LoadDynamics ^{TM}

Version 2.1

USER'S MANUAL

User's Manual

LoadDynamics^{TM}
A Model For Developing Probabilistic Forecasts of Load Conditions

Version 2.1

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PREFACE

Model Overview

LoadDynamics^{TM} is a load forecasting tool. The model provides probabilistic information about future load conditions and thus aids the development of local area investment strategies. The model was developed as part of an EPRI project to produce area investment planning tools for the electric power industry. Two factors motivated the development of the LoadDynamics^{TM} approach for characterizing load uncertainty:

> First, for distribution planning, a key issue is at what point in the future will load growth result in a given level of demand. This determines the time to the next investment decision, since distribution capacity requirements are based on load levels. Thus, a complete description of potential load trajectories over time is required in order to determine the time to the next decision.
>
> Second, load growth follows trends. For example, area load typically might grow at a low, steady rate for several years and then transition to rapid growth for a time. This suggests that modeling future load conditions should start with characterizing key parameters associated with the possible trends – the average durations of the trends, and the likelihoods of shifting among the trends.

Two types of load forecasts are allowed. The user can specify the number of years for the forecast. In this case the model generates a probability distribution on possible load levels for each year, $p(load|year)$. For this type of run, two graphical outputs can be produced: 1) a plot of the average load versus forecast year, and an upper and lower bound on load versus forecast year; 2) a plot of the cumulative probability of reaching a given load versus the forecast year.

Alternatively, the user can specify the largest load level that is to be considered. The model is then run for enough years so that the cumulative probability of reaching the specified maximum load is 1.0. This type of model run generates probability distributions on the time to reach load, $p(time\ to\ load|load)$. This information is generated for all possible loads from starting load to maximum load. For output, the full distributions are converted to three-branch discrete distributions using a moment matching technique. The technique creates three-branch discrete distributions that have the same first five moments as the full distributions. The user can examine selected three-branch distributions with a graphical output that is built into the user interface.

Computer Implementation

The analytical engine for LoadDynamics^{TM} is written in C++. The interface is written in Visual Basic. The model requires a small set of data that is input via one input form. Graphical outputs capabilities are built into the user interface.

Acknowledgments

The ideas for the LoadDynamics^{TM} approach originated in discussions with Jonathon Lesser of Green Mountain Power and Bob Chow of Ontario Hydro. Peter Morris and Charles Feinstein formulated the load uncertainty model. Steve Chapel, with help from Mukund Thapa, designed the computer implementation of the mathematical model. Steve Chapel implemented the model as a C program and Steve Wan and Steve Chapel developed the user interface.

TO REPORT PROBLEMS AND GET HELP RUNNING THE MODEL, CONTACT EPRI USER SUPPORT:

The EPRI project manager
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(650) 855-2608
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1 INTRODUCTION

1.1 Installing the Model

The accompanying CD disk contains the setup program that will install Version 2.0 of the model. The system requirements for the model are:

- Windows 95/98/NT,
- 32mb of RAM,
- 8mb of free space on a hard drive,
- Acrobat Reader 4.0 installed on the host machine.

Acrobat reader is used by the model to display the help file. If the user does not have the software, it can downloaded for free from Adobe's web site (www.adobe.com).

To install LoadDynamics^{TM} you need to do the following. First, if you have older version of the model installed on our computer, you will need to uninstall the program. You do this by selecting *Start* | *Settings* | *Control Panel* | *Add/Remove Programs* | *LoadDynamics* | *Add/Remove* and then following the directions that the uninstall program provides. You can then install the new program by:

1. inserting the disk for Version 2.0 into your CD / DVD drive;
2. clicking on the **Start** button;
3. scrolling up and clicking on the **Run** button;
4. typing **D:\Setup.exe** (if **D:** is not the drive identifier for the CD drive, enter the appropriate drive identifier); and
5. clicking the **OK** button. Follow the instructions as indicated during the installation.

Note: for correct installation, turn off virus checking and disconnect your computer from the network.

After you have followed these steps, you can upgrade the model to Version 2.1 by downloading the upgrade program from EPRI's web site (www.EPRI.com) and running the install program that is part of the upgrade package.

Unless the user specifies otherwise during installation, the installation program will create a subdirectory to your `Program Files` directory, will name the subdirectory `LoadDynamics`. The model and its data files are placed in this subdirectory. The DLL files are placed in the `c:\windows\system` directory.

Note: Three example data sets are provided with the software. The input files are `corr_nocorr.ldp`, `assessor.drs`, and `assessor_jump.drs`. `corr_nocorr.ldp` is the input file used for the first tutorial, Section 3).

The user can uninstall the program by selecting "Start | Settings | Control Panel | Add/Remove Programs | LoadDynamics".

1.2 Learning to Use the Model

LoadDynamics^{TM} is an easy model to use. We recommend the following four steps as an efficient way to become familiar with (1) the mechanics of running the model and (2) the methodology that underlies the model calculations:

1. Review Section 2 to become familiar with the user interface, the input data, and the outputs.
2. Do the first tutorial, Section 3, that uses the growth trend example data set (`corr_nocorr.ldp`)
3. Do the second tutorial, Section 4, that uses the Load Assessor tool.
4. Read Section A that describes the analytical methodology.

1.3 Running the Model

While we do not recommend using the model to create load forecasts until you have completed the tutorials in Sections 3 and 4, you can verify that the model is installed and working by performing the following steps:

1. open the model by clicking *START*,
2. select *Programs*,
3. highlight *LoadDynamics* and

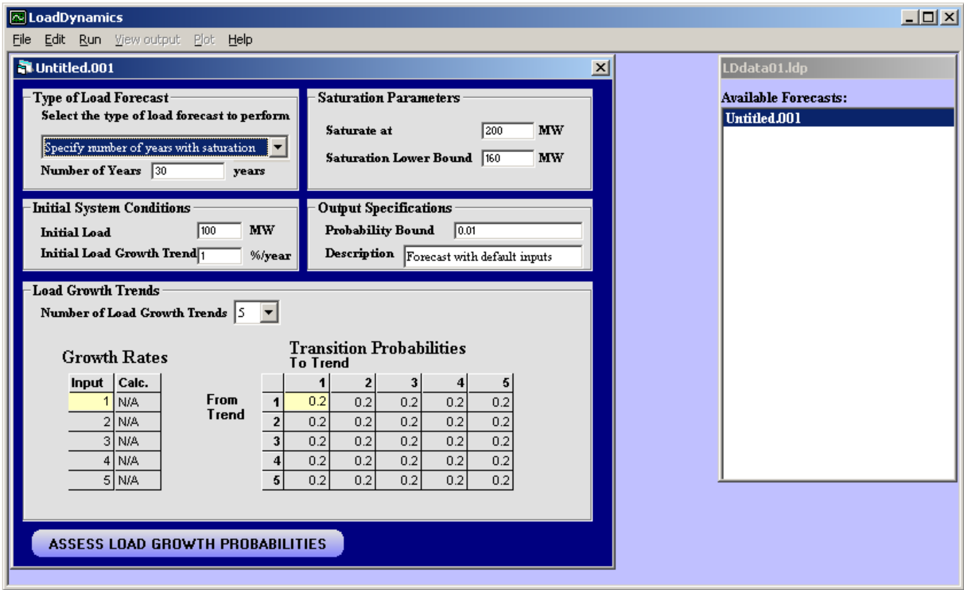

Figure 1-1: Load Dynamics Main Screen After Opening a New Data File

4. click on the *LoadDynamics* icon.

5. use the *File* menu and click *New* to open a new data set.

Following these steps will result in the window shown by Figure 1-1. If it does not you should contact EPRI for help. Assuming that the window is displayed correctly, you should exit the program (select the *File* menu and click *Exit*) and proceed to follow the steps outlined in Section 1.2 above.

1.4 Error Traps

The software traps most data inconsistencies at the user interface level. However, there are certain situations where error conditions are recognized only after the model is processing the data. In order to ensure robustness of the software, the software traps run-time generated errors and reports them back to the user in a Window as a RUN-TIME ERROR. When this happens the user is asked to click OK, and the model returns to the main window.

In some (hopefully rare!) instances, the error message is one that should not have occurred and occurs only because of an internal inconsistency in the software. In this case, Please contact EPRI User Support with the exact message as it appears on your screen.

In other situations, the error message will point you in the right direction and you can attempt to modify the data for the case and re-run the model. However, in this case too, should the message be unclear or if you have any questions, please do not hesitate to contact EPRI.

1.5 What's New

Version 2.0 introduced several enhancements. These include:

- The Load Assessor tool was added to the model. This tool facilitates development of the required load-growth input parameters. For a description see Section 2.3
- The speed of the load forecasting algorithm was increased dramatically.
- The user interface was improved.

The latest enhancements, Version 2.1, introduce the ability to model uncertain block load increases (the potential for jumps in area load). Version 2.1 also fixes several small software problems. For a list of the latest program changes see the installation instructions that accompany the upgrade to Version 2.1.

1.6 Contacting EPRI User Support

TO REPORT PROBLEMS AND GET HELP RUNNING THE MODEL, CONTACT EPRI USER SUPPORT:

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2 USING THE MODEL USER INTERFACE

2.1 Overview

Figure 2-1 illustrates the steps necessary for running the model. After the model is started a set of menus is available to the user (*File*, *Edit*, *Run*, *View Output*, *Plot*, *Help*). These menus contain all of the commands for running the model. Each menu is explained in Section 2.2. After starting the program the user should use the menu commands to carry out the steps shown in the diagram.

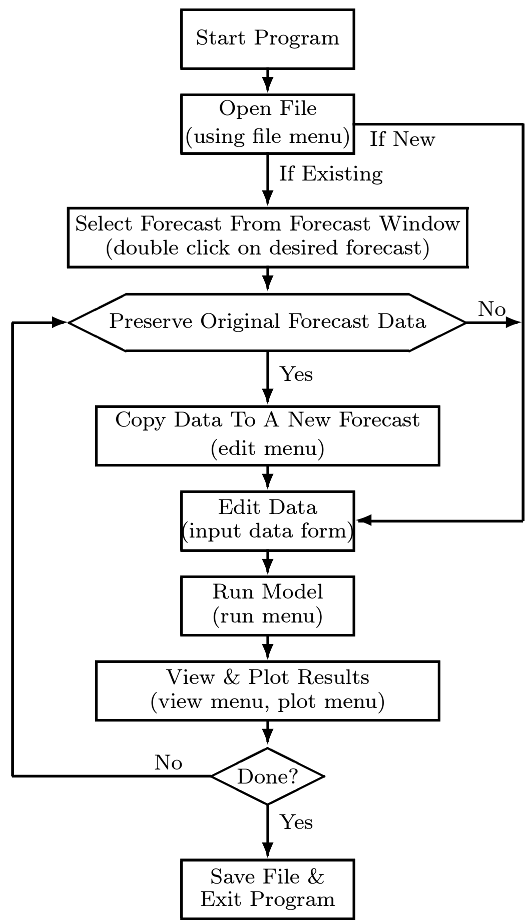


Figure 2-1: Steps For Using LoadDynamics^{TM}

2.2 Using the Menu Commands

When the model is started, a start-up window is displayed. This screen has the name of the program, the version number, and the list of individuals that developed the program. The user must click the *OK* button to close the start-up screen.

Once the opening screen is closed, the main window for the program is displayed. Using the main window menu system you can edit files, save files, run the model and view results. The main screen with the file menu open is shown below in Figure 2-2.

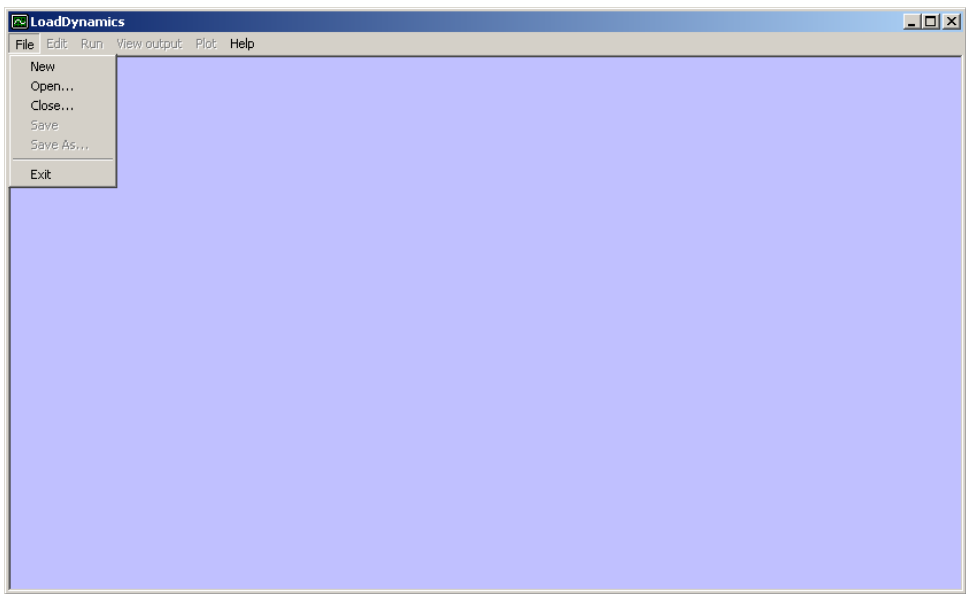


Figure 2-2: Main Screen With File Menu Open

2.2.1 The File Menu

The file menu is used to open new and existing input data sets and to save input data sets. The file menu options are described next.

New Causes the program to clear all data and open a new set of data with default values. If a case is being worked on, the user is given an option to save the current data.

Open Causes the program to prompt the user for an existing forecast file through the standard Windows open dialog box. If a case is being worked on, the user is given an option to save the current data.

Close Closes the forecast data file currently being worked on. The user is given an option to save the current data.

Save Saves the forecast data to disk. If it is a new case the user is asked to select a name and location through the standard Windows file save dialog box.

Save As Saves the forecast data to disk under a user-specified name and location. The user is asked to select a name and location through the standard Windows file save dialog box.

Exit Exits the program. If the forecast data has changed and has not been saved, the user is prompted and given the option to save the forecast data.

