Jitia's Navigator Tree helps the modeler fully utilize the hierarchical qualities of the software. The Navigator, shown in Figure 2, is a dockable window that provides an "explorer" style view of a model. Using the navigator view of model structure, the modeler can quickly locate and view any group of the model. The Navigator provides a means of seeing the hierarchical structure of a model, navigating to (opening) the various diagrams, keeping track of which diagram has focus, re-organizing the model hierarchy, finding and viewing Macros, viewing the contents of each group or macro, accessing object properties and even building a model.

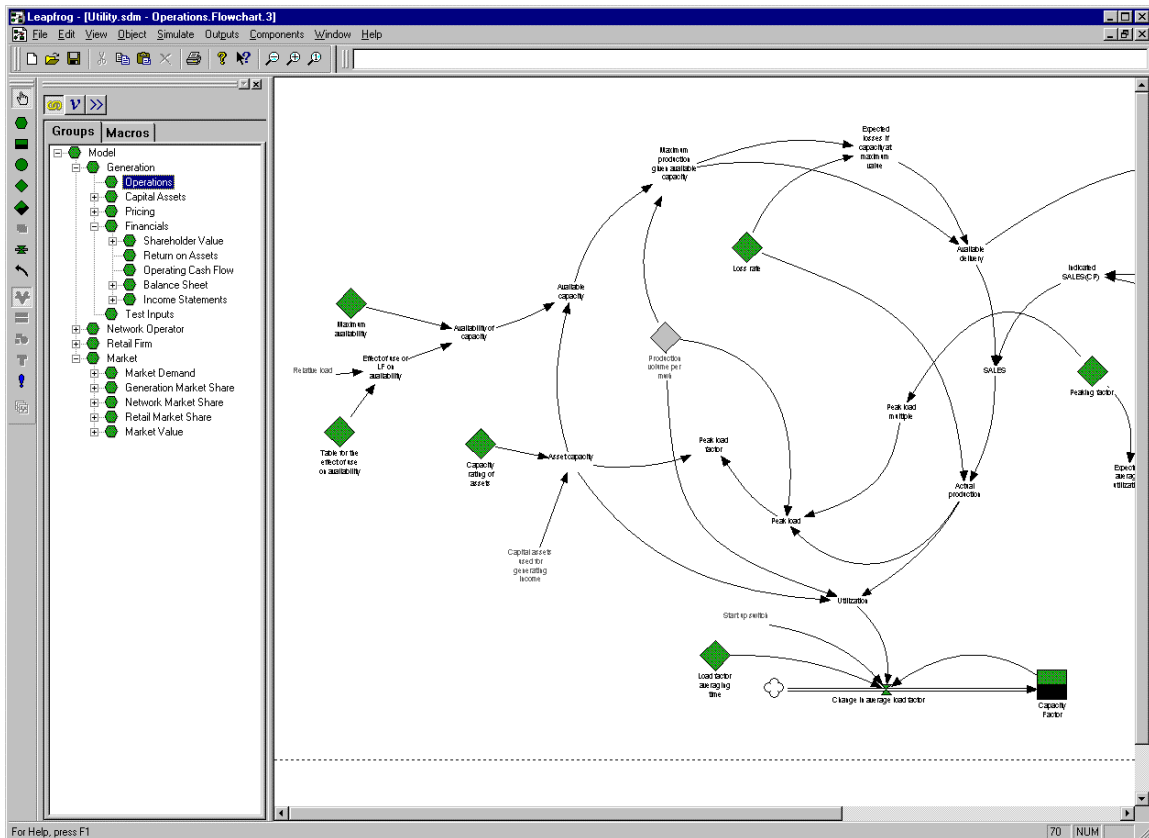


Figure 2

The Navigator, shown docked to the left toolbar in Figure 2, displays the model structure in the Groups tab. The Macros tab (contents not shown) displays user defined functions and subroutines. To open the diagram associated with a group or Macro the modeler simply double clicks on the appropriate group or macro. The Navigator remains linked to the in focus diagram, indicating what group has focus as the modeler shifts around the model.

To view the contents of a particular group or macro within the Navigator alone, a second pane to the Navigator window can be displayed as shown as in Figure 3. This pane provides the means to view various types of information associated with a group or macro. The Diagrams tab list all diagrams associated with a Group. By design each group has at least one definitional diagram containing all variables defined within the group. However, Groups may have additional diagrams, called sideviews, to display subsets of the group structure or to display structure that spans one or more sub-groups. The Variables tab list the model variables defined within the Group. Basic properties of each variable -- such as variable type, name, and equation -- are displayed in columnar format. For display purposes, variables may be sorted by column simply by clicking on the column heading. The variable properties dialog may be accessed from this view by double clicking on any variable, and variables may be created, moved, copied, or deleted using the Navigator. In addition to providing hierarchical access to models, the navigator can be used to copy structures from one model to another.

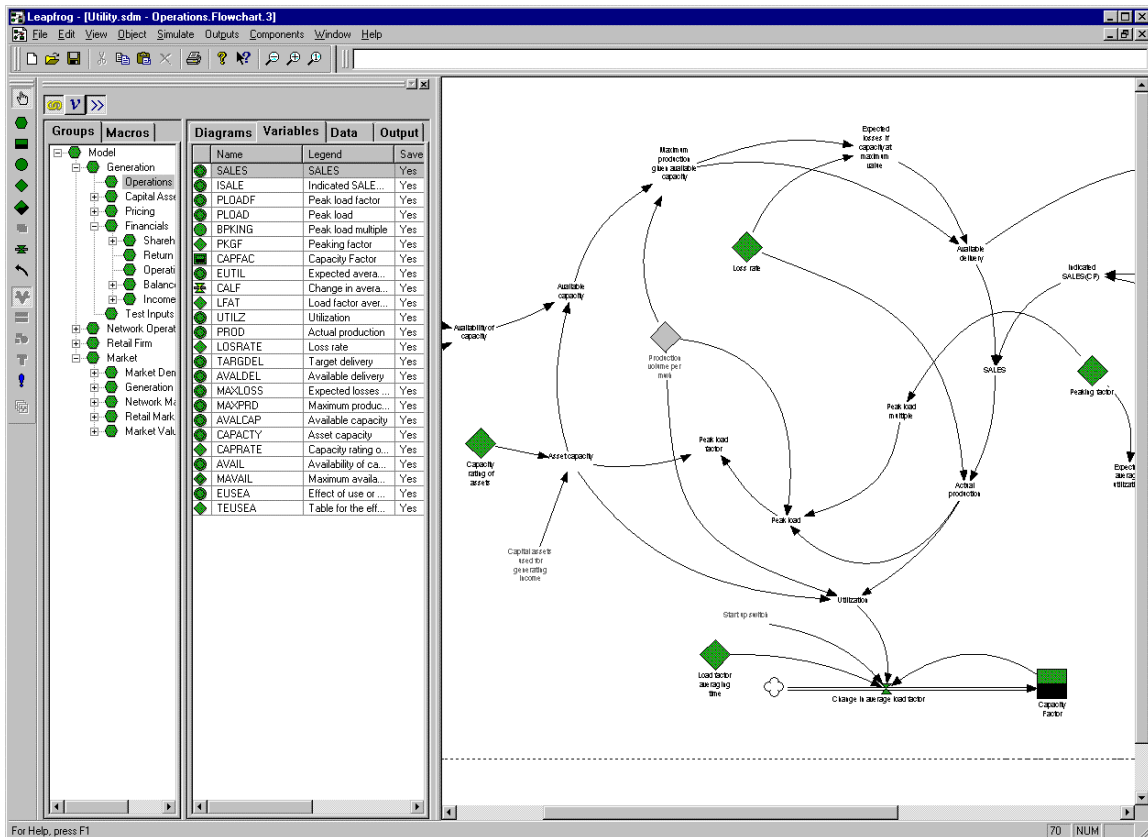


Figure 3

## Dialogs and Extensions

Variable dialogs are an important feature of any graphical development environment. These dialogs are used to enter, review, and modify equations, comments, and units for each variable in the model. Jitia provides a non-modal dialog, which remains open as the user moves between variables. The contents of the dialog are updated to display

information for the currently selected variable. This provides a powerful means of reviewing causality or for making a series of related changes to the model. In order for the modeler to be able to keep diagram structures visible, the Jitia dialog is small enough to be parked in one corner or part of the screen while the modeler traces through model structure. As implied, the variable properties dialog need not be closed to shift focus from one variable to another.

