

Logical Decisions[®]
Portfolio Version

Decision Support Software for
Resource Allocation

User's Manual

Logical Decisions, Fairfax, VA, USA

This manual supports Logical Decisions® Portfolio, Integrated Version 6.I.

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S E C T I O N

Introduction

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Introduction

Logical Decisions[®] Portfolio (LDW Portfolio) is an enhancement to Logical Decisions[®] for Windows[™] (LDW) that lets you select a set of alternatives instead of a single alternative based on the LDW ranking results.

LDW Portfolio is designed for situations where you want to select a set of alternatives based on budgetary and other constraints. One common application is in selecting a set (or “portfolio”) of research and development (R&D) projects to fund based on a limited total budget. When selecting the projects, you want to pick those projects that have the best expected performance relative to their price. That is, you want to get the most “bang for the buck.”

LDW Portfolio uses the ranking results from an LDW analysis for the “bang” part of the equation. It then lets you add cost and other information to identify the portfolio of alternatives that best meet your needs.

How LDW Portfolio Enhances LDW

LDW is designed to help you select a single alternative from a set of possibilities. The main result of an LDW analysis is a utility score for each alternative that summarizes its overall desirability. The assumption is that you will evaluate your alternatives and then select the one alternative that best meets your objectives – the one with the highest overall utility.

But suppose your problem is slightly different. Suppose that instead of just selecting one alternative you want to select several alternatives. There are many ways you could go about this. Four possible approaches are

- Pick the highest ranking alternatives first
- Pick the highest benefit/cost ratio alternatives first
- Use LDW to rank sets of alternatives, and
- Use an optimization tool to select a set of alternatives

Pick the highest ranking alternatives first. . You could use LDW’s ranking results and pick the first alternative from the list, then the second, then the third and so on until you ran out of budget money. This approach clearly works, but is it the best? There are two big problems with this method. First, it might not give you the most “bang for the buck”, and second, you may have other constraints on your selection that make it unacceptable to select certain combinations of alternatives.

Pick the highest benefit/cost ratio alternatives first.. A second approach is to compute the benefit/cost ratio for each alternative and then to pick the alternatives with the highest ratios until the budget runs out. This approach is a little better than the first, but there is still no guarantee that you will get the most possible benefit for your budget or that you will meet your other programmatic constraints. LDW Portfolio lets you select this approach if it is appropriate for your problem.

Use LDW to rank portfolios of alternatives. A third approach is to use LDW to directly rank all of the possible portfolios of alternatives. This is the ideal approach, since with a good LDW model you can identify the portfolio of alternatives that best meets your budgetary, programmatic and other goals. The biggest problem with this approach is that the number of possible sets of alternatives increases very rapidly as the number of alternatives increases. The number of sets of alternatives can become unwieldy even for relatively small numbers of alternatives. Another potential problem is that it can be difficult to compute the levels for portfolios of alternatives based on the levels for the individual alternatives. However, this method is the preferred approach in the case where selecting one alternative changes the desirability of other alternatives.

Use an optimization tool to select a set of alternatives. The final approach is the one used in LDW Portfolio. LDW Portfolio takes the overall scores of the alternatives from an LDW model and uses an optimization method to find the set of alternatives with the highest combined score that also meets the budget. The optimization solver can quickly search through thousands of possible portfolios of alternatives and find the one portfolio in all the possibilities that is the best. Another benefit of this approach is that you can add other programmatic constraints that ensure that your mix of alternatives meets other goals such as diversity, equity, and acceptable use of resources.

The LDW Portfolio Tool

LDW Portfolio is an enhancement to standard LDW. It lets you enhance the LDW model by adding budget and other constraints. LDW Portfolio then performs an optimization that finds the set of alternatives that has the maximum total benefit while meeting your budgetary and other constraints. LDW Portfolio performs a true optimization using 0-1 integer programming – a method from the field of operations research that can find the very best set of alternatives that meet the constraints. LDW Portfolio also lets you use the benefit/cost approach if that is appropriate

LDW Portfolio is integrated into the LDW tool. It uses the overall benefit (utility) scores for the alternatives from LDW as the basis for its optimization. It also uses cost and resource usage information for each alternative stored in LDW measures.

LDW Portfolio can include cost and budget information for multiple years. You can define a budget for each year and a cost for each alternative for each year. The optimization solver will make sure that the selected alternatives cost less than the allowed budget for every year. LDW also lets you define variations of your alternatives that have different costs and benefits without having to explicitly evaluate them on the measures.

You can experiment with the effects of different budgetary and other constraints by defining different “scenarios.” Each scenario has its own budget for each year and can also have its own set of programmatic constraints.

LDW Portfolio allows a variety of programmatic constraints.

- You can force any alternative into or out of the final selection.

- You can add if-then constraints that ensure that alternative A is only chosen if alternative B is also chosen.
- You can define groups of alternatives and force all of the alternatives in the group into or out of the selection, force either one or none of the alternatives to be selected, all or none of the alternatives to be selected, exactly one of the alternatives to be selected or at least one of the alternatives to be selected.
- You can add resource constraints such as available personnel and ensure that your selected alternatives don't use more than the available amount of the resource.
- Finally, you can add allocation constraints that specify a minimum percentage of the budget that must be spent on alternatives belonging to a particular group.

You can add all of these constraints in an easy, intuitive way that shields you from the complexities of the model structure.

Sensitivity analysis and the efficient frontier

LDW Portfolio lets you perform sensitivity analysis on your budgets to see how the total benefit increases as the available budget increases. The result is a true efficient frontier showing the maximum benefit that can be achieved at each budget level while still meeting the programmatic constraints. Contrast this to other tools that just order the alternatives by their cost/benefit ratios and don't even look for the alternatives that maximize benefits at each budget level, let alone try and meet the programmatic constraints.

Organization of This Manual

Section 2 briefly describes how LDW Portfolio is integrated into LDW. Section 3 provides a tutorial overview of how to use LDW Portfolio. Section 4 describes how to define scenarios. Section 5 discusses how to select portfolios of alternatives. Section 6 describes the efficient frontier for an analysis. Section 7 describes alternative variants. Finally, Section 7 describes strategies for portfolio analysis using several examples. A short appendix describes the mathematics used to adjust utility numbers.

S E C T I O N

LDW Portfolio Integration

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LDW Portfolio Integration

LDW Portfolio is an enhancement to the standard Logical Decisions[®]. To activate the portfolio features, you need a special key that you will receive when you purchase the LDW Portfolio package. When you start the software after entering the key, you will see the usual LDW user interface with a new Portfolio menu item added to the main menu bar. The LDW Portfolio features are located under this menu item.

The additional portfolio menu items are:

- Define Groups - Define groups of alternatives that you can use to organize your analysis and also use as a basis for adding constraints
- Portfolio Window - Display a window showing your grouped alternatives and which ones have been selected in the current portfolio
- Efficient Frontier - Display a window showing how the total possible benefit increases as your budget increases
- Select/Change Scenarios - Define and select scenarios that can include alternate budgets, constraint sets and solution methods
- Define Alternative Variants - Display a window where you can define variations on your alternatives that provide a differing percentages of benefits for different budgets.

All of the information generated in the portfolio menu options is stored directly in your .ldw Logical Decisions files.

S E C T I O N

Tutorial Overview

3

Tutorial Overview

This section provides an overview of the capabilities and method of use of the LDW Portfolio tool. It will be based on a research and development funding example. The example will start with an existing Logical Decisions file and will go through the steps needed to identify the portfolio of projects that should be funded.

The R&D Project File

The LDW file for the tutorial is called “R&D Projects 2008.ldw.” It consists of 25 large R&D projects of the type that might be funded by a national government. The goals hierarchy is structured in a way that has all of the cost related measures under a goal called “Costs” and all of the measures that indicate the quality of the projects under a goal called “Benefits.” There are two preference sets – “Congress” and “President,” with somewhat different weights for the measures under the Benefits goal. In both cases the weight for the Costs goal and the measures under it is zero. This is because costs and manpower will be addressed as constraints in LDW Portfolio. The costs and benefits for the R&D projects are MADE UP, and have no relationship to any real R&D initiatives that might address these issues.

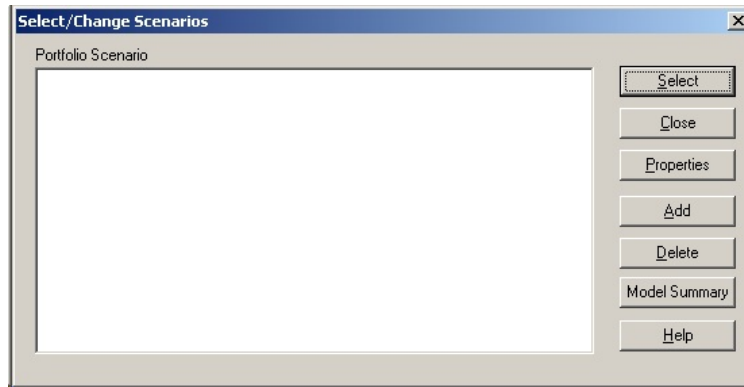
As was mentioned above, the three measures under the Costs goal will be used as constraints in the LDW Portfolio tool. The “2008 Budget” and “2009 Budget” measures have the total cost for each alternative for the two years in billions of US dollars. The “Manpower” measure indicates how many “scientists” would be required to staff each project. Scientists are considered to be a scarce resource in this example.

Loading the LDW Portfolio File

The first step in developing a LDW Portfolio model is to load the LDW file the model will be based on. To begin, start LDW Portfolio and open the file with the File::Open option. The .ldw file will contain all of the information for the initial LDW ranking of the alternatives and for the LDW Portfolio analysis as well.

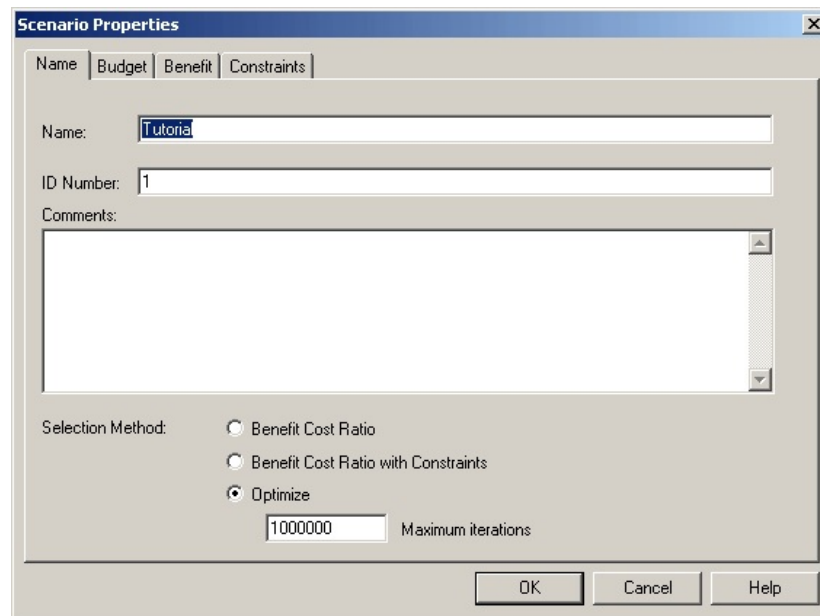
Defining a Scenario

LDW Portfolio stores portfolio specific data in an object called a Scenario. Initially there are no scenarios defined. To add a new scenario, select the Portfolio::Select/Change Scenarios option. When you do this, you will see the dialog box shown below.



To add a new scenario, click the “Add” button in this dialog box.

When you do this, you will see the Scenario dialog box shown below. This is where you will do much of the structuring for a LDW Portfolio analysis.

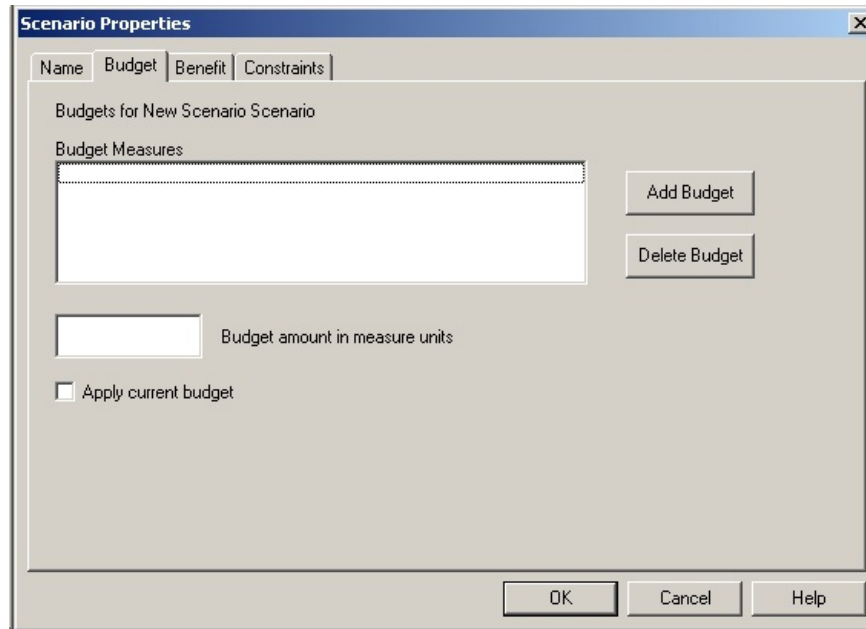


The first tab is the Name tab. You should change the name of the Scenario to “Tutorial” in the Name edit box. The other important option on this tab is the portfolio selection method. We will discuss selection methods in more detail later when we describe selecting a portfolio in the Portfolio Window. For now, keep the default of “Optimize”.

We will now work our way through the tabs to complete the definition of the scenario.

Defining the Budgets

The next tab is Budget, which is shown below.

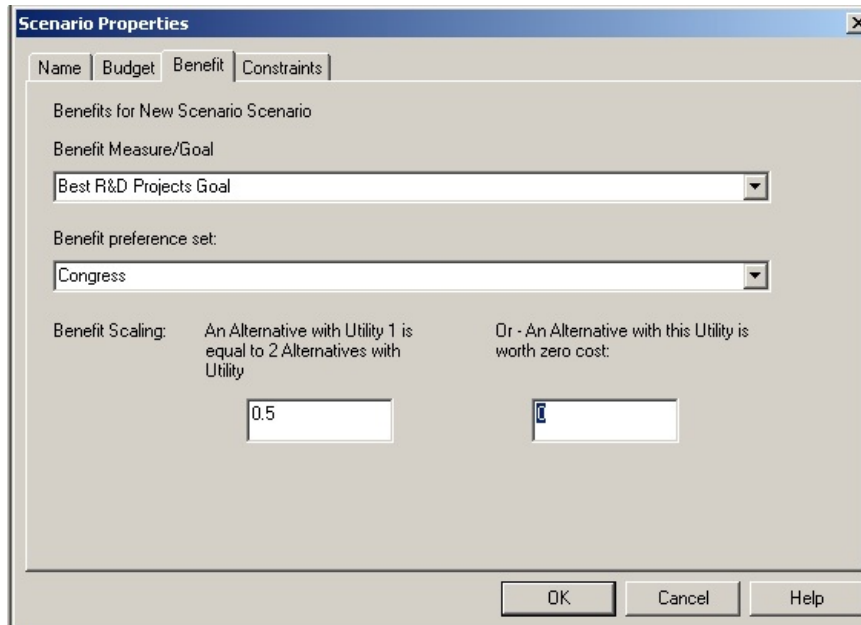


Here we will define two budgets, 2008 and 2009. Click the Add Budget button and select the 2008 Budget measure from the list. The level for each alternative is that alternative's cost for the 2008 budget year if it is selected. Add an initial budget of 200 (billion dollars) in the Budget Amount edit box and make sure that the "Apply current budget" box is checked.

Click Add Budget again to add the 2009 Budget measure to the budgets for this Scenario. The initial 2009 budget is \$250 billion.

Defining the Benefits

"Benefit" is the next tab in the Scenario properties dialog box. When you click this tab you will see the screen shown below.



The first step is to select the benefit measure or goal. We will use the Benefits goal for benefits, so select it from the Benefit Measure/Goal list and make sure that Congress is selected in the Benefit preference set list.