2.2.2 The Edit Menu

The edit menu is used to create and edit forecast data sets. A single input data file can contain data sets for many forecasts. Figure 2-3 shows the main screen with the edit menu open, and with the two windows that are used to create and edit forecast data sets.

When a new or existing file is opened, the window on the right is opened. It contains the list of available forecast data sets that are associated with the open input data file. By double clicking on a forecast in the window on the right, the window on the left (the *Input Data Screen*) is opened and loaded with the input variables for the selected forecast *(When a new file is opened one forecast data set is automatically created, labeled as "untitled.001," the Input Data Screen is opened, and the default data values are shown).* Figure 2-3 shows the situation in which a new file has been opened.

The edit menu is enabled *only* when a data file is open and the *Input Data Screen* is active. The *Edit* menu options are described next.

Add Forecast Creates a new forecast data set with default values and loads the default data values in the *Input Data Screen.*

Copy Forecast Opens a dialog box and asks the user for the name of the new forecast data set. After the user supplies the name and clicks *OK*, the current

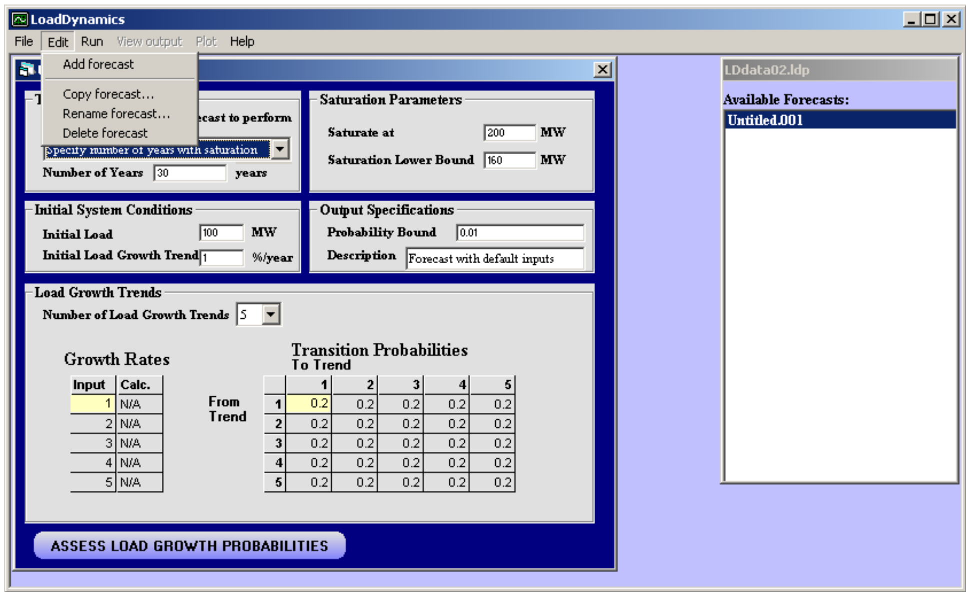


Figure 2-3: Edit Menu

data loaded in the *Input Data Screen* are copied to the new forecast and the new forecast is loaded into the *Input Data Screen*.

Rename Forecast Opens a dialog box and asks the user for the new name. After the user supplies the name, the selected forecast data set is renamed.

Delete Forecast: Removes the selected forecast from the forecasts in the current data file and closes the *Input Data Screen*.

2.2.3 Input Data

LoadDynamics^{TM} requires a relatively small number of input variables. The user must specify:

1. Type of forecast,
2. Initial system conditions (load level and annual growth rate),
3. Information on load growth trends (growth rates and transition probabilities),
4. Load saturation parameters, and

5. Output parameters.

These data values are input using the *Input Data Screen*. With the exception of transition probabilities, developing the input variables is straightforward. Here we provide a brief description of the variables. Table 2-1 lists the inputs, gives valid ranges of values, and provides a very brief explanation for each.

Type of Forecast

Two types of load forecasts are allowed. The user can specify the number of years for the forecast. In this case the model generates a probability distribution on possible load levels for each year, $p(load|year)$. For this type of run, two graphical outputs can be produced: (1) a plot of the average load versus forecast year, and an upper and lower bound on load versus forecast year; (2) a plot of the cumulative probability of reaching a given load versus the forecast year.

Alternatively the user can specify the largest load level that is to be considered. The model is then run for enough years so that the cumulative probability of reaching the specified maximum load is 1.0. This type of model run generates probability distributions on time to reach load, $p(time\ to\ load|load)$. This information is generated for all possible loads from starting load to maximum load. For output, the full distributions are converted to three-branch discrete distributions using a moment matching technique. The technique creates three-branch discrete distributions that have the same first five moments as the full distributions (*mean, variance, skewness, etc.*).[1] The user can examine selected three-branch distributions with a graphical output that is built into the user interface.

Note: The drop-down menu for the type of forecast actually has four options. There are the $NumberofYears$ and $MaximumLoad$ options both without $Saturation$. There are also these two options with $Saturation$.

[1] This is based on Gaussian quadrature. Miller A. and Rice T. 1983. *Discrete Approximations to Probability Distributions.* Management Science, 29, 3, 352-362.

Input Variable	*Explanation & Valid Range*
Type of Forecast	
1. Type of forecast	Alternatives are: 1) No. years; 2) Max. load; 3) No. years/with saturation; 4) Max. load w/saturation. *User selects from list in dialog box.*
2. Number of years	This is number of years for a "number of years forecast." $0 < years \leq 100$
3. Maximum load	This is maximum load for a "maximum load forecast." $maximum\ load > initial\ load$
Initial Conditions	
1. Initial load	Initial load is peak load at start of study. $initial\ load \geq 0$
2.Initial growth rate	This is the growth rate at the start of the study. $initial\ growth\ rate \geq growth\ rate\ of\ first\ trend$ $initial\ growth\ rate \leq growth\ rate\ of\ last\ trend$
Saturation Parameters	
1. Saturation	Load that saturates the area - maximum load possible. $saturation > initial\ load$
2. Sat. Lower Bound	Above this load, the saturation logic is applied. $0 < SLB \leq (.95\ saturation)$
Load Growth Trends	
1. No. of trends	This is the number of growth rate trends. *User selects from the list.*
2. Calc. Growth Rates	The estimated growth rates associated with the trends. *This is not an input – it is calculated when the model is run. See explanation in text.*
3. Input Growth Rates	The growth rates associated with the trends. $Rate_i \geq 0$ *and* $Rate_{i+1} > Rate_i$
4. Transition Prob.	See explanation in text. $0 \leq P(transition) \leq 1.0$
Outputs	
1. Probability Bound	For plotting bounds on load uncertainty (see explanation in text). $0 \leq Probability\ Bound < 0.5$
2. Desc. of scenario	A user specified label.

Table 2-1: Summary of Input Variables

Saturation Parameters

Saturation and Saturation Lower Bound are simply defined. Saturation is the maximum load that can occur in an area. As load approaches saturation, one would expect that load growth would slow. For load levels below "saturation lower bound" there is no slowing effect. This idea is handled in the load model in the following manner. For load levels above the saturation lower bound, the transition probabilities associated with positive load growth states are reduced. The amount of reduction is controlled by an attenuation factor. [2]

Load Growth Trends

The model allows two to six load growth trends. Each growth trend has an associated annual growth rate. Based on the load growth rates, the forecasting algorithm calculates a base load growth rate and the closest integer approximation associated with each rate. When the model is run, the calculated estimates of growth trends are shown in the *Input Data Screen*. Prior to running the model, the values are shown as *N/A*.

In the model, the load growth rates are defined as the base growth rate raised to the integer exponent calculated for each user defined growth rate. This provides for a very efficient calculation method.

Note: when two or more of the growth rates are very close numerically, the model may generate the same integer exponent for the rates. This will result in an error message and model termination. The occurrence of this error depends on the range of growth rates relative to the closeness of individual rates. When the range is wide and some rates are close, the error will occur.

Transition Probabilities

The rows in the trend transition matrix represent the trend at the beginning of a year (row 1 represents trend 1, row 2 represents trend 2 and so on). Each row contains a set of values. These values are probabilities of transition from the original trend to a new trend. The diagonal elements are the probabilities of remaining in the same trend. The off-diagonal elements are the probabilities of shifting to new trends.

The question is, how does one come up with a reasonable set of transition probabilities? There are two alternatives: (1) use the *LoadAssessor* add-in module, or (2) directly assess the load growth trends and transition probabilities.

[2] The technical details for modeling load saturation are documented in project technical papers. The interested reader can obtain these from the EPRI project manager.

The *LoadAssessor* is activated by clicking the button *ASSESS LOAD GROWTH PROBABILITIES*. If the user clicks this button, the add-in assessment tool is activated. This tool requires that the user answer a set of questions concerning current load level and growth, and future load growth scenarios. Based on the answers, the tool estimates the inputs for the growth trends and transition probabilities. See Section 2.3 for a description of the Load Assessor Model, including the input and output screens.

To assess the growth rates and transition probability inputs directly, the user must:

- Select the set of annual growth rates that might be observed for the forecast period,
- Assess the average amount of time that load tends to stay in each trend,
- Assess the likelihood of shifting from one specific growth trend to another specific growth trend.

This probability assessment procedure is sufficient because of two facts. First the diagonal elements in the transition matrix are determined by the average time that growth follows a specific rate before shifting. This is discussed in Section A. The equation for average time in trend is:

$$Average\ Time\ In\ State = \frac{1}{1 - P(Staying\ in\ Same\ State)}$$

Second the probabilities in any row must add to one. Thus, the assessment procedure is the following:

1. Estimate the probabilities along the diagonal elements of the matrix by assessing the average time in each growth state.
2. Estimate the off-diagonal elements of each row by assessing the relative likelihood of transition to one specific load growth state versus transition to the other possible non-diagonal states, constraining the row probabilities to add to one.

2.2.4 Run Menu

Selecting the *Run* menu causes the model to make a forecast using the data in the *Input Data Screen*. The results can then be examined with the *View output* and *Plot* menus.

2.2.5 View Output and Plot Menus

Two types of load forecasts are allowed: a *number of years* forecast and a *time to load* forecast. In the first, the user specifies the number of years for the forecast and the model generates a probability distribution on possible load levels for each year, $p(load|year)$. For this type of forecast two graphical outputs are available: (1) a plot of the mean load, and an upper and lower bound on load versus the forecast year; (2) a plot of the cumulative probability of reaching a given load level for each year of the forecast period. For the second type of plot, the user selects the load levels to plot from a dialog box.

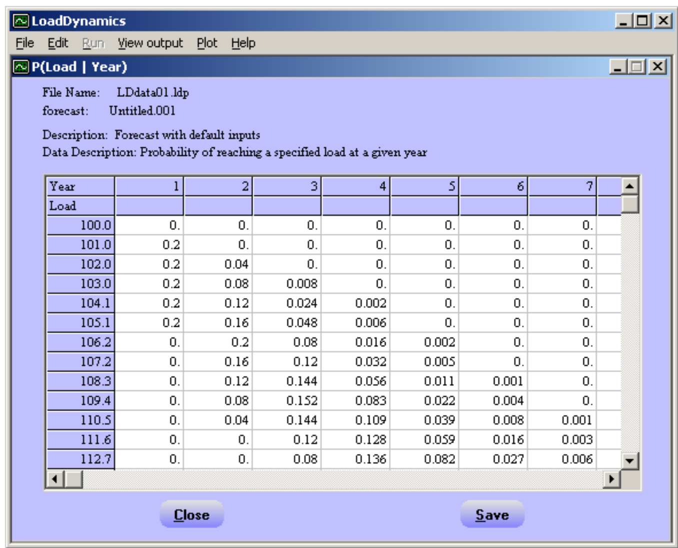
Alternatively, the user can specify the largest load level that is to be considered. The model is then run for enough years so that the cumulative probability of reaching the specified maximum load is 1.0. This type of run generates a probability distribution on time to reach a given load, $p(time\ to\ load|load)$. This information is generated for all possible loads from starting load to maximum load. For output, the full distributions are converted to three-branch discrete distributions using a moment matching technique. The technique matches the first five moments of the full distributions. The user can examine selected three branch trees with a graphical output that is built into the user interface.

NOTE: LoadDynamics does not directly allow for printing of the tables and graphic output. It does however allow the user to save the output data as tab-limited text files. These files can be read both by word processors and spreadsheet programs. The option to read saved output with spreadsheet programs facilitates further analysis and allows flexibility in creating graphics and printing of both graphics and raw data.

The *Year vs. Load* and *Time to Load* tables, described below, have buttons that allow the user to save forecast data.

The *View output* menu items are described next.

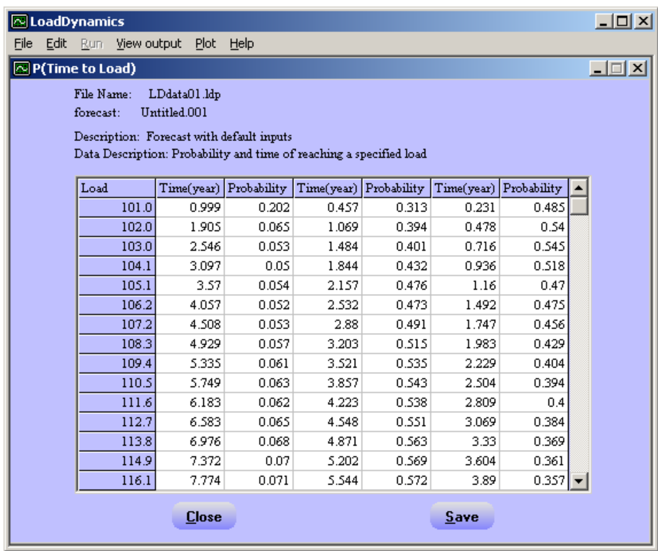
Year vs. Load This output option is available if the user makes a *number of years* forecast. Selecting this menu item displays a table that gives the probability of being at specific load levels in any given year. Figure 2-4 shows the table that is generated. The user can save the data as a text file by clicking the Save box on the form.