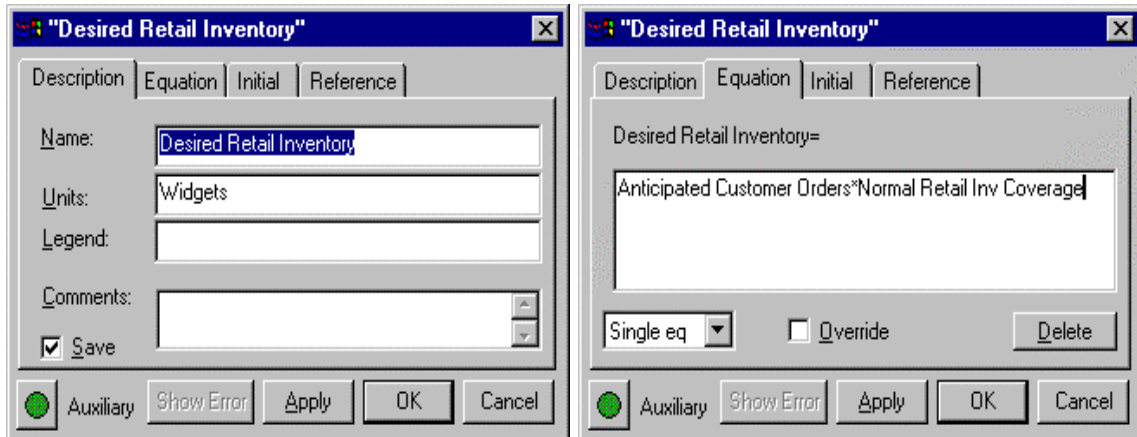


Figure 4

While building a model, the modeler requires easy access to model information such as variables, linked variables, functions, and dimensions. This need has been addressed elsewhere by including many options and lists in the variable dialog. Jitia has met this requirement by providing several "Extension Pads" which contain lists of useful information. The "Global" pad shown in Figure 5 provides the user with access to various model objects often used in defining an equation such as a global listing of variables (sortable and filterable), a listing of built-in and user-built functions, a listing of available array dimensions and elements, and a listing of model units. Selecting an object from this list will place it in the appropriate field of an open variable properties dialog. In addition to special interaction with the variable dialog, the user may drag and drop selected variables to output sets or to the parameter change list. In addition to making effective use of screen real estate, the global pad maintains a separate context from the dialog and may be used repetitively for many equations. With effective use of these pads, the modeler will spend less time searching for items in various pull down lists.

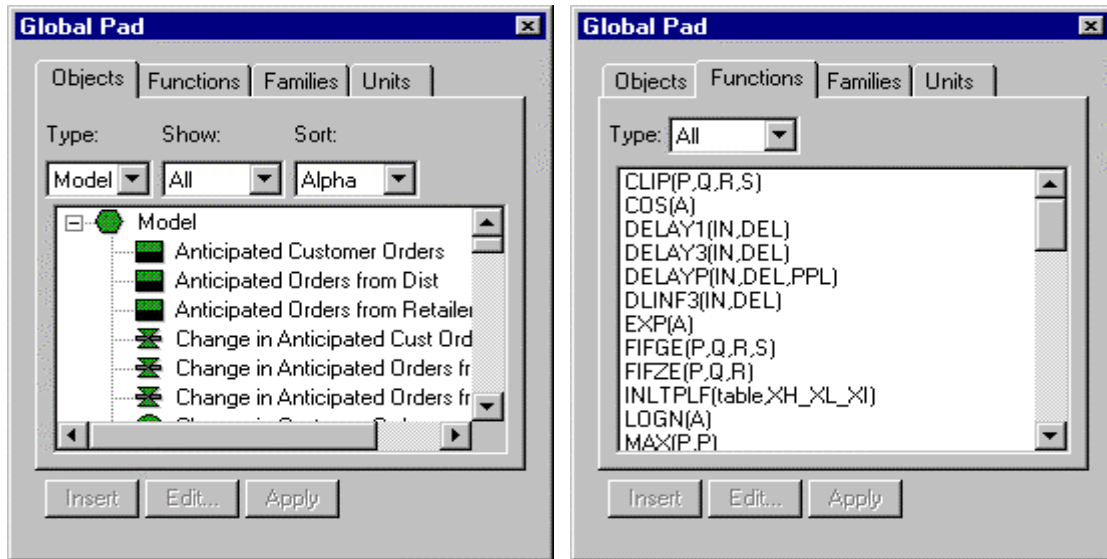


Figure 5

Jitia's "Links" extension pad, shown in Figure 6, displays both an "Inputs" listing and a "Where Used" listing for whatever variable is in focus. The Inputs List may be used for inserting variables into equations when the user has graphically structured a model but yet to define the equation. It may also be used for tracing through inputs or where used locations since the inputs may be expanded to display their inputs and so on. The Where Used list may also be expanded to display the next level of use and so on, as shown in Figure 6. The modeler may use the "Links" pad to shift the focus of the variable properties dialog, either through a right click menu selection or by selecting the "edit" button on the pad. This enables the modeler to use the "Inputs" pad and dialog in conjunction to trace through model equations.

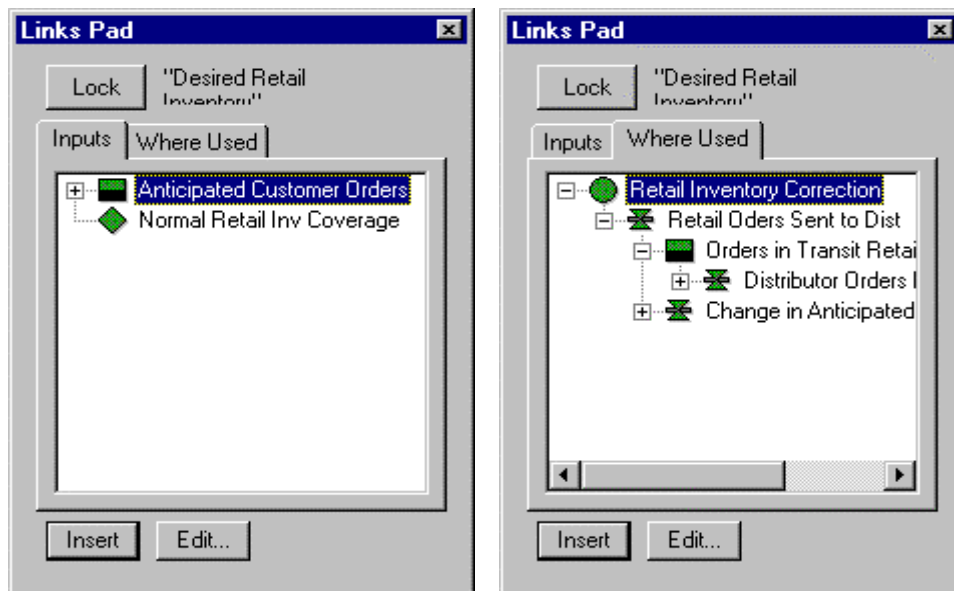


Figure 6

All "Extension" pads are dockable windows that may remain open and be used independently of the variable properties dialog. In fact, the "Global" pad may be used with a variety of Jitia dialogs, and the "Links" pad will display links for "in focus" variables when the variable properties dialog is closed.

