PRINCIPLES OF DESIGNING AND DEVELOPING SPREADSHEET-BASED DECISION SUPPORT SYSTEMS

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2004

This document is dedicated to my parents for their continuous love and support.

ACKNOWLEDGMENTS

I would like to thank Ravindra K. Ahuja for being my advisor and friend throughout this work. I am very grateful for the opportunities he has given me to research, write, and teach this material. I am also thankful to my fiance Onur Seref for his constant love and encouragement.

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August 2004

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A decision support system (DSS) is a model-based or knowledge-based system intended to support a managerial decision making user. A spreadsheet-based DSS uses spreadsheets to organize data and perform some spreadsheet functions. It uses a basic programming language to design user interface and implement model algorithms and calculations. A DSS should also offer the user some options to resolve his problem for a comparative analysis which may enhance the decision making process. This thesis proposes design principles and a development process for building a spreadsheet-based decision support system.

CHAPTER 1
INTRODUCTION

1.1 An Introduction to DSS

Equipped with the modeling and algorithmic skills taught in the standard Operations Research (OR) curriculum, many industrial engineering graduates feel ready to solve real-world problems. With a knowledge and understanding of theory and applications of mathematical programming, simulation techniques, and supply-chain management, they are ready to help their companies solve any distribution, forecasting, or planning problems. But then, as they interact more with coworkers and managers, they realize that the models they have learned cannot be applied easily to many of the real word problems they now face.

Many of these problems are decision-making problems which require simple solutions without the details of the mathematical models used to solve them. Most managers would prefer a software solution for such decision problems. However, most industrial engineering graduates know the right model but not how to package a model and present it with a friendly graphical user interface (GUI). The managers need to be able to easily use it, see the results with graphs or charts, and modify inputs to analyze different business scenarios. The desired software programs should also be able to pull data from larger databases and manipulate it appropriately.

This is a widely prevalent problem which is not addressed in the current OR curriculum. Models need data which is mostly available in spreadsheets or databases. Hence, OR graduates need to know how to extract data from these data sources. They need to know how to check data integrity and perform data analysis and data manipulation. As OR practitioners, OR graduates are support

staff members and are required to build systems for non-OR users. They must know how to package OR models so that they can be comfortably used by top managers and other co-workers. Real-life decision making often requires building interactive systems, which OR graduates must know how to design and implement. To summarize, OR graduates must learn sufficient information technology skills to that they can build intelligent information systems, alternatively, called decision support systems, which can run sophisticated models at the back-end, but are friendly enough at the front end to be used comfortably by any user.

A decision support system (DSS) gives its users access to a variety of data sources, modeling techniques, and stored domain knowledge via an easy to use GUI. For example, a DSS can use the data residing in spreadsheets, prepare a mathematical model using this data, solve it or analyze it using problem-specific methodologies, and assists the user in the decision-making process through a graphical user interface. The importance of DSS development skills has become well noted in the literature: "Given the growing complexity and uncertainty in many decision situations, helping managers use quantitative models to support their decision making and planning is an important research topic" ([1]). DSS applications are usually intended to be designed for non technical users presented with an easy to use interface.

OR graduates are frequently being employed in positions that require developing DSS which are gaining widespread popularity. As more and more companies install enterprise resource planning (ERP) packages and invest in building data warehouses, those who are able to create decision technologies driven applications that interface with these systems and analyze the data they provide will become increasingly valuable. Indeed, imparting DSS development skills, which combine OR skills with IT skills, will make graduates highly sought after in the modern workplace.

Developing courses that teach OR students how to build DSS has been a challenging task so far since it requires the availability of platforms which allowed the integration of various technologies (data, models, codes, etc.). However, in the past few years, several platforms have become available which allows such integration. One such platform is Microsoft Excel. Excel, which is the most widely used spreadsheet package among managers and engineers, allows data storage and model building. Excel also has many built-in program as well as many add-on programs available that wallow optimization and simulation of various models built in Excel. Excel also has a macro programming language, Visual Basic for Applications (VBA), which allows building GUIs and manipulating Excel objects. Thus, Excel provides a platform using which fairly sophisticated DSS applications can be built.

1.2 Defining DSS

A decision support system (DSS) is a model-based or knowledge-based system intended to support managerial decision making. A DSS is not meant to replace a decision maker, but to extend his/her decision making capabilities. It uses data, provides a clear user interface, and can incorporate the decision maker's own insights. Some of the major DSS capabilities are the following.

1. A DSS brings together human judgment and computerized information for semi-structured decision situations. Such problems cannot be conveniently solved by standard quantitative techniques or computerized systems.

2. A DSS is designed to be easy to use. User friendliness, graphical capabilities, and an interactive human-machine interface greatly increase the effectiveness of a DSS.

3. A DSS usually uses models for analyzing decision-making situations and may also include a knowledge component.

4. A DSS attempts to improve the effectiveness of decision making rather than its efficiency.

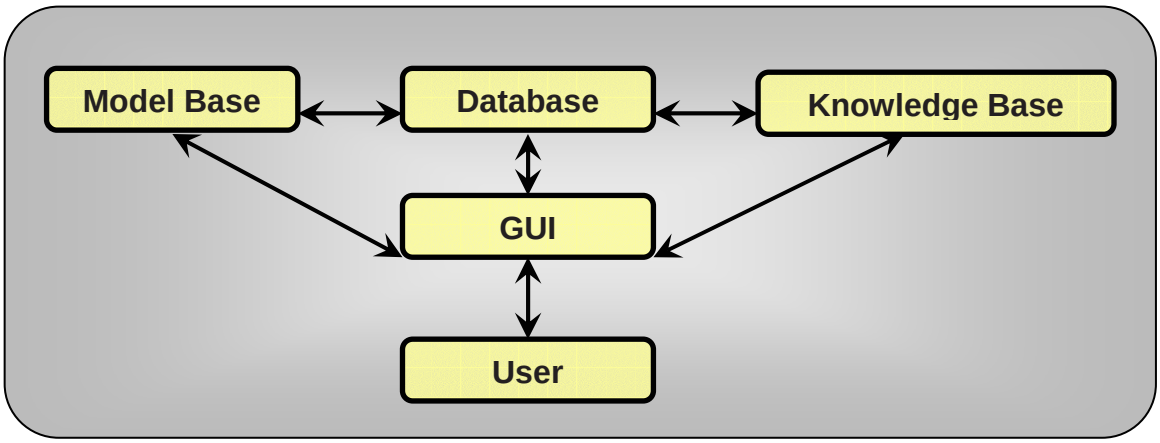


Figure 1–1: A schematic view of a decision support system.

5. A DSS provides support for various managerial levels from line mangers to top executives. It provides support to individuals as well as groups. It can be PC-based or

A DSS application contains five components: database, model base, knowledge base, GUI, and user (see Figure 1.1). The database stores the data, model and knowledge bases store the collections of models and knowledge, respectively, and the GUI allows the user to interact with the database, model base and knowledge base. We now present a more detailed look at each of these components.

Database The database provides the data with which decisions are made. The data may reside in spreadsheets or a data warehouse, a repository for corporate relevant decision-making data. The database allows a user to access, manipulate, and query data. Some examples of databases would include a spreadsheet containing personal banking account information or a data warehouse containing shipment records of various products.

Model Base A model base contains statistical, financial, optimization, or simulation models that provide the analysis capabilities in a DSS. Some popular

optimization models include linear programming, integer programming, and nonlinear programming. The DSS allows the ability to invoke, run, and change any model or combine multiple models. An example of a model base would be an integer programming model used to solve a capital budgeting problem. Most common DSS applications are primarily model driven. A key DSS component is its resolve options. A user should be able to manipulate their input values to compare multiple results for scenario analysis. The DSS should be designed for repeated use to aid in a recurring decision situation. It should be dynamic enough to handle various problem sizes, input values, and objectives.

Knowledge Base Many managerial decision making problems are so complex that they require special expertise for their solution. The knowledge base part of a DSS allows this expertise to be stored and accessed to enhance the operation of other DSS components. For example, credit card companies use a DSS to identify credit card thefts. They store in their knowledge base the spending patterns that usually follow credit card thefts; any abnormal activity in an account would trigger checking for the presence of those patters and a possible suspension of the account.