Year	1	2	3	4	5	6	7
Load							
100.0	0.	0.	0.	0.	0.	0.	0.
101.0	0.2	0.	0.	0.	0.	0.	0.
102.0	0.2	0.04	0.	0.	0.	0.	0.
103.0	0.2	0.08	0.008	0.	0.	0.	0.
104.1	0.2	0.12	0.024	0.002	0.	0.	0.
105.1	0.2	0.16	0.048	0.006	0.	0.	0.
106.2	0.	0.2	0.08	0.016	0.002	0.	0.
107.2	0.	0.16	0.12	0.032	0.005	0.	0.
108.3	0.	0.12	0.144	0.056	0.011	0.001	0.
109.4	0.	0.08	0.152	0.083	0.022	0.004	0.
110.5	0.	0.04	0.144	0.109	0.039	0.008	0.001
111.6	0.	0.	0.12	0.128	0.059	0.016	0.003
112.7	0.	0.	0.08	0.136	0.082	0.027	0.006

Figure 2-4: Example Output - Table of Probabilities: Year vs. Load

Time to Load This output option is available if the user makes a *time to load* forecast. Selecting this menu item displays a table that give three-branch probability distributions on the time it takes to reach specific load levels. Figure 2-5 shows the table that is generated. The user can save the data as a text file by clicking the save box on the form.



Load	Time(year)	Probability	Time(year)	Probability	Time(year)	Probability
101.0	0.999	0.202	0.457	0.313	0.231	0.485
102.0	1.905	0.065	1.069	0.394	0.478	0.54
103.0	2.546	0.053	1.484	0.401	0.716	0.545
104.1	3.097	0.05	1.844	0.432	0.936	0.518
105.1	3.57	0.054	2.157	0.476	1.16	0.47
106.2	4.057	0.052	2.532	0.473	1.492	0.475
107.2	4.508	0.053	2.88	0.491	1.747	0.456
108.3	4.929	0.057	3.203	0.515	1.983	0.429
109.4	5.335	0.061	3.521	0.535	2.229	0.404
110.5	5.749	0.063	3.857	0.543	2.504	0.394
111.6	6.183	0.062	4.223	0.538	2.809	0.4
112.7	6.583	0.065	4.548	0.551	3.069	0.384
113.8	6.976	0.068	4.871	0.563	3.33	0.369
114.9	7.372	0.07	5.202	0.569	3.604	0.361
116.1	7.774	0.071	5.544	0.572	3.89	0.357

Figure 2-5: Example Output - Table of Probabilities Time to Load

The *Plot* menu items are described below.

Year vs. Load This output option is available if the user makes a *number of years* forecast. Selecting this menu item displays a plot of the probability of being at specific load levels in any given year. Figure 2-6 shows an example of the plot that is generated.

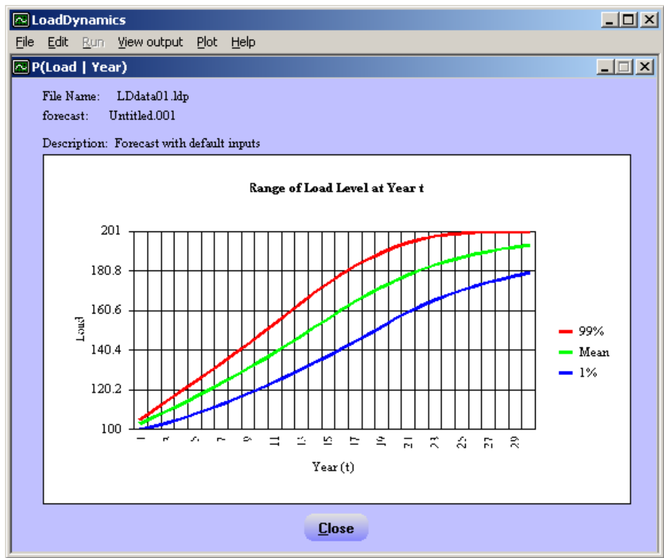


Figure 2-6: Example Output - Plot of Probabilities: Year vs. Load

Cumulative Probability This output option is available if the user makes a *number of years* forecast. Selecting this menu item opens a dialog box and the user must selects one or more load levels for the plot. The model then displays a plot of the cumulative probability of the time it requires to reach that load level. Figure 2-7 shows an example of the plot that is generated.

Time to Load This output option is available if the user makes a *time to load* forecast. Selecting this menu item opens a dialog box and the user must select a load level for the plot. The model then displays a plot of the three-branch tree of the time it requires to reach that load level. Figure 2-8 shows an example of the plot that is generated.

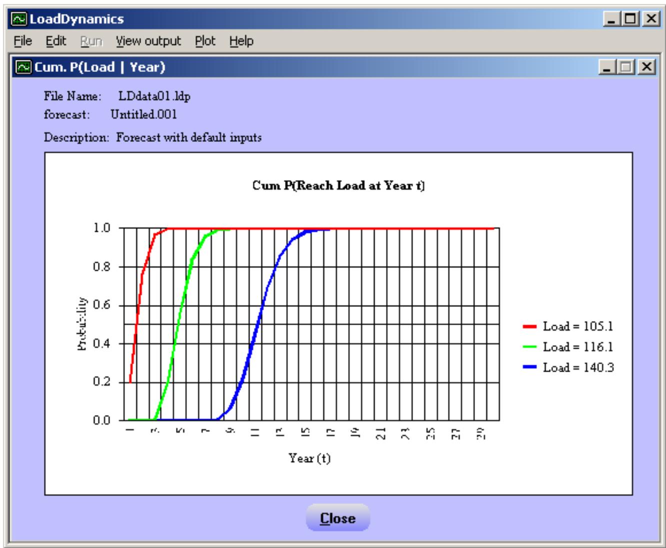


Figure 2-7: Example Output - Plot of Cumulative Probability of Reaching a Specified Load by Year t

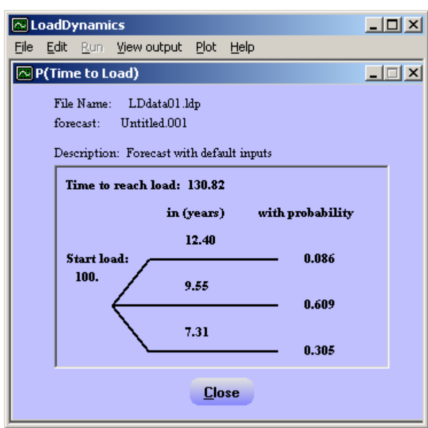


Figure 2-8: Example Output - Three-Branch Distribution on Time to Load

2.2.6 Help Menu

The help menu items are described below.

Contents and Index If the user selects contents from the help menu, the contents of the on-line manual are provided.

Disclaimer If disclaimer is selected, a window containing the EPRI legal disclaimer is displayed.

About This provides copyright information and the version number of the model

2.3 Using the Load Assessor Tool

2.3.1 Introduction

Load Assessor estimates the load growth trends and the transition probabilities required by the LoadDynamics^{TM} and Investment Strategy Models. The estimating methodology requires data obtained from a set of questions about future potential load conditions. The approach and questions were developed in collaboration with utility distribution planners. The objective was to base the methodology on a practical set of questions that the model users can answer.

2.3.2 Using the Load Assessor User Interface

When the Load Assessor starts, the window below (Figure 2-9) replaces the LoadDyanmics^{TM} main window. The user must then use the File Menu to open a new or existing case. All Load Assessor files are of the form `*.drs`. `assessor.drs` is the example case distributed with the software. Note that the File menu also allows the user to save Load Assessor cases and to copy Load Assessor results directly to the LoadDynamics^{TM} input screen, "Copy Results to Growth Scenarios."

Note: The data in the input screens shown here are for the data file assessor.drs.

Home Screen

As soon as a case is opened, a series of steps are listed in the home window along with the status of completion for each step (To Do, Done, Data Error, Incomplete). Figure 2-10 shows the Home Screen for an existing case in which all of the data have been input, and the model parameters estimated. There are five steps in the assessment process:

1. Specify current load and growth
2. Specify load growth scenarios
3. Specify growth rate holding times
4. Specify maximum area load potential
5. Calculate load model parameters

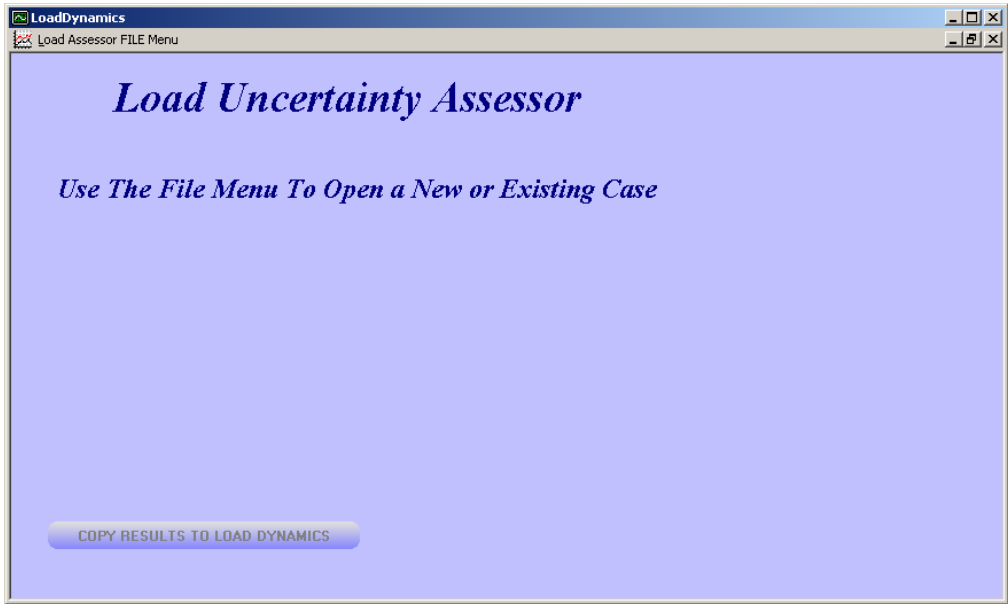


Figure 2-9: Load Assessor Main Screen

When a case is opened, new or existing, the status of data inputs are indicated on the home screen. With a new case the user is constrained to proceed through the assessment steps in sequence - the model will not allow skipping a step, and valid data must be provided for each step before the model will allow the user to go to the next step. The assessment software performs error checking for each screen.

When the user is satisfied with the load assessor results he or she can (1) save the results, and (2) copy the results to the LoadDynamics^{TM} model input form. Copying the data to LoadDynamics^{TM} Model inputs can be done via either the File menu or the button at the bottom of the home screen.

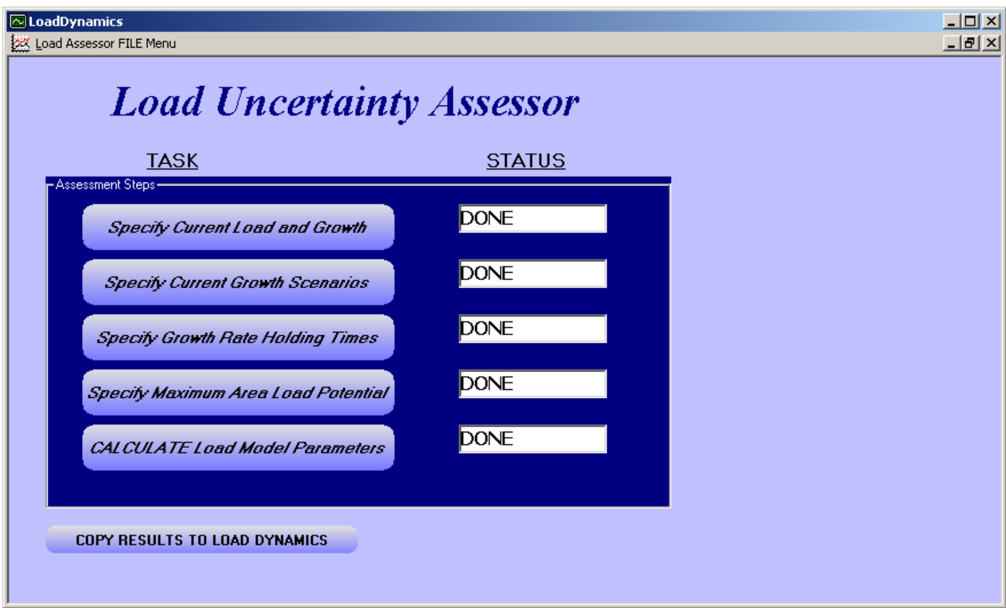


Figure 2-10: Load Assessor Home Screen

Step1: Specifying Current Load and Growth

The data screen for assessment step 1, Specify Current Load and Growth, is shown in Figure 2-11. Here the user must specify current area load and load growth, and the time interval for the forecast assessment.

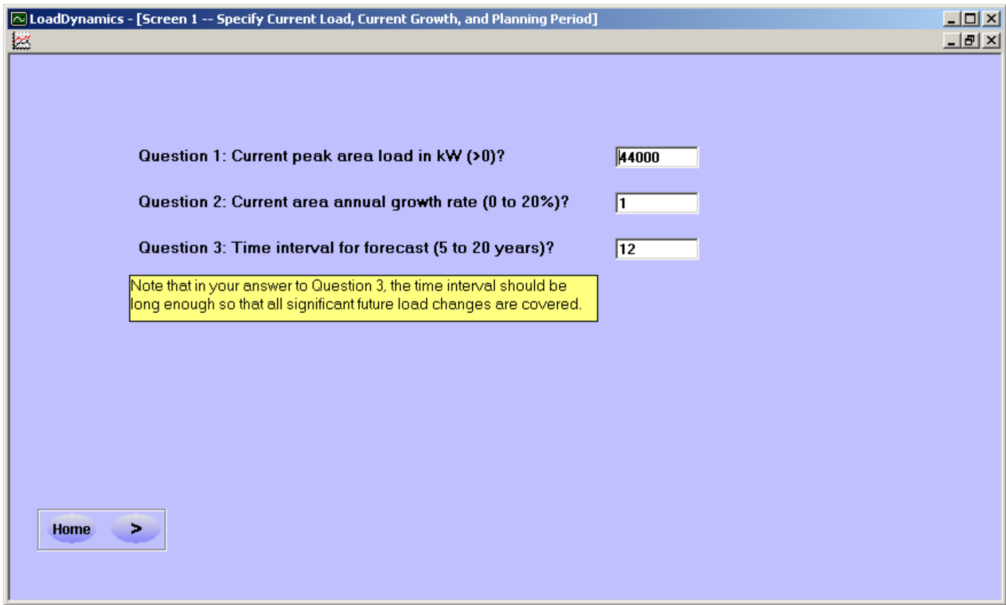


Figure 2-11: Current Load and Growth

Step2: Specifying Load Growth Scenarios

The data screen for the second assessment step, Specify Load Growth Scenarios, is shown in Figure 2-12. The purpose of the second screen is to describe potential future load growth scenarios. The basic idea is that the user must specify a set of alternative growth conditions that could occur over the planning period. Before filling in the data required by this form, the user should read the instructions by pressing the Instructions button.