## Text Views

In addition to graphical views of the model, Jitia also supports model text. A text view, as shown in Figure 7, is generated using the "Create Text View" dialog shown in Figure 8. A text view follows the classical Dynamo layout with variable type indicators preceding each equation. Groups are indicated using "\*" statements in the text listing. The text view is not a free form text editor. However, a right click menu may be accessed for any selected variable. The modeler can edit or plot the variable, enter parameter values, or jump to the diagram for the selected item. The text view is automatically updated with changes that are applied with the variable dialog.

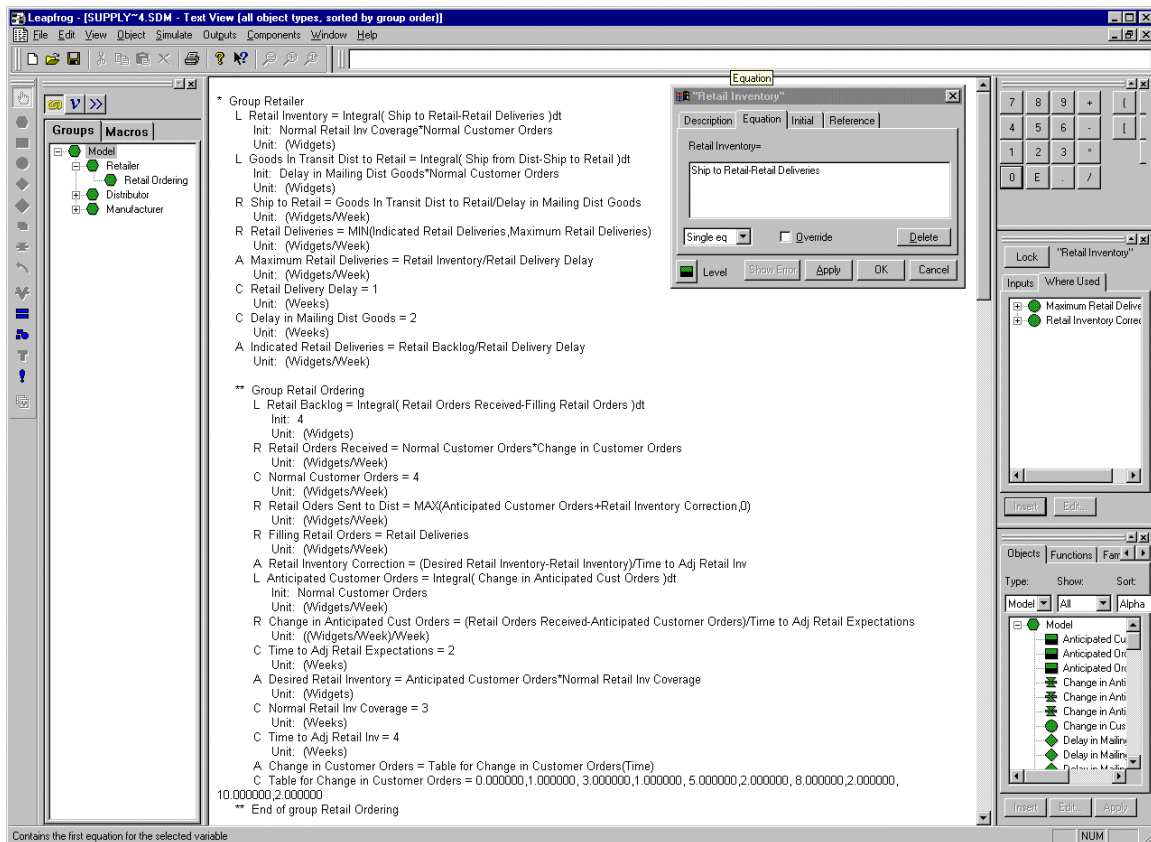


Figure 7

The text view may list the entire model, a particular group, or a selected model portion. In the "Create Text View" dialog, Figure 8, the modeler can specify all model objects or limit the view to a particular type of model object, or limited combination, such as levels only or levels and rates only, etc. In addition, the modeler can display any or all variable



fields such as equations, units, or comments. Multiple sort options exist as well. Finally, the text view supports an advanced filter option where the modeler can generate a text view of model objects containing a specific text string. For example, the modeler could create a view containing all variables with the word "Retail" in the variable name or all variables with the word "caution" in the comment field. As with the diagram views, more than one text view can be open at a time -- or a combination of diagrams and text views. When used in conjunction with the variable dialog, these filtered text views provide an extremely powerful mechanism for finding all occurrences of a specific string and making appropriate changes.

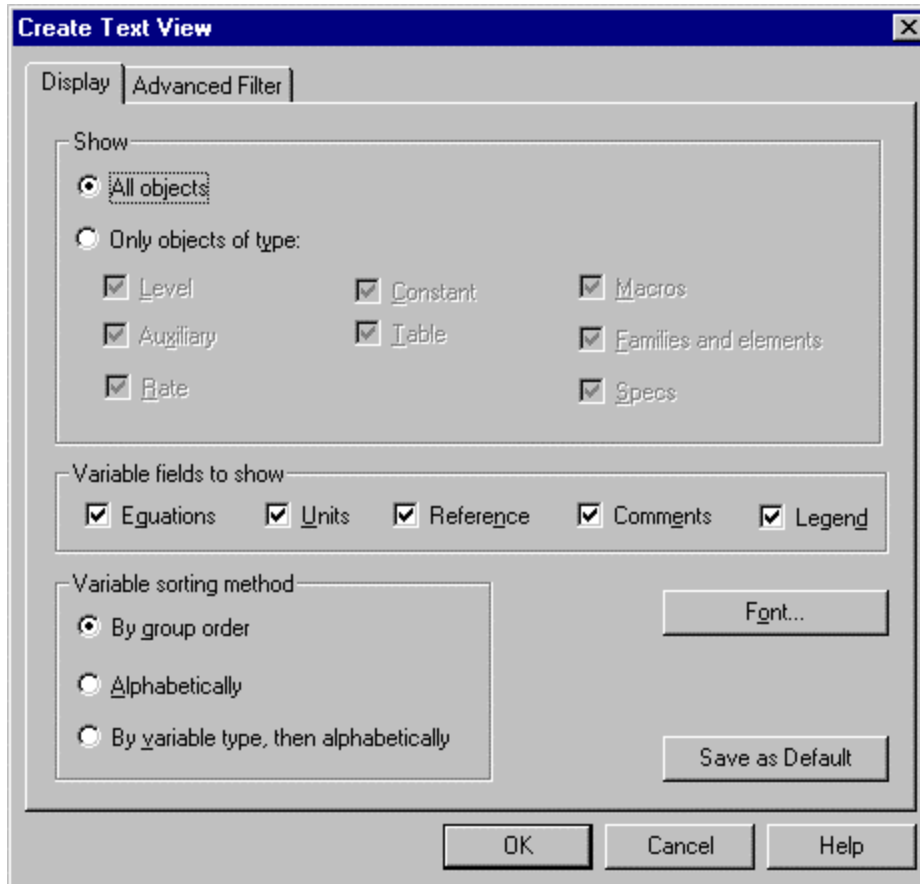


Figure 8

## Output Displays

Simulation results may be viewed in either line plots or numerical grids. The model analyst is able to generate these outputs from anywhere that the variable may be selected. These outputs may be reached from the diagram, the navigator, text view, or the extension pads. A variable may be added to an existing plot using the convenient drag and drop interface.

In addition to on demand "click to plot" capability, Jitia lets the user define and save outputs for future reference. A saved output set may contain any number of outputs

(plots or tabular displays), and a model may contain any number of output sets. Outputs may contain plots of multiple variables and supports two y-axis. Once an output set is created, new plots may be created either by dragging a variable into the output set or by opening the output definition dialog, shown in Figure 9. Variables can be added to the Output definition by selecting them from the "Global" pad or by dragging from either a diagram or the Navigator and dropping them into either the output definition dialog or open output. Output Sets are displayed with a convenient tree control that can be used to access the output sets and outputs in a logical hierarchical manner.