GUI The graphical user interface (GUI) covers all aspects of communication between a user and a DSS application. The user interface interacts with the database, model base, and knowledge base. It allows the user to enter data or update data, run the chosen model, view the results of the model, and possible rerun the application with different data and/or model combination.

The user interface is perhaps the most important component of a DSS because much of the poser, flexibility, and ease of use of a DSS are derived from this component.

User The person which use the DSS to support the decision making process is called the user, or decision maker. A DSS has two broad classes of users: managers and staff specialists, or engineers. When designing a DSS, it is important to know for which class of users the DSS is being designed. In general, managers expect a DSS to be more user-friendly than do staff specialists.

A DSS should be distinguished from more common management information systems (MIS). An MIS can be viewed as an information system that can generate standard and exception reports and summaries for managers, provide answers to queries, and help in monitoring the performance of a system using simple data processing. A DSS can be viewed as a more sophisticated MIS where we allow the use of models and knowledge bases to process the data and perform analysis.

1.3 Excel Spreadsheets

Microsoft Excel spreadsheets have become one of the most popular software packages in the business world, so much so that business schools have developed several popular Excel based courses. A spreadsheet application has functionality for storing and organizing data, performing various calculations, and using additional packages, called Add-Ins, for more advanced problem solving and analysis. Excel spreadsheets are easy for a user to interact with and easy for a student to use

while developing the DSS. We consider two aspects of Excel to be important in developing a DSS: basic functionality and extended functionality.

Excel basic functionality includes referencing and names, functions and formulas, charts, and pivot tables. These are standard tools that may be common to most spreadsheet users. Excel extended functionality includes statistical analysis, the Solver and modeling, simulation, and querying large data. These tools are especially important for building a decision support system. The ability to model a problem and solve it or simulate it adds the model base component of the DSS we are building. It is important that a DSS developer become familiar with the capabilities of Excel so that they know what they can offer the user when developing a decision support system.

1.4 VBA for Excel Programming Language

VBA for Excel is a programming language that allows for further manipulation of the Excel functionalities. VBA for Excel also allows the developer to create dynamic applications which can receive user input for the model base component of the DSS. VBA allows users without knowledge of Excel to be able to use spreadsheet-based DSS applications. There are several important features of VBA for Excel.

Some of these features include recording macros and working with variables, procedures, programming structures, and arrays in VBA. VBA for Excel is an easy to understand programming language. Even if a student has not programmed

before, they should be able to program several types of applications after a basic introduction to VBA.

A DSS developer can also create a user interface in VBA. These features includes building user forms, working with several different form controls, using navigational functions, and designing a clear and professional application. VBA is beneficial as it places all of the complicated spreadsheet calculations and any other analysis in the background of a user-friendly system.

Some of the extended Excel functionality topics can be further enhanced by using VBA. The modeling, simulation, and query features of Excel can become dynamic using VBA commands. These techniques are especially important to understand in order to build complete DSS applications.

1.5 The DSS Development Process

We present a chapter on the DSS development process to explain how the Excel spreadsheet functionality and VBA programming features can be combined to develop a complete DSS application. We propose five basic steps for this development process: i) outlining the application, its model and assumption; ii) determining how many spreadsheets will be needed and for what purposes; iii) constructing a general layout of the user interface features; iv) outlining the programming procedures needed; and v) ensuring that resolve options will be integrated into the DSS. We describe these steps in detail and give several examples in this chapter.

We also present a chapter on GUI design and programming principles. There is much literature on these two topics which are important in developing any DSS. We summarize the issues that are most relevant to developing spreadsheet-DSS applications in this chapter.

1.6 Case Studies

We present two case studies to illustrate the relevance and importance of decision support systems in the fields of industrial and systems engineering and business. We strive to accomplish this by showing how to develop DSS applications which integrate databases, models, methodologies, and user interfaces.

These case studies consist of developing a complete decision support system and are based on an important application of IE/OR or business. Through case studies, graduates will learn how IE/OR and business techniques apply to real-life decision problems and how those techniques can be effectively used to build DSS applications.

These case studies are just some of the numerous case studies we develop in order to illustrate how DSS applications can be developed by combining information technology tools with operations research and business tools to solve important decision problems.

CHAPTER 2
DSS DEVELOPMENT PROCESS

2.1 Defining the Development Process

Now that we have discussed in great detail the components of a spreadsheet-based decision support system (DSS), we need to learn the process of putting these components together to build a complete DSS application. Before entering formulas into Excel or coding sub procedures in VBA, it is necessary to construct an overall layout for the DSS and give some thought to the design and implementation of the application. We propose five basic steps for developing a DSS: i) Application Overview: create a layout of the entire application to understand the flow from the user input to the model calculations to the output, ii) Spreadsheets: determine how many spreadsheets you will need to best handle input, calculations, and output, iii) User Interface: outline what interface you will need to receive input from the user and navigate them through the application, iv) Procedures: outline what sub and/or function procedures you will need in your code to receive the input, perform the calculations, and display the output, v) DSS Components: decide what resolve options the user may have.

These steps have been our guidelines to developing decision support systems. We do not claim that they are necessary to follow, but rather suggest them as good guidelines when developing a DSS application. In this chapter we give several examples from case studies we have developed using these proposed steps. The following chapters give a more detailed explanation of each case study's development using these five steps. We wish to illustrate the variety, and consistencies, possible in developing DSS applications.

2.2 Application Overview

The Application Overview is the most important step in developing a DSS. In this step, we consider the entire flow of the application. We usually begin this flow at the "Welcome" sheet. A "Welcome" sheet should have the title of the DSS and some description of what the application does. Any assumptions or necessary model explanations may be given in this description. There may also be some images on this initial sheet related to the application topic. Then there should be one button to "Start" or "Begin" the application. Even though this sheet is simple, it is an important introduction for the user to what your DSS is and how they can begin to use it.

The user should then encounter some method for providing input. This may involve a form or set of forms, or the user may be brought to a new sheet where further instructions are provided. Deciding which method or methods to use is important and depends on the application. For example, if you only need one or two pieces of information from the user, you may not even need a form or an entire sheet for input; instead, you may use an Input Box. In some applications, you may need large sets of data for your analysis. In that case, you may only prompt the user to import data from a text file or database to a spreadsheet. Once you have decided which method is most appropriate for your application, you may need to spend more time designing the interface; however, we will return to this in a later step. It is important to complete the Application Overview before designing the interface so that you have a clear idea of what the entire application will incorporate.

After receiving the input, the model should be ready and calculations can be performed. It is a good idea at this point to have an overview of what is required for your model calculations. You may need to know the model formulation before you can finish deciding what the user input will be. The first thing to decide is

if this DSS will be computing simple calculations, performing an optimization, or running a simulation. The details of these models can be outlined in a later step, but for the purpose of the Application Overview, you should have an idea of what will be involved. This general model outline will help you in determining the details of your spreadsheet design and procedures later. Once input is received and the model calculations are performed, we need to determine what output will be displayed to the user. Will there be charts or graphs, or histograms or tables? Does some of the input need to be re-displayed to the user? Again, these options will depend on the application. It is important to consider the output as it is a driving force in why the user is using the DSS. It is a good check to see if you are computing everything the user may be interested in.

The last part of the Application Overview is reviewing the DSS components. In Chapter 1, we define in detail what a DSS is comprised of. These include, the model base and user interface discussed above. However, a DSS should also provide some resolve options for the user. The user should be able to change some of their initial input values and resolve the problem. The user may also want to add some constraints to an optimization or redefine their objective function. We suggest that these resolve options are made available on the output sheet. We will give more examples of these DSS components in the following sections.

Table 2–1: Summary: Application Overview

Welcome Sheet	Flow begins; introduction to what DSS is and how to begin using it.
Input	Provided by user via set of forms, input spreadsheet, or Input Boxes.
Model Calculations	Formulation of objectives and necessary input; decide if computing simple calculations, performing an optimization, or running a simulation.
Output	A driving force in why the user is using the DSS.
Resolve Options	Use can modify input, redefine constraints, or change objectives.

Figure 2–1: An example of a "Welcome" sheet.