Scaling the benefits

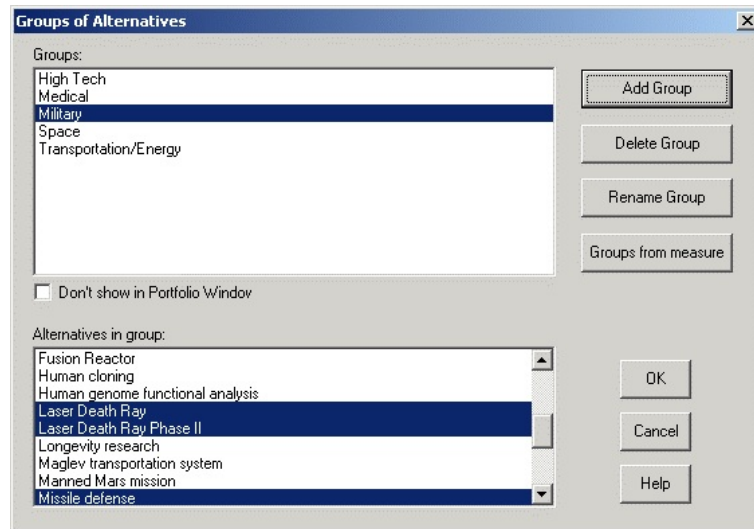
The benefit (utility) numbers provided by LDW do not have a natural zero point. This means we don't initially know the answers to questions like "What level of benefits would I not be willing to pay anything for?" and "What level of benefits is worth exactly half of a benefit of 1.0?" This is OK if we are only selecting one alternative, since we only need to know which alternative has the highest benefit. In LDW Portfolio, we will be adding the benefits of different alternatives together. We can't do the addition correctly unless our benefits scale has a natural zero point. To define the zero point for the benefits scale, we need to answer one of two questions. We need to tell LDW Portfolio either the benefit score that we would just pay nothing for or we need to say what benefit score is worth exactly half of a benefit score of 1.0. The two questions both define the zero point for the benefits scale, so the answer for one of the questions forces the answer to the other.

To answer the question, suppose that we have defined an alternative in LDW that is so bad that we would not be willing to pay anything for it, but that is not so bad that we would be willing to pay someone to not select it. In other words, the alternative is worth exactly zero dollars. Let's say that the alternative called "Zero Value Alternative" is, surprisingly enough, worth exactly zero dollars. Then its benefit amount is the amount that will define the zero point of the adjusted benefit scale. If we look at the utility of the Zero Value Alternative for the Benefits goal in Results::Ranking Results option, we see that its -0.032. So this is the benefit that we would pay exactly zero dollars to get. We'll tell this to LDW Portfolio by entering -0.032 in the edit box called "An alternative with

this benefit is worth zero dollars”. When you do this, you’ll see that the edit box called “An alternative with benefit I.0 is worth two alternatives with benefit:” now has .484 in it. This is the benefit computed by LDW Portfolio to be worth exactly half as much as a benefit of I.0.

Defining groups of alternatives

The next part of the structuring process is to define groups of alternatives. Since groups are independent of scenarios, we will temporarily close the Scenario properties dialog box and select the Portfolio::Define Groups option. Later we will add constraints to our Scenario based on the groups we define here. The Define Groups dialog box is shown below.



Initially there are no groups of alternatives. To define a group, click the “Add Group” button. You be asked to name the group and can then select the alternatives you want in the group from the “Alternatives in Group” list. You can select as many alternatives as you want from the list. You can go back and change the group later by selecting the group in the Groups list and selecting or unselecting alternatives in the Alternatives in Groups list. You can delete the group entirely by clicking the “Delete Group” button and rename it with the “Rename Group” button. We’ll define the following groups:

Military

- Laser Death Ray
- Laser Death Ray Phase II
- Missile Defense

Medical

- Anti-obesity pill
- Body part replication
- Human cloning
- Human genome functional analysis
- Longevity research
- SARS Vaccine

- Space
 - Earth to space elevator
 - Earth to space elevator phase II
 - Manned mars mission
 - Missile defense
 - Next generation space vehicle

- Transportation/Energy
 - Biomass to oil
 - Driverless car
 - Flying car
 - Fuel cell car
 - Fusion reactor
 - Maglev transportation system

- High Tech
 - Deep sea research station
 - Earth core explorer
 - Nanotech fabricator
 - Paper computer screen
 - Quantum computer
 - Wireless personal ID

Defining constraints

Now we will define the programmatic constraints for the Tutorial scenario. Return to the Scenario properties dialog box by selecting the Portfolio::Select/Change Scenarios option and then clicking the Properties button. Then click the Constraints tab.

First we will add a constraint to make sure we never pick the “Zero Value Alternative” which was included only to help scale the utility values for the alternatives. To force the alternative out of the selection, first click the “Add Constraint” button on the constraints page. You will see the “Add Constraints” dialog box. Make sure that the Alternative tab is selected and select the “Zero Value Alternative” from the list at the left of the page. To exclude this alternative, click the “Force out” radio button at the right of the page. Finally, to add the constraint, click the “Add Constraint” button. LDW Portfolio will add the constraint and the dialog box will remain open so you can add more. When you close the dialog box by clicking the “Done” button, the new constraint will be displayed in the “Constraints” list.

We also need constraints to ensure that Phase II projects are not funded unless Phase I projects are. To add an if-then constraint for the “Laser death ray Phase II” alternative, click the “If-then” tab in the Define Constraints dialog box. Select “Laser death ray phase II” from the “If” list and select “Laser death ray” from the “Then” list. Make sure that the “Then” radio button is selected and click the “Add Constraint” button. This will add a constraint to ensure that the “Laser death ray phase II” alternative is never selected unless the “Laser death ray” alternative has also been selected.” We will add a similar constraint for the “Earth to space elevator phase II” alternative.

Suppose we feel that the “Human cloning” and “Body part replication” alternatives are redundant and we don’t want to fund both of them. We can

ensure this with an “If-Then Not” constraint. On the If-Then page of the Define Constraints dialog box, select “Human cloning from the list on the left and “Body part replication” from the list on the right. Make sure that the “Then Not” radio button is selected and click the “Add Constraint” button. The If-Then Not constraint type is symmetric, so it doesn’t matter which alternative we select in the two lists.

Now we’ll add a resource constraint. Suppose that there are 500 interchangeable scientists available to work on the various alternatives. We need to ensure that the selected projects collectively do not require more than 500 scientists to complete them. To add the constraint, select the Resource tab in the Define Constraints dialog box. Select Manpower from the list labeled “Resource (Measure)” and enter 500 in the Amount box. Since this is the maximum number of scientists available, select the “Less than or equal constraint” radio button. This completes the definition of the constraint, so click the “Add Constraint” button to add it to the model.

Now we’ll add some group constraints. We’d like to select at least one alternative from each group so we’ll add a series of constraints to ensure that. To add the group constraints, select the Group tab in the Define Constraints dialog box. Select the “Military” group from the list of groups and select the “At least one” radio button. Click the “Add Constraint” button to add the constraint. Repeat this process for each of the other groups.

Finally we’ll add a constraint to ensure that at least 25 percent of the total budget goes to Military alternatives. To do this, select the Allocation tab on the Define Constraints dialog box. Select “Total” from the list of budgets at the top of the page and select “Military” from the list of groups. Enter 25 as the minimum percent to allocate in the box at the bottom of the page. Click “Add Constraint” to complete the process.

The Portfolio Window

Now the model has been completed and we are ready to select the set of alternatives that has the highest benefits while still meeting the budget and other constraints. We do this in the Portfolio window. When you select the Portfolio::Portfolio Window option you will see a window like the one shown below.

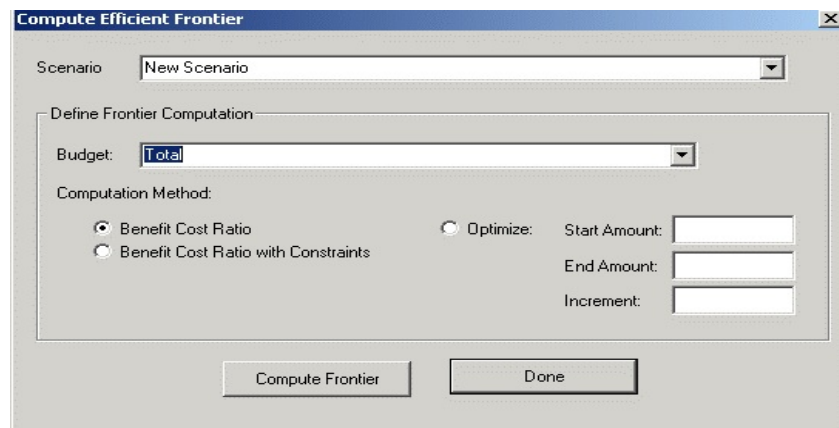


The Portfolio window shows the groups and alternatives for the current model. The budgets for the active scenario are shown at the top of the window. When you click the Run Scenario button, LDW Portfolio will use the solution method selected for the active scenario to find the portfolio of alternatives that provides the highest benefit while still meeting the applicable constraints. The selected alternatives are highlighted in green. Groups with at least one alternative selected are also highlighted in green.

It is possible that there is not any set of alternatives that meets all of the constraints that you have defined. If this happens, LDW Portfolio will report that it could not find a solution, but will not be able to tell you exactly which constraints prevented a solution from being found. It is up to you to review your constraints for consistency and to make the necessary adjustments.

Displaying the Efficient Frontier

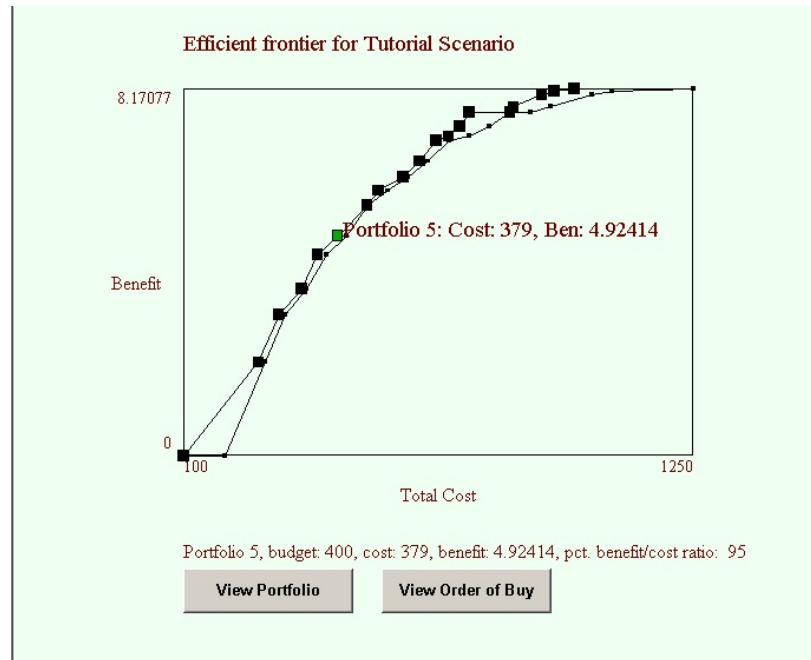
The final activity we can do with the model to display the efficient frontier. The efficient frontier is the set of portfolios that provide the most benefit for the cost. You display the efficient frontier by selecting the Portfolio::Efficient Frontier option. When you do this, you will see the dialog box shown below.



To generate an efficient frontier case, enter the following parameters:

Scenario:	Tutorial
Computation Method:	Optimize
Budget:	Total
Start Amount:	50
End Amount:	750
Increment:	50

This selection will do a sensitivity analysis over the year Total budget for the Tutorial scenario. The optimization will be run a number of times, starting with a Total budget of 50 billion, then 100 billion, and so on until 750 billion. The other constraints remain in force. The total budget at each increment is allocated proportionally between the 2008 and 2009 budgets according to the proportions defined in the Tutorial scenario. When you click the “Compute Frontier” button, LDW will display a window like that shown below.



In the figure, the small squares represent the budget for each increment and the large squares represent the costs and benefits of the selected portfolios. To see the cost and benefit numbers for a particular portfolio, click on its square. To see the details of the portfolio, click the "View Portfolio" button and LDW Portfolio will display the portfolio window for the most recently clicked portfolio. You can also click the "View Order of Buy" button to see the order of buy window. The order of buy window will be discussed in the Efficient Frontier section (section 6).

The next sections of this manual will discuss the capabilities of the LDW Portfolio tool in more detail.

S E C T I O N

Defining Scenarios

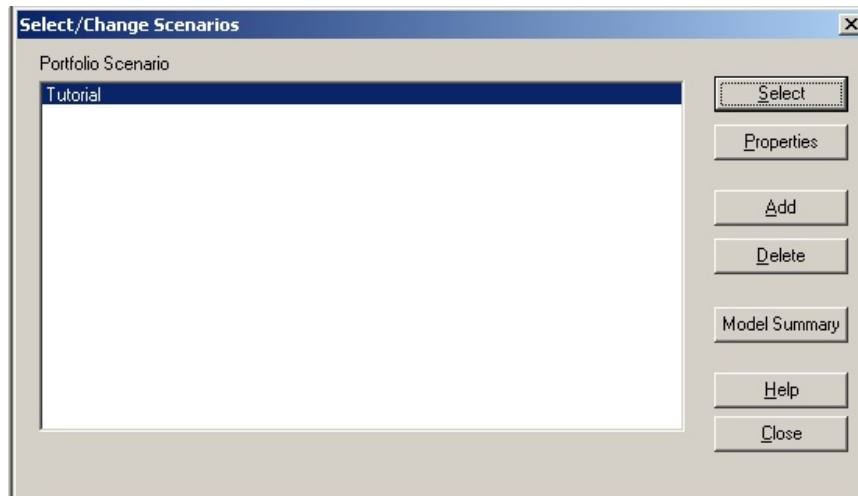
4

Defining Scenarios

The first step in expanding an LDW analysis for selecting Portfolios is to define a Scenario. Standard LDW uses preference sets to save information about utility functions and weights. Similarly, Scenarios are used in LDW Portfolio to store information about costs, benefits and constraints. You can have as many Scenarios as you need, just like you can have as many Preference Sets as you need.

Adding a Scenario

You add and delete scenarios by choosing the Portfolio::Select/Change Scenarios option. When you select this option, you will see the dialog box shown below.



This dialog box is for adding and deleting scenarios and for selecting the active scenario. To define the particulars of your scenario, click the Properties button to see the Scenario Properties dialog box, which is discussed later in this section.

To add a new scenario, click the Add button. If you have already defined other scenarios you will then be given the option of copying an existing scenario or creating a new default scenario. When you create a new scenario, LDW will show you its properties dialog box.

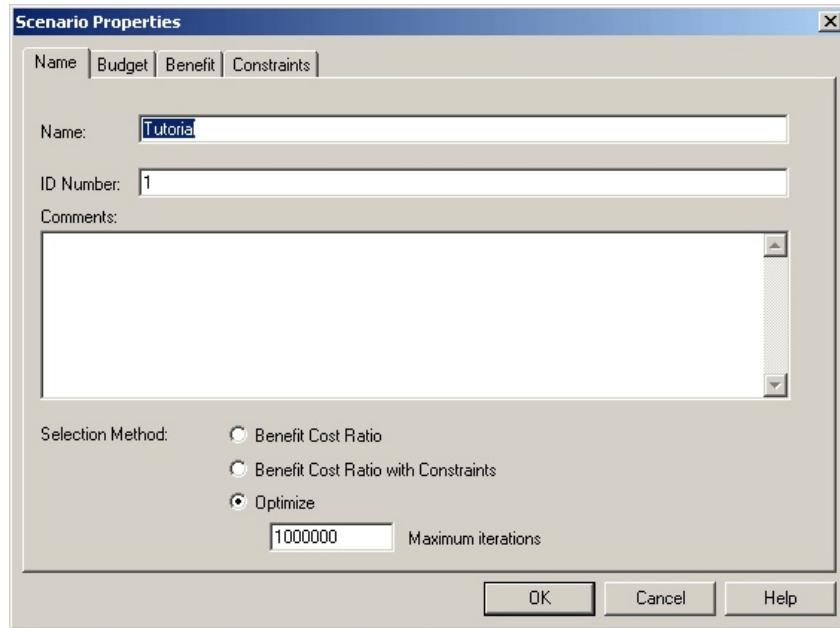
To delete a scenario, click its name in the list on the left of the dialog box and click the Delete button.

When you click the Select button, the Scenario currently highlighted in the list is made the active scenario and LDW closes the dialog box. You can close the dialog box without changing the current active scenario by clicking the Done button.

The Model Summary button will be discussed later in this section.

Defining a Scenario's Properties

To define a Scenario's properties, click the Properties button in the Select/Change Scenarios dialog box shown above. When you do this, you will see the Scenario Properties dialog box. The Name tab of this dialog box is shown below.