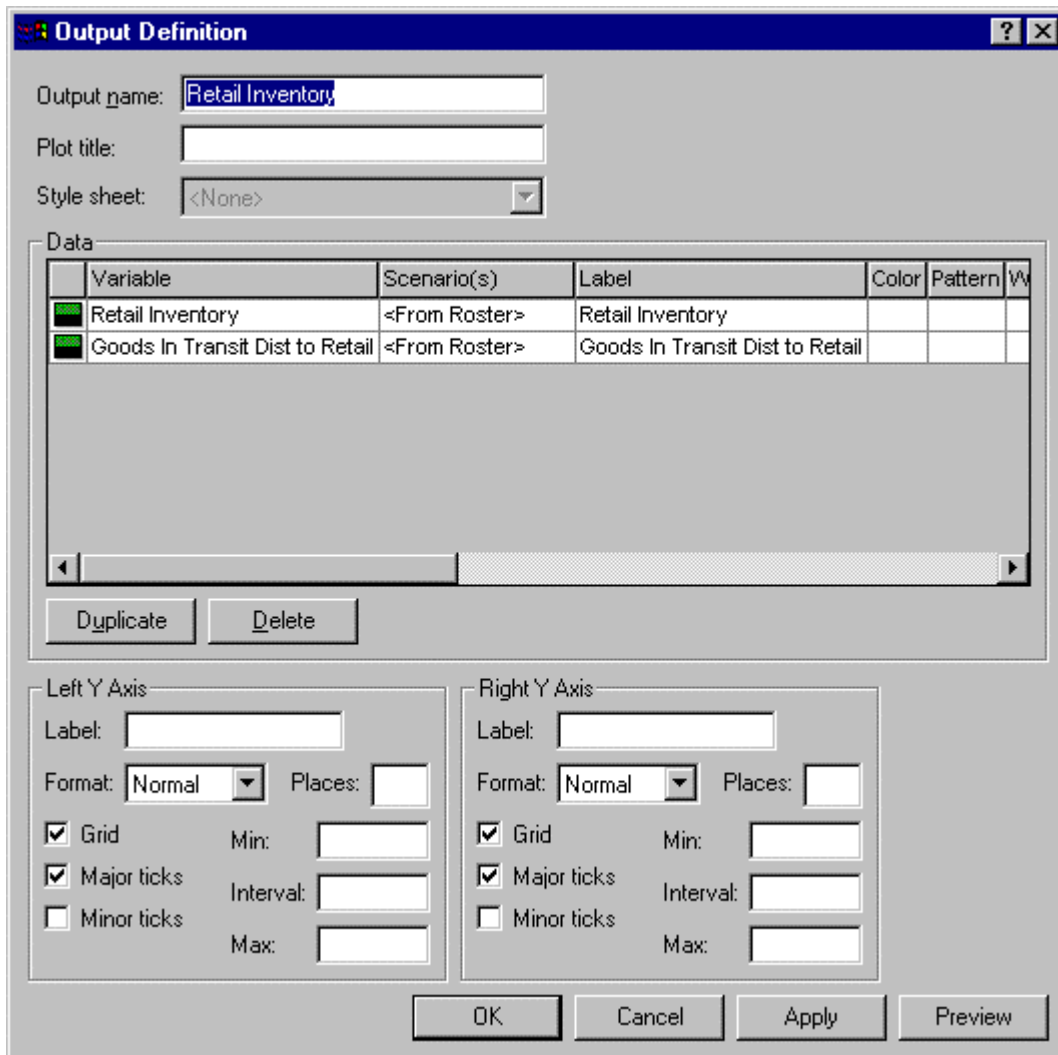


Figure 9

The "click to plot," shown in Figures 10 and 13, is a running plot set maintaining a listing of the last ten items plotted using the "click to plot." The modeler opens a "click to plot" view using a right menu selection from the diagram, Navigator, text view, or extension pads. Once a "click to plot" view is open, any of the last ten variables plotted using the "click to plot" view is accessible. When the modeler plots new items in the "click to plot" view, the tenth item is dropped in the list as the new item is added. Additional variables can be placed on a plot by dragging a variable in from either the diagram, Navigator, text

view or pads or by opening the output definition dialog. Temporary "click to plot" outputs may be added to a permanent output set by dragging an output from the "click to plot" set into a permanent output set. In addition, tabular output for any plot can be viewed by selecting a "grid" view from a right menu selection (and vice versa from a "grid" view).

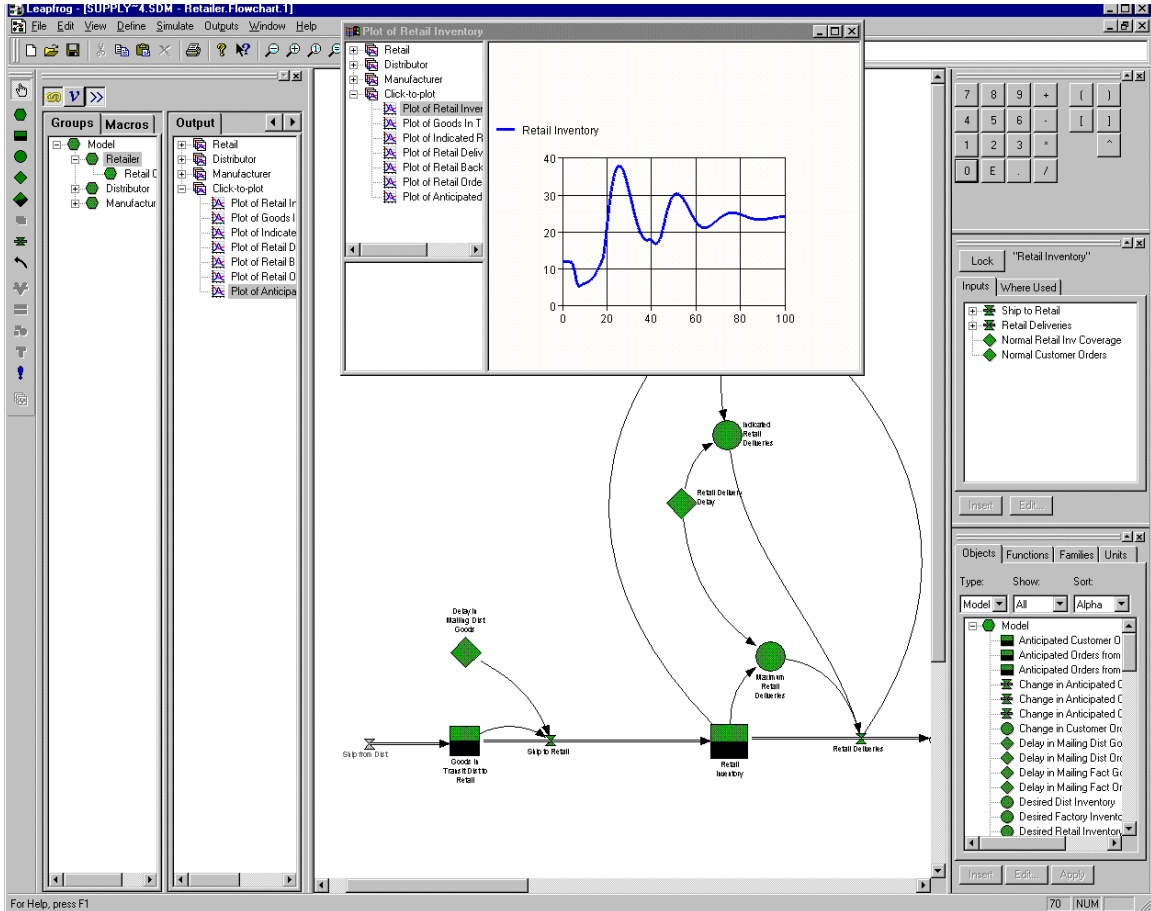


Figure 10

## Arrays

Large models often employ arrays so as to replicate structures without replicating equations. This feature was introduced into Dynamo, a text based language, in the 1970s and has been implemented in most of the graphical packages currently on the market. Jitia implements several features that improve the human interface with arrays in the graphical environment. The most visible innovation is within the variable properties dialog, Figure 11. Instead of explicitly typing the subscript dimension names as an extension of the variable name, a tree structure has been utilized to indicate the array dimensions that apply to a variable and which array elements may have unique equations.