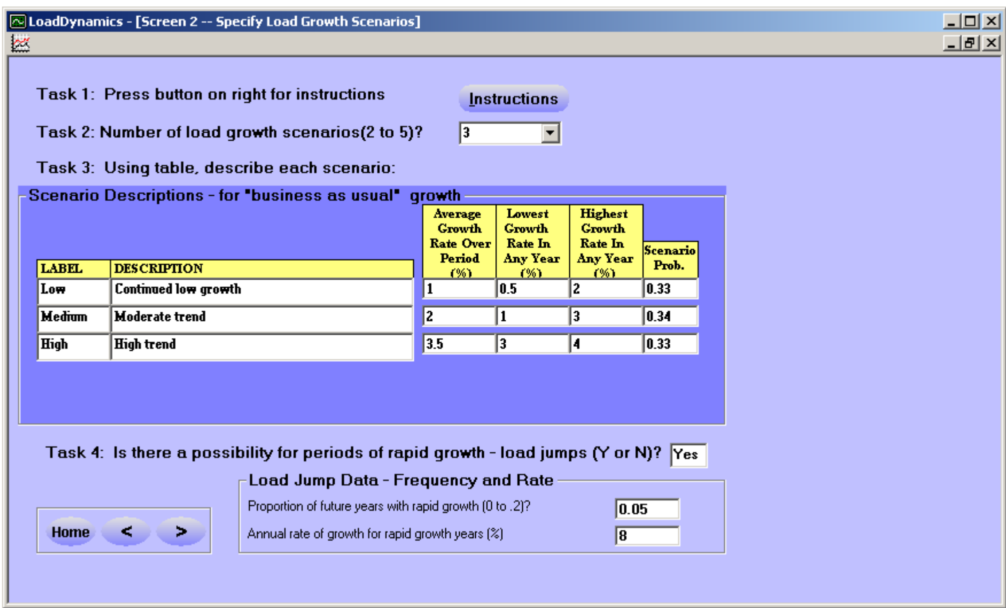


Figure 2-12: Load Growth Scenarios

The data inputs for the scenarios are described in Table 2-2:

Input	*Explanation*
Number of Scenarios	The user must choose a number (2 to 5) from the drop-down box.
Label	A short label used to describe each scenario.
Description	A longer, more descriptive characterization of each scenario.
Average Growth Rate Over Period (%)	For each scenario, the user must specify the average growth rate that is expected for the entire forecast period.
Lowest Growth Rate In Any Year (%)	For each scenario, the user must specify the lowest growth rate that can occur in any year for the forecast period. This growth rate must be lower than the average growth rate for the period.
Highest Growth Rate In Any Year (%)	For each scenario, the user must specify the highest growth rate that can occur in any year for the forecast period. This growth rate must be higher than the average rate for the period.
Scenario Probability	For each scenario, the user must specify the probability that the scenario will occur. The probabilities for the scenarios must add to 1.0.
Is There a Possibility For Periods of Rapid Growth?	If there is a possibility of having short periods (one year or less) of rapid growth, enter Y
Proportion of Future Years With Rapid Growth	If the user specifies Y to the question *Is there a possibility for periods of rapid growth*, they must indicate the proportion of future years where rapid growth is expected to occur (0 to 0.2)
Annual Rate of Growth For Rapid Growth Years	If the user specifies Y to the question *Is there a possibility for periods of rapid growth*, they must indicate the associated annual percentage growth rate (this rate must be at least twice as large as the highest rate entered in the "highest growth rate in any year" column of the *Scenario Descriptions* table.)

Table 2-2: Data Elements for Scenario Descriptions

Step3: Specifying Growth Rate Holding Times

The data screen for the third assessment step, Specify Growth Rate Holding Times, is shown in Figure 2-13. Before entering any data, the user should click the Instructions button and get specific information about the data inputs. This screen shows three one-year growth rates and the user must supply average holding times for these rates. These rates come from user-supplied inputs from the previous screens - the minimum and maximum one-year rates from the scenario inputs, and the current growth rate from the first input screen.

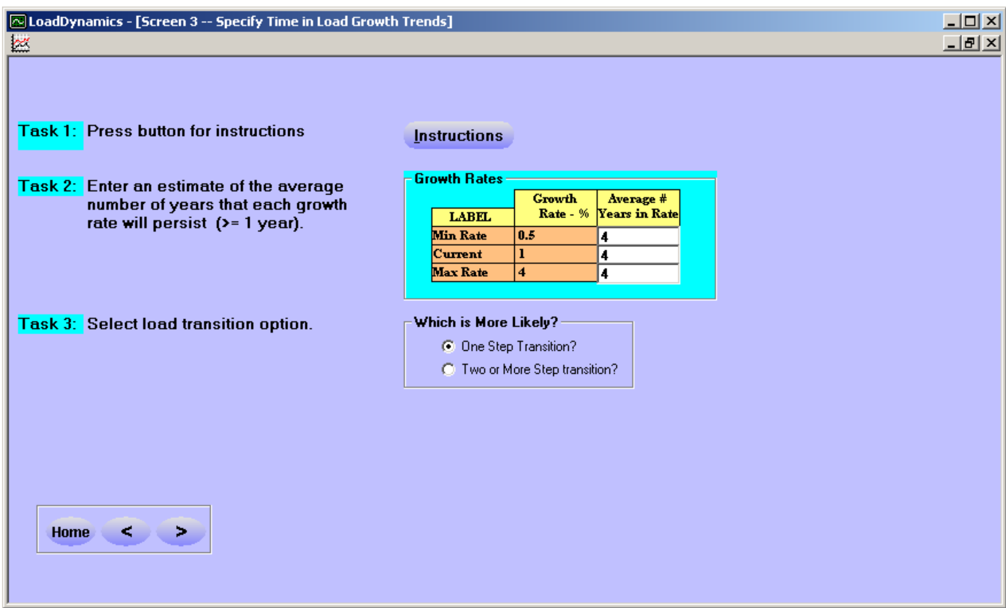


Figure 2-13: Growth Rate Holding Times

Input	*Explanation*
Average Years in the Rate	This is what we have termed "holding time." Given that load is growing at a rate, this is the time that load is expected to continue to grow at that rate. This measures the tendency for load to stay in a particular growth trend.
Load Transition Option	When load growth shifts from one trend to another, the user must specify which of two conditions is more likely. (1) A transition of one trend-step versus, (2), a transition of two or more trend-steps. For example, is it more likely that load will shift from a low rate to a medium rate or from low to a high rate, bypassing the medium rate?

Table 2-3: Data Elements for Growth Rate Holding Times

Step 4: Specifying Maximum Area Load Potential

The data screen for the fourth assessment step, Specify Maximum Area Potential Load, is shown in Figure 2-14. Before entering any data, the user should click the Instructions button and get specific information about the data inputs.

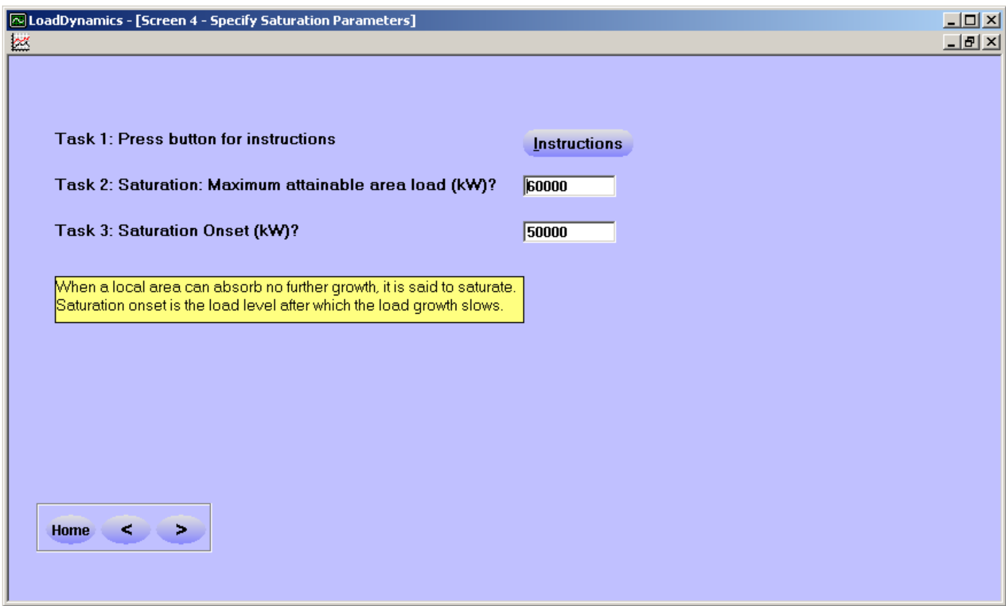


Figure 2-14: Maximum Area Potential Load

Input	*Explanation*
Maximum Attainable Area Load (kW)	This is the load level when the area is completely built-out. It is the level at which the area can absorb no further growth.
Saturation Onset	When saturation begins to occur, load growth begins to slow. Saturation onset is the load level after which load growth begins to taper-off.

Table 2-4: Data Elements for Maximum Area Load Potential

Step 5a: Calculate Load Model Parameters

The data screen for the final assessment step, Calculate Load Model Parameters, is shown in Figure 2-15. This screen shows the results after the Estimate Parameters button has been clicked.

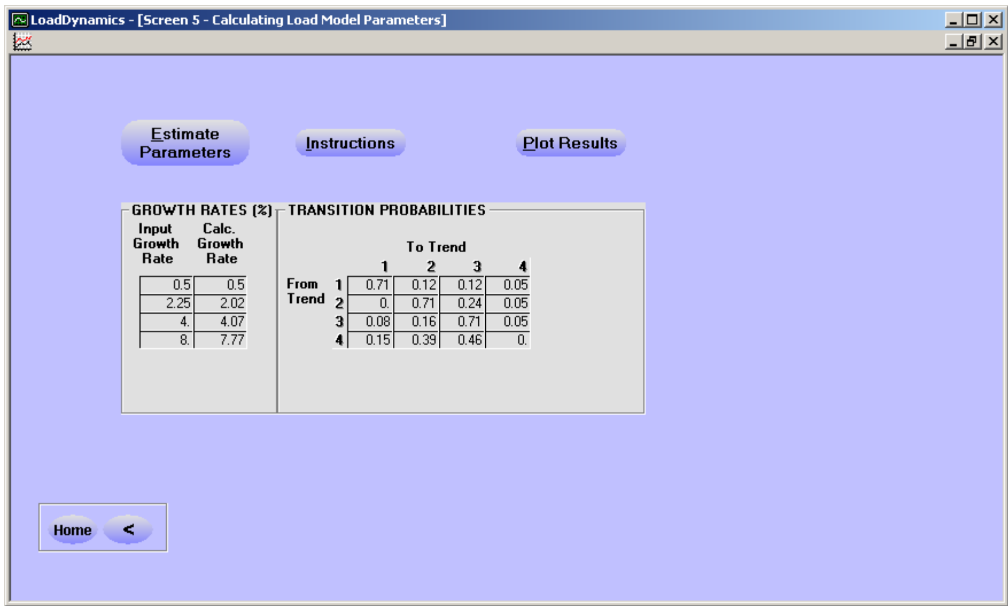


Figure 2-15: Calculate Load Model Parameters

The functionality of the form for calculating the load model parameters is summarized in Table 2-5 below:

Button	*Explanation*
Estimate Parameters	If this button is clicked, the estimation model is run to produce a new set of growth trends and transition probabilities. If a new or modified data exist in any of the screens, the transition matrix will not be shown until the model is run.
Plot Results	If this button is clicked, a plot of the probabilistic load forecast is produced. This plot is shown in Figure 2-16 below.
Instructions	This provides information on how the growth trends and transition probabilities are estimated.

Table 2-5: Functionality of Calculate Model Parameters Form

Step 5b: View Probabilistic Forecast

If the user clicks the Plot button in the Calculate Parameters screen, the probabilistic forecast is plotted. This is shown in Figure 2-16. For each year in the planning period, the maximum, minimum and average load are plotted.

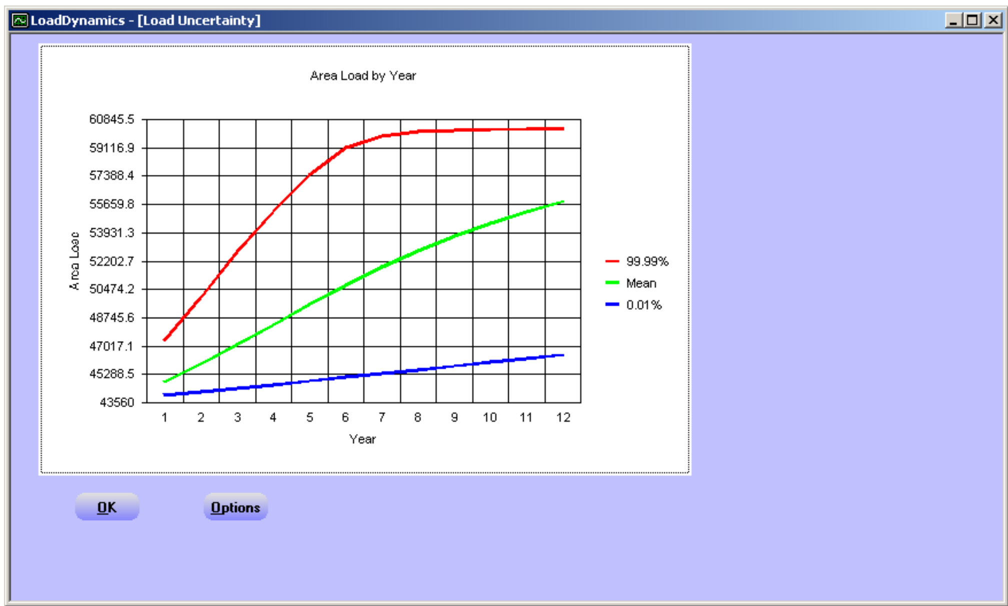


Figure 2-16: Plot of Probabilistic Forecast

If this load forecast does not accurately reflect the user's assessment of the possible loads for the area, the Options button should be clicked. Clicking the Options button brings up a dialog box with the following information:

1. If the upper bound on load is too high (low), then you should try reducing (increasing) the average growth rate for the high growth scenario. You can also change the maximum possible load level, saturation level.
2. If the lower bound on load is too low (high), then you should try increasing (reducing) the average growth rate for the low growth scenario.
3. If the expected value for load is too high (low) then you can reduce (increase) the probabilities for the higher growth scenarios and / or increase (decrease) the probabilities for the lower growth scenarios.