The screenshot shows the "Scenario Properties" dialog box with the "Name" tab selected. The dialog has four tabs: "Name", "Budget", "Benefit", and "Constraints". The "Name" tab contains the following fields and controls:

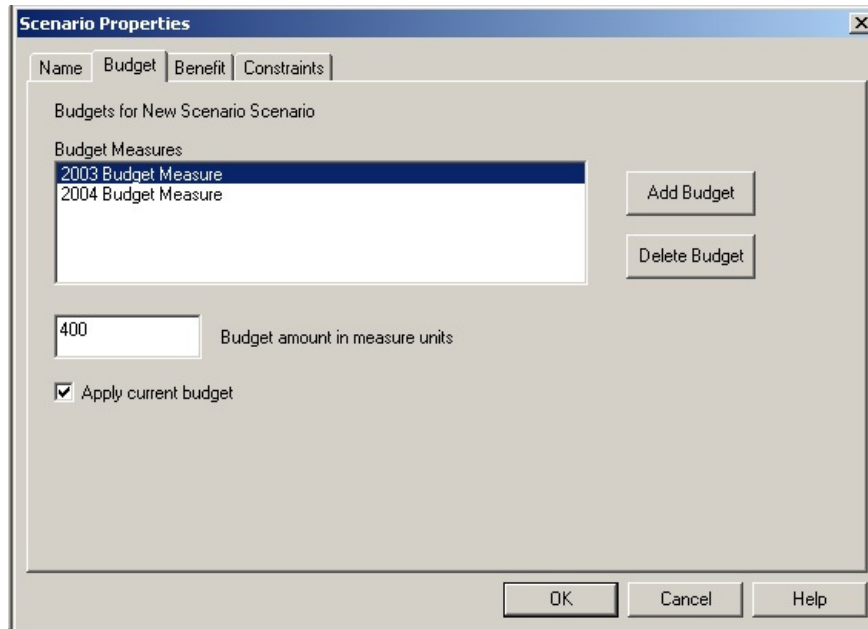
- Name:** A text box containing the word "Tutoria".
- ID Number:** A text box containing the number "1".
- Comments:** A large, empty text area with a vertical scrollbar.
- Selection Method:** Three radio buttons:
 - Benefit Cost Ratio
 - Benefit Cost Ratio with Constraints
 - Optimize
- Maximum iterations:** A text box containing "1000000" next to the label "Maximum iterations".

At the bottom right of the dialog are three buttons: "OK", "Cancel", and "Help".

In the name tab, you can enter a name and ID number and comments for the scenario. You also specify how the portfolio is selected by clicking the "Benefit/Cost Ratio", "Benefit/Cost Ratio with Constraints", or "Optimize" radio button. If you select the Optimize method, you can also specify a maximum number of iterations for the solution procedure. The details of how these methods work are discussed in the Selecting Portfolios section.

Defining Budgets

Budgets are the primary constraint on the number and quality alternatives you can select in a portfolio. You define budgets in LDW Portfolio on the Budget tab of the scenario properties dialog box shown below.



LDW Portfolio lets you have as many different budgets as you like. Budgets could represent different years, different sources of money, or different accounting areas, such as capital costs and O&M costs.

Budgets in LDW Portfolio are associated with measures. Each budget is linked to a specific measure and has the same name as the measure. Budgets also have a budget amount, which should be entered in the units of the measure. For example, if the 2003 Budget measure has units of thousands of dollars, then a budget of \$10,000 should be entered as 10. Finally you can decide whether to apply the budget or not in a given scenario. If you apply the budget, LDW will only select portfolios that have a total cost less than or equal to the budget. The cost of a portfolio on a budget is computed as the sum of the level of all of the alternatives selected in the portfolio on the budget measure. If you don't apply the budget, LDW Portfolio will compute and display the costs of portfolios on the budget, but will not constrain portfolio costs to be less than the budget.

To define a budget, click the Add Budget button and select the budget measure from the list that appears. Then enter the budget in the edit box and check the "Apply current budget" box.

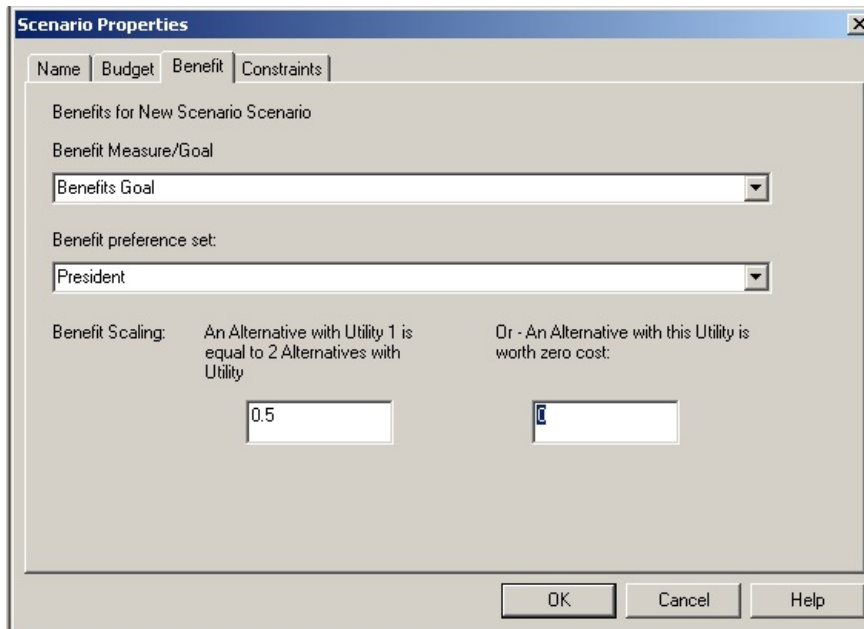
If you use a measure as a budget in LDW Portfolio, it is recommended that you don't have any weight in on it in the goal that is used to compute benefits. This is to avoid "double counting" the importance of the budget measure by including it as part of the benefit score for each alternative and also as a constraint for including or excluding alternatives. There are two ways of ensuring the budget measures are not included in benefits. If you are using the overall goal as the benefit variable, you can add a Cost goal that includes all of the budget measures underneath the overall goal and ensure that the Cost goal has zero weight in the overall goal's utility function. Alternatively, you can add a Benefit goal under the overall goal, that does not include the budget measures

and then set the Benefit goal utility as the benefit variable. Setting the benefit variable is discussed below.

Defining Benefits

Benefits are the variable that LDW Portfolio tries to maximize when selecting portfolios. Often benefits are computed as the sum of the utilities of the selected alternatives on the overall goal in the LDW goals hierarchy. However, you can select any goal or measure as the benefits variable.

You define the benefits for a scenario in the Benefit tab of the scenario dialog box as shown below.



The screenshot shows the 'Scenario Properties' dialog box with the 'Benefit' tab selected. The dialog has four tabs: 'Name', 'Budget', 'Benefit', and 'Constraints'. The main area is titled 'Benefits for New Scenario Scenario'. It contains the following fields and options:

- 'Benefit Measure/Goal': A dropdown menu with 'Benefits Goal' selected.
- 'Benefit preference set': A dropdown menu with 'President' selected.
- 'Benefit Scaling': Two radio buttons and two text input fields. The first radio button is selected and is labeled 'An Alternative with Utility 1 is equal to 2 Alternatives with Utility'. Its corresponding text input field contains '0.5'. The second radio button is labeled 'Or - An Alternative with this Utility is worth zero cost' and is unselected. Its corresponding text input field is empty.

At the bottom of the dialog are three buttons: 'OK', 'Cancel', and 'Help'.

To define the benefit variable, first select the measure or goal you want from the Benefit Measure/Goal list. Then select the preference set you want to use from the Benefit Preference Set list. LDW Portfolio will use the utility of the selected measure or goal on the selected preference set as the benefits measure. LDW will compute the benefit of a portfolio as the sum of the scores for the selected alternatives on the benefit variable.

Scaling the benefit variable

This section addresses a subtle but important point about the utility scores that are generated by LDW. That point is that it is not necessarily correct to add the utility scores from different alternatives into a total benefit. This is because the utility scores do not have a natural zero point, meaning that you might be willing to pay to select an alternative that gets a zero on the benefit variable or that you might not be willing to pay for an alternative that gets more than zero.

In this case you should rescale the benefits variable so that you are just willing to pay zero dollars for an alternative that scores zero on the benefit variable.

If you are careful in setting up your measures and utility functions you can avoid needing to rescale, but if you need to, here is how to do it.

You don't need to rescale utilities in standard LDW, since even though utility numbers have no natural zero point, we can use them to find which alternative has the highest utility. Since we are only picking one alternative, we don't need to know anything else, because however we rescale the utility the highest ranking alternative will remain the same.

But in LDW Portfolio, we are not just selecting the one alternative that has the highest utility, we want to select the set of alternatives that has the highest combined utility and that still meets the budgetary and other constraints.

Since the figure of merit is the sum of the utilities of the selected alternatives, we need to be able to add up the utility numbers. And to add up the utility numbers we need to establish a zero point for our utility numbers. Don't worry though, because it's not too hard to do this!

LDW Portfolio adjusts the utility numbers on the basis of your answer to a question about different hypothetical alternatives. There are two questions you can answer, but they both lead to the same adjustment, so that the answer to one question implies the answer to the other question. The Appendix discusses the questions and the adjustment in more detail.

Identifying the zero-worth utility

The first question is the most obvious. LDW Portfolio asks you what utility score for an alternative would make it worthless. That is, what utility would make it so that you would not be willing to pay any money at all to get that alternative. Let's call that the zero-worth utility. In other words, if you are willing to pay different amounts of money to get different utility scores, what utility score are you willing to pay exactly zero for? To answer the question, you will need to think about the meanings of different utility scores. A good starting place might be to think about an alternative that gets a utility of zero on all the measures. This means that the alternative gets the least preferred level on all of the measures in LDW. Depending on how you defined the measure ranges, this might be a poor but acceptable alternative or a horrible one. The question you need to answer is whether you would pay any money to get this alternative. There are three possibilities,

- You would be willing to pay something to get the alternative,
- You would have to be paid something to be willing to take the alternative, or
- You would be just as happy to take the alternative as to not take it if as long as you didn't have to pay for it.

Let's talk about the last case first. If you are just as happy to get the alternative or not as long as you don't have to pay, that means that the alternative with zero utility has just about zero worth to you. This is good because it means that no adjustment to the utility scale is needed.

If you would have to be paid to take an alternative that has a zero utility score, that means that it is worth less than zero dollars to you. That means that there will be a utility score that is greater than zero that you would not pay anything for. Probably the easiest way to determine the zero-worth utility is to go back into LDW and create an alternative that has the least preferred level on all the measures. This will have a utility of zero, but a monetary value of less than zero. To make its monetary value equal to zero, you will need to improve its utility on one or more measures. By gradually increasing the score on one or more important measures and carefully thinking about the resulting hypothetical alternative, you should be able to identify when the alternative has a monetary worth of just zero. Then you can use LDW's ranking results display to see what overall utility score the alternative gets. This is the zero-worth utility for your problem. To tell the zero-worth utility to LDW Portfolio, enter it in the box labeled "OR - An alternative with this benefit is worth zero dollars:"

The situation where you would pay to get an alternative with zero utility is similar. In this case, the zero-worth utility will be less than zero. You can do use the same procedure in LDW to identify the zero-worth utility. First create a zero utility alternative as described above. Then gradually reduce the alternative's value by lowering its level on one or more important measures. You will be lowering the level(s) below the least preferred level for the measure(s), but there is no reason you can't do this. Again, by carefully thinking about the resulting alternative, you should be able to identify the point where its worth is just zero. The overall utility score for the alternative will be less than zero, but that is OK. That is the zero-worth utility for your problem. Enter that number as described above.

Identifying the Half-Worth Utility

Sometimes identifying an alternative and corresponding utility that is worth exactly zero can be difficult, so LDW Portfolio provides a second method for establishing the zero point for benefits. In this method, LDW Portfolio asks you to identify an alternative that is worth exactly one half as much as an alternative that gets an overall utility score of one. We will call this the half-worth utility.

One way you might think about this is to first think about an alternative that has the most-preferred level on all of the LDW measures. This alternative will have an overall utility of one. Next think of an alternative that has a utility of 0.5 on all of the measures. Generally this means a level on each measure that is halfway between the least and most preferred levels, but be careful! If you have utility functions in LDW that aren't straight lines, the levels that correspond to a 0.5 level will be different. To find out the 0.5 utility level for a measure use the Review::Compute Utilities option in LDW. It might be useful to explicitly define the 0.5 utility alternative in LDW to make sure you can understand it completely.

Once you have defined the 1.0 utility and 0.5 utility alternatives, ask yourself this question. Would you rather have the 1.0 utility alternative or two of the 0.5 utility alternatives. We need to assume for the moment that its OK to pick the 0.5 utility alternative twice and that two 0.5 alternatives are twice as good as one 0.5 alternative. There are three possible answers to the question.

- The 1.0 alternative is equally as good as the two 0.5 alternatives,

- The I.0 alternative is preferred to the two 0.5 alternatives, or
- The two 0.5 alternatives are preferred to the I.0 alternative.

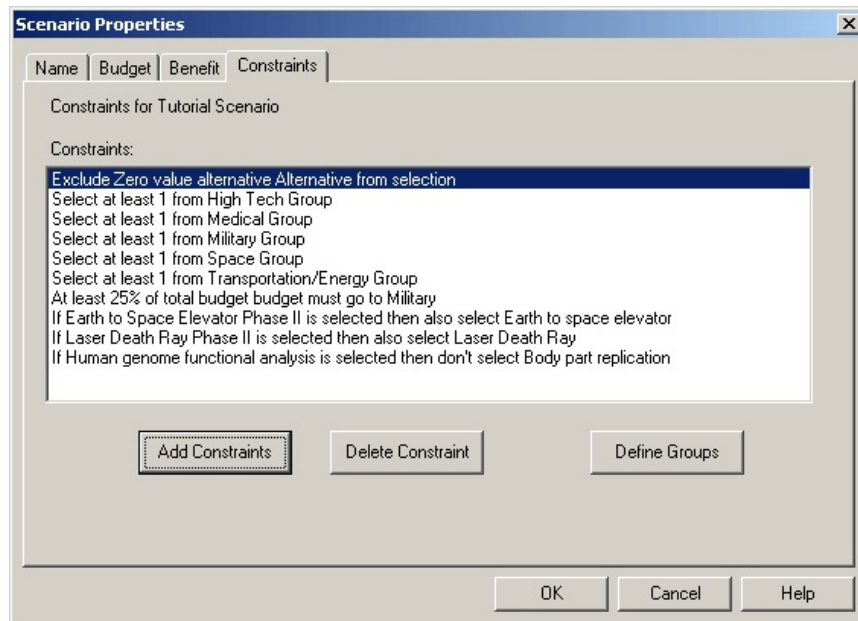
In the first case, you are just as happy to get the two 0.5 alternatives as the single I.0 alternative. That means that the 0.5 alternatives are worth exactly half as much as the I.0 alternative and that the half-worth utility is equal to 0.5. In this case no adjustment to the utility scale is needed.

If you prefer the I.0 alternative, that means that it is worth more than twice as much as a 0.5 alternative. That means that there will be a utility score that is greater than 0.5 but less than 1.0 that would make the two alternatives worth the same as the I.0 alternative. Probably the easiest way to determine the half-worth utility is to go back into LDW and modify the 0.5 alternative that you created above. To make its monetary value equal to half that of the I.0 alternative, you will need to improve its utility on one or more measures. By gradually increasing the score on one or more important measures and carefully thinking about the resulting hypothetical alternative, you should be able to identify when two of the alternatives are worth of just as much as one I.0 alternative. Then you can use LDW's ranking results display to see what overall utility score the alternative gets. This is the half-worth utility for your problem. To tell the half-worth utility to LDW Portfolio, enter it in the box labeled "An alternative with benefit I.0 is equal to 2 alternatives with benefit:"

The situation where you prefer the two 0.5 utility alternatives to the I.0 alternative is similar. In this case, the half-worth utility will be less than 0.5. You can do use the same procedure in LDW to identify the half-worth utility. First create a 0.5 utility alternative as described above. Then gradually reduce the alternative's value by lowering its level on one or more important measures. Again, by carefully thinking about the resulting alternative, you should be able to identify the point where you equally prefer two of these alternatives to one of the I.0 alternatives. The overall utility for the adjusted alternative is the half-worth utility for your problem. Enter that number as described above.

Defining Constraints

The final step of the scenario definition process is to define constraints. Constrains are restrictions on the portfolio that can be selected. They ensure that certain alternatives or groups of alternatives are either always selected or always excluded. They can also be used to link alternatives and to ensure that critical resource restrictions are met. You define constraints in the Constraints tab of the scenario properties dialog box as shown below.



In the dialog box, the large edit box has a list of the currently defined constraints. Constraints are always listed as English phrases rather than mathematical equations.