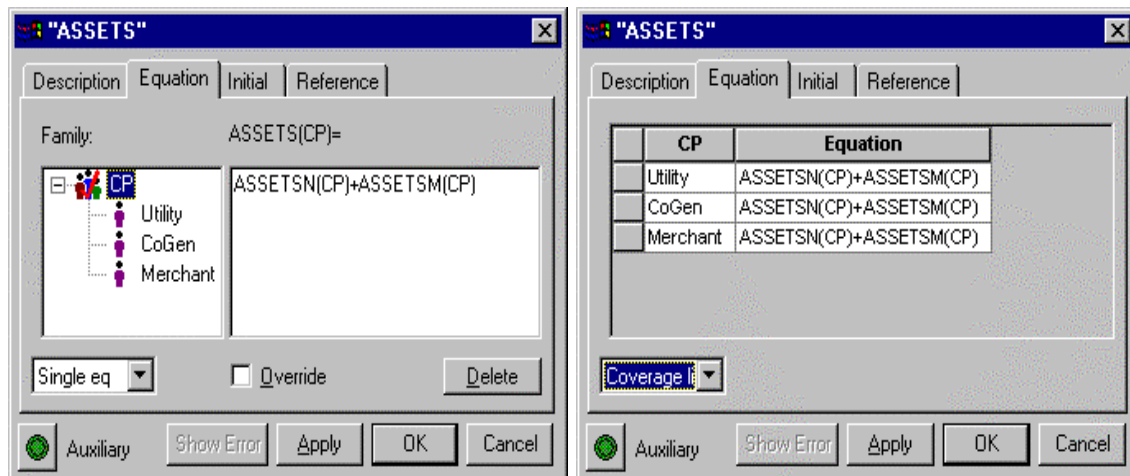


Figure 11

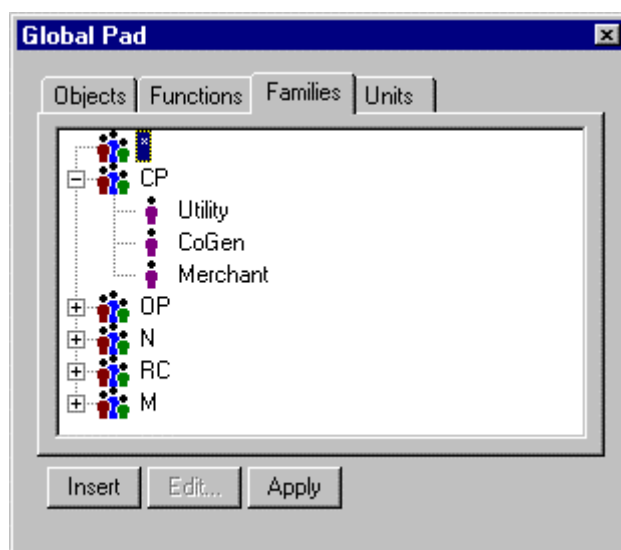


Figure 12

To add a dimension to a variable one simply chooses that dimension from the "Global" pad, shown in Figure 12. The Dimension now appears in the tree structure to the left of the equation, as shown in Figure 11. Once the modeler has accepted the change to that variable, all references to that variable will be updated to include the new dimension. The modeler may enter a general equation that applies to all elements of the array (as in Figure 11), enter an equation for each element, or enter a general equation and then enter overrides for unique elements (or any combination of rows or planes when multi-dimensional). For arrayed variables, the variable properties dialog provides three mechanisms for displaying equations. The single equation view displays one equation at a time using the tree structure as a display control. The list view displays all unique equations defined. The coverage view displays the assigned value for each element independent of whether a unique equation has been defined. Equations may be edited from any of these views.

In addition to adding or editing subscripts variable by variable, the modeler may add or remove array dimensions to or from a selection of variables or selection of groups. Whenever a dimension is changed for a variable or group of variables, every use of that variable within the model is automatically updated to reflect the change.

Another Jitia innovation simplifies viewing simulation results for arrayed variables. Here too, the familiar tree control has been used. When displaying a plot of one or more arrayed variables, Jitia will generate a tree control containing the appropriate dimensions for that plot (See Figure 13). The modeler uses this tree to select elements to display. With these model building and output display features, Jitia provides an easy to use graphical support for arrayed variables.

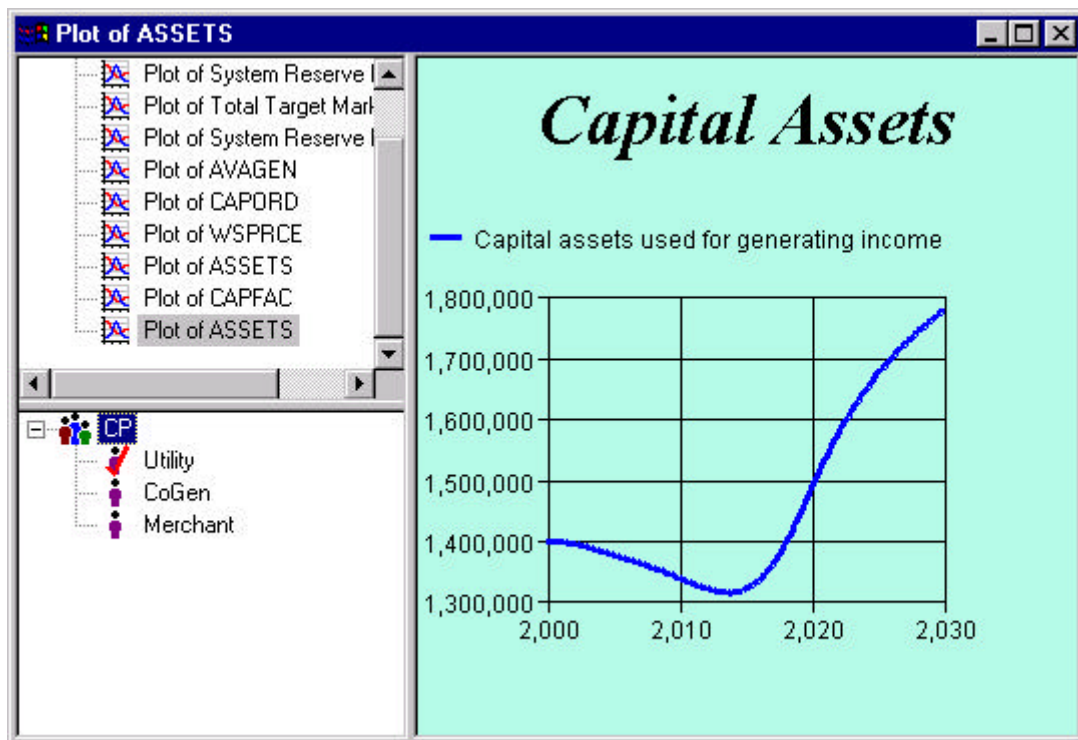


Figure 13

## Table Functions

Jitia continues to support DYNAMO table functions. In addition, Jitia offers a new variable type that provides graphical table function capability. These table variables may be combined with the array definition features to simplify the use of table data for large models. If appropriate, the user can establish a single table for an entire array. The element override capability can then be used to define only the exception cases. This reduces the effort and complexity of dealing with a model that uses an array of hundreds of tables, many of which may be identical.

Jitia's Graphical Table Builder, Figure 14, lets the user enter selected points either graphically or using the keyboard. The "Snap To" feature can be used to specify the desired level of precision. The Table Builder dialog is fully resizable.