You can also change the highest yearly growth rate for the high growth scenario.

4. If load is growing too slowly (too rapidly), you should try increasing (reducing) the highest yearly growth rate for the high growth scenario.

This completes Section 2, *Using The Model User Interface*.

3 TUTORIAL 1: USING GROWTH TREND EXAMPLE DATA SET

Two tutorials are provided. The first demonstrates how to read an existing data set, run the model and view outputs. The second illustrates how to use the Load Assessor tool to create a load forecast.

This tutorial has four steps:

1. Start the LoadDynamics^{TM} program and open an existing input file.
2. Select a forecast data set from the list of forecasts and run the model.
3. View plotted output data.
4. View a table of output and save the output data as a text file.

3.1 Step 1: Start Program and Open a Data File

For step 1 the user should:

- Open the model by clicking *START*,
- Select *Programs*,
- Highlight *LoadDyanamics* and
- Click on the *LoadDynamics* icon and when the start-up screen is displayed, click *OK*,
- Open the data set by selecting the *File|Open* menu and selecting `corr_nocorr.ldp` and clicking *Open*.

The program will open the input file `corr_nocorr.ldp` and display the forecast list. The program will also open the first load forecast in the forecast list and display the input variables. This is show in Figure 3-1. Note that at this point the *Run* menu is activated.

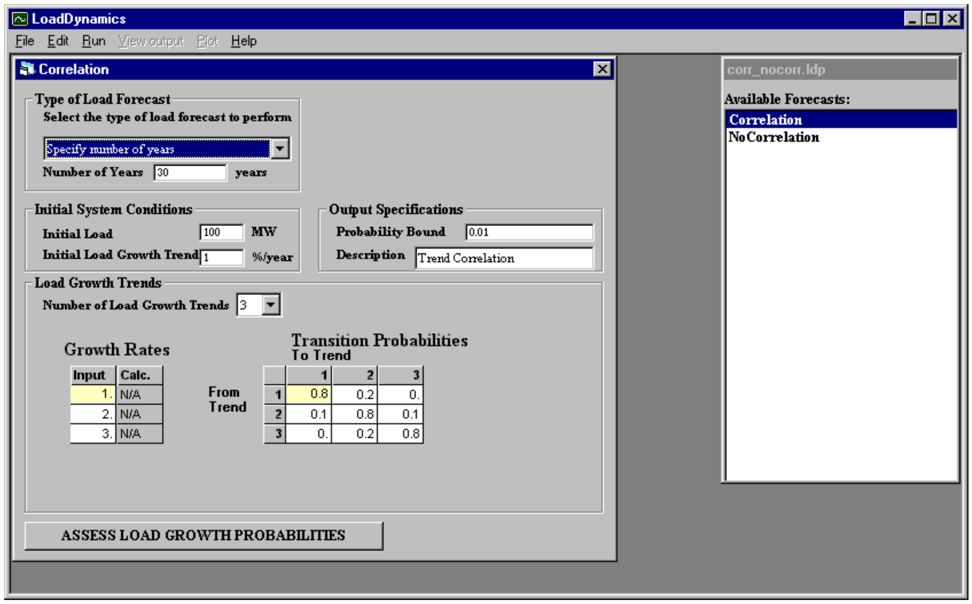


Figure 3-1: Tutorial One: Result of Step 1

3.2 Step 2: Run The Model

Notice the values for the input variables. For this case the type of forecast is $Number\ of\ Years$ and the starting load and growth are $100MW$ and 1% respectively. Also note the values for the growth trends and transition probabilities. The significance of these values are discussed in Section A, Analytical Methodology. The purpose here is to demonstrate the mechanics of using the model.

The user should click on the *Run* menu. This will run the model and show a dialog box indicating that the model has run. The user should click the OK box and proceed to the next step.

3.3 Step 3: View Plotted Output

Because this is a $Number\ of\ Years$ forecast, the user has the option of viewing plotted output for (1) the probability of being at a given load level in any year, and (2) the cumulative probability distribution on the time it takes to reach a given load level. We will now view both of these output plots. To view the first graph the user should click on the *Plot* menu and

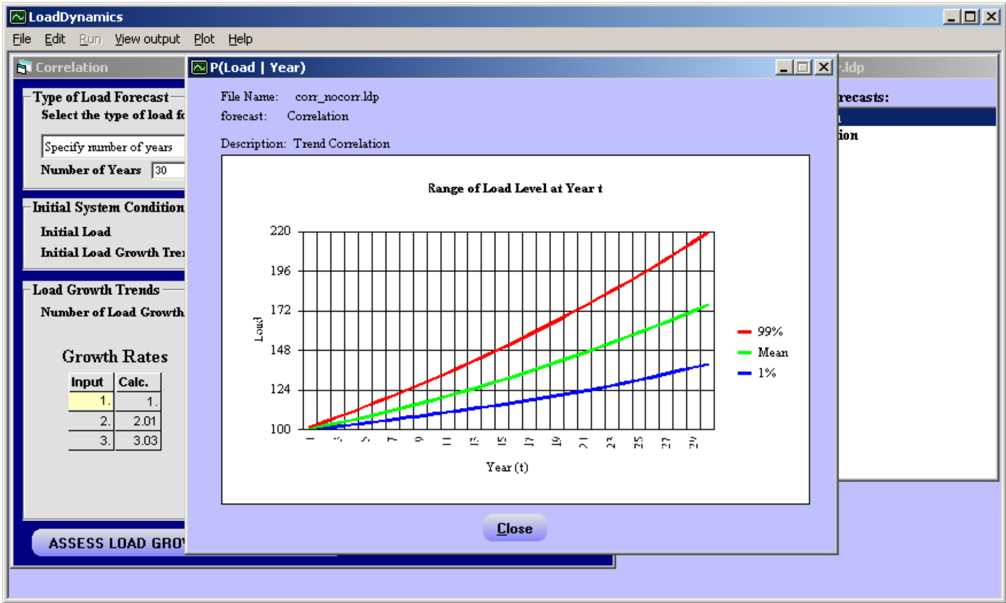


Figure 3-2: Tutorial One: Result of Step 3a

select *Year vs. Load*. This will produce the graph shown by Figure 3-2. This graph plots the average load growth over the period as well as the upper and lower bounds on load for each year. When the user has finished viewing the plot they can click *Close* to close the plot window.

To view the second plot, click on the *Plot* menu and select *Cumulative probability*. This will bring up a dialog box where the user can select one or more load levels. The user should select `105.10` and `120.81` and click *Plot*. The program then produces the graph, shown by Figure 3-3. This graph shows the cumulative probability distributions on the time it takes to reach the load levels `105.10` and `120.81` respectively. When the user has finished viewing the plot they can click *Close* to close the plot window.

3.4 Step 4: View Output Table and Save as Text File

The final step in this Tutorial is to view the output table and to save the table as a text file. To do this select the *View output* menu and select *Year vs. Load*. This will bring up the window shown in Figure 3-4. The rows are the possible load levels. Columns define the years, 1 to 30 in this case. The cells in the table give the probability of being at a specific load

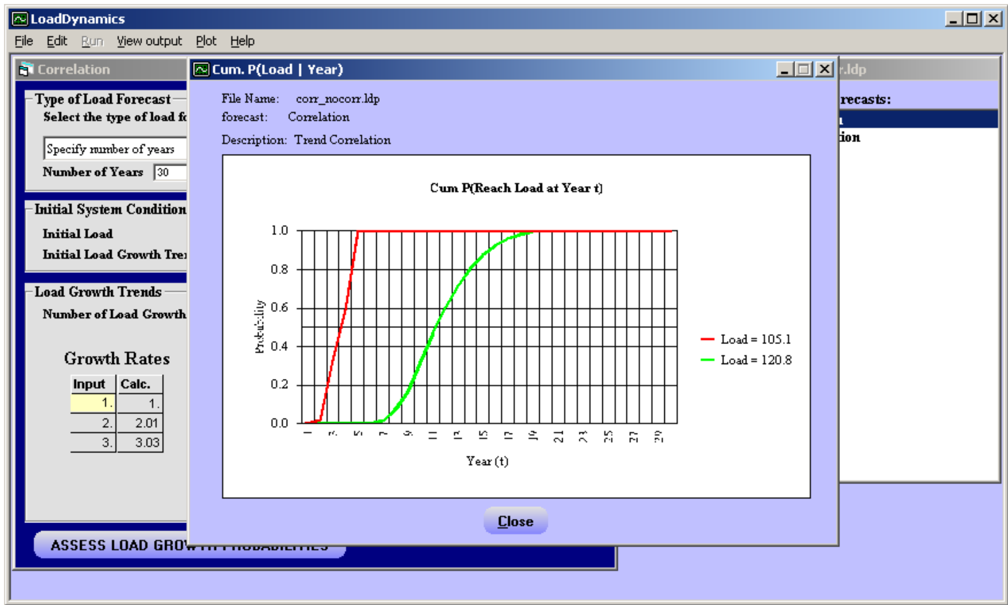
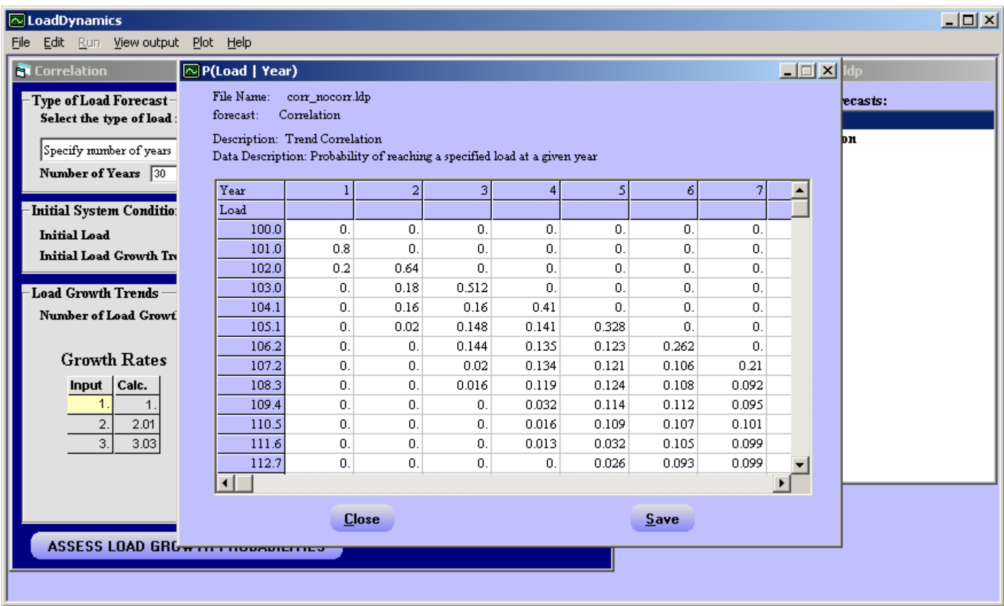


Figure 3-3: Tutorial One: Result of Step 3b

level in a specific year: $p(load_i|year_t)$.

To save the data, click the *Save* button. This brings up a standard Windows save dialog box asking for the name of the file where the data are to be saved. The data are saved in a tab-limited format. The file can be read both by spreadsheet and word processing programs.

To end this tutorial, click the *Close* button on the output table screen and click the *File*|*Exit* menu.



Year	1	2	3	4	5	6	7
Load							
100.0	0.	0.	0.	0.	0.	0.	0.
101.0	0.8	0.	0.	0.	0.	0.	0.
102.0	0.2	0.64	0.	0.	0.	0.	0.
103.0	0.	0.18	0.512	0.	0.	0.	0.
104.1	0.	0.16	0.16	0.41	0.	0.	0.
105.1	0.	0.02	0.148	0.141	0.328	0.	0.
106.2	0.	0.	0.144	0.135	0.123	0.262	0.
107.2	0.	0.	0.02	0.134	0.121	0.106	0.21
108.3	0.	0.	0.016	0.119	0.124	0.108	0.092
109.4	0.	0.	0.	0.032	0.114	0.112	0.095
110.5	0.	0.	0.	0.016	0.109	0.107	0.101
111.6	0.	0.	0.	0.013	0.032	0.105	0.099
112.7	0.	0.	0.	0.	0.026	0.093	0.099

Input	Calc.
1.	1.
2.	2.01
3.	3.03

Figure 3-4: Tutorial One: Result of Step 4

4 TUTORIAL 2: USING LOAD ASSESSOR TO CREATE A PROBABILISITIC FORECAST

This Tutorial is based on a "real world" forecasting problem. The Tutorial illustrates how the Load Assessor tool can be used to generate the inputs required to make a probabilistic load forecast.

The forecast situation is the following: Blue Mountains Power Company provides electric distribution service to a remote ski area. Presently there is slow peak load growth (1/2 to 1 percent per year) in the area, but there is some chance of rapid growth if the ski corporation decides to implement business expansion plans. At some point in the future, the ski corporation plans to expand capacity by adding additional ski lifts and snow making equipment. The exact timing of the expansion is very uncertain.

The planners at Blue Mountains Power believe that some distribution capacity needs to be added very soon in order to respond to the planned expansion of the local ski area. However the expansion of the ski area has not yet begun. The ski area management claims that the first phase of their plans would add about 8 MVA load and the second phase would add another 8 MVA. The exact timing of the planned expansion is very uncertain. The question that planners face is when, if ever, will the expansion take place?