2.3 Spreadsheets

There may be two to several sheets in a DSS application. The first sheet should always be the "Welcome" sheet as we discussed above. For example, in Figure 2.1, we show the "Welcome" sheet from a case study we developed for a Portfolio Management and Optimization DSS. We give a description of the DSS and describe the model assumptions. We also reference the source of our model formulation. We also have some images related to portfolios. Then we have a "Start" button which the user can press to begin the application.

The remaining sheets are for input, calculations, and output. We may have these as separate sheets or some elements may be combined on fewer sheets. Suppose we need a sheet for input. We can prepare the sheet by placing appropriate labels for tables or input locations. We may also name some ranges at this point which will help us later when coding. Below is an example from a case study we

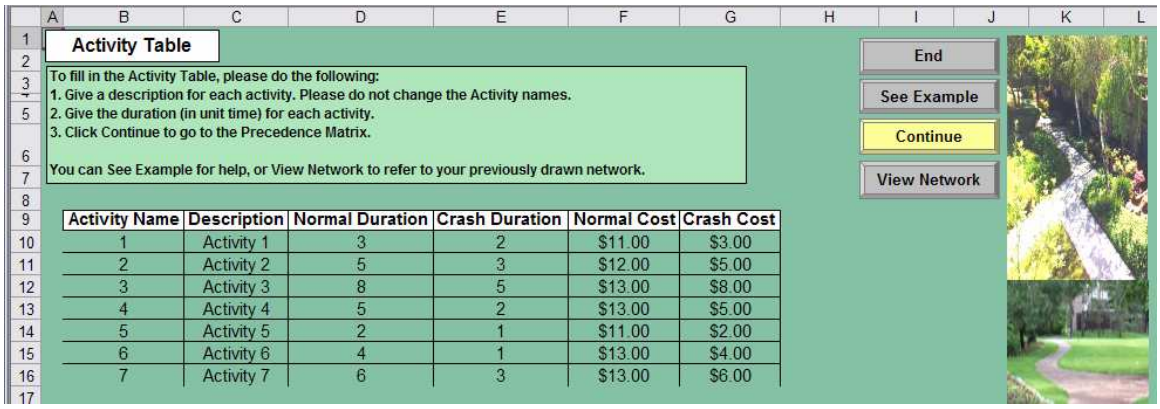


Figure 2–2: An example of using spreadsheets to take input from the user.

developed for using the Critical Path Method (see Figure 2.2). In this application, we take the user through several input sheets. In each sheet, we have a table for a set of input values. In some cases, spreadsheet may be a better user interface than forms for receiving input; we discuss this in more detail in the next section.

You may also have an application which requires a large set of data. This data may be imported from a text file or database, or input by the user. In Figure 2.3, we have an input sheet from a Stochastic Customer Forecasting case study. This sheet contains the historical data that is used to make future forecasts. In this application we give the user the option to enter this data manually or import it from a text file.

You may not need an input sheet for every application. Let us consider the case where the input sheet may be combined with the calculations sheet or output sheet. For example, in the figure below, we have a sheet from a Technical Analysis case study in which the input, calculations, and output are all on one sheet (see Figure 2.4). Here the user can modify the input using spreadsheet controls and press the "Resolve" button to update the calculations in the table. The output is summarized in a small table on the right of the screen.

Again, you may not even use a sheet at all for your input. You may simply take input from a user form and then use that directly in a calculations sheet or

Historical Data

Exit | Continue

Calendar Year	2001

Calendar Day	Month (Jan = 1, Dec = 12)	Week Day (Mon = 1, Fri = 5)	Number of Customers
2	1	2	1825
3	1	3	1257
4	1	4	969
5	1	5	1672
8	1	1	1098
9	1	2	691
10	1	3	672
11	1	4	754
12	1	5	972
15	1	1	816
16	1	2	717
17	1	3	728
18	1	4	711
19	1	5	1545
22	1	1	873
23	1	2	713
24	1	3	626
25	1	4	653

Figure 2–3: An example of a large set of data imported from a text file.

Output for Option A

You may vary the **Risk Rate** and **Time Horizon** to view possible profits with trading strategies varying between the given lower and upper bounds.
(X = **Buying Condition** (# months), Y = **Selling Condition** (# months).)

You may change the **Risk Rate** and/or **Time Horizon** values and press **RESOLVE.**

END | View Calc | RESOLVE

Risk Rate
0.05

Time Horizon	Year	Month
From:	1920	Jan
To:	1980	Jan

At Max Profit	$102,040.09
Number of Buys	48
Number of Sales	48

Possible Profits

X , Y	5	6	7	8	9	10
5	$10,233.79	$7,079.46	$6,473.93	$95,934.60	$62,661.52	$79,071.97
6	$8,563.46	$7,657.79	$7,411.76	$102,040.09	$66,421.09	$95,071.75
7	$6,447.52	$6,015.40	$5,570.67	$74,798.37	$46,452.35	$59,905.42
8	$6,282.46	$5,864.61	$5,547.53	$74,487.71	$49,013.22	$63,208.94
9	$7,222.25	$7,105.53	$5,552.11	$92,524.69	$60,874.79	$80,833.86
10	$7,203.04	$7,518.56	$6,884.64	$85,553.75	$57,997.05	$87,176.47

Figure 2–4: An example of having input, calculations, and output on the same sheet.

Simulation Calculations

END BACK

Current Savings	$20,000.00
Current Salary	$45,000.00
Salary Increase	5.00%
Percent Salary to Invest	10.00%

Asset Allocation			Current Investment		
T. Bills	Bonds	Stocks	T. Bills	Bonds	Stocks
0.50	0.30	0.20	$2,250.00	$1,350.00	$900.00

		Market Returns (from Bootstrapping)			Ending Portfolio Returns			
Age	Year	T. Bills	Bonds	Stocks	T. Bills	Bonds	Stocks	Total Returns
35	1	0.0312	-0.0559	0.0656	$2,320.20	$1,274.54	$959.04	$4,553.78
36	2	0.0351	0.0967	-0.3503	$4,802.23	$3,024.64	$950.09	$8,776.96
37	3	0.08	-0.0263	0.2141	$7,418.63	$4,570.37	$3,270.97	$15,259.98
38	4	0.0182	0.1002	-0.0491	$10,420.92	$8,414.75	$4,356.71	$23,192.38
39	5	0.0035	0.0568	0.3242	$14,381.24	$11,896.44	$9,123.58	$35,401.26
40	6	0.0031	0.1002	0.2141	$20,636.04	$18,474.62	$12,673.58	$51,784.24
41	7	0.012	-0.0008	0.3055	$29,254.23	$24,188.11	$19,841.44	$73,283.77
42	8	0.0772	0.1811	0.2402	$42,881.03	$40,071.76	$26,592.68	$109,545.47
43	9	0.0616	0.0967	0.1681	$61,675.78	$55,156.05	$37,341.40	$154,173.24
44	10	0.0018	0.0553	-0.085	$80,722.15	$74,319.61	$41,101.50	$196,143.26
45	11	0.0035	-0.0122	0.2402	$102,092.72	$88,273.73	$70,817.21	$261,183.66
46	12	0.0157	-0.0531	0.1847	$136,550.80	$112,384.84	$90,006.58	$338,942.23
47	13	0.005	0.2444	-0.1159	$174,379.35	$191,309.33	$87,115.40	$452,804.08
48	14	0.0476	0.0618	0.0401	$241,623.44	$217,705.79	$136,843.61	$596,172.85
49	15	-0.0002	-0.0026	0.1245	$302,480.76	$268,913.24	$194,715.51	$766,109.51
50	16	0.0182	-0.0394	-0.1078	$394,789.07	$332,514.15	$198,472.04	$925,775.26

Figure 2–5: An example of a complicated calculations sheet.

in some calculations procedures and take the user directly to the output sheet. Since we are developing spreadsheet-based DSS applications, we will usually take advantage of the spreadsheet features to aid us in performing calculations. For this reason, we will usually have a calculations sheet. This sheet may be viewed by the user or, in most cases, hidden from the user. A calculations sheet should be hidden if the intended user may not be familiar with the details of the calculations but is solely interested in the results. In Figure 2.5, we have a complicated calculations sheet from a simulation performed in a Retirement Planning case study. There are several spreadsheet functions and formulas in the sheet as well as some input cells whose values have been updated after a user has completed an input form. Since the sheet calculations are somewhat complicated, we do not show this sheet to the user during the normal flow of the application; however, we do give the user the option to view the calculations if they want to. We normally, take the user directly from the input form to the output sheet in this application.