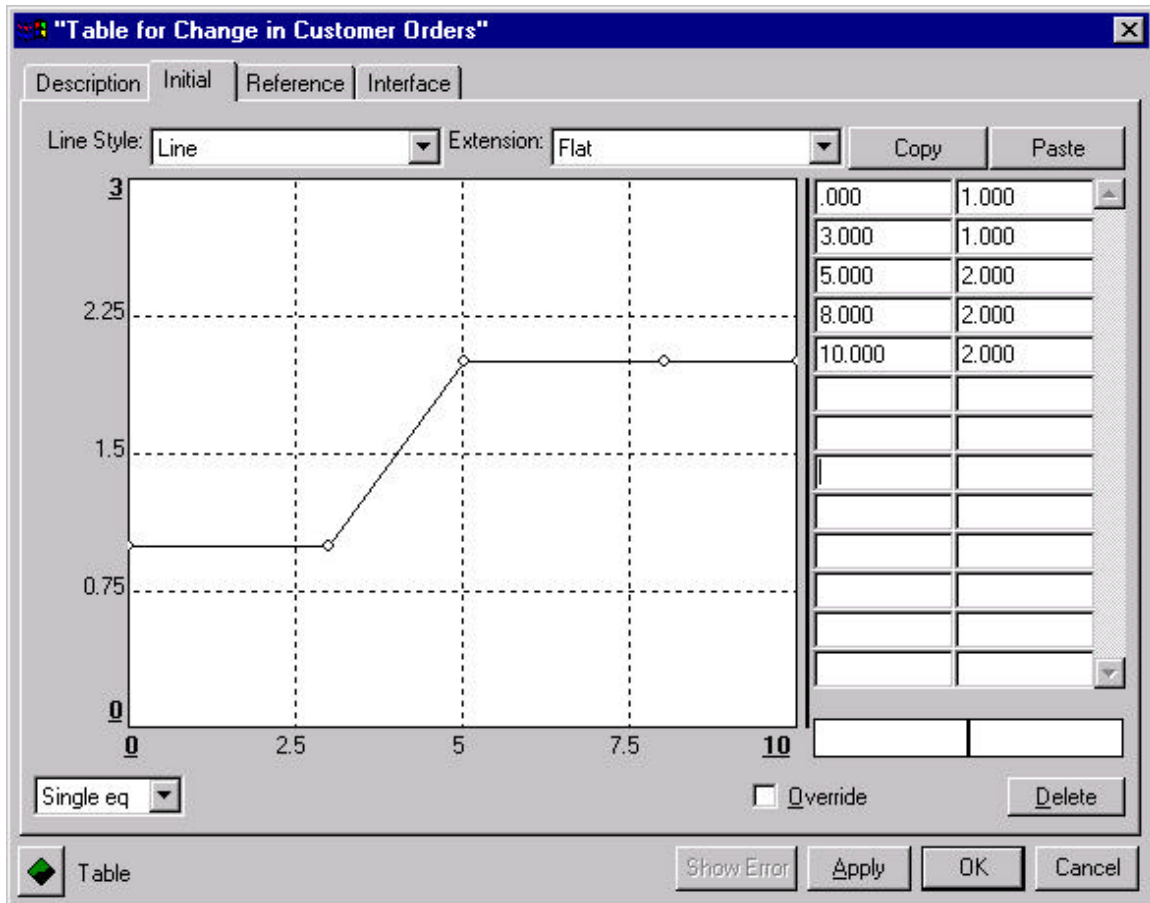


Figure 14

## Macros

Macros provide a powerful method for creating reusable model components. Jitia provides full support for all DYNAMO Macro features. In addition, Jitia supports the use of arrays for internal Macro variables.

The Macro definition facility can be used to build user defined functions and model subroutines. Macros can be used to extend the language and to provide model specific or problem specific components. Jitia Macros are able to invoke other Macros, but recursion is not allowed.

Macros, like other model structure, may be created graphically in Jitia. From the Navigator, the modeler may add a new macro, Figure 15. Each Macro has a page onto which the modeler may use the normal tools (levels, rates, auxiliaries, and constants) to graphically create the Macro. Input and output arguments are indicated within the variable properties dialog when defining macro variables. Calling order for the Macro

function calls are specified using the Navigator. Macros may be used, just as built-in functions, within any Rate or Auxiliary equation in the model. Figure 15 illustrates the simultaneous use of the navigator, diagram, and text view to show the same macro.

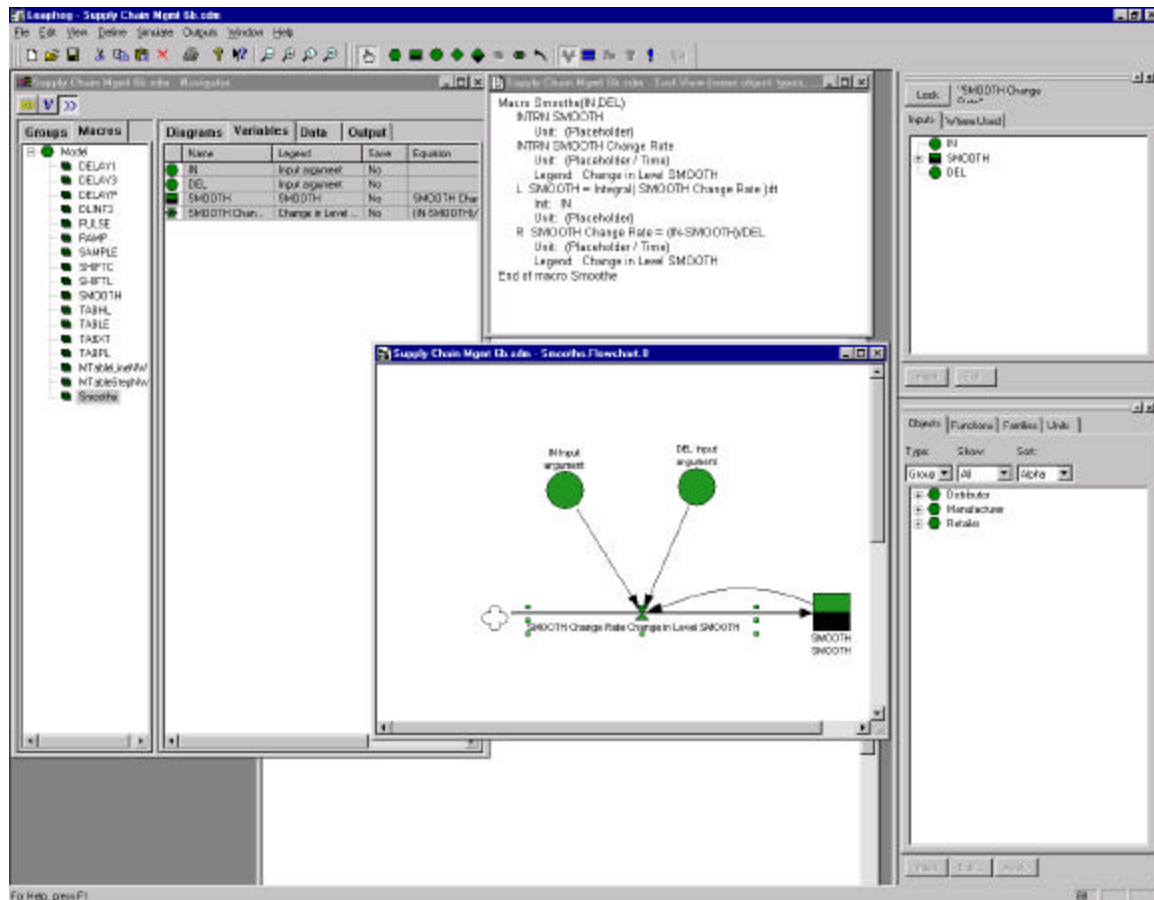


Figure 15

## Scenario Management

Jitia provides powerful scenario management capabilities that help the model builder manage and record the model building and analysis process. The most prominent of these are the parameter change list and the scenario roster.

Jitia's parameter change list is a running log of parameters and associated values that have been altered from the base model to create a scenario. Jitia applies these changes to the model when the scenario is simulated. The modeler is able to add and edit values in the parameter list via a variety of methods from the diagram or navigator or the change list itself. Changes need not be executed immediately; the modeler may leave this global workpad in the background while continuing to build and edit the model and simulate when desired. The parameter change list is a built-in part of Jitia's integrated environment, providing a simple mechanism for the model builder to test different parameter values or generate scenarios without committing to permanent model changes.