This Tutorial shows how to use the Load Assessor tool to address this question. There are three steps:

1. Start the Load Assessor program and open a new input file.
2. Run the Load Assessor tool to create the input parameters for a forecast.
3. Run LoadDynamics^{TM} and view the plotted output.

4.1 Step 1: Start Program and Open a New File

For step 1 the user should: (1) open the model by clicking $START$, (2) select $Programs$, (3) highlight *LoadDyanamics* and click on the *LoadDynamics* icon, (4) click OK on the start-up screen, and (5) use the $File|New$ menu to open a new data set. The program will open a new input file and display the forecast list and the $Data\,Input\,Screen$. This is show in Figure 4-1.

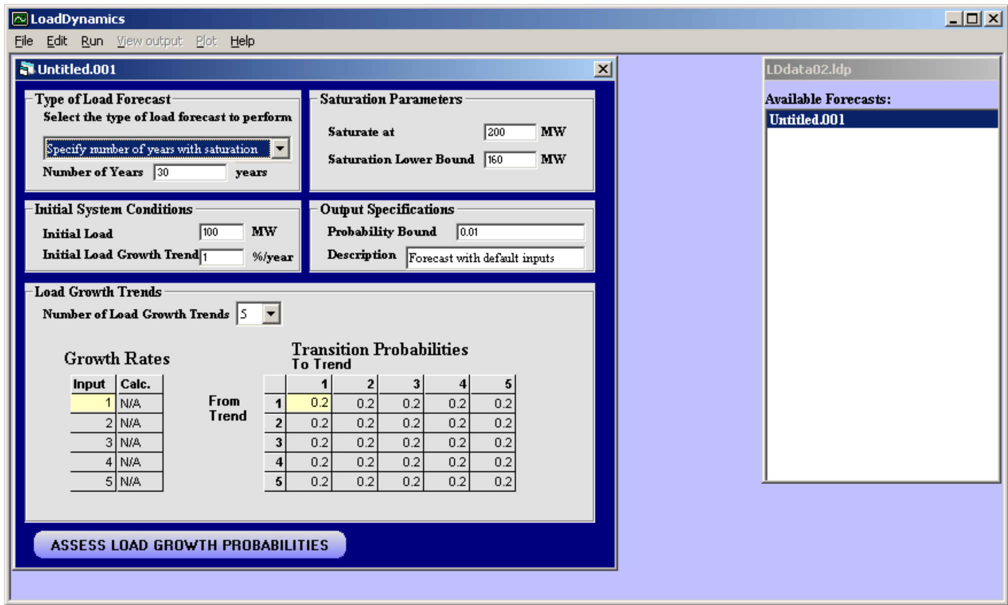


Figure 4-1: Tutorial Two: Start LoadDynamics^{TM} and Open a New Forecast File

4.2 Step 2: Run the Load Assessor Tool

Note: the Load Assessor input screens are described in detail in Section 2.3. The screens are not reproduced here except to show key input values and outputs.

To run the Load Assessor tool, the user must click the button *ASSESS LOAD GROWTH PROBABILITIES* on the *Data Input Screen*. This will open the main Load Assessor screen. The user should then use the $File|New$ *Load Assessor Data* menu to open a new load assessor input file. The result is shown in Figure 4-2.

The load assessor has four data screens and a calculation screen that contains the resulting transition matrix. The input variables and associated study assumptions are summarized in Table 4-1. Table 4-1 contains all of the data necessary to fill-in Screens 1, 3, and 4. To input data for Screen 1, click the $Specify$ *Current Load and Growth* button. After entering the data on each screen, click the → button to move to the next screen.

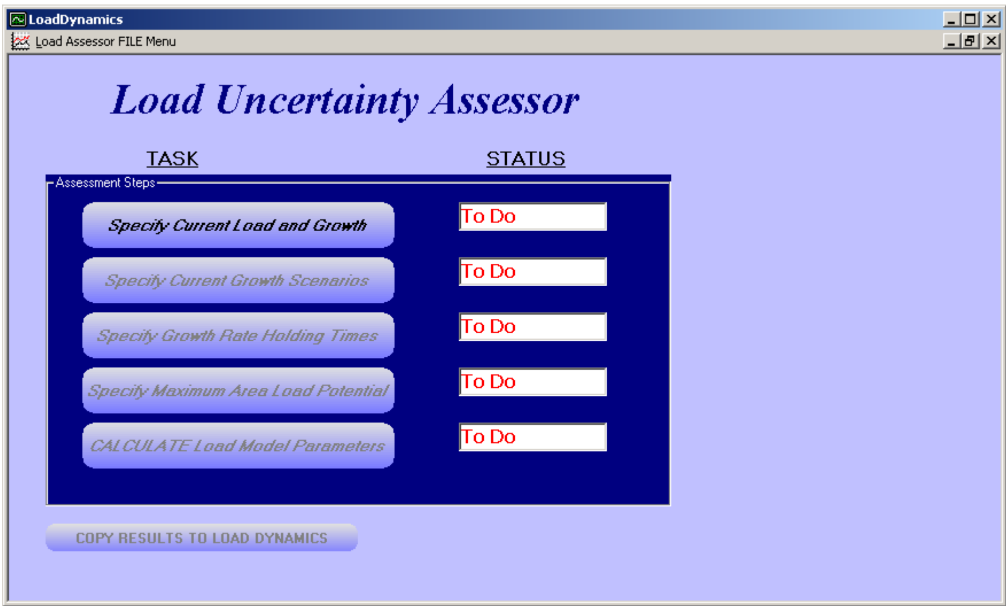


Figure 4-2: Tutorial Two: Start Load Assessor and Open a New Assessor File

	Input Variable	*Study Assumption*	
Screen 1	Current Load	34,000 kVA	
	Current Growth Rate	0.5%	
	Forecast Period	12 Years	
Screen 2	Load Growth Scenarios	Avg. Growth Scenario 1:	0.5%
		Avg. Growth Scenario 2:	1.0%
	Load Jump	Possibility:	Yes
		Proportion yrs. w/rapid growth:	0.1
		Rapid growth rate (%):	12
Screen 3	Holding times	Min. rate (0%):	4 years
		Current rate (0.5.%):	4 years
		Max. rate (1.5%):	2 years
Screen 4	Saturation	55,000 kVA	
	Saturation onset	40,000 kVA	

Table 4-1: Summary of Load Assessor Data Screens

4.2.1 Screen 1 - Current Load and Growth

Current peak load is 34,000 kVA and load is growing at about a half percent per year. The period over which load is to be predicted is 12 years.

4.2.2 Screen 2 - Load Growth Scenarios

Up to five scenarios can be used to describe future *business as usual* load growth behavior. These scenarios must be mutually exclusive descriptions of what can happen, under normal conditions, to load over the planning period. Each scenario must be described along four dimensions: the average growth rate over the entire planning period, the lowest possible growth rate in any year, the highest possible growth rate in any year, and the likelihood of the scenario actually occurring. The sum of the likelihoods must be 1.0.

Two scenarios were used for this analysis: (1) the current slow load growth, 0.5 percent, continues through the planning period; (2) the current slow growth doubles and the average over the period is 1.0 percent.

The *business as usual* scenarios do not reflect the possibility that the ski area expansion occurs sometime during the planning period. This is modeled using the load-jump feature. For this case the utility analysts expect that there is about a one chance in ten over the next ten years that the first phase of development will occur adding 8,000 kVA to existing load (about 12% of 34,000). If this occurs, they believe that there is about a one chance in ten that the second phase of development will occur – adding another 8,000 kVA load. The model inputs for these assumption are:

1. the proportion of future years with rapid growth – about one in ten for this case or 0.1,
2. the growth rate for the rapid growth periods – 12 percent.

Figure 4-3 shows the scenario input screen and related data. The user should input the data to match the values shown in Figure 4-3.

4.2.3 Screen 3 - Growth Rate Holding Times

One of the underlying assumptions in the Load Assessor is that load growth tends to persist and follow multi-year trends. These trends are represented by assessing the likelihood of the persistence of the load growth rate in any

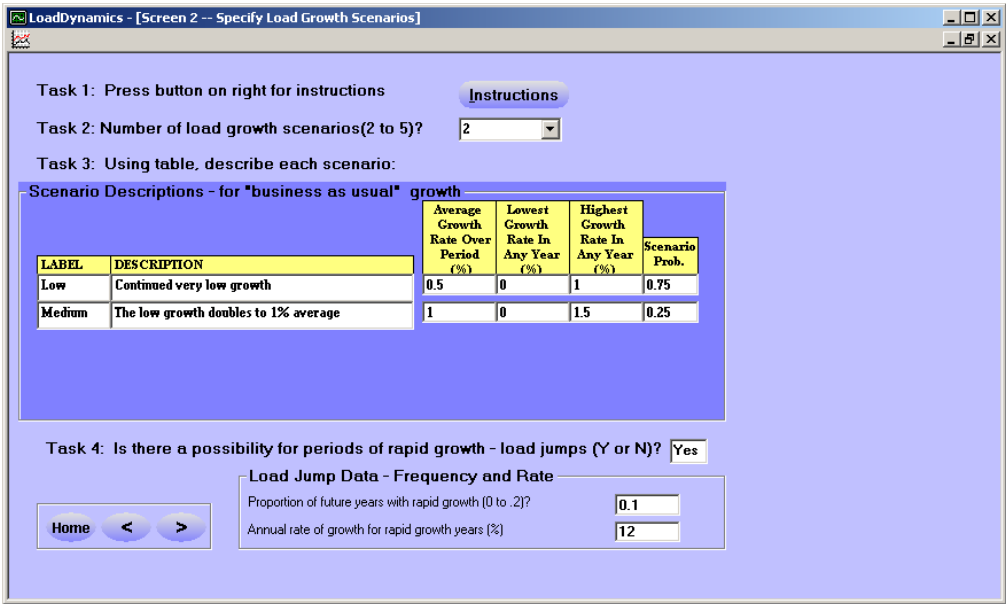


Figure 4-3: Tutorial Two: Load Assessor Scenario Inputs

year over the next several years. Screen 3 is used to record growth rate duration information. The duration of a load growth rate is often referred to as the holding time of the rate. Holding times must be provided for three annual growth rates: minimum, maximum and current.

4.2.4 Screen 4 - Maximum Area Load

The maximum area load is estimated to be about 55,000 kVA. This is the load level when the area is completely built-out. Saturation onset is the point where load growth starts to slow due to build-out. For the study, saturation onset is assumed to be 40,000 kVA.

4.2.5 Screen 5 - Transition Matrix

After the data are entered, the Load Assessor is run to generate the growth trends and transition probabilities. After entering the data for Screens 1-4, click on the $\rightarrow$ button to go to Screen 5. Then click the *Estimate parameters* button to run the model and generate the growth trends and transition probabilities. If one or more of the growth trends is greater than

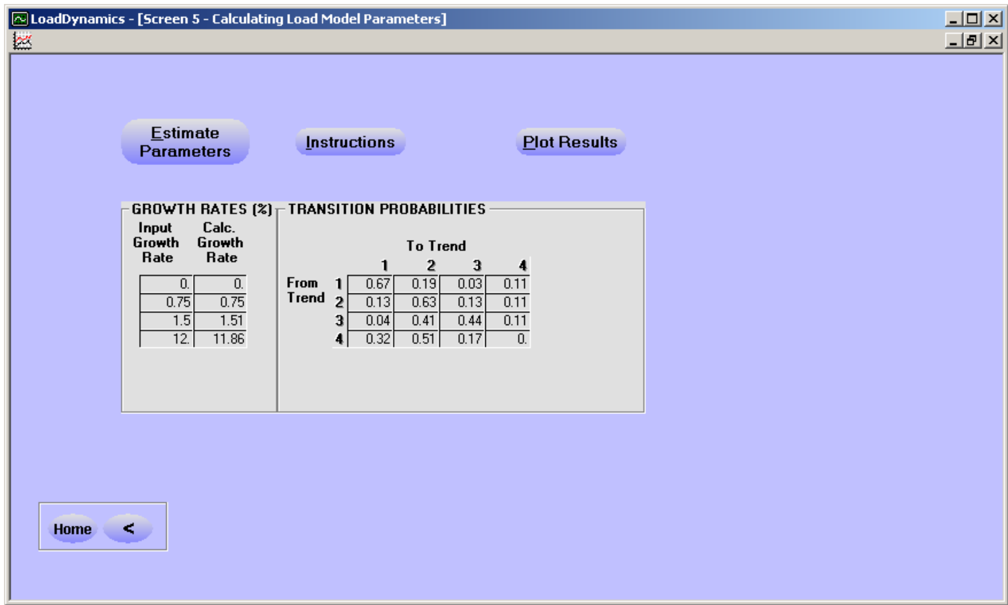


Figure 4-4: Tutorial Two: Estimated Growth Rates and Transition Probabilities

20 percent, a dialog box informs the user of this and offers the options to continue, Yes or No. If Yes is selected the model estimates the parameters. If No is selected, the model is not run, and user can modify the input data before continuing.

The transition matrix that results from the above inputs is shown in Figure 4-4. The growth rates and transition matrix that are found by the Load Assessor comprise a mathematical representation of the input data captured in the screens described above. The mathematical representation is selected to minimize the error between the forecasts provided by the scenarios and the forecasts provided by the mathematical representation.

The resulting forecast results can also be plotted by clicking the *Plot Results* button. The result is shown by Figure 4-5.

Most users will find the information provided in the plot sufficient to decide whether the load assessment captures the appropriate load uncertainty. If the uncertainty has not been captured, the answers to the questions in screens 1 through 4 can be changed, which will change the plotted results. This modification process can be repeated until the results are satisfactory.