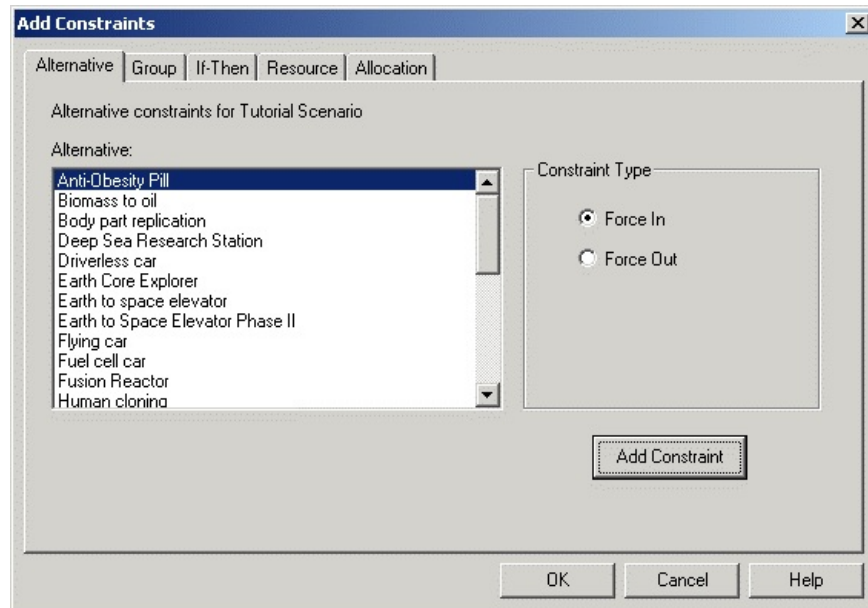
You can delete an existing constraint by selecting it from the list and clicking the Delete Constraint button.

Adding Constraints

LDW Portfolio lets you add the following types of constraints to your scenario.

- force alternatives in or out of the selection,
- if-then constraints,
- constraints based on groups of alternatives,
- resource constraints, and
- allocation constraints.

To add a constraint, click the Add button. You will see the “Define Constraints” dialog box shown below.



Each tab in the Add Constraints dialog box lets you define a different type of constraint. To add a constraint, select the tab for the constraint type and then select all of the parameters needed for the constraint. When you are finished, click the Add Constraint button to add the constraint to the current Scenario.

The Define Constraints dialog box will remain open so that you can add more constraints. When you are finished adding constraints, click the OK button. The parameters for the different constraint types are discussed below.

Force alternatives in or out of the selection

Alternative constraints let you force individual alternatives to be selected or not selected. Generally you will want to do this on a temporary basis, to see the effect on the total benefit of adding or removing a particular alternative, or to see why an alternative was selected or not selected.

To define an alternative constraint, first select the Alternatives tab in the Define Constraints dialog box. This is the tab shown above. Next select the alternative you want to constrain from the list at the left of the dialog box. Then use the radio buttons at the right of the dialog box to select whether to force the alternative in or out of the set of selected alternatives when running the model. To add the constraint to the scenario, click the Add Constraint button.

If-then constraints

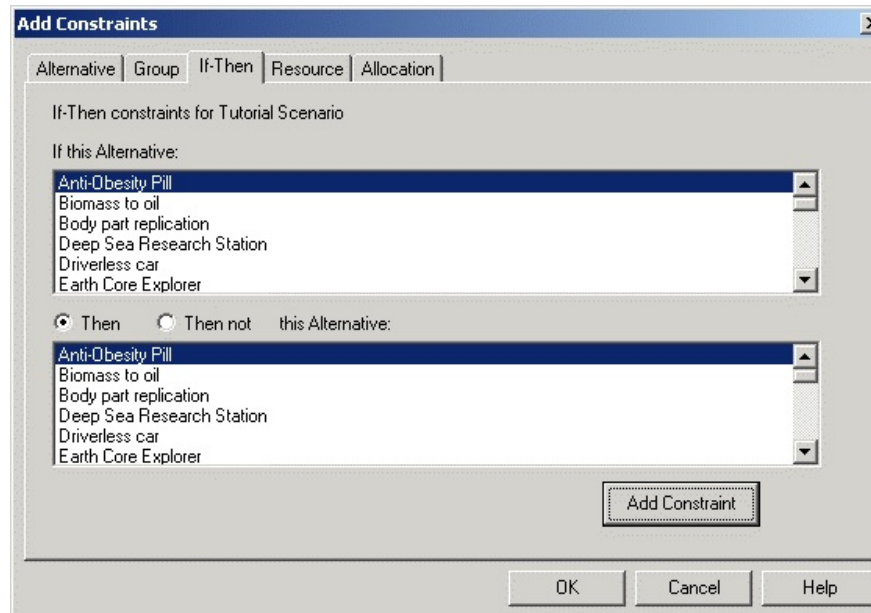
If-then constraints let you define relationships between individual alternatives. They let you require that if alternative A is selected when running the model then alternative B must also be selected. An alternate form of the if-then constraint lets you require that alternative B is NOT selected if alternative A is

selected. The if B then Not A constraint can also be interpreted as Not Both A and B.

If-then constraints can be useful if project B is a follow-on to project A that could not be done unless project A was also done.

If-then NOT constraints can be useful if alternatives A and B both meet the same need and would be redundant if they were both selected.

To define an if-then constraint, first click on the If-Then tab in the Define Constraints dialog box. You will see the page shown below.



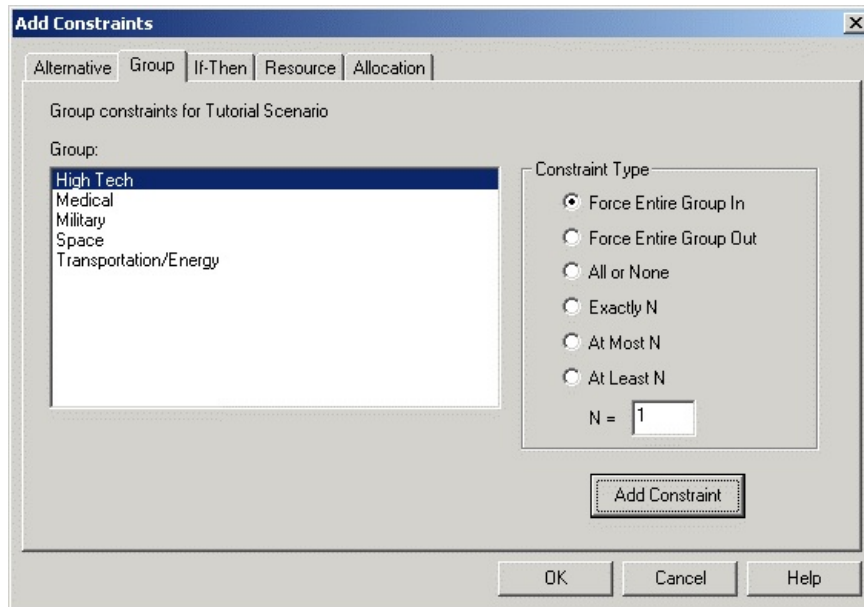
Select the “If” alternative from the top list and the “Then” alternative from the bottom list. Then click on one of the radio buttons at the top of the list on the right to select whether the constraint will be if-then or if-then NOT. Finally, to add the constraint to the Scenario, click the “Add Constraint” button.

Constraints based on groups of alternatives

You can define a variety of constraints based on groups of alternatives. This ability is the reason why LDW Portfolio lets you define groups in the first place. You define group constraints under the Group tab in the Add Constraints dialog box.

Before you can add group constraints, you must define groups. Defining groups is discussed after the discussion of adding constraints.

You can define the following constraints for any group that you have defined.



Force entire group in. Force all of the members of the group into the set of selected alternatives when the model is run. Usually you will want to do this on a temporary basis to see the effect on the total benefit of selecting all of the alternatives in the group.

Force entire group out. Force all of the members of the group out of the set of selected alternatives when the model is run. Usually you will want to do this on a temporary basis to see the effect on the total benefit of not selecting any of the alternatives in the group.

All or None. Select either all of the members of the group or none of them. This can be useful if all of the alternatives in the group are interrelated in some way and it only makes sense to select them as a group.

Exactly N. Force N of the alternatives in the group into the mix, but no more than N, where N is the number in the edit box at the end of the list of constraint types. This is similar to the One or None type of constraint, but implies that the alternatives in the group provide an essential feature and that N of them must be selected to make a viable portfolio.

At Most N. Ensure that no more than N of the members of the group is selected. This can be useful if the alternatives in the group serve a similar purpose and selecting more than N of them would be redundant.

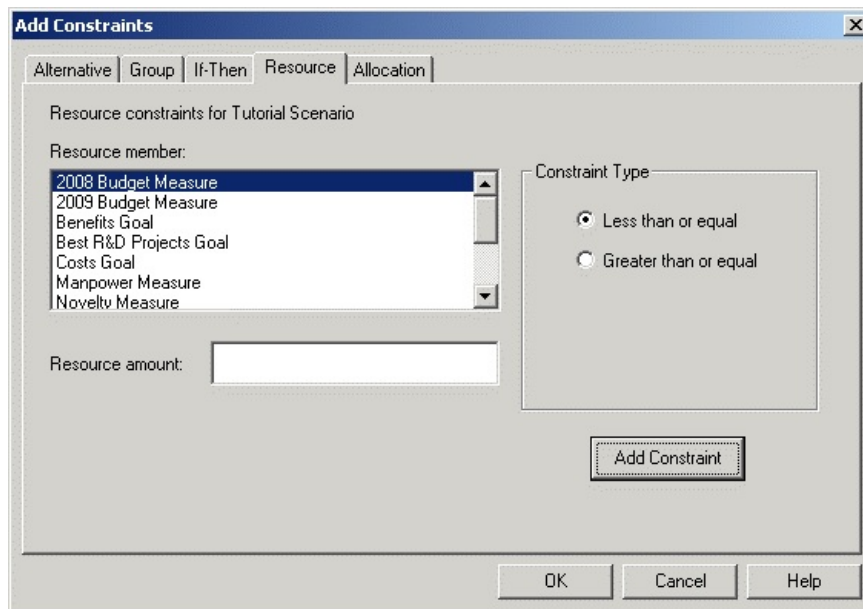
At Least N. Ensure that at least N of the alternatives in the group is selected, where N is the number in the edit box at the end of the list of constraint types. This is similar to the Exactly N constraint type, but implies that the alternatives in the group are not mutually exclusive.

To define a group constraint, first click on the Group tab in the Add Constraints dialog box. You will see the page shown above. Select the group from the list on the left side of the dialog box. Then click on one of the radio buttons on the right to select the type of group constraint you want. If necessary, enter N in the edit box at the bottom of the list of types. Finally, to add the constraint to the Scenario, click the Add Constraint button.

Resource based constraints

You can define constraints based on the cumulative amounts of resources used by the selected alternatives. The resources can be any limited quantity used cumulatively by the different alternatives. Examples could be manpower to work on the alternatives, specialized equipment needed for the alternatives or money from secondary budget sources. The resource constraints can also represent aspiration levels of different quantities that have to be met by the selected group of alternatives. Examples might be budgetary amounts spent in particular states or projects that cumulatively provide a minimum level of personnel to work on a particular task.

The resources are represented by Logical Decisions measures. To define a resource constraint, click the “Resource” tab in the “Define Constraints” dialog box. You will see the page shown below.



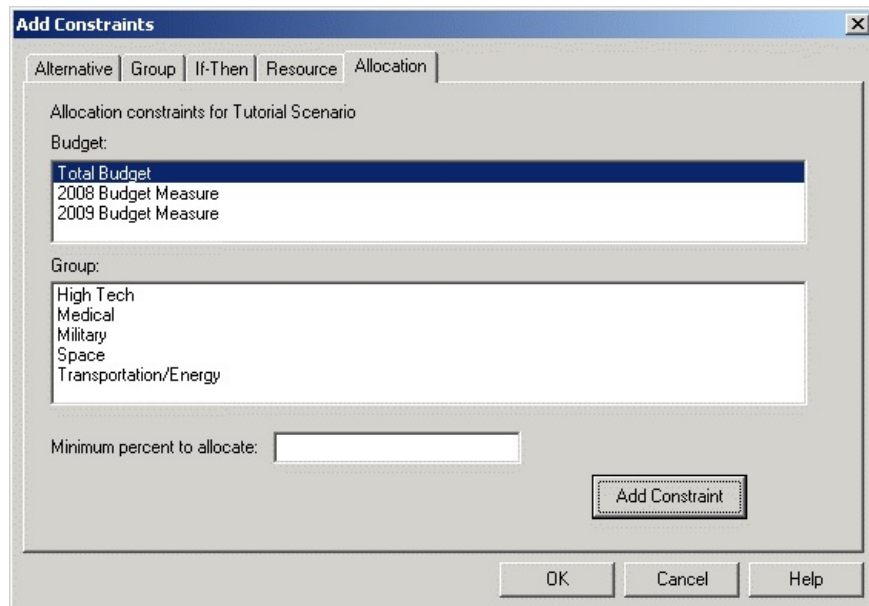
The screenshot shows the 'Add Constraints' dialog box with the 'Resource' tab selected. The title bar reads 'Add Constraints'. Below the tabs, the text 'Resource constraints for Tutorial Scenario' is displayed. A list box labeled 'Resource member:' contains the following items: '2008 Budget Measure' (selected), '2009 Budget Measure', 'Benefits Goal', 'Best R&D Projects Goal', 'Costs Goal', 'Manpower Measure', and 'Novelty Measure'. To the right, the 'Constraint Type' section has two radio buttons: 'Less than or equal' (selected) and 'Greater than or equal'. Below the list box is a text input field labeled 'Resource amount:'. At the bottom right of the dialog is an 'Add Constraint' button. At the very bottom of the dialog are 'OK', 'Cancel', and 'Help' buttons.

Select the Logical Decisions measure that the resource constraint will be based on. Then enter a level in the measure’s scale that will represent either a minimum or maximum acceptable cumulative amount on the measure for the selected alternatives. Then click on the greater than or less than radio button to specify whether the constraint will force the total to be less than or equal to or greater than or equal to the specified amount. To add the constraint, click the Add Constraint button.

Allocation constraints

Allocation constraints let you ensure that a certain percentage of the annual or total budget goes to a particular group of alternatives. For example, you could define a group of alternatives comprised of all those from a particular corporate division. You could then define an allocation constraint that ensures that at least 20 percent of the budget goes to alternatives from that division. You need to be careful that your allocation constraints total less than 100 percent or there will be no feasible way of meeting them all. In addition, since the allocation is based on budget rather than cost, you need to ensure that the percent of the budget allocated is less than the sum of the cost of the alternatives in the group. For example, if the sum of the costs of the alternatives in a group is \$100, and you add an allocation constraint that says 20% of a \$1,000 budget must go to the group, the model will be infeasible, since there is no solution that can allocate \$200 to the group.

To define an allocation constraint, click the “Allocation” tab in the “Define Constraints” dialog box. You will see the page shown below.



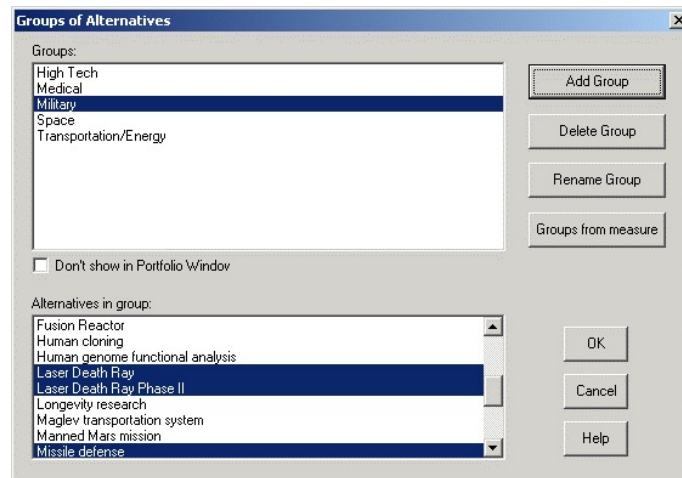
The screenshot shows the "Add Constraints" dialog box with the "Allocation" tab selected. The dialog is titled "Add Constraints" and has a close button (X) in the top right corner. It contains several sections:

- Alternative | Group | If-Then | Resource | Allocation** (tabbed menu)
- Allocation constraints for Tutorial Scenario**
- Budget:** A list box containing "Total Budget", "2008 Budget Measure", and "2009 Budget Measure". "Total Budget" is currently selected.
- Group:** A list box containing "High Tech", "Medical", "Military", "Space", and "Transportation/Energy".
- Minimum percent to allocate:** An empty text input field.
- Add Constraint** button.
- OK**, **Cancel**, and **Help** buttons at the bottom.