You may have some other hidden sheets related to the calculations. For example, in simulation we usually store the results of the runs to user for creating histograms or other summary reports. This detailed sheet should be hidden from the user in the application flow, but can be made available for viewing if the user is interested. By using the Application.ScreenUpdating method and Worksheets.Visible property we can prevent the user from seeing these calculation sheets while they are being used for the model calculations. Probably the most important sheet for the user is the output sheet. This sheet should summarize the results of the calculations clearly so that the user can understand the behavior of whatever system they were modeling or analyzing. It is usually a good idea to have some graphical results as part of the output sheet. For example, in Figure 2.6, we have the results sheet from an Inventory Management case study. Here the graph illustrates the ordering strategy found by the model calculations. There are also some tables used to summarize the numerical results of the solution.

In DSS applications using simulation, it is usually good to have some histograms as part of the output sheet. In Figure 2.7, we have some histograms summarizing the results of a Reliability Analysis case study. We have a histogram showing the frequency of various system failure time values using a bar graph along with an overlaid scatter plot to show the cumulative probability of each value. Below that, we have another histogram representing the frequency with which different machine types have caused the system failure; this histogram is shown as a pie chart. We give the user several options from this output sheet including to return to and rerun the simulation or return to the initial input phase to resolve the problem.

In some cases, you may have several charts or larger summary tables that may not fit into one output sheet. In that case, we recommend making a navigational output sheet which will allow the user to view these individual reports. For

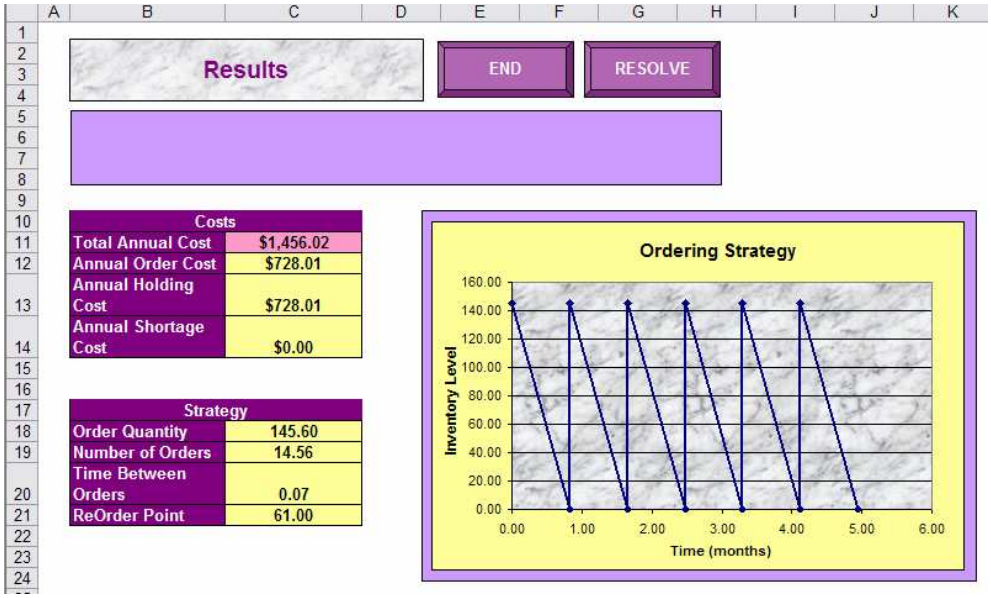


Figure 2–6: An example of using a graph to illustrate results in an output sheet.

example, In Figure 2.8, we show a navigational output sheet from a Supply Chain Management case study. This sheet allows the user to view several different summary pivot tables (see Figure 2.9). From these pivot tables, the user can also view corresponding pivot charts displayed as separate chart sheets (see Figure 2.10). The user can always return to the navigational output sheet from any of these reports.

Whichever results are relevant to your application, you should ensure that they are presented to clearly in the output sheet. "End" and "Resolve" options should also be found in the output sheet as well as options to "View" input or calculation sheets.

2.4 User Interface

Designing a user interface is an important element of developing a user-friendly DSS. We discuss good graphical user interface (GUI) design in a later section; for now we will discuss what role the user interface plays in the DSS development. There are three main categories of user interface in spreadsheet-based

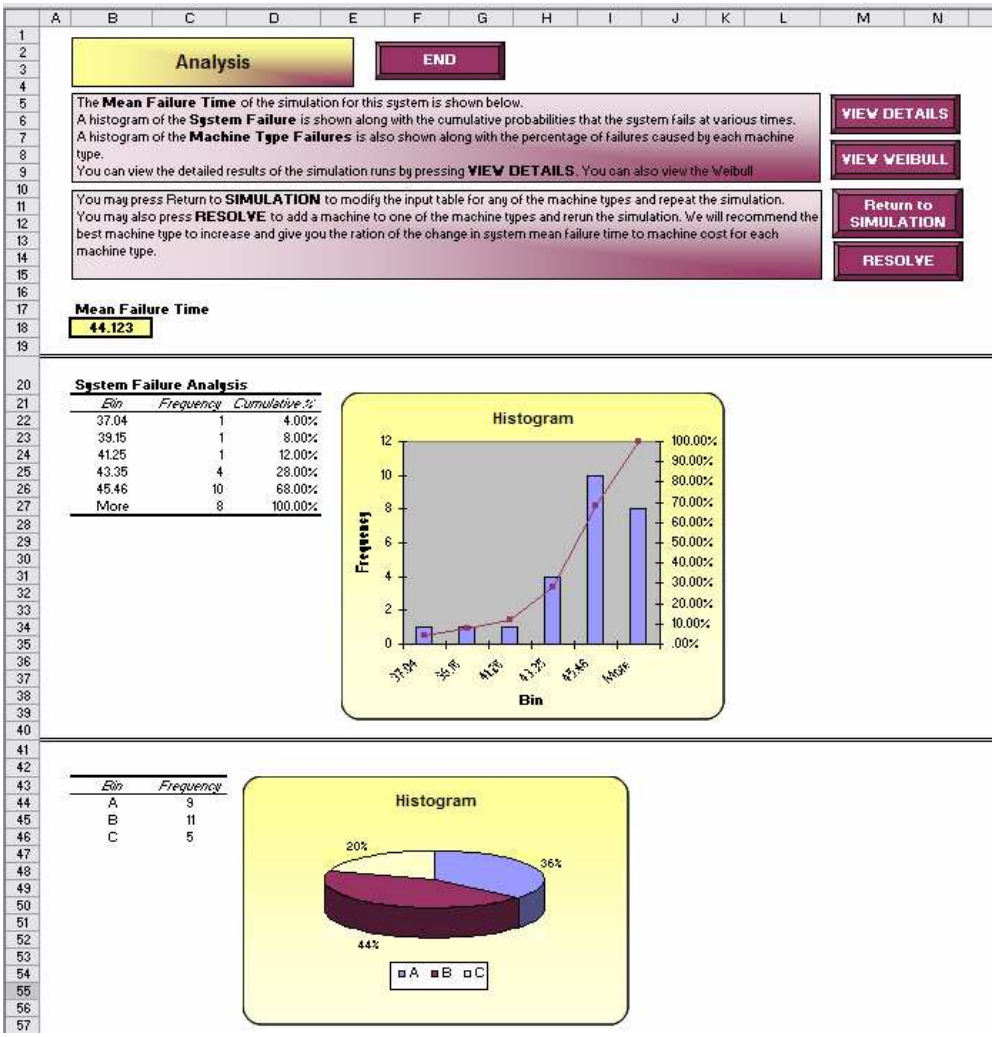


Figure 2–7: An example of histograms in the output sheet of a simulation-based DSS.

Table 2–2: Summary: Spreadsheets

Welcome Sheet	Title and description of the DSS; images; “Start” button.
Input Sheet	User input; large data input; can be combined with other sheets.
Calculations Sheet	Spreadsheet calculations; simulation results; usually hidden from user.
Output Sheet	Summary tables and reports; graphs, charts or histograms; navigational output buttons; “End,” “Resolve,” and “View” buttons.