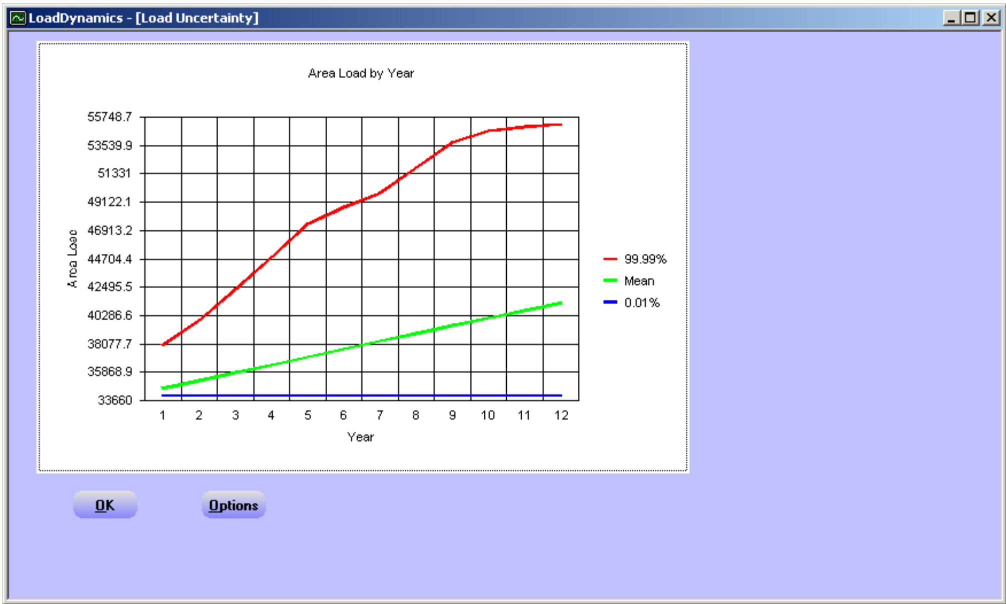


Figure 4-5: Tutorial Two: Plot of Load Forecast

After the user has input the Load Assessor data successfully and obtained the results shown in Figure 4-4, they should click OK followed by the $Home$ button to return to the Load Assessor home screen. At this point they should copy the results to the LoadDynamics^{TM} *Data Input Screen* by clicking the button *Copy Results to Growth Scenarios*. Clicking this button will show a dialog box to confirm if the results are to be copied and the assessor exited. The user should click OK. If the current load assessor data have not been saved, a dialog box will ask if the user wishes to save the data. For this tutorial, the user can select either Yes or No (saving the data file is not required by this tutorial). The estimated growth rates and transition probabilities will be copied to the LoadDynamics^{TM} *Data Input Screen*. Other required data will also be copied including starting load and growth, the planning period, and the load saturation parameters. This is shown in Figure 4-6.

4.3 Step 3: Run LoadDynamics^{TM} and View Plotted Output

The user should click on the *Run* menu. This will run the model. The first model calculation is to estimate the load growth trends from the input

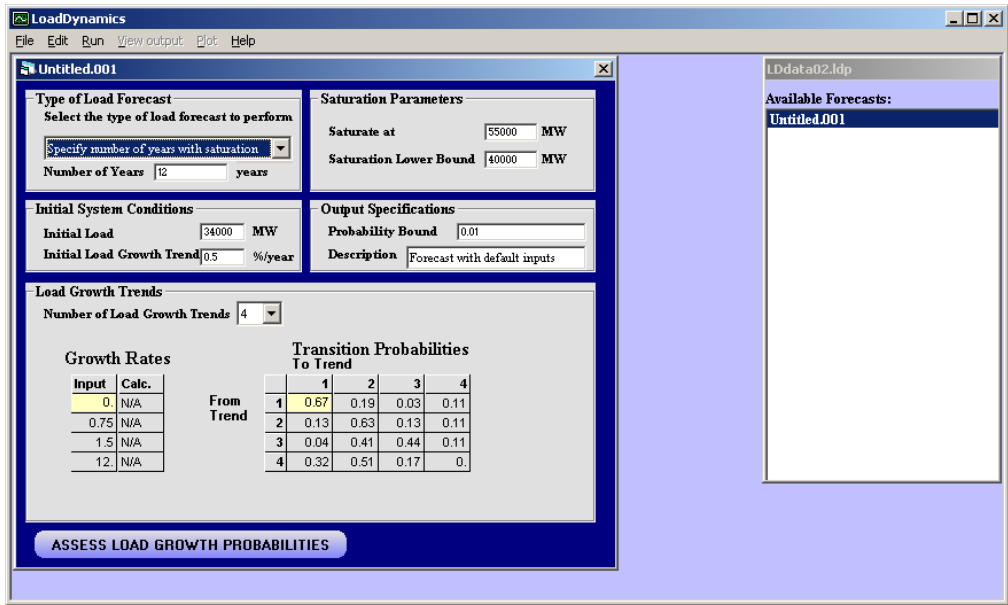


Figure 4-6: Tutorial Two: *Data Input Screen* after Copying Load Assessor Results

trends. Because one of the estimated trends is greater than 20 percent, a dialog box is displayed indicating this fact and asking the user if they wish to continue. The user should click *Yes*. The model will then complete the run and display a dialog box indicating that the model has run. The user should click the *OK* box and view the output using the *Plot* menu. Figure 4-7 shows the results for selecting the *Year vs. Load* option.

Returning to the original question that planners face, when, if ever, will the ski area expansion plans take place? Phase 1 expansion would add 8MVA and Phase 2 another 8 MVA. To examine this question we can plot the cumulative probability distribution of the time to reach 42 MVA and 50 MVA from the current 34 MVA load levels. This is plotted by clicking on the *Plot* menu and selecting *CumulativeProbability*. Then select load levels 41912.20 and 50144.33 from the dialog box and click *PLOT*. The result is shown in Figure 4-8

These plots of the cumulative probability of the time required to reach the two load levels demonstrate that:

The likelihood of reaching the load level represented by both phases of

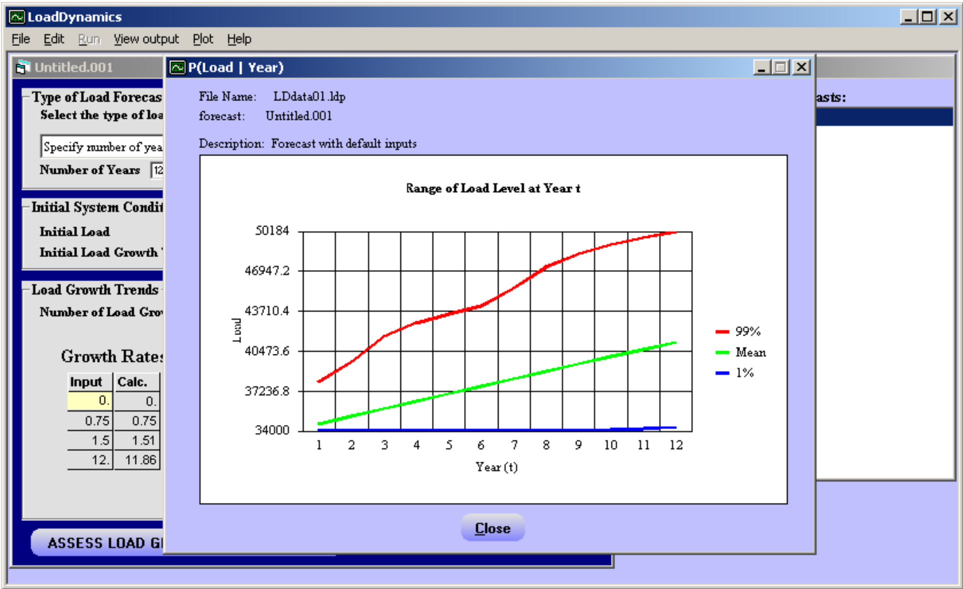


Figure 4-7: Tutorial Two: Plot of Year Versus Load

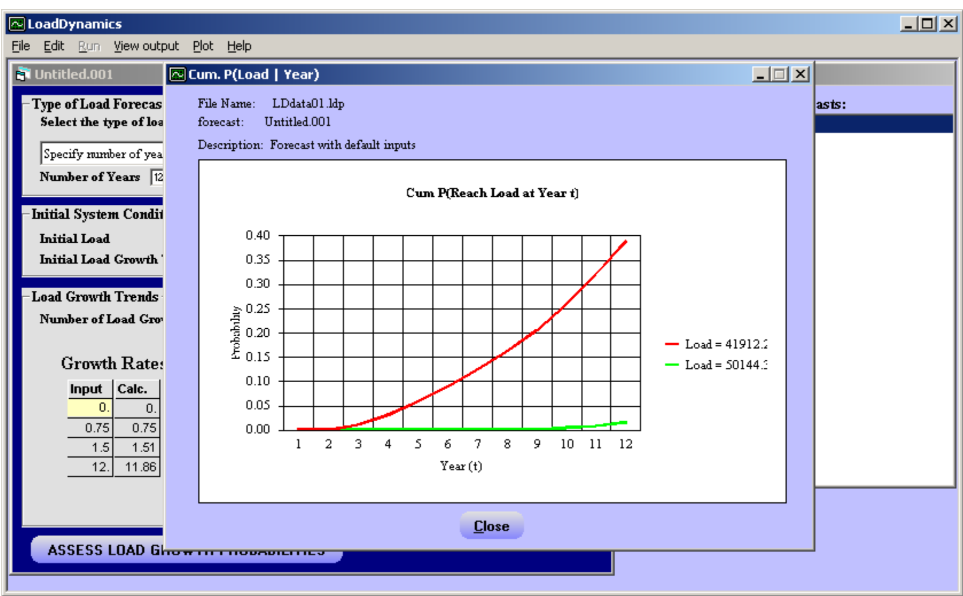


Figure 4-8: Tutorial Two: Cumulative Probability Distributions - Time to Reach Load

expansion is very unlikely. The probability that load will reach $50,000$ kVA by the end of the planning period is essentially zero.

The chances of just the first stage expansion (load reaching $42,000$ kVA) is higher. There is about a 25 to 30 percent chance that the first stage expansion will have occurred by year 10.

To complete this Tutorial exit the program by selecting the $File|Exit$ menu option. The program will ask you if you want to save your inputs. If you wish to do so, select OK.

A ANALYTICAL METHODOLOGY

A.1 Model Logic

This section describes the logic that underlies the LoadDynamics^{TM} Model. The purpose of this section is to 1) explain why this particular approach was chosen, and 2) provide information that will help the user make informed judgments when developing inputs and interpreting results.

A key observation that led to the modeling approach is that load is uncertain but correlated over time; i.e., trends occur. The question is how to use this observation when developing load projections. One approach would be to project the current trend into the future. For example, suppose that area load has followed a consistent growth trend for a few years, and we believe that the trend will persist. In this situation, simple extrapolation could be used to forecast the future. We could make the extrapolation more sophisticated. For example we could guess about 1) when growth is likely to transition to a new trend and 2) the level of the new trend.

However, there is a problem with extrapolations – they are like driving by looking in the rear view mirror. At some point, the actual path that future load follows will change. This change results in a very large number of possible trajectories. Thus picking a load trajectory or two is not going to provide a very good basis for evaluating how different investment strategies might play out.

LoadDynamics^{TM} is based on the idea that it is useful to describe load growth in terms of multiple trends that persist for uncertain durations. A simple yet robust mathematical representation of such a phenomenon is a Markov chain described by a transition matrix.[3] The Markov representation of the load trend idea is illustrated in Figure 1-1. The top half of the figure shows a situation where, over time, load growth follows trends. Key questions are 1) how long does load follow a given trend, and when it transitions to a new trend, 2) what is the level of the new trend. The bottom half of the figure illustrates how transition probabilities provide answers to these questions. Transition probabilities represent the uncertainty in the level of the next trend and the uncertainty in the time to the next trend.

The interpretation for the situation shown in Figure 1-1 is the following. There are three trend states. For the low trend state there is a probability

[3]For a discussion of Markov models see Howard R.A. 1960. *Dynamic Programming and Markov Processes.* John Wiley, New York.

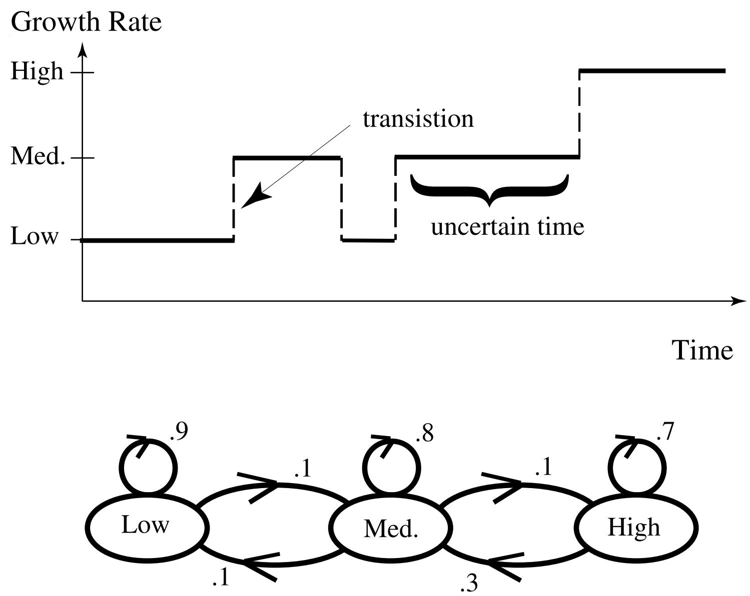


Figure 1-1: The "Load Trend" Concept and its Representation as a Markov Chain

of 0.9 that the trend will persist into next year, and a probability of 0.1 that growth will transition to the medium trend. For the high growth trend, the chance of staying in that high trend is 0.7 and the chance of shifting to the medium trend is 0.3. For the medium trend there is a 0.8 chance that the trend persists, a 0.1 chance that growth transitions to the high trend, and a 0.1 chance that the transition is to the low trend.

This characterization of load trend uncertainties captures information on the probability of transition to a new trend. It also represents the tendency to stay in a given trend. For example, for the probabilities given above, the average times that load growth will be in the low, nominal and high states are 10, 5, and $3\frac{1}{3}$ years respectively:

$$Average\ Time\ In\ Trend = \frac{1}{1 - P(Staying\ in\ Same\ Trend)}$$

LoadDynamics^{TM} is based on a Markov representation of load growth dynamics. Using his approach and given potential future growth trends, the model generates all possible load trajectories. Based on the trajectories, it is straightforward to produce statistics on future load growth paths.