You can base an allocation constraint on the budget for any single budget or for the total of all the budgets in the analysis. Select the budget you want from the Budget list and then select the group to apply the constraint to from the Group list. Specify the minimum percentage to allocate to the group in the edit box at the bottom of the page. Finally, click the “Add Constraint” button to enter the constraint.

Defining groups of alternatives

Groups of alternatives are used in defining group constraints and are also the organizing scheme for the Portfolio Window. There is one set of groups in an LDW analysis, which is used for all the scenarios. To define groups of alternatives, select the Portfolio::Define Groups option or click the Define Groups button on the Constraints tab of the Scenario Properties dialog box. When you do one of these options, you will see a dialog box like the one shown below.



A group is just a set of alternatives that should be treated as a unit. It might be that you need to select either all or none of the alternatives in a group or that you need to select at most one of the alternatives.

To add a new group to your model, click the Add Group button in the dialog box. LDW will ask you to enter a name for your group and will then add it to the list at the top of the dialog box. Next, select the members of the group from the list of alternatives in the “Alternatives in group” list. You can add as many alternatives as you want to the group. You can see or change the alternatives in different groups by clicking a group name in the Groups list. When you have finished defining your groups click OK.

There is no limit to the number of groups you can define.

Alternatives can be in more than one group.

You can choose not to display a group in the Portfolio window by selecting it and checking the “Don’t show in Portfolio Window” box.

You can modify a group by clicking its name in the Group list of group names and then selecting or unselecting alternatives from the list of alternatives. To delete a group that is no longer needed, select the group’s name from the list and click the Delete Group button.

Defining groups automatically. You can automatically define groups by clicking the “Groups from measure” button. When you do this, you will be asked to select a LDW measure that uses labels. LDWP will create a group for each different label used by at least one alternative. For example, suppose that you have a measure called “Height” that had the labels “Tall”, “Medium” and “Short”. If you select the Groups from measure option using Height, LDWP will create three groups, a Tall group, a Medium group and a Short group. The members of the Tall group would be the alternatives that have the level Tall on the Height measure, and so on.

The model summary view for a scenario

You can view a summary of the model for a scenario by clicking the Model Summary button in the Portfolio::Select/Change Scenarios dialog box. LDWP will create a display like the one shown below.

Alternative	Benefit	2008 Budget	2009 Budget	Total Cost
Laser Death Ray	0.48065	\$30.00	\$0.00	\$30.00
SARS Vaccine	0.64692	\$15.00	\$15.00	\$30.00
Fuel cell car	0.73665	\$20.00	\$20.00	\$40.00
Biomass to oil	0.65298	\$10.00	\$20.00	\$30.00
Laser Death Ray Phase II	0.43011	\$0.00	\$40.00	\$40.00
Fusion Reactor	0.34126	\$60.00	\$60.00	\$120.00
Next Generation Space Vehicle	0.14409	\$30.00	\$60.00	\$90.00
Missile defense	0.32725	\$40.00	\$80.00	\$120.00
Longevity research	0.31929	\$10.00	\$10.00	\$20.00
Anti-Obesity Pill	0.53290	\$30.00	\$20.00	\$50.00
Paper computer screen	0.63058	\$60.00	\$20.00	\$80.00
Wireless personal ID	0.59124	\$5.00	\$10.00	\$15.00
Driverless car	0.54223	\$40.00	\$30.00	\$70.00
Quantum computer	0.42333	\$60.00	\$60.00	\$120.00
Nanotech fabricator	0.46622	\$100.00	\$100.00	\$200.00
Maglev transportation system	0.62262	\$30.00	\$50.00	\$80.00
Human genome functional analysis	0.49706	\$25.00	\$25.00	\$50.00
Manned Mars mission	0.51581	\$100.00	\$100.00	\$200.00
Earth to space elevator	0.52833	\$100.00	\$0.00	\$100.00
Human cloning	0.51762	\$15.00	\$10.00	\$25.00
Body part replication	0.54193	\$24.00	\$10.00	\$34.00
Earth to Space Elevator Phase II	0.36811	\$10.00	\$100.00	\$110.00
Flying car	0.31536	\$40.00	\$40.00	\$80.00
Deep Sea Research Station	0.52414	\$20.00	\$30.00	\$50.00
Earth Core Explorer	0.42862	\$75.00	\$50.00	\$125.00
Zero value alternative	-0.00093	\$1.00	\$1.00	\$2.00

Constraint summary

- Exclude Zero value alternative Alternative from selection
- Select at least 1 from High Tech Group
- Select at least 1 from Medical Group
- Select at least 1 from Military Group
- Select at least 1 from Space Group
- Select at least 1 from Transportation/Energy Group
- At least 25% of total budget budget must go to Military
- If Earth to Space Elevator Phase II is selected then also select Earth to space elevator
- If Laser Death Ray Phase II is selected then also select Laser Death Ray
- If Human genome functional analysis is selected then don't select Body part replication

In the display, there is a row for each alternative. An alternative’s row shows its benefits and costs as defined in the active scenario. The cost is shown for each budget measure and for the total of all budget measures.

Below the entries for the alternatives LDW displays a summary of the constraints for the scenario. The constraint summaries are the same as those shown in the scenario properties dialog box.

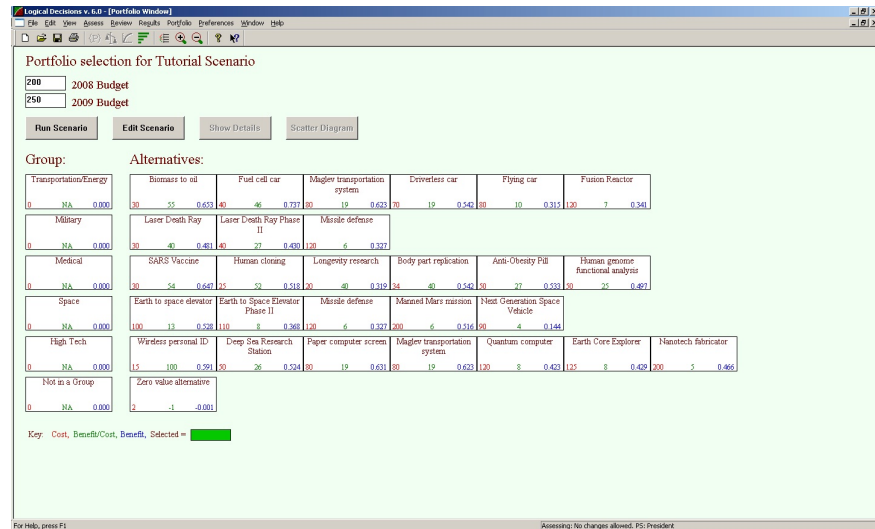
S E C T I O N

Selecting Portfolios

5

Selecting Portfolios

Once you have defined your scenarios and groups, you are ready to select portfolios of alternatives. You do this in the portfolio window view. The Portfolio:Portfolio Window display option creates a window like the one shown below.



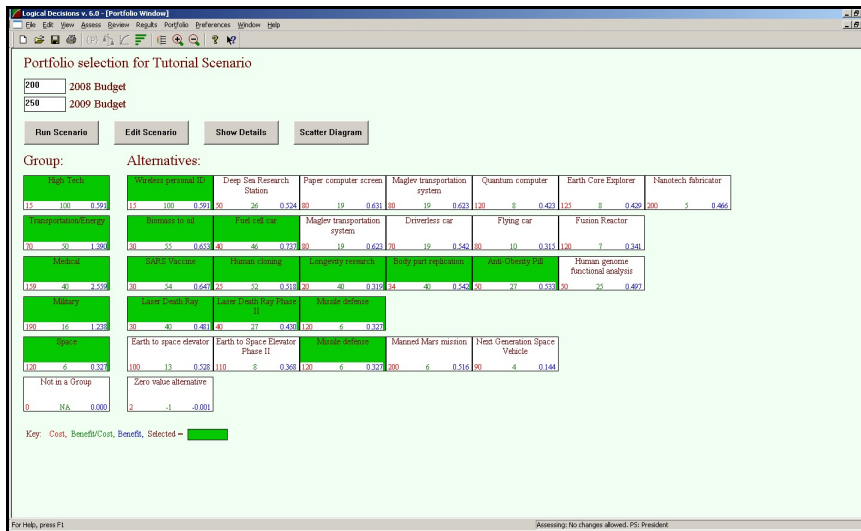
The portfolio window shows the alternatives in your analysis organized by group. At the top of the window, you see the budgets for the current scenario.

Selecting a portfolio

To select a portfolio, enter your budgets in the edit boxes and click the Run Scenario button. LDW will find the portfolio of alternatives that maximizes benefits while meeting the budget and other constraints for the active scenario. LDW will use the solution method you selected for the current scenario.

It is possible that LDW will not be able to find any portfolio of alternatives that meets the budgetary and other constraints. If this happens, LDW will display an error message and not highlight any alternatives or groups.

LDW will highlight the alternatives it has selected in green as shown below.



LDW also highlights a group in green if at least one of its alternatives has been selected.

The three numbers at the bottom of the box for each alternative display its total cost (in red), its total benefit (in blue) and its normalized benefit/cost ratio (in green). LDW computes the normalized benefit/cost ratio by first computing the ratio of benefit to total cost for each alternative and then normalizing so that the alternative with the highest benefit/cost ratio gets a score of 100.

The numbers at the bottom of the box for each group reflect the total cost, benefit and normalized benefit/cost ratio for the alternatives selected in the group.

Sorting the alternatives and groups

You can use the Preferences::Sort option to sort the groups and the alternatives within each group in the portfolio window. You can sort alternatives and groups by name, ID number, total cost, benefit or benefit/cost ratio.

Modifying the active scenario

The portfolio window is based on the active scenario. The active scenario is the one that you most recently selected with the Portfolio::Select/change Scenarios option.

When you change budgets in the portfolio window, LDW updates the default budgets that you initially defined in the scenario properties dialog box.

You can make other changes to the active scenario by clicking the Edit Scenario button in the portfolio window. LDW will display the scenario properties dialog box, where you can change the budget and benefit measures, the portfolio

selection method and the constraints for portfolio selection. When you return to the portfolio window, your changes will be reflected.

Viewing the details of a portfolio

You can view the details of the current portfolio by clicking the Show Details button in the portfolio window. LDW will create a display like the one shown below.

	A	B	C	D	E	F
1	Alternative selection results for Tutorial Scenario					
2						
3	Total budget	\$450.00	Budget allocated	\$434.00	Percent allocated	0.96444
4	Total cost for all Alternatives	\$1,911.00	Budget not allocated	\$16.00	Percent not allocated	0.03556
5						
6	Selected Alternatives	Benefit	Cost	Benefit to Cost ratio		
7						
8	Laser Death Ray	0.48065	\$30.00	0.01602		
9	SARS Vaccine	0.64692	\$30.00	0.02156		
10	Fuel cell car	0.73665	\$40.00	0.01842		
11	Biomass to oil	0.65298	\$30.00	0.02177		
12	Laser Death Ray Phase II	0.43011	\$40.00	0.01075		
13	Missile defense	0.32725	\$120.00	0.00273		
14	Longevity research	0.31929	\$20.00	0.01586		
15	Anti-Obesity Pill	0.53290	\$50.00	0.01066		
16	Wireless personal ID	0.59124	\$15.00	0.03842		
17	Human cloning	0.51762	\$25.00	0.02070		
18	Body part replication	0.54193	\$34.00	0.01594		
19						
20	Total	5.77753	\$434.00	0.01331		
21	Average	0.52523	\$39.45	0.01331		
22						
23	Alternatives not selected	Benefit	Cost	Benefit to Cost ratio		
24						
25	Fusion Reactor	0.34126	\$120.00	0.00284		
26	Next Generation Space Vehicle	0.14409	\$90.00	0.00160		
27	Paper computer screen	0.63058	\$80.00	0.00788		
28	Driverless car	0.54223	\$70.00	0.00775		
29	Quantum computer	0.42333	\$120.00	0.00353		
30	Nanotech fabricator	0.46622	\$200.00	0.00233		
31	Maglev transportation system	0.62262	\$80.00	0.00778		
32	Human genome functional analysis	0.49706	\$50.00	0.00994		
33	Manned Mars mission	0.51581	\$200.00	0.00260		
34	Earth to space elevator	0.52833	\$100.00	0.00528		
35	Earth to Space Elevator Phase II	0.36811	\$110.00	0.00335		
36	Flying car	0.31536	\$90.00	0.00394		
37	Deep Sea Research Station	0.52414	\$50.00	0.01048		
38	Earth Core Explorer	0.42862	\$125.00	0.00343		
39	Zero value alternative	-0.00093	\$2.00	-0.00047		
40						
41	Total	6.34683	\$1,477.00	0.00430		
42	Average	0.42312	\$98.47	0.00430		
43						

In the display, the top lines indicate the budget allocation. The Total Budget is the sum of the individual budgets. The Budget Allocated is the sum of the total budgets for the alternatives selected in the portfolio. The Budget Not Allocated is the difference between the total budget and the budget allocated. The Percent Allocated is the portion of the total budget used by the selected alternatives. The Percent Not Allocated is the percentage of the total budget represented by the budget not allocated. The Total Cost of All Alternatives is the sum of the total costs for all alternatives, selected and non-selected.

Below the budget information are the details of the selected and non-selected alternatives. The selected and non-selected alternatives are shown in separate sections with a line for each alternative. Each alternative's line includes its total cost, benefit and benefit/cost ratio. The total for each of these amounts is shown at the bottom of each section.

Below the selected and non selected alternatives are summaries for the groups and constraints, as shown below.

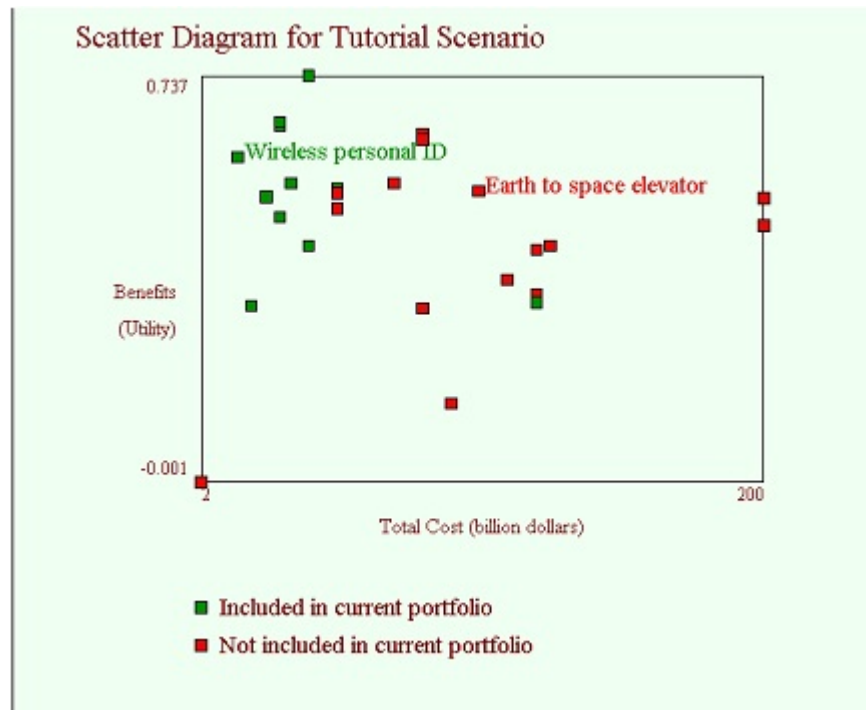
43						
44	Group selection	Number selected	Total benefit	Total cost	Pct. of selected cost	Pct. of total budget
45						
46	Military	3	1.33600	\$193.00	43.77680	43.77680
47	Medical	5	2.55666	\$159.00	36.62594	36.62594
48	Space	1	0.33725	\$123.00	27.84977	27.84977
49	Transportation/Energy	2	1.36863	\$70.00	16.12603	16.12603
50	High Tech	1	0.58124	\$15.00	3.45622	3.45622
51						
52						
53	Constraint results					
54						
55	Exclude Zero value alternative Alternative from selection. Zero value alternative not selected					
56	Select at least 1 from High Tech Group: 1 selected from High Tech					
57	Select at least 1 from Medical Group: 5 selected from Medical					
58	Select at least 1 from Military Group: 3 selected from Military					
59	Select at least 1 from Space Group: 1 selected from Space					
60	Select at least 1 from Transportation/Energy Group: 2 selected from Transportation/Energy					
61	At least 25% of total budget budget must go to Military. Pct = 42.2222					
62	If Earth to Space Elevator Phase II is selected then also select Earth to space elevator. Earth to Space Elevator Phase II selected, Earth to space elevator not selected					
63	If Laser Death Ray Phase II is selected then also select Laser Death Ray. Laser Death Ray Phase II selected, Laser Death Ray selected					
64	If Human genome functional analysis is selected then don't select Body part replication. Human genome functional analysis not selected, Body part replication selected					
65						

The group selection section shows the details of the selection for each group of alternatives. The line for each group includes the number of alternatives selected from the group in the portfolio, the total cost and benefit represented by the alternatives selected in the group, as well as the percentage of the total cost (the sum of the costs of all the selected alternatives) and the percentage of the total budget represented by the total cost of the selected alternatives in the group.