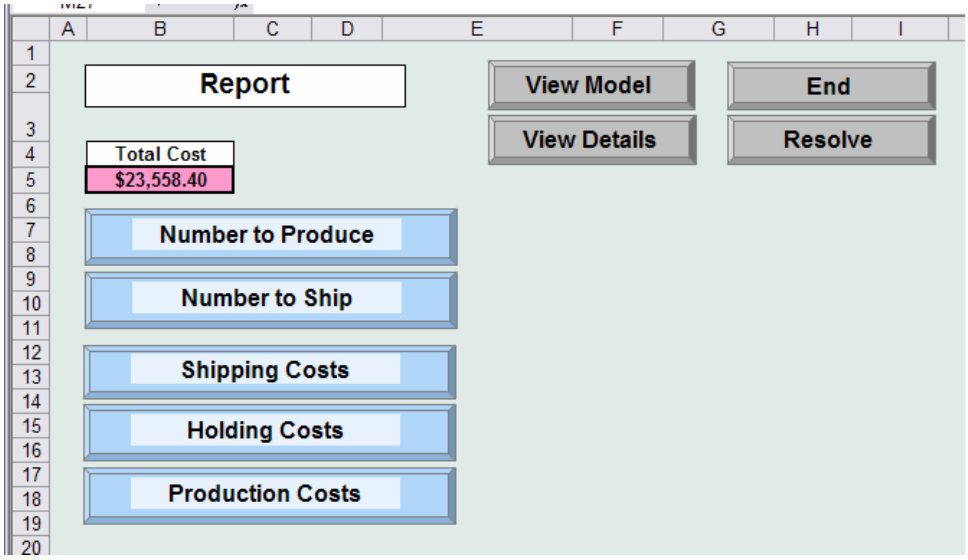


Figure 2–8: An example of a navigational output sheet.

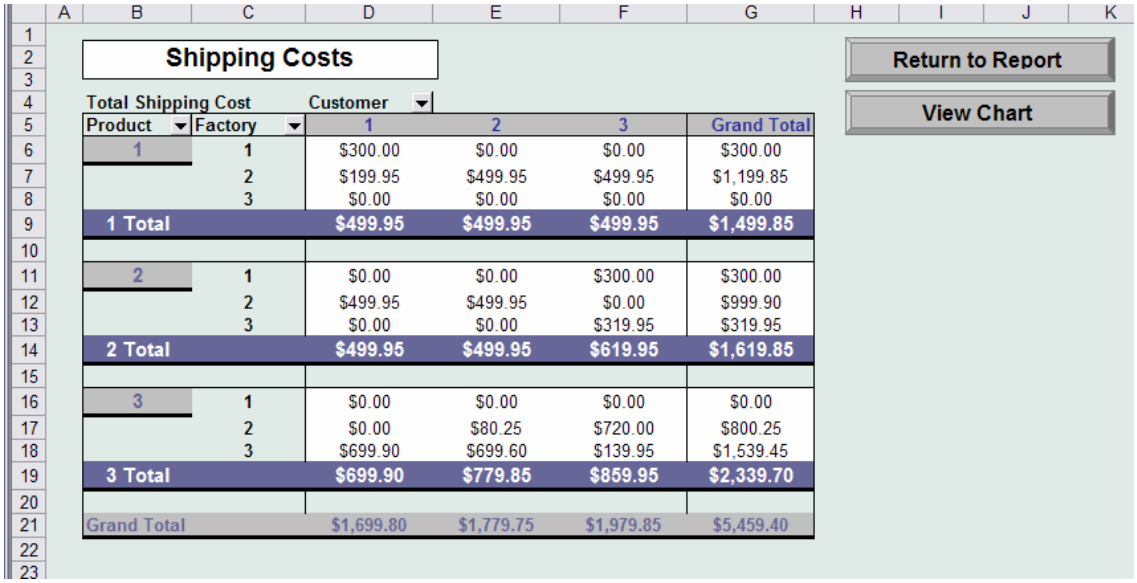


Figure 2–9: An pivot table report sheet is one of the output sheets.

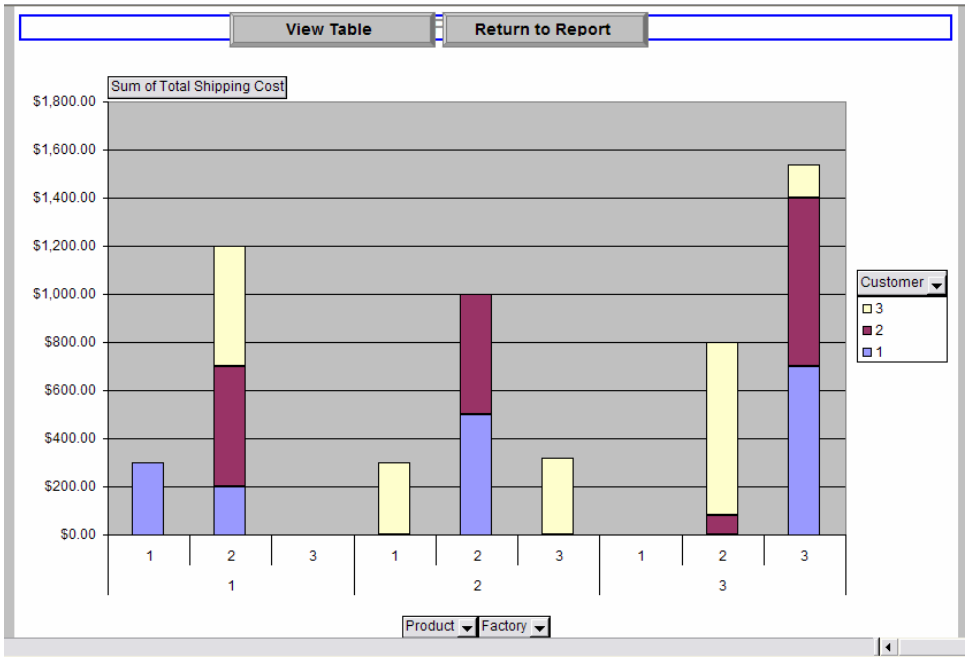


Figure 2–10: The corresponding pivot chart is another report sheet.

DSS applications: user forms, form controls on the spreadsheet, and navigational buttons on the spreadsheet.

Let us begin by discussing navigational buttons. As we have already mentioned, the first button you should create is the "Start" button which is located on the "Welcome" sheet (see Figure 2.1). This button should be assigned to a macro which brings the user to the input interface. On all other sheets, input, calculation, and output sheets, there should at least be an "End" button. The user should always have the option to "End" or "Exit" the application. Note: Whether you use "End" or "Exit" or any other phrase for this action, be sure that you are consistent across all sheets in the application. We discuss consistency in user interface design more in the GUI design section.

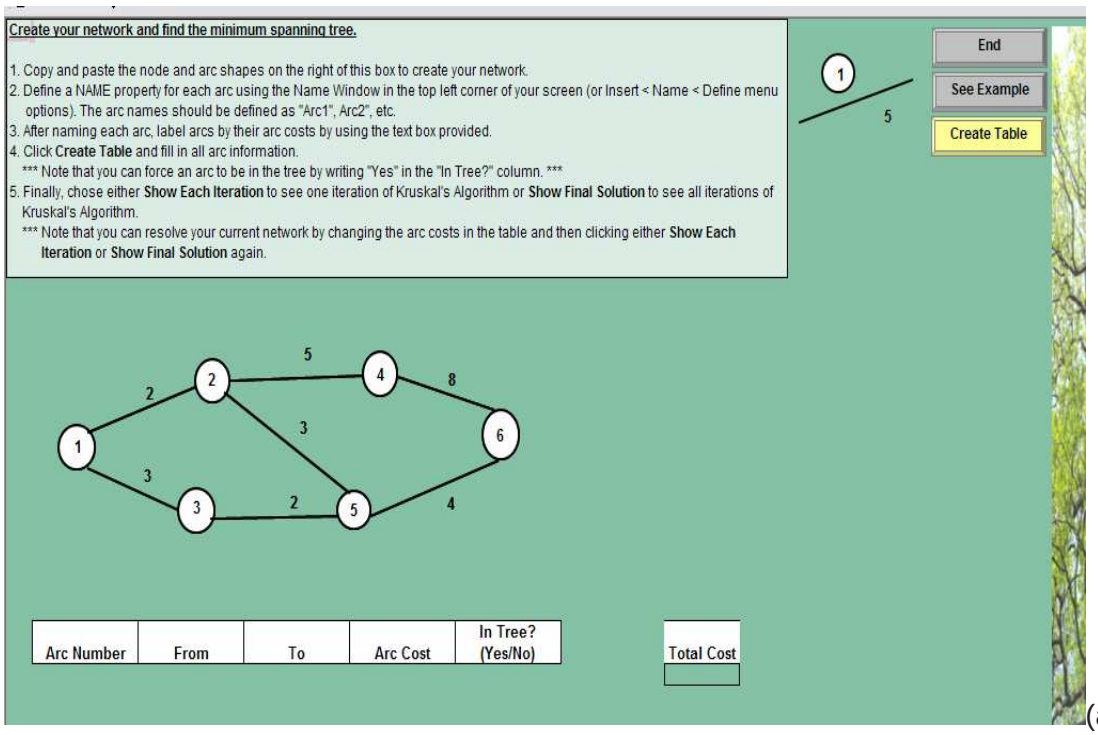
You may also have some other navigational buttons such as "Next," "Continue," or "Back" if you intend for the user to be able to step through the sheets or revisit sheets. This is especially important if you have hidden the sheet tabs or are