A.2 Comparison With Traditional Approaches

There are many possible approaches for developing forecasts of future load. It is worth noting how LoadDynamics^{TM} differs from some of the more traditional forecasting methods. A typical forecast is an extrapolation of historical average growth. Variance in actual growth might be used to estimate the uncertainty. There are several problems with simple extrapolations. First they do not provide information on potential load dynamics. Extrapolation contains no specification of the timing or the likelihood of transitions from the current growth path to possible alternative paths. As a result, they do not provide information that can help planners identify transitions or turning points.

Second, basing forecast uncertainty on the variance in historical growth rates implicitly assumes that the variance in future load does not change over time. The implicit assumption is that uncertainty does not change over time and there is no "learning by waiting." This implicit assumption is inconsistent with the fact that load growth can follow trends and that the likelihood of specific future load conditions may depend on the current conditions. For example the probability of shifting to a high growth rate may be different depending on whether you are currently experiencing low growth or moderate growth.

A third issue is with the way that historical trend statistics are typically estimated. A standard technique is to estimate an average growth rate by fitting a regression line through historical data. The slope of the line represents average growth. The variance is estimated using the regression residuals. The problems here are: 1) historically, load may have followed several trend patterns for different periods of time (the regression line defines the average trend), and 2) the curve fitting approach provides no information on the duration of the various trends.

The fourth problem is with the use of the historical data. The past is not necessarily representative of the future. This is especially true when estimating future conditions for small areas. Growth trends are driven by real events such as changes in zoning laws and shifts in the local economic conditions. If the future is expected to be different than the past, the forecasts should reflect potential future conditions.

A.3 Model Structure

LoadDynamics^{TM} model and software uses a tree structure to characterize possible load trajectories. In this section the tree representation is described.

To illustrate the tree representation, suppose the load uncertainty situation is such that there are two trends, a nominal trend and a high trend. The transition probabilities are given in Table 1-1.

	To Nominal	*To High*
From Nominal	.8	.2
From High	.4	.6

Table 1-1: Example 1: Transition Probabilities

This table shows that if the current load growth is nominal, the chance of staying in that nominal trend is 0.8 and the chance of shifting to high is 0.2. If the current growth trend is high, the chance of staying in the high trend state is 0.6 and the chance of going to nominal is 0.4. Further, suppose that at the start of the planning period, year = 0, load is 100 and the load growth is in the nominal trend state.

For this example, we define the growth rates to be one percent and two percent for the nominal and high trends respectively ($\alpha = .01$ and $\beta = .02$). Given these definitions, the load at the next time, $t + 1$, is given by the expression:

$$load_{t+1} = load_t(1 + trend\ growth\ rate)$$

Specifically, if the load growth rate is high, the load for the next period is:

$$load_{t+1} = load_t(1 + \beta)$$

Figure 1-2 is a tree that describes some possible growth trajectories. For simplicity, the figure covers the possible trajectories for only two years. This set of assumptions produces four trajectories for the two year period.

The LoadDynamics^{TM} software develops a similar tree by creating a set of nodes. Each node is characterized by the load level, the probability of that

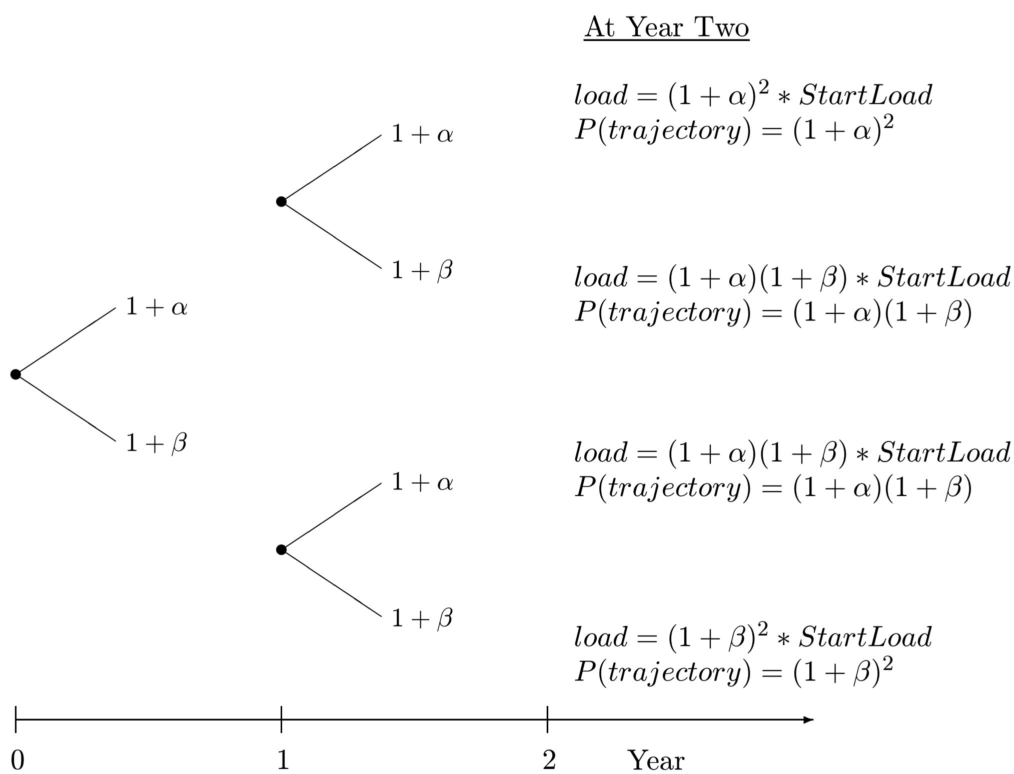


Figure 1-2: An Example of Possible Growth Trajectories

load, the growth trend that produced the node, and the index of the node that the node originated from. The collection of all nodes, with parent-child or precedence relationships, describes all possible load growth trajectories.

A.4 Growth Trend Correlation and Load Uncertainty

In this section we provide an example to demonstrate that load growth uncertainty is quite sensitive to the degree that $load_t$ is correlated with $load_{t+1}$, the existence of load growth trends.

Suppose that historical annual growth rates are observed and that half the years have a nominal 1% growth rate and half the years have a high, 4% growth rate. No attempt is made to measure directly the duration of these trends. Instead, from this data, the inference is drawn that, in any year, the load growth is equally likely to remain in the same trend or to make a transition to the other possible trend. Given this inference, the transition probabilities for any year are 50% of staying in the current trend and 50% of shifting to a new trend. These probabilities are given in Table 1-2.

	To Nominal	*To High*
From Nominal	.5	.5
From High	.5	.5

Table 1-2: Example 2: Transition Probabilities

The difficulty with this approach is not enough information has been observed to specify the transition probabilities. What has been observed is the long term average for the chance of being in one of the two load states in a given year. This is known as a steady-state probability distribution. Indeed, this distribution can be derived from the transition probability matrix, but the steady-state distribution is not sufficient to determine the matrix (the relationship between the steady-state probability distribution and the transition probability matrix will be described in a forthcoming technical paper). In fact, for the two-state case, equal steady-state probabilities imply only that the diagonal elements of the transition probability matrix are equal. Thus, given the observation that growth rates tend to be in each state half of the time, the transition matrix could also have the values in Table 1-3.

The difference in load growth behavior implied by the two transition ma-

	To Nominal	*To High*
From Nominal	.8	.2
From High	.2	.8

Table 1-3: Example 3: Transition Probabilities

trices is in the expected duration of each trend state. In the first case, the expected duration in each state is two years. In the second case, it is five years. A consequence of this difference is that the variances in the load forecasts produced by the two transition matrices are not the same. Indeed, the variance in the first case is somewhat less than in the second case.

In general, correlation between $growth_t$ and $growth_{t+1}$, rather than independence, will yield larger variance in possible load over time. If correlation is present, trend duration is a key parameter for developing probabilistic forecasts of load conditions. To illustrate the effect, LoadDynamics^{TM} was applied to two alternative sets of load growth transition probabilities. These are described in Table 1-4.

NO CORR	*To Low*	*To Nominal*	*To High*
From Low	.25	.50	.25
From Nominal	.25	.50	.25
From High	.25	.50	.25
CORR	*To Low*	*To Nominal*	*To High*
From Low	.80	.20	0
From Nominal	.10	.80	.10
From High	0	.20	.80

Table 1-4: Transition Probabilities for the "NO-CORR" and "CORR" Cases

In the "NO CORR" set there is no correlation between the growth states in period t and period $t+1$. Specifically, the likelihood of the next periods load growth rate does not depend on the current period's growth rate – the transition probabilities are the same for the *low*, *nominal*, and *high* trends.

In the second set of transition probabilities, there is strong correlation. For example, if the growth rate is low, there is a much higher probability of

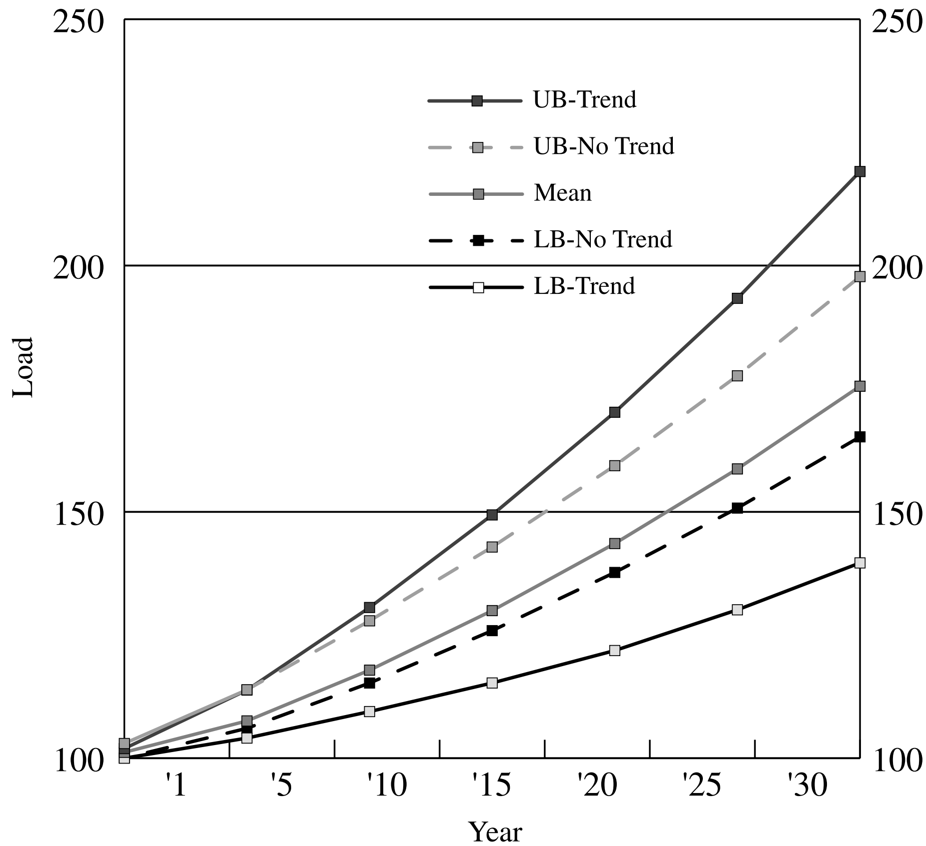


Figure 1-3: An Example of The Effects of Correlation on Forecasted Load

staying in the low state rather than shifting to another state. The same is true for the nominal and high growth states. In this example, load growth persists in a state once it transitions to that state. Thus the growth rates for periods t and periods $t+1$ are correlated. Trends exist. The effect of the correlation on forecasted load is plotted in Figure 1-3.

A.5 The Load Jump Method

A.5.1 The Basic Idea

The idea is simple. There is a chance that for any year the system will enter a *load jump* state. Let the chance of being in the jump state be represented by probability p. We separate growth states into *normal* or *business as usual* and *jump*. Under these assumptions, the transition matrix can be partioned into four components.

$$T = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix}$$

The upper block of T represents the transition probabilities for the *business as usual* growth states. P_{11} is an n x n matrix that specifies the transition probabilities among the *business as usual* growth trends. P_{12} is a column vector each of whose elements is the probability that a jump transition occurs from any *business as usual* growth state. See assumption 1, below. The lower block of T, $[P_{21} P_{22}]$, is an $n+1$ vector of transition probabilities for the *jump growth trend*. The scalar P_{22} is the probability that a jump is followed by another jump. See assumption 2, below.

A.5.2 Implementation

Given an n x n *business as usual* transition matrix, the only other required data is the probability that a jump occurs, conditional on the current state. We interpret this as the steady-state probability, p, that the load growth is found in the jump state. That is an approximation. The augmented matrix T is specified by the following four assumptions.

1. *Leakage* from any state to jump is constant.
2. Transitions among *normal or business as usual, BAU,* growth rates are proportional to their original values.
3. A jump cannot transition to itself, and the transitions out of the jump state are given by the BAU steady-state probabilities.
4. The steady-state probability of being in the jump state is given, p.

Thus for the matrix T, above, it can be shown that P_{12} is a vector of n elements equal to

$$\frac{p}{1-p}.$$

P_{22} is zero by the assumption that a jump cannot transition to itself. P_{11} is obtained by multiplying the BAU matrix by the scalar

$$\frac{1-2p}{1-p}.$$

Scalar multiplication follows from the assumption that transitions among BAU growth rates are proportional to their original values. Finally it can be shown that the elements of P_{21} are obtained by multiplying the steady-state probabilities given by the BAU matrix by $1-p$.

A.5.3 Details

This is not a proof of the validity of the implementation. The purpose is to provide some of the details behind the assumptions.

If the above transition matrix is rewritten as

$$T = \begin{bmatrix} P & q\underline{1} \\ \pi_0 & 0 \end{bmatrix}$$

where π_0 is the steady-state probability vector given by the BAU matrix, q is a scalar and $\underline{1}$ is an n-vector each of whose components is unity, then the steady state transition probabilities, π_1 and p, can be found from the equations:

$$\begin{aligned} \pi_1 P + p\pi_0 &= \pi_1 \\ q\pi_1\underline{1} + 0p &= p \\ \pi_1\underline{1} + p &= 1. \end{aligned}$$

From these equations (recall that p is given) $q = p/(1-p)$. Each element of the vector $q\underline{1}$ is the *leakage* from the BAU matrix that is the result of the potential for a load jump. Further, $P = (1-q)BAU$ and $\pi_1 = (1-p)\pi_0$.

This completes the Analytical Methodology appendix.