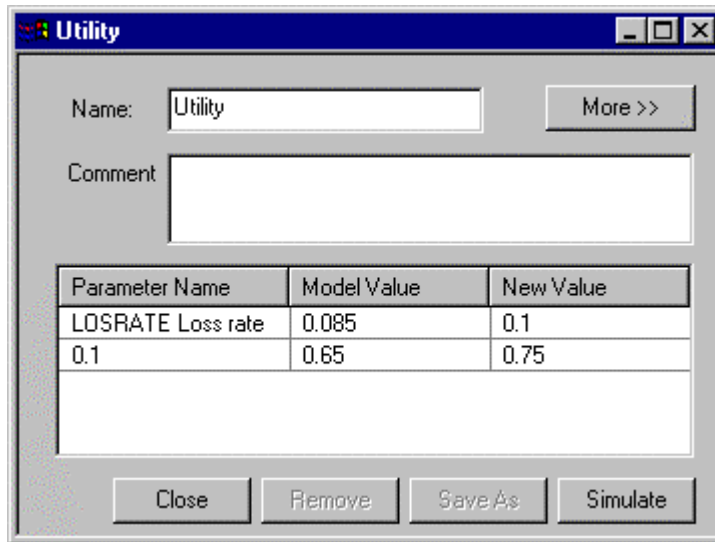


Figure 16

An additional feature of the parameter change list is that the contents of the change list may, at any time, be saved as a permanent parameter set. Saved parameter sets may be retrieve at a later session to build upon or simply to include in future scenarios.

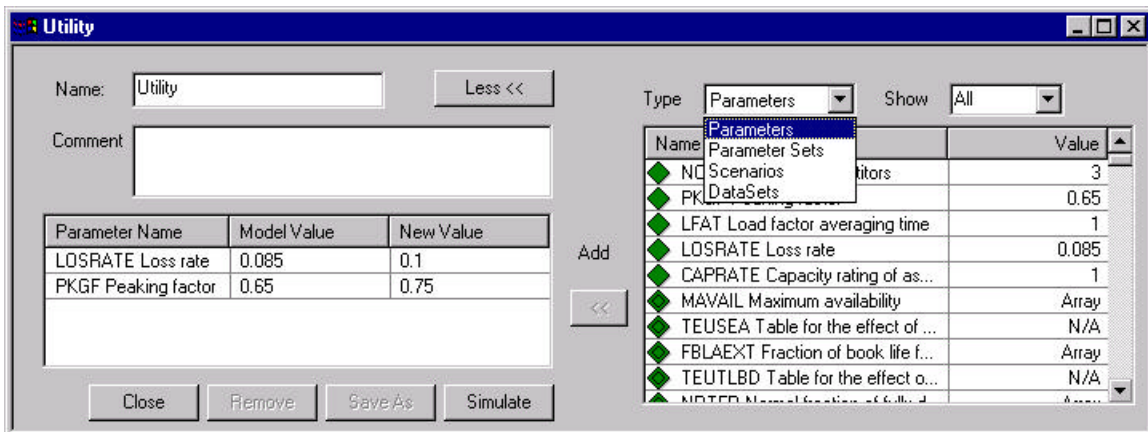


Figure 17

For keeping track of scenarios that have been executed, Jitia keeps a scenario roster. Not only does the scenario roster keep track of previous simulations but also provides the modeler with a means to select specific runs for plots, tables, and presentations. In addition, to the scenario name, the scenario roster records the base model, parameter sets and changed parameter values used to generate the scenario.



## Advanced Simulation Methods

Euler integration has been the standard method in System Dynamics from the field's inception. In addition to Euler integration, Jitia provides several methods that employ adaptive time step algorithms. These methods use estimated error calculations to determine the appropriate solution interval. Jitia supports Runge-Kutta 2-3 and 4-5 methods that are similar to methods provided by DYNAMO and other packages. In addition, Jitia supports two implicit integration methods that are able to solve "stiff system" problems.

The implicit integration algorithms use a jacobian matrix to solve the set of ordinary differential equations. This method is necessary for some types of physical and scientific problems where the model is "stiff." In a stiff system, the dynamic solution may require very small time interval for some portions of the solution period. Whereas during much of the solution period, the system tends to change more slowly and can be integrated with larger time intervals. The striking of a match is an example. Before striking and afterwards, the behavior of the match tends to be relatively stable and can be modeled using relatively large time increments; however, while the match is actually being struck, things change rapidly and require very small solution intervals for an accurate simulation. Another example that has been simulated in Jitia is a blood-clotting model. Prior to perturbation, the clotting model is relatively stable. Once perturbed, the chemical reactions that produce the clotting occur very quickly. In order to produce reasonably correct behavior with Euler integration, it is necessary to use a time step on the order of .00001 seconds for a process that takes 100 to 200 seconds. In order to simulate a full 200 seconds of behavior, it is necessary to execute the model for 20 million DT's. Using Jitia, this simulation required approximately 10 minutes on a moderately configured PC. (This was more than 1 million equations per second). By contrast, Jitia's implicit integration method reached a solution in less than two seconds and obtained a more accurate result.

In addition to the adaptive time step integration methods, Jitia provides an Improved Eulers integration as a second fixed step method. Improved Eulers averages forward and backward Eulers to improve the accuracy of the standard forward Eulers used in Jitia. For large business and policy models, Jitia's Euler integration methods provide large capacity and high performance.

## Advanced Analysis Tools

Jitia provides a Wizard driven tool kit for conducting a variety of standard analysis routines that require multiple simulations. These include:

- Leverage Analysis -- conducts multiple simulations varying individually, over their specified ranges and increments, the parameters within the chosen parameter set;
- Grid Search -- conducts multiple simulations to cover entire parameter space specified by the set of parameters chosen, their specified ranges, and specified increments;
- Monte Carlo Analysis -- conducts multiple simulations randomly selecting parameter combinations that fall within the parameter space specified by the set of chosen parameters, their specified ranges, and probability distributions;

- Optimization -- conducts multiple simulations seeking to minimize a specified model output by varying a selected set of parameters within each allowable range;
- Potentiation -- conducts multiple simulations varying in pairs model parameters (with specified values) to assess where combinatorial sensitivity is greater than sum of individual sensitivities.

The wizard guides the modeler through selecting outputs to be viewed upon completion of the analysis, along with selecting parameters to be varied for generating the analysis. Save/sample periods can be set for output variables, while associated ranges and increments or distributions must be set for parameters. Analysis can be paused and resumed at a later date. Jitia stores output information for each individual simulation run within a database. The user can access results for immediate assessment or retain for later review. If individual runs within the analysis are of interest, the modeler may be select the individual runs and re-execute them using the complete save set for the model. Thus, the model builder can analyze any run in detail. This feature is very powerful for analysing those cases where an outlying result is obtained.