only making one sheet visible at a time; which we recommend for a more professional presentation. In the case where input, calculations, or output are combined, you may also have some functional buttons on the spreadsheet such as "Solve."

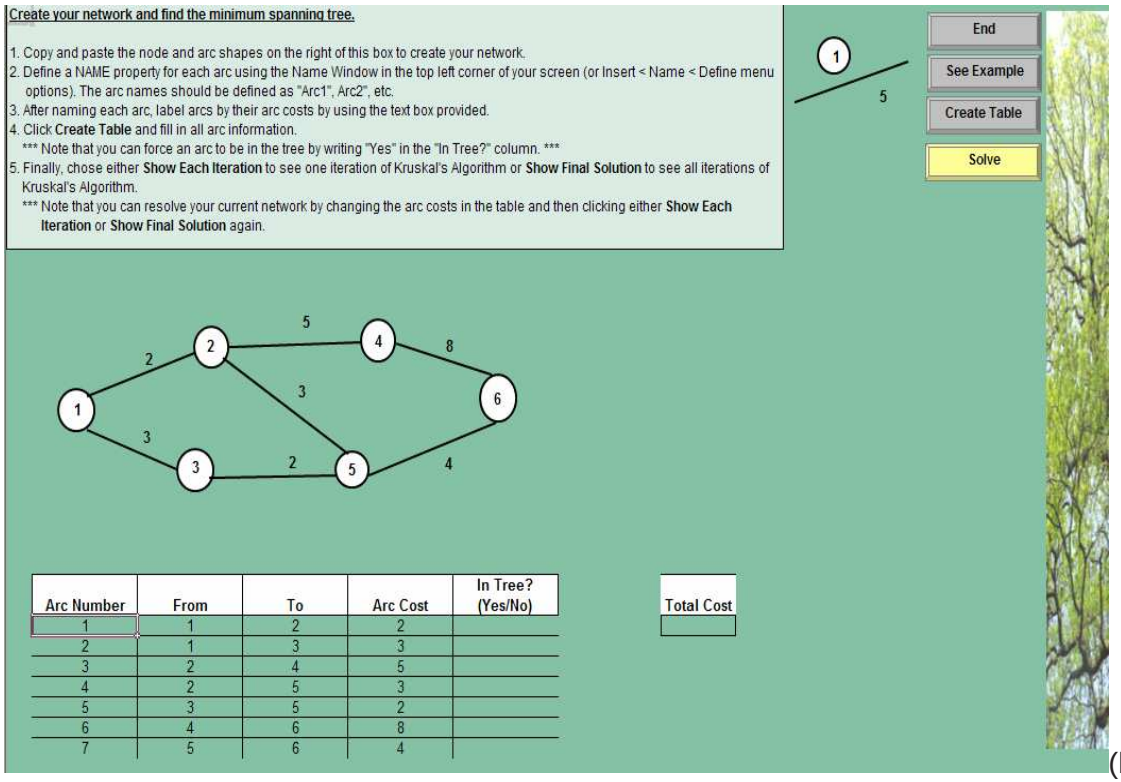
For example, in Figure 2.11, we have one such sheet in a case study on the Animation of the Kruskal Algorithm. In this case study, we take the user directly from the "Welcome" sheet to the sheet shown in the figure. We highlight the "Create Table" button as it the next button they should press (see Figure 2.11(a)). When they press this button, they are prompted to give the dimensions of their network, and then a table with the corresponding number of rows is created. After the table is created, we now make a new button visible called "Solve" (see Figure 2.11(b)). We un-highlight the "Create Table" button and highlight the "Solve" button since this is the next button the user should click. This button will run the procedure which animates Kruskal's algorithms and finds the minimum spanning tree solution.

Aside from using functional or navigational buttons on the spreadsheet, a user interface may also use form controls on the spreadsheet. Refer to Figure 2.4 to see an example of text boxes and combo boxes used on a spreadsheet in which input was taken from the user on the same sheet where calculations and output were displayed. Another example is shown in Figure 2.12. This example is from the Inventory Management case study. Here we have three option buttons representing different methods which can be used to find the best order strategy. These option buttons are mutually exclusive and two of them also have dynamic features. The bottom two buttons have some associated cells for extra input which are shaded darker when unmarked and made lighter when marked (see Figure 2.12(b)).

Form controls on the spreadsheet are useful when there are many resolve options in the application. In this case, you want to give the user easy access to the input in order to be able to change it multiple times. It is important to keep the



(a)



(b)

Figure 2–11: An example of buttons on the spreadsheet to work with input and calculations.

layout of the spreadsheet clear and uncluttered when using placing form controls adjacent to other input cells, calculations, or output. We discuss these interface design issues in a later section.

In some cases, there may be an even tradeoff between using functional buttons or form controls on the spreadsheet versus creating a user form. For example, in Figure 2.13(a), we have used two functional buttons to allow a user to "Add" and "Remove" stocks to and from their portfolio in the Portfolio Management and Optimization case study. In this particular case study, we have put this functionality on the spreadsheet because it is a feature the user may use often. The user may go to a new sheet to view stock comparisons and then return to edit their portfolio; the user may also go to an optimization sheet to view investment strategy results and then return to edit their portfolio and resolve. However, if this were not the case, that is if the user did not need to create or edit their portfolio multiple times, we may have created a user form to perform this functionality. In Figure 2.13(b), we show an example of such a form used in a Beta of Stocks case study. In this case, the user only selects their portfolio once.

In most DSS applications, if there is a large enough set of input required from the user, we suggest creating user forms. User forms can be advantageous in that there are many options for placing and manipulating controls on a user form. The controls can also be more clearly displayed as they are not interfering with other cells on the spreadsheet. Another advantage of user forms is that they can be displayed to the user at any time; that is, they are not attached to a specific spreadsheet. This can be especially useful for resolve options.