The Constraint Results section summarizes each of the non-budgetary constraints. The information on the line for a constraint depends on the type of constraint, but indicates how the constraint was met.

Viewing a scatter diagram of the portfolio

You can see a scatter diagram of the currently selected portfolio by clicking the Scatter Diagram button in the Portfolio Window. LDW will create a display like the one shown below.



In the diagram, the axes of the graph are the total cost and benefit. The alternatives in the analysis are shown as small squares, colored green for selected alternatives and red for unselected alternatives. You can see the name for an alternative by clicking on its square and hide the name by clicking on the name text.

Portfolio selection methods

The multi-objective decision analysis approach used in standard LDW is appropriate for situations when it is necessary to select only one from a group of alternatives. In many other situations it is appropriate to select more than one alternative. These “portfolio selection” problems are what LDW Portfolio is designed to address.

A variety of approaches to portfolio problems have been developed. Which method is most appropriate depends on the specifics of the problem, the tools and resources available for analyzing the problem and the technical sophistication of the analysts and decision makers.

The simplest portfolio selection case is when there is no reason not to select all the alternatives. In this situation you can just pick all the alternatives, or as many as you want, and you’re done.

Of course, this situation is rare, since there are generally reasons that prevent you from selecting all the alternatives. Frequently it’s because it would be too

expensive to select all the alternatives. In other cases there may be programmatic reasons why only a certain number of alternatives is needed. Restrictions that prevent the selection of all the available alternatives are called “constraints”.

Approaches based on standard LDW

The simplest types of constraints are those that restrict the number of alternatives to be selected. For example a particular problem might have 10 alternatives, but a requirement that only 3 alternatives be selected. In this case, you can use standard LDW to rank the 10 alternatives and select the highest ranking 3.

Another approach based on standard LDW is to frame the problem to evaluate portfolios of alternatives rather than individual portfolios. In this approach, you develop and then rank portfolios of alternatives. You then select the highest ranking portfolio.

In many ways this is the best method for evaluating portfolios of alternatives, since you can consider any interactions between the alternatives in a portfolio when scoring it. You can develop a set of evaluation measures that looks at the costs and benefits of the portfolio as a whole, making it much easier to develop appropriate value functions and weights.

The problem with this approach is that there are generally too many possible portfolios. Consider a problem with 10 alternatives. If each alternative can be either selected or not selected, the total number of possible portfolios is 2 for alternative 1 x 2 for alternative 2 and so on, equaling 2^{10} or 1,024. The number of possible portfolios continues to double with each additional alternative, quickly making any attempt to analyze each possible portfolio of alternatives infeasible.

One way to deal with the problem of too many possible portfolios is to use what is called the “greedy algorithm”. The greedy algorithm consists of selecting alternatives one by one and at each stage selecting the remaining alternative with the highest overall score. So, to apply the greedy algorithm to a portfolio evaluation that uses standard LDW, the first step would be to evaluate all of the portfolios that include just one alternative. Suppose the single alternative portfolio that ranks highest is alternative X. We select X to include in the portfolio. Next we would evaluate all two alternative portfolios that include X. Suppose the highest ranking of these portfolios is the one consisting of X and Z. We select Z to add to the portfolio. The process continues by adding alternatives one by one until there is no single alternative that would increase the overall value of the current portfolio.

Benefit/cost ratio method

Perhaps the most common approach for selecting portfolios of alternatives is benefit/cost analysis. With this option, LDW Portfolio evaluates the alternatives from two perspectives – their costs and their benefits. Benefits are those features that make an alternative more desirable, while costs are those features that make it less desirable.

In the Benefit/Cost selection method, LDW Portfolio sorts the alternatives in order of decreasing benefit cost ratio and then uses the greedy algorithm to pick the alternatives one by one. This approach can work well if there are few interactions between the alternatives and relatively simple cost constraints.

An important advantage of the benefit/cost ratio approach is that it identifies a unique ordering of the alternatives which can be used to identify the recommended portfolio for each possible budget. With zero budget, we select no alternatives. As the budget increases, we buy the alternative with the highest benefit/cost ratio first, the one with the second highest ratio second and so on. Once an alternative is bought at a given budget level, it is also bought at all higher budget levels. For this reason, the list of alternatives ordered by benefit/cost ratio is called an “order of buy”.

It can be shown that the greedy algorithm used in the benefit/cost ratio approach results in portfolios that are the optimal solution (the portfolio with the highest benefit for a given cost) for their total portfolio cost. However, between the points selected by the greedy algorithm there may be other solutions. This means that unless the available budget happens to fall on one of the amounts selected by the greedy algorithm there may be a portfolio with a higher total benefit that meets the budget but is missed by the greedy algorithm.

The benefit/cost approach does not work if there are multiple budget or other constraints, since a single cost benefit/ratio can't be computed. A possible workaround is to combine the costs using accounting methods or an LDW goals hierarchy.

Benefit/Cost ratios with constraints

The benefit/cost ratio with constraints method extends the benefit/cost ratio method by allowing alternatives or groups of alternatives to be forced into or out of the portfolio and also to ensure that either one or none or exactly one of the alternatives in a group is selected. One way this method can be used is to develop groups of alternatives representing functional or operational areas. For example, the analysis of a trip to Europe discussed in the Strategies for Portfolio Analysis section has the functional areas of the flight, the hotel and the optional activities. A range of alternatives or variations can be developed for each of these areas, such as flying coach, business or first class.

A value function with one benefit measure for each functional area can then be developed. The alternatives outside of a functional area will each get a zero on the functional area's benefit measure. For example all of the hotel alternatives will get a zero on the flight measure. The zero point for each measure is the value of selecting no alternative for that area and the maximum utility point is the value of selecting the best alternative for the area.

If the problem requires selecting at least one alternative from an area, the cost of the least expensive alternative can be considered to be a sunk cost and the benefit measure for that area can be rescaled so that the lowest cost alternative has a value of zero. In the example, we have to select at least one option from the flight alternatives, so we can rescale the measure to get a 0.0 for coach, a 1.0 for first class and an intermediate value for business class.

The weight for each measure can be assessed as the swing weight for moving between no alternative (or the least preferred required alternative) and the most preferred alternative in the functional area.

If the problem is structured so that exactly one alternative must be chosen in each functional area, then LDW Portfolio can do the cost/benefit calculations using incremental rather than absolute costs and benefits. In this situation, the least desirable portfolio is the one made up of the least desirable alternative in each functional area. We can call this the baseline portfolio. The cost of the baseline portfolio consists only of the sunk costs of the cheapest alternative in each functional area, and thus can be considered to be zero incremental cost.

As we increase the budget over the baseline sunk cost, the next alternative added to the portfolio is the one with the highest incremental benefit/cost ratio over the baseline alternative in its functional area. Since we only need one alternative from each functional area, we replace the original alternative from the functional area with the newly selected one in the revised portfolio. We continue the process by identifying the alternative with the highest incremental benefit/cost ratio over the items in the current portfolio and moving it into the portfolio while removing the current alternative from its functional area.

Optimization using 0-1 integer linear programming

The portfolio selection problem can be described mathematically as an optimization problem of the form:

Maximize (total benefits) subject to (total costs \leq total budget)

The contribution to the total benefit from an individual alternative is its value from an LDW evaluation if it is selected and none if it is not. Similarly, the cost of an alternative is its estimated cost if it is selected and none if it is not. The contributions of individual alternatives to both costs and benefits are summed to arrive at the totals.

This type of problem is called a “0-1 integer linear programming program” in the operations research literature and methods for efficiently finding the optimum solution (the portfolio with the most benefit for a given budget) have been developed. These types of problems are related to standard linear programming problems, but require more sophisticated solution algorithms.

The primary advantage of this approach is that it can find an optimum portfolio for any budget, not just those found in portfolios made from a benefit/cost order of buy. In addition, the programming formulation allows for multiple constraints to be imposed, not just a single budget constraint. Additional constraints can be used for multiple cost categories, for example, budgets from multiple years or amounts allocated by different payers. Constraints can also be programmatic, such as requiring at least one alternative to be selected from a particular group of alternatives, or requiring that alternative B can only be selected if alternative A is also selected.

One drawback of the programming approach is that the portfolio can change dramatically with even a small change in the budget. This is because the solution algorithm looks at all possible alternatives and does not work from an order of buy. For example, a small budget increase might allow the solver to

replace one big alternative with several smaller ones that provide just a little more total benefit.

The 0-1 integer programming approach uses a solution method called “branch and bound” that evaluates many different portfolios in order to find the best one. Each evaluation is called an iteration, and it can take thousands or millions of iterations to find the best portfolio for a large problem. To reduce the time needed for computation, LDWP gives you the option of limiting the number of iterations. You set the limit on the first page of the Scenario properties dialog box. If LDWP reaches the limit before it has found the optimum portfolio, it will stop and return the best portfolio it has found so far.

S E C T I O N

The Efficient Frontier

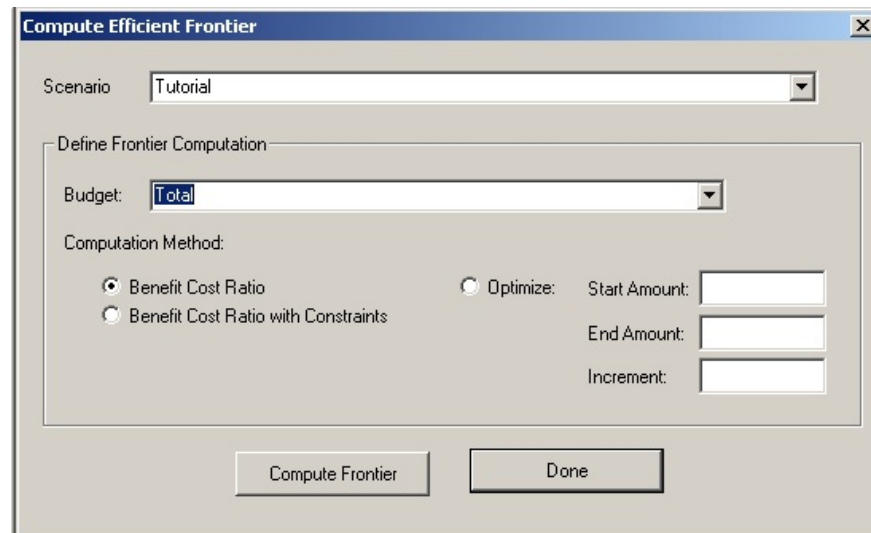
6

The Efficient Frontier

A portfolio is on the efficient frontier if there are no portfolios that can be found that have both a lower cost and a greater or equal benefit. Thus the efficient frontier is made up of those alternatives that have the greatest benefit for each budget level. Portfolios on the efficient frontier with high costs must have proportionally high benefits, since if their benefits were lower than those of a portfolio with lower cost, by definition they would not be on the efficient frontier.

The efficient frontier provides a set of portfolios that provide the most benefit for any given budget.

You can compute and view the efficient frontier by selecting the Portfolio::Efficient Frontier option. LDW will display the dialog box shown below.



At the top of the dialog box, you can select the scenario that the efficient frontier will be based on. Below that is a list of the budgets for the scenario with the addition of a total budget if the scenario includes more than one budget.

At the bottom of the dialog box are three computation options – Benefit/Cost ratio, Benefit/Cost ratio with constraints, and Optimize.

LDW will compute the efficient frontier based on the selected budget and computation method. If you select the Benefit/Cost ratio option, LDW will sort the alternatives by benefit/cost ratio based on the selected budget and then use the greedy algorithm to add alternatives one by one to the current portfolio. First, the alternative with the highest benefit/cost ratio will be picked, then the

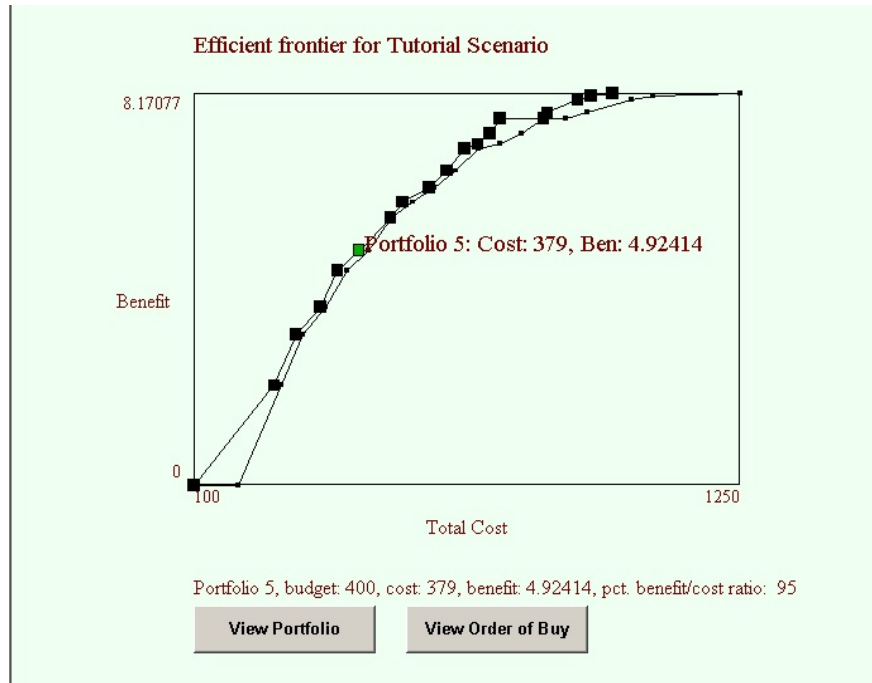
alternative with the second highest ratio and so until all of the alternatives have been picked. This set of portfolios, one with one alternative, one with two alternatives and so on, forms the efficient frontier.

If you select the Benefit/ cost ratio with constraints method, LDW will select alternatives one by one as in the Benefit/Cost ratio method with the following differences. The initial portfolio will consist of the set of all alternatives that are either forced in or that are the lowest cost member of a group where at least one alternative must be selected. Then, whenever a new alternative is added to the current portfolio, LDW will check if the alternative belongs to a group that requires at most one alternative to be selected. If so, LDW will remove any alternative from that group from the portfolio before adding the new alternative. In selecting alternatives to add, LDW will look at the incremental benefit/cost improvement of the new alternative over the existing alternative from a group in selecting the next alternative to add.

If you select the Optimize method, LDW will solve a series of 0-1 integer programming problems to identify the efficient frontier. The Optimize method does not have a systematic method for adding alternatives one by one to the portfolio. Instead, it evaluates all possible portfolios of alternatives and finds the portfolio that provides the highest benefit while still meeting the budget and other constraints. Thus to find the efficient frontier with the Optimize method, you need to tell LDW what budget levels evaluate. You do this by setting the start and end budget levels as well as a budget increment. LDW will first find the optimum portfolio for the starting budget and then find the optimum for the starting budget plus the increment and so on until it finds the optimum for the end budget. If you select the total budget and there is more than one budget measure, LDW will proportionally allocate the total budget among the budget measures based on the relative sizes of the budgets in the selected scenario.

Displaying the efficient frontier

When LDW has completed its calculations, it will display a window like the one shown below.



In the display, portfolios are shown as black squares plotted on a cost vs. benefits graph. The smaller black dots represent the budget allowed at a particular level. If the small box is to the right of a large portfolio box, it means that LDW was not able to find a portfolio that fully spends that budget amount.

To see the cost and benefit for a particular portfolio, click on its square. To hide the details for a portfolio click on its text.

If you click the View Portfolio button, LDW will display a portfolio window with the alternatives selected in the portfolio highlighted.



This portfolio window is a little different from the standard one, since it has several buttons at the top that let you move around the efficient frontier. The “Prev.” button will highlight the alternatives that are different in the current efficient frontier portfolio than the previous one. If a green box is highlighted, the alternative is in the current portfolio, but was not in the previous portfolio. If a white box is highlighted, the alternative was in the previous portfolio, but is not in the current portfolio. The “Next” button has the same functionality, but compares the current portfolio to the next more costly one on the efficient frontier. In this case, a highlighted green box means the alternative is in the current portfolio, but is not in the next one, while a highlighted white box means the alternative is in the next portfolio, but is not in the current one.