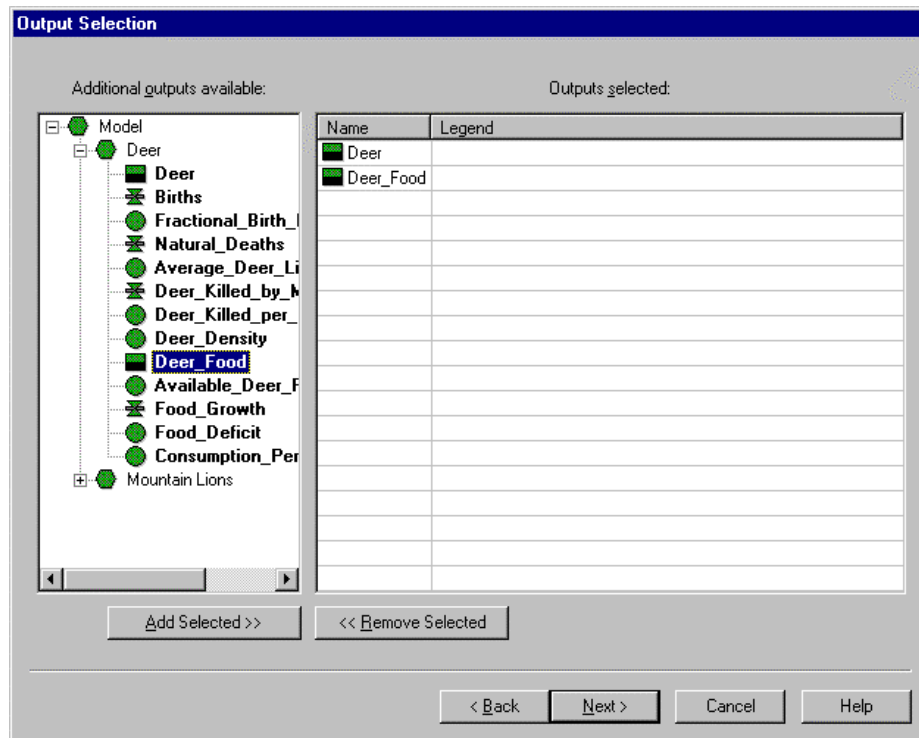


Figure 18

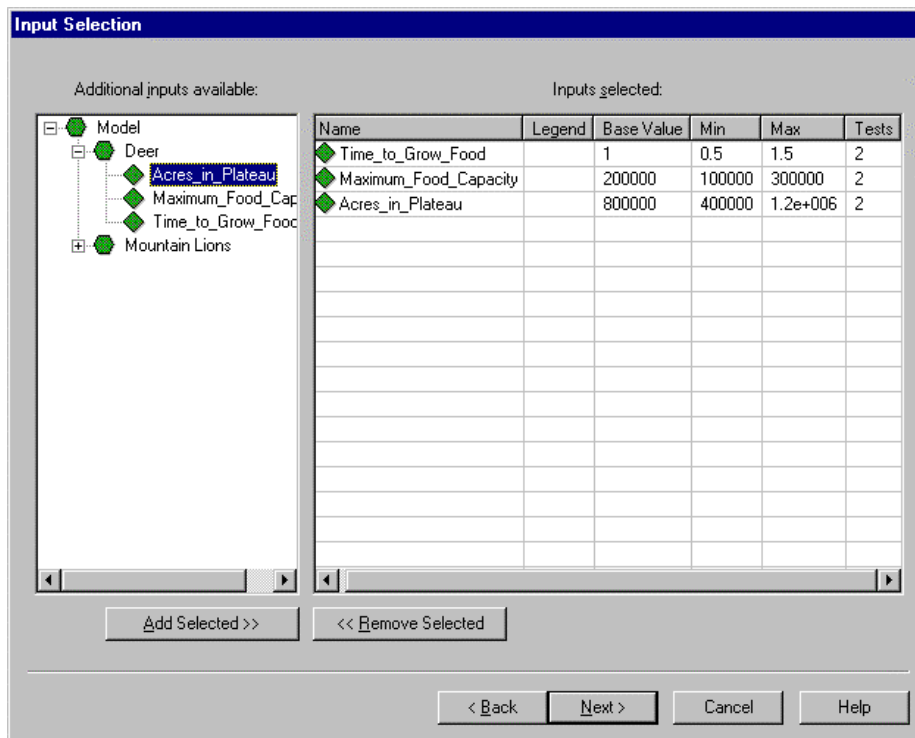


Figure 19

## Summary

PA Consulting Group's Business Dynamics Practice introduces Jitia as a new simulation software designed specifically to promote and support the construction and analysis of medium to large models in a graphical user environment. Hierarchical model construction using groups enables the model builder to organize the stock and flow diagrams within a model onto multiple pages within a hierarchical framework. The Navigator helps view, navigate and edit both the hierarchical organization of a model and the basic components of the model. The new design of the variable properties dialog along with the introduction of the extension pads help the modeler quickly enter equations and trace through model structures. Improved subscript features bring the power of model subscripting into a usable and friendly graphical user interface. Graphical construction of Macros offers the modeler an easy to use device for creating user-defined functions and subroutines. The advanced analysis tools provide an easy to use Wizard to guide the modeler through the setup and execution of a range of powerful model analysis requiring multiple simulation runs. Finally, the expanded selection of integration methods allows Jitia to be used for a range of scientific and engineering problems, including stiff systems, where standard Eulers integration is insufficient.

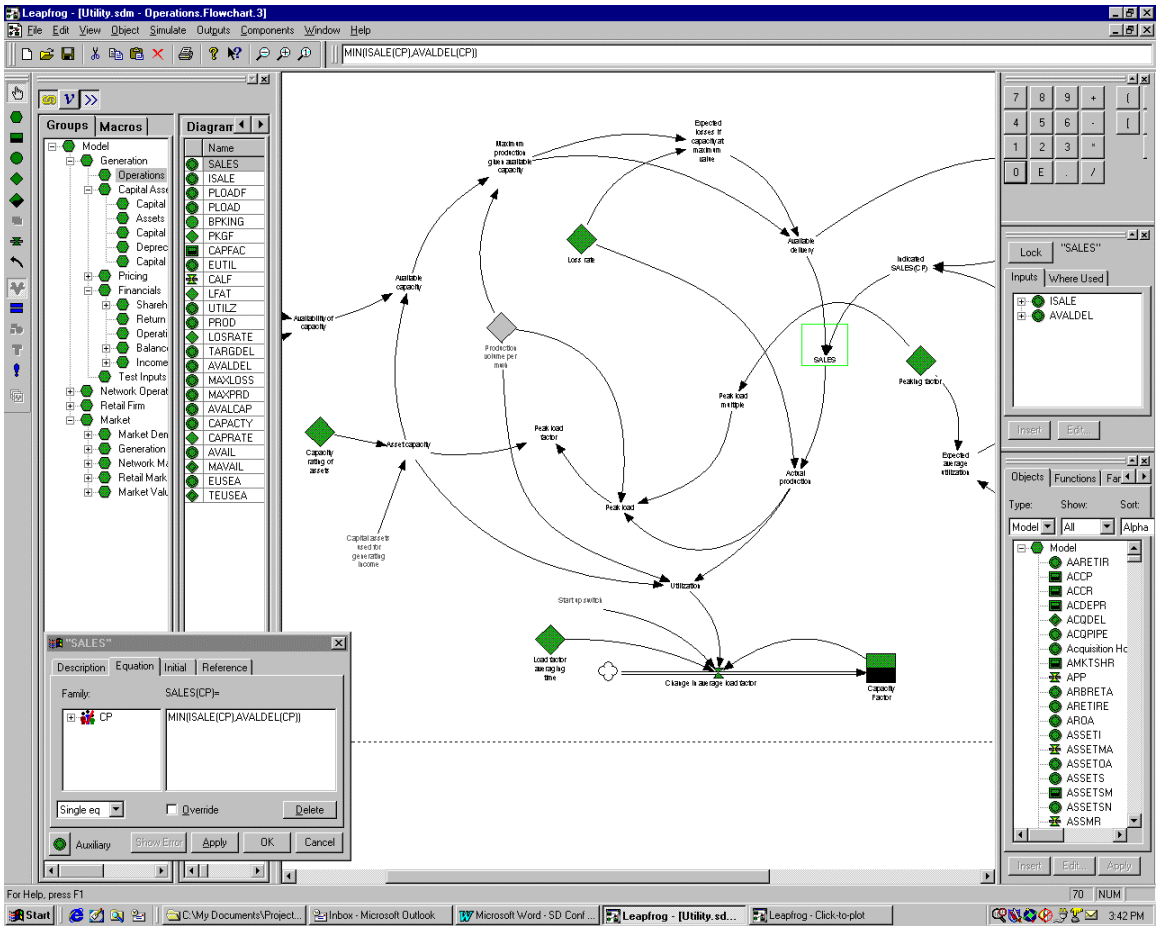


Figure 20