If a user wishes to resolve the problem and presses a "Resolve" button on an output sheet, the input form can be redisplayed to them directly without even moving to a new sheet. In Figure 2.14, we have an example of a user form from a Retirement Planning case study. This form is dynamic in that the first frame below

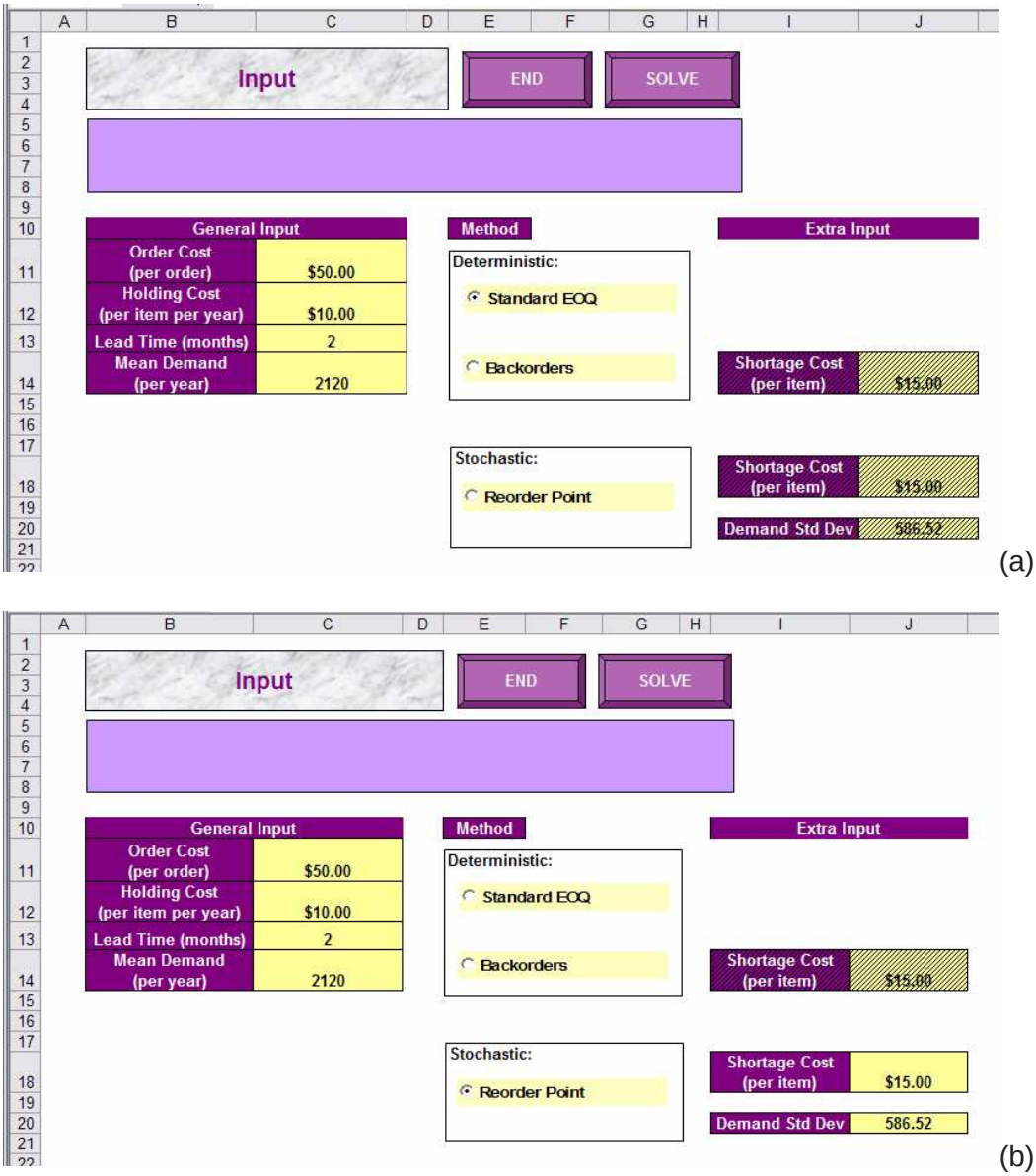
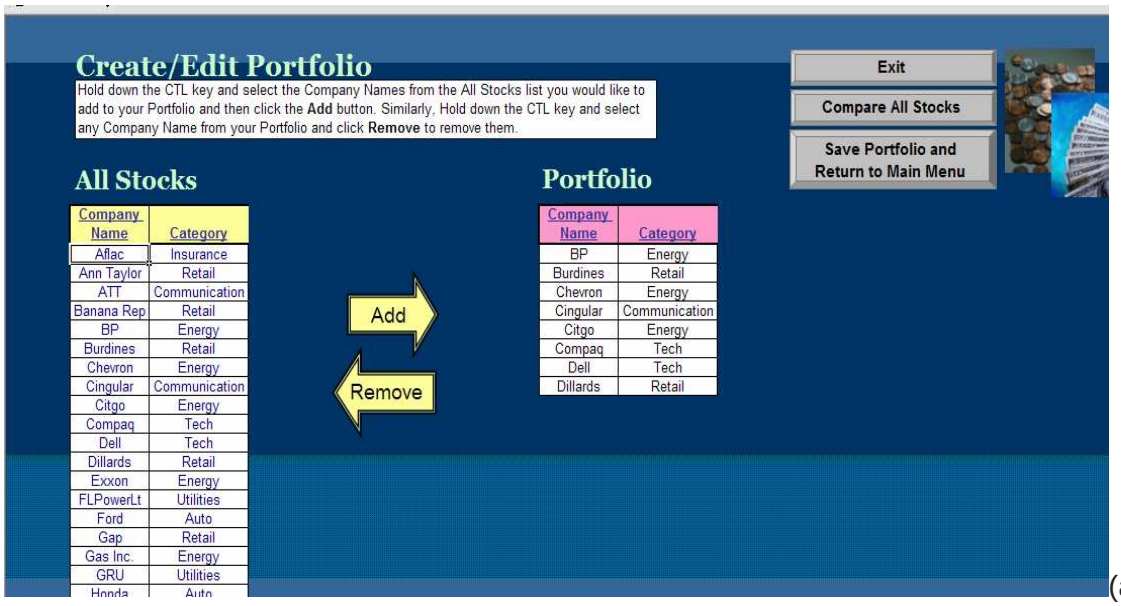
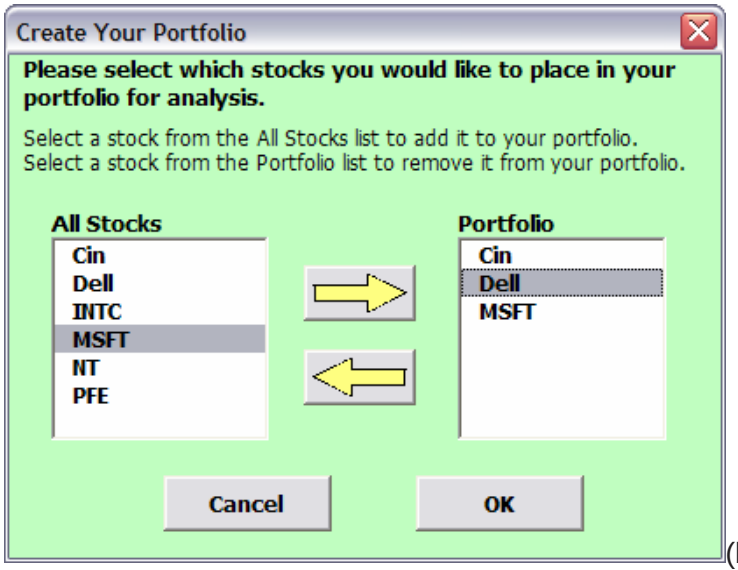


Figure 2–12: An example of dynamic form controls on the spreadsheet.



(a)



(b)

Figure 2–13: An example of controls on a form and spreadsheet.