The green arrow buttons let you move between the portfolios on the efficient frontier.

The View Order of Buy Window

When you click the “View Order of Buy” button in the efficient frontier window. There are two variants of the view order of buy window. The order of buy display is the default if the benefit/cost or benefit/cost with constraints method was used to compute the efficient frontier. The “piano roll” display is the default if the optimize method was used.

The order of buy display

The order of buy display shows the order in which alternatives are added to (or removed) from the best portfolio as the budget increases. An example of the order of buy display is shown below.

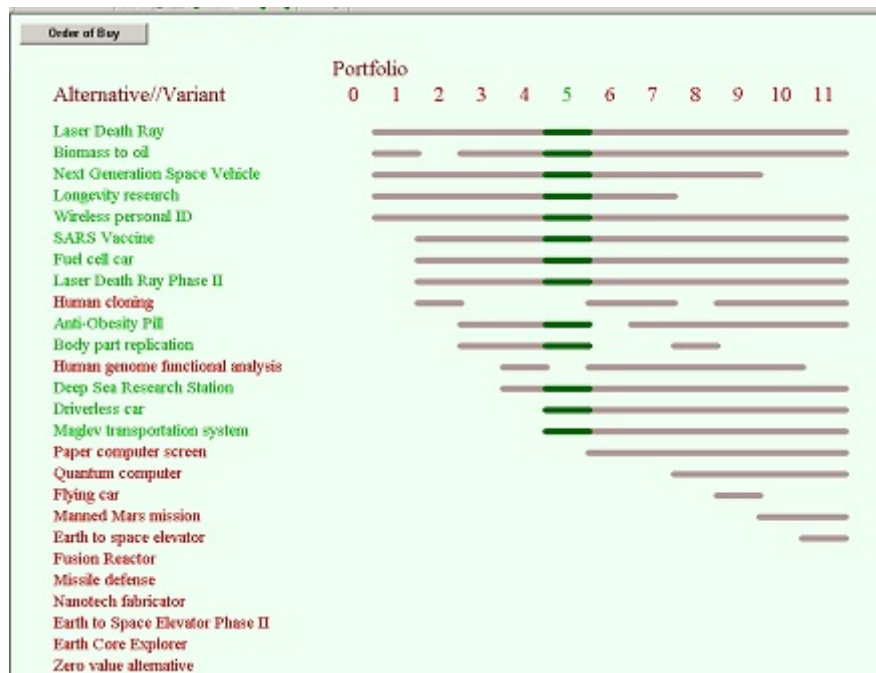
Piano Roll			
Portfolio	Total Cost	Benefit /Cost	Items added/removed
0	0	0	Added:
1	183	47	Added: Laser Death Ray, Biomass to oil, Next Generation Space Vehicle, Longevity research, Wireless personal ID
2	290	99	Added: SARS Vaccine, Fuel cell car, Laser Death Ray Phase II, Human cloning Removed: Biomass to oil
3	379	100	Added: Biomass to oil, Anti-Obesity Pill, Body part replication Removed: Human cloning
4	479	95	Added: Human genome functional analysis, Deep Sea Research Station
5	579	87	Added: Driverless car, Maglev transportation system Removed: Human genome functional analysis
6	650	84	Added: Paper computer screen, Human genome functional analysis, Human cloning Removed: Anti-Obesity Pill, Body part replication
7	700	84	Added: Anti-Obesity Pill
8	809	74	Added: Quantum computer, Body part replication Removed: Longevity research, Human cloning
9	880	70	Added: Human cloning, Flying car Removed: Body part replication
10	910	68	Added: Manned Mars mission Removed: Next Generation Space Vehicle, Flying car
11	960	65	Added: Earth to space elevator Removed: Human genome functional analysis

In the display, the portfolios are in order of increasing total cost. The line for each portfolio shows the total cost of the portfolio, the relative benefit/cost ratio for the portfolio and the items added or removed from the previous portfolio.

The display also has an option to toggle to the piano roll display, which shows the portfolios in an alternate graphic format.

The piano roll display

The piano roll display graphically shows the alternatives included in any particular portfolio, as shown in the example below.



The alternatives are listed on the left and there is a column for each portfolio. In the column for a portfolio, the alternatives included in that portfolio are indicated with a line segment. By looking at the row for an alternative, you can

quickly see how often it is included in portfolios on the efficient frontier. You can click on the number for a portfolio to highlight its included alternatives. If there are more portfolios than fit in the window, scroll arrows will appear to let you control which portfolios are displayed.

A button lets you toggle from the piano roll display to the order of buy display.

S E C T I O N

Alternative Variants

7

Alternative Variants

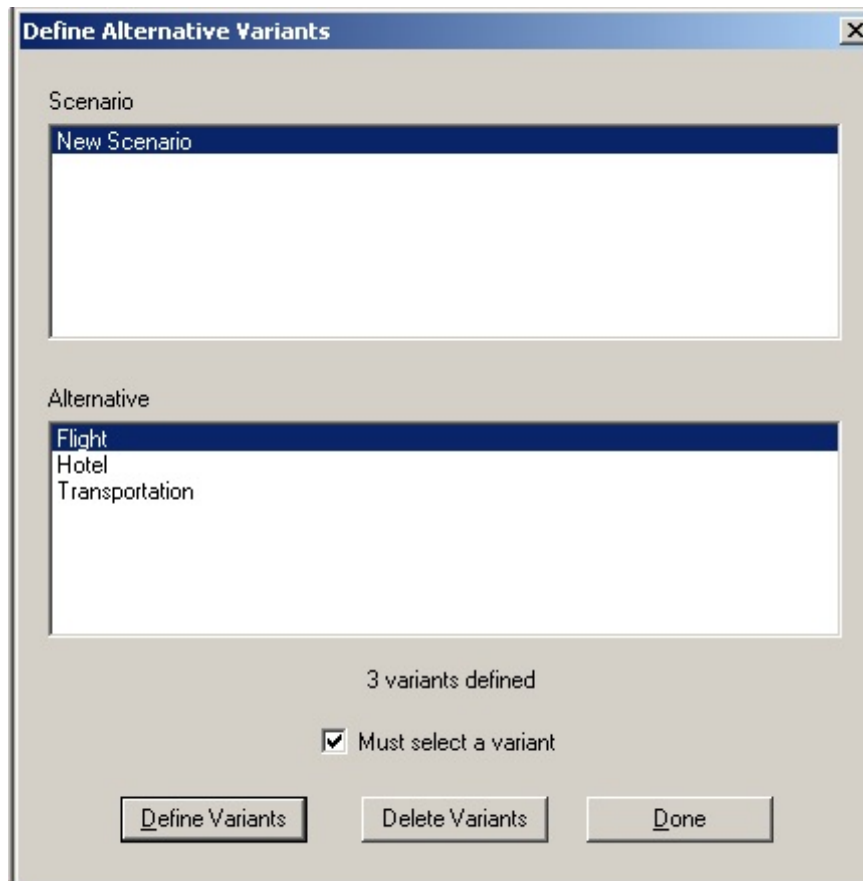
In many budget allocation situations it is possible to assign different budget levels to a particular alternative. For example, if the alternatives represent departments within a company, there may be many possible funding levels for that department. Another situation is when you can purchase several copies of an alternative, for example, a police department might buy several identical patrol cars and might get a discount on multi-car purchases.

In these types of situation it can be difficult to quantify the differences using a LDW utility function. For example, it may be difficult to predict exactly how a department will change its activities given a reduced budget. In the police car example, it might be felt that there is a decrease in the marginal benefit of each additional car, but hard to see how you would score a second car differently than the first.

In these situations, managers and decision makers could well feel more comfortable scoring the benefits as a percentage of the benefit of the initial alternative. For example managers might feel that funding 80% of a department's budget request would provide 90% of the benefit or that the second patrol car in a fleet could provide 75% of the benefit of the first.

With these situations in mind, LDW Portfolio lets you define what are called Alternative Variants that have their benefits proportional to a default alternative. Using alternative variants, you can include the default alternative in your set of alternatives to be scored using a LDW utility function, but then define variations on that alternative that are scored and/or priced as a percentage of the default.

To define alternative variants, select the Portfolio::Define Alternative Variants option. LDW will display the dialog box shown below.



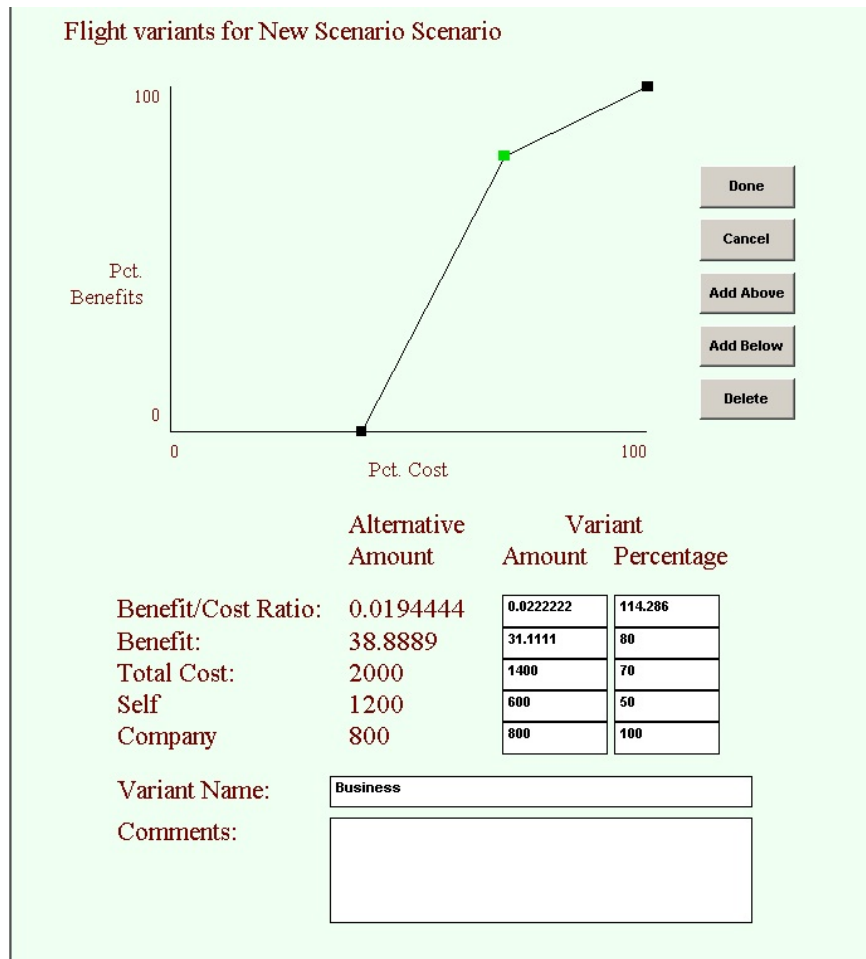
In the dialog box, you first select the scenario, since alternative variants are associated with a scenario. Then you select the alternative to define the variants for. When you select an alternative in the list, LDW will display the number of variants defined so far for the alternative.

You can delete all of the variants for an alternative by clicking the Delete Variants button.

If you check the Must select a variant box, LDW will be forced to select one of the variants you define for the selected alternative. If you don't check the box LDW can select either one or none of the variants.

One of the assumptions of alternative variants is that at most one of them may be selected for a given portfolio.

To define new variants for the selected alternative, click the Define Variants button. LDW will display a window like the one shown below.



In the display, the default alternative is shown at the 100 percent cost and 100 percent benefit point. The variants are shown in relation to the default variant. In LDW Portfolio, both the default variant and the other variants can have a different name from the alternative. In the screen above, from a business traveling example, the alternative's name is Flight, the default variant's name is First Class and the other variants are named Business and Coach.

To define a new variant, click the Add Above or Add Below button. If you click the Add Below button, LDW will add a new variant halfway between the selected variant and the one just below it. If there is no variant below the selected variant, LDW will add the new variant at the benefit/cost point halfway between the selected variant and the 0 cost, 0 benefit point.

If you click the Add Above button, LDW will add a new variant halfway between the selected variant and the one just above it. If there is no variant above the selected variant, LDW will add the new variant at the point with twice the cost and benefit of the selected variant.

Once you have added a variant, it becomes selected and you can edit its cost and benefit.

You can change the cost and benefit of the selected variant by dragging its point around the graph. The numbers in the edit boxes will be updated to reflect your changes.

You can also change the variant by entering values in the edit boxes. There are edit boxes for Benefit/Cost ratio, Benefit and for each budget measure for the active scenario, as well as for the total budget. You can enter values either directly or as percentages. If you enter a value or percentage for total cost, LDW will proportionally adjust the values and percentages for each budget measure.

At the bottom of the window are edit boxes where you can change the name of the selected variant and enter comments.

LDW Portfolio treats variants much like alternatives when it is selecting portfolios. Alternative variants have their own section in the portfolio window and are shown in place of their alternative in other LDW Portfolio displays.

S E C T I O N

Strategies for Portfolio Analysis

8

Strategies for Portfolio Analysis

LDW Portfolio provides a variety of options for selecting portfolios. This section discusses several strategies for organizing and conducting a portfolio selection that are appropriate for different types of problems. The following applications will be discussed:

- selecting a portfolio of projects by creating an order of buy;
- identifying funding levels using alternative variants;
- selecting a mix of alternatives and alternative variants using optimization.

Selecting a portfolio of projects by creating an order of buy

The first example is a relatively simple analysis of a set of R&D projects. The analysis is contained in a file called R&D projects simple.ldw.

In the analysis a set of 23 alternatives is evaluated on a single measure, called Benefit. The measure scale goes from 0 to 100, with 100 representing the most preferred level. We assume that the measure is scaled so that the decision maker would not be willing to pay anything for an alternative with a benefit of 0, but would pay something for an alternative with a benefit of 1 out of 100.

You can see the alternatives and their scores on the benefit measure in the ranking results graph shown below.

Ranking for Benefits Measure
(Utility)

Alternative	Utility	Level
Fuel cell car	72.8	72.848
Biomass to oil	64.2	64.222
SARS Vaccine	63.6	63.598
Paper computer screen	61.9	61.913
Maglev transportation system	61.1	61.092
Wireless personal ID	57.9	57.857
Driverless car	52.8	52.804
Body part replication	52.8	52.773
Anti-Obesity Pill	51.8	51.842
Earth to space elevator	51.4	51.37
Deep Sea Research Station	50.9	50.939
Human cloning	50.3	50.267
Manned Mars mission	50.1	50.08
Human genome functional analysis	48.1	48.147
Laser Death Ray	46.5	46.455
Nanotech fabricator	45.0	44.967
Earth Core Explorer	41.1	41.091
Quantum computer	40.5	40.545
Fusion Reactor	32.1	32.084
Missile defense	30.6	30.639
Longevity research	29.8	29.819
Flying car	29.4	29.413
Next Generation Space Vehicle	11.8	11.756

Preference Set = President

The analysis has a single cost measure, called Cost which has units of billions of dollars. We assume that the alternatives are all independent of one another, so that there is no need for additional constraints on selecting the alternatives.

This simple structure makes this analysis suitable for the benefit/cost selection method. A scenario called R&D Projects was defined to support the portfolio selection. The benefits and costs were defined as described above and benefit/cost ratio was chosen as the selection method.

The alternatives were organized into groups, although it was not strictly necessary since there were no group constraints. The groups can be seen in the portfolio window display shown below.

We are now ready to select alternatives by computing the efficient frontier. We can just select the defaults in the dialog box and we will create a display like the one shown below.

Identifying funding levels using alternative variants

This example expands the discussion of the trip to Europe example discussed earlier. It is contained in a file called Travel to Europe.ldw.

The example concerns planning a business trip from the United States to Europe. There are three required elements to the trip: the flight, the hotel and transportation to the airport. The company will fund a bare bones trip, but the traveler can add her own funds to upgrade one or more of the elements.

The analysis consists of three alternatives corresponding to the three required elements: Flight, Hotel, and Transportation. Each alternative has several variants, as shown below in the Portfolio Window for the analysis.

Alternative:	Variants:													
Hotel	Hotel			Two Star			Three Star			Four Star				
1600	NA	55,556	80	NA	0.000	240	NA	27,778	400	NA	38,889	1600	NA	55,556
Transportation	Drive			Cab			Limo							
250	NA	5,556	60	NA	0.000	100	NA	3,889	250	NA	5,556			
Flight	Coach			Business			First Class							
2000	NA	38,889	800	NA	0.000	1400	NA	31,111	2000	NA	38,889			

Key: Cost, Benefit/Cost, Benefit, Selected =

For example, the Flight alternative has three variants, Coach, Business and First Class.