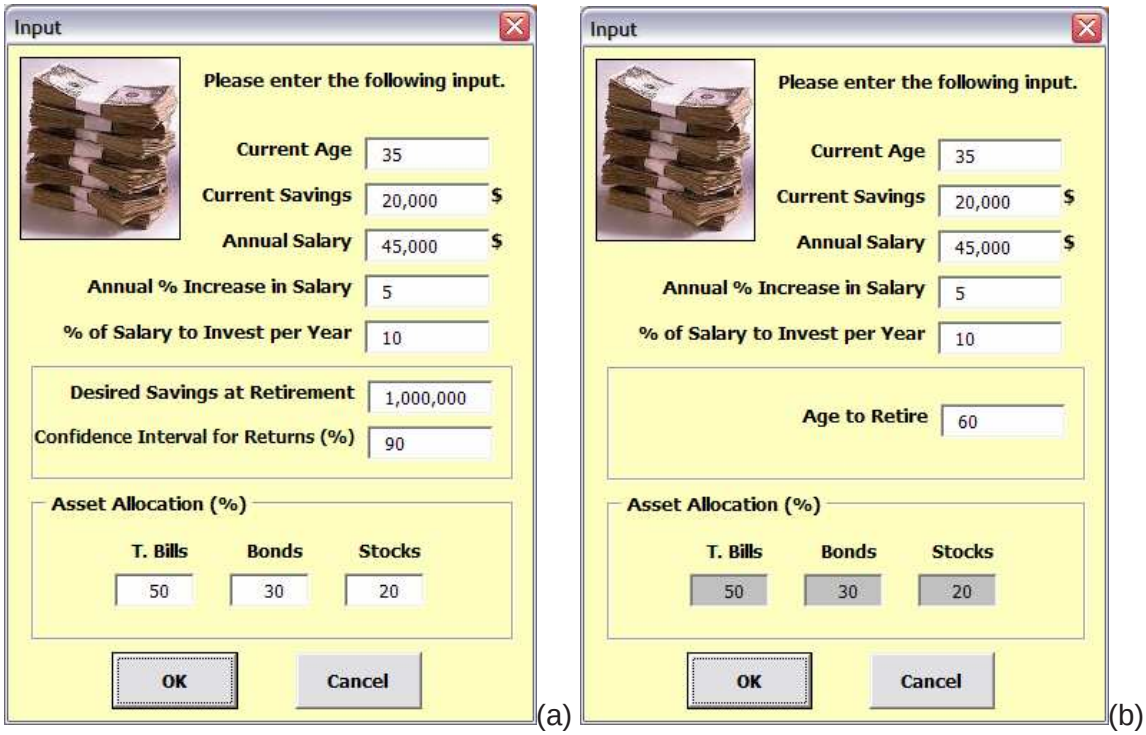


Figure 2–14: An example of dynamic form controls.

the text boxes may change depending on a previously selected option. In Figure 2.14(a), the user is providing values for "Desired Savings at Retirement" and "Confidence Interval for Returns" whereas in Figure 2.14(b) this framed is changed to prompt the user for the "Age to Retire." The second frame on this form, for "Asset Allocation," is also dynamic. In Figure 2.14(a) the user is prompted to enter this information, but in Figure 2.14(b) the textboxes are grayed and locked since the information is not relevant for this option.

Another way to use user forms in a situation where the user may need to modify input multiple times is to create a "floating" form. The advantage of this type of user form is that the user can select or modify cells in the spreadsheet without having to close the form first. In Figure 2.15, there is an example of a floating form from a case study for Animating the Simplex Method. This form is used to allow the user to select the entering variable for each iteration. The user selects the entering variable from the tableau on the spreadsheet and can then view

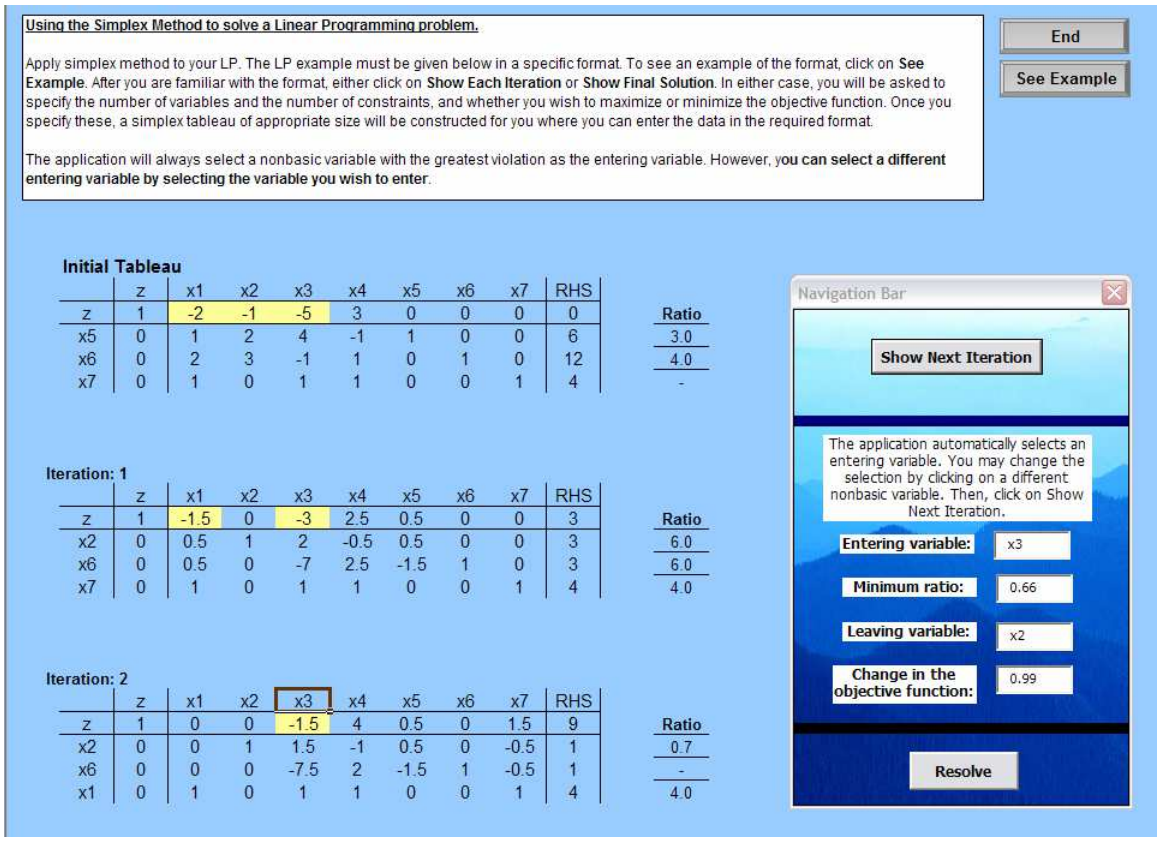


Figure 2–15: An example of a "floating" form.

the results for that scenario on the floating form. The form is hidden when the user moves to another sheet.

2.5 Procedures

The next step in developing a DSS application is to make an outline of what procedures you will need to conduct the flow and execute the calculations. As discussed in Chapter 15, we encourage you to organize your code into several smaller procedures which may be called from other main procedures or associated with buttons on the spreadsheet. We recommend making an outline of these procedures in your code before you begin the details of the implementation. We always begin our applications with a Main sub procedure which is associated with the "Start" button on the "Welcome" sheet. From the Main procedure, we usually

Table 2–3: Summary: User Interface

Navigational Buttons	These buttons, such as “Start,” “Next,” “Back,” or “End” should be on every sheet to navigate the user through the application.
Functional Buttons	These buttons, such as “Create Table” or “Solve,” may be used if multiple functions occur on one sheet.
Controls on the Spreadsheet	Placing controls on the spreadsheet allows users to easily modify input for multiple solution calculations.
User Forms	User forms are most commonly used when large amounts of input are needed; they are often advantageous.

begin by clearing previous data and initializing variables; this can also be done by calling a ClearPrevious procedure. We then either take the user to an input sheet or show them an input form. Consider the following example.

```
 Sub Main()
    Call ClearPrevious
    frmInput.Show
    Worksheets(‘‘Input").Visible = True
    Worksheets(‘‘Welcome").Visible = False
End Sub

Sub ClearPrevious()
    ’clear ranges on other sheets
    Worksheets(‘‘Calc").Range(‘‘InputValues").ClearContents
    Worksheets(‘‘Output").Range(‘‘Results").ClearContents
    ’initialize variables
    Set InputRange = Worksheets(‘‘Input").Range(‘‘InputStart")
End Sub
```

There should then be some procedure which receives the input from the user. If we are using user forms as the interface for receiving input, then this code would be in the event procedures for the form. Consider the following example.

```
 Sub cmdOK_Click()
        'set variables equal to control values
        NumRuns = txtNumRuns.Value
        InputSize = txtInputSize.Value
        ReDim InputArray(InputSize)
        Unload Me
End Sub
```

Once the input is received, the calculations should be ready to perform. These calculations may involve running a simulation with some loop structure or evoking the solver with the Solver commands. The calculation procedure/s may be called when the "OK" button is clicked on a user form or they may be assigned to a "Solve" or "Continue" button on an input spreadsheet. Consider the following example.

```
Sub DoSimulation()
        For i = 1 to NumRuns
            'create random values
            'perform calculations
        Next i
End Sub

Sub DoOptimization()
    SolverReset
    SolverOK SetCell:= , MaxMinVal:= , ByChange:=
    SolverAdd CellRef:= , Relation:=