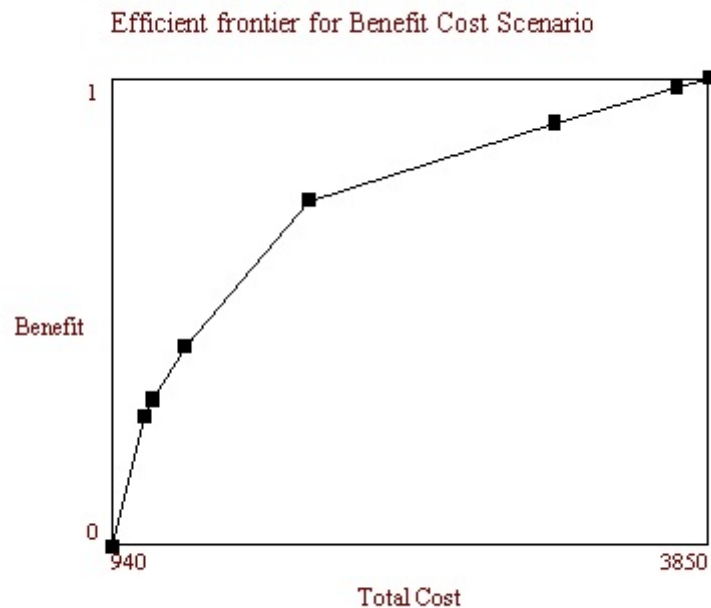
Each element has an associated measure representing the benefit from that part of the trip. These measures are called Flight Benefits, Hotel Benefits, and Transportation Benefits. Each one uses a 1 to 100 scale, with 100 being the most preferred level. The measures are weighted using the Smart method to reflect the relative importance and range of desirability of the variants for each alternative. The alternative variants get a score of from 0 to 100 on their own measure and a score of 0 on the measures for the other alternatives. The default variant for each alternative is the one that has a level of 100 on the alternative's measure.

In addition to the benefit measures, there are three cost measures, Company, Self, and Total. Each variant has a portion that is funded by the company and a portion that the traveler pays herself. The Total measure is the sum of the Company and Self measures. The Model Summary display summarizes the costs of the variants, as shown below.

2					
3	Alternative	Benefit	Self	Company	Total Cost
4					
5	Drive	0.00000	\$0.00	\$80.00	\$80.00
6	Cab	3.88889	\$20.00	\$80.00	\$100.00
7	Limo	5.55556	\$170.00	\$80.00	\$250.00
8	Hostel	0.00000	\$0.00	\$80.00	\$80.00
9	Two Star	27.77780	\$0.00	\$240.00	\$240.00
10	Three Star	38.88890	\$160.00	\$240.00	\$400.00
11	Four Star	55.55556	\$1,360.00	\$240.00	\$1,600.00
12	Coach	0.00000	\$0.00	\$800.00	\$800.00
13	Business	31.11110	\$800.00	\$800.00	\$1,400.00
14	First Class	38.88889	\$1,200.00	\$800.00	\$2,000.00

We can select the portfolio in two ways. The selection methods are implemented in two scenarios – Benefit Cost and Optimize. The Benefit Cost scenario implements the Benefit Cost Ratio with Constraints selection method. This method extends the standard benefit cost method by allowing the requirement that exactly one variant must be selected for each alternative. The method initially selects the lowest cost for each variant as a baseline and then replaces variants by identifying the variant with the greatest incremental benefit cost ratio over the currently selected variant. Because the method uses benefit cost ratios, only a single cost measure can be used. The Total cost measure was selected as the single budget measure for the Benefit Cost scenario for this reason.

The efficient frontier for the Benefit Cost scenario is shown below.



The least expensive portfolio consists of the Coach, Drive and Hostel variants and costs \$940. The next portfolio replaces the Hostel with the Two Star hotel, since the Two Star variant has the highest incremental benefit cost ratio of the unselected variants.

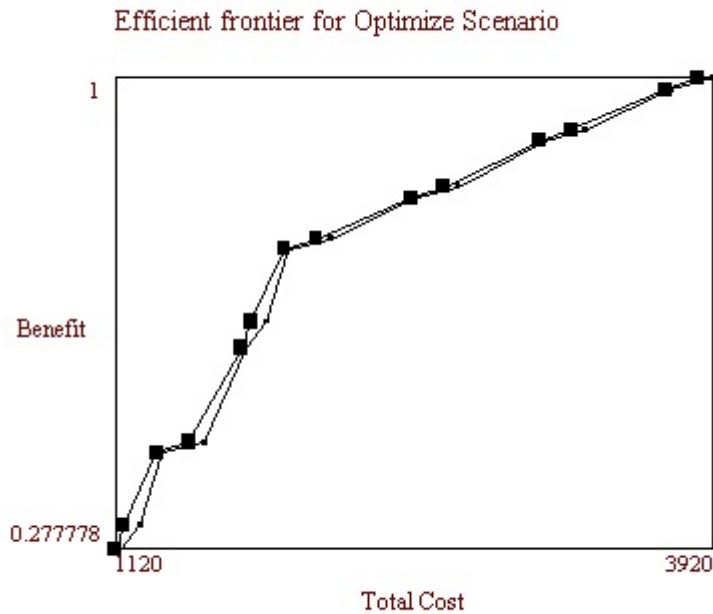
Note that the efficient frontier has the convex shape that is characteristic of the benefit cost ratio method. This occurs because variants with high benefit cost ratios are selected first and have the steepest slope on the graph, meaning that the slopes for the variants selected later will be shallower than the slopes of the variants selected earlier.

In the Optimize scenario we use the 0-1 Integer Programming method to select portfolios. This method has the advantage of being able to ensure that we meet both of the budget constraints rather than just a total budget constraint.

In contrast to the Benefit Cost approach, the optimization approach does not have a fixed selection order. Instead, the optimization tries to get the maximum possible benefit for any given budget. This means that the solver will often pick big, high value variants first and then “fill in” with smaller variants until the budget is met.

Because there is no fixed selection order, we must instead tell the solver which budgets we would like it to look at. When computing an efficient frontier, we specify which budget to vary, the budget to start with, the amount to increment each budget and when to start.

In the example, the company is only willing to pay up to \$1120. So, it makes sense to fix the Company budget at \$1120 and vary the amount we pay ourselves to see how the total benefit improves as we increase the Self budget. The result for an efficient frontier going from 0 to \$3000 in increments of \$100 is shown below.



You can see that the curve is not convex as is the case with the Benefit Cost approach. The graph shows a “knee” in the curve at the sixth portfolio, which consists of the Three Star hotel, Business Class flight and Cab transportation. This portfolio is also found by the Benefit Cost method.

Selecting a mix of alternatives and alternative variants using optimization

This example expands on the travel to Europe example by adding activities and side trips. These are all optional and would not be paid for by the company. The new activities are a day trip, a meal at a three star restaurant and a spa treatment. The day trips are a hiking trip, a bus tour and a harbor cruise. While all of the day trips are optional, it would only be possible to do one of them. The most desirable activity is the spa treatment, but it is only available if you stay in the Four Star hotel. The file for this example is Travel to Europe with Activities.ldw.

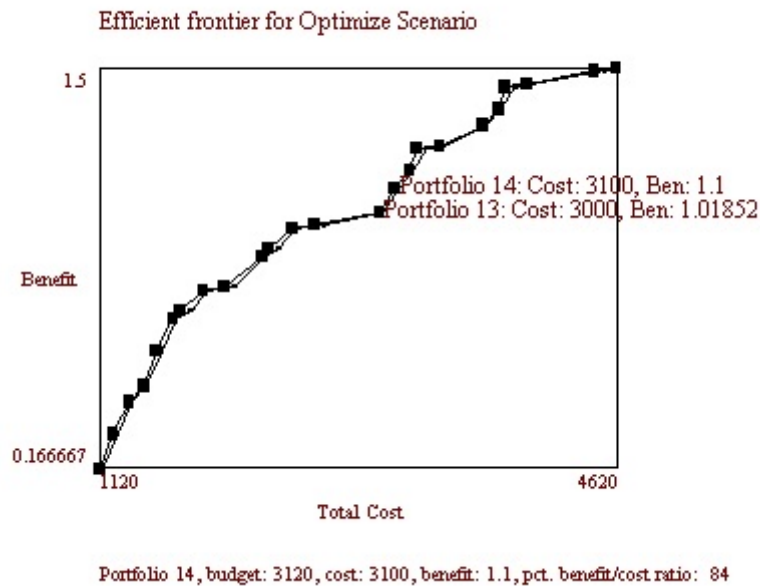
To model these activities in LDW, we add an alternative for each of the activities. Then we add groups for the three day trips and the two other

activities. We add a measure for the benefits of the activities. Then we add a constraint in the Optimize scenario to ensure that at most one of the day trips is selected in any portfolio.

Modeling the constraint that the spa treatment can only be done if we stay at the Four Star hotel is a little more complicated. Since LDW does not allow constraints involving variants, we will replace the hotel variants with corresponding alternatives. First we delete the Hotel alternative and add four new alternatives representing the different hotel options. We create a group called Hotel and add the four hotel alternatives to the group. Finally, we add a constraint saying that exactly one alternative from the Hotel group must be selected. This grouped set of four alternatives will be treated exactly the same as the four alternative variants by the solver.

Now we are ready to add the spa treatment constraint. We add an If-Then constraint saying that if we pick the Spa Treatment alternative we must also pick the Four Star hotel.

This leads to some interesting results. We generate the efficient frontier using the Optimize method as shown below.

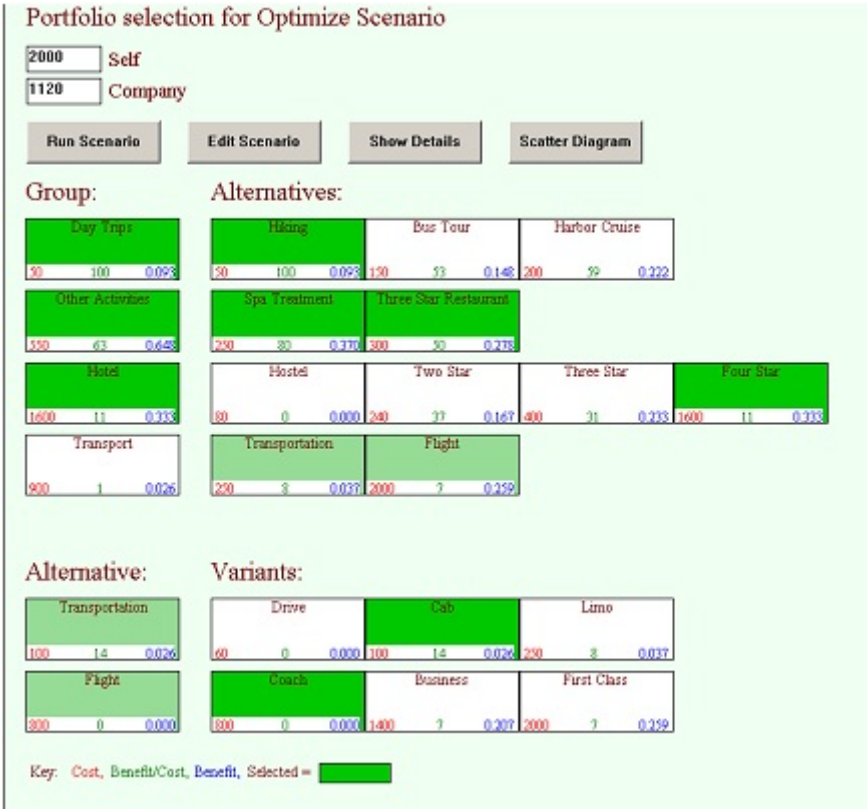


You can see what looks like two more or less convex curves, one for the portfolios below number I3 and one for the portfolios above number I3. The Portfolio Window for portfolio I3 is shown below.



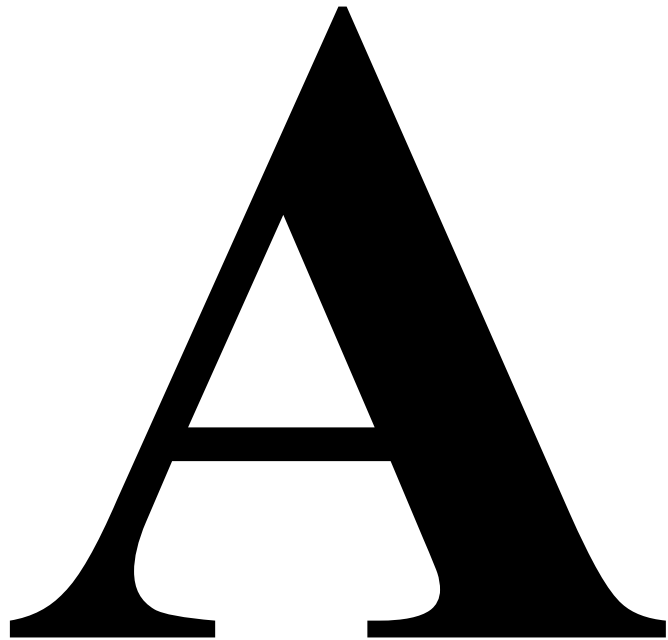
In portfolio I3, the self budget is \$1900, which allows quite a few upgrades, including a First Class flight, Three Star Restaurant meal and the Harbor Cruise. What you don't get is the highly desirable Spa Treatment, since you are not staying at the Four Star Hotel.

Things change dramatically as we go from portfolio I3 to portfolio I4, as shown below.



In scenario I4, we decide to upgrade to the Four Star hotel and get the Spa Treatment. To be able to do this however, we have to downgrade from First Class to Coach and go Hiking instead of taking the Harbor Cruise. Note that we didn't give up the Cab and Three Star Restaurant meal, though. All of the portfolios after portfolio I4 include the Four Star hotel and Spa Treatment.

A P P E N D I X



Appendix

Adjusting utility numbers

The utility results created from a LDW model are generally not zero based. This means that we don't know when a project is worthless, so that we would not pay any money to fund it. It also means that we don't know when a project is worth $\frac{1}{2}$ as much as another project, so that we would only pay half as much to fund it as we would to fund the first project. This also applies to all other possible fractions. These difficulties result from the fact that the utilities in LDW are interval scales that are unique only up to a linear transformation. I believe this is also true of AHP based scales, despite what the AHP proponents say. This means that LDW utilities can't be used in a linear programming model without some modifications. This appendix describes the two ways of making the necessary modifications that are used in LDW Portfolio. The first method asks the decision maker to directly state a 50% benefit point and scales everything from that. The second method asks the decision maker to identify a benefits level worth zero dollars and uses this information to infer the 50% benefit point.

Using a 50% benefit point to rescale LDW utilities

Assume we have a set of LDW alternatives that we wish to select from using LDW Portfolio and that we need to adjust the utility numbers so that they can be added.

Suppose that we quiz the decision maker and find that alternative H with a utility of x is worth exactly half that of alternative A that has benefit 1.0. We don't need to know how many dollars A is worth, just that it has utility 1.0 and is worth twice as much as H.

Now we'll adjust the utility function with a linear transformation so that A still has a utility of 1.0 but that H has an adjusted utility of 0.5. Since utilities are equivalent up to a linear transformation, this won't affect the underlying preference information.

We want the transformation to take numbers of u and convert them to numbers of u' using a linear formula

$$u' = au + b.$$

And we want $u' = 1$ when $u = 1$ and $u' = 0.5$ when $u = x$.

This gives two equations in two unknowns

$$I = a \cdot I + b, \text{ and}$$
$$0.5 = ax + b.$$

solving the equations for a and b gives

$$a = 0.5/(I - x) \text{ and } b = I - a.$$

Using a zero value alternative to rescale LDW utilities

Suppose that in quizzing our decision maker we find that alternative Z with utility z is worth exactly zero dollars. That is, the decision maker would not be willing to pay anything to get this alternative, but also would not pay anything to avoid it. If we know this then we can easily compute x, the utility value that is worth exactly half of alternative A's utility of I.0 as

$$x = (I + z)/2.$$

This is because if a utility of I.0 is worth D dollars and a utility of z is worth 0 dollars that the average of the two utilities $(I + z)/2$ must be worth the average of the dollars $(D + 0)/2 = 0.5D$ or exactly half of alternative A. This follows because we are assuming that dollars and utility are both linear in terms of preference, utility by definition and dollars by necessary assumption of the linear programming model. Note that we don't need to know the dollar value D of the alternative with a utility of I.0 to make this calculation, which is good, since that value would generally be different than that alternative's cost.

Once we know x we can use it to compute the scaling constants a and b as was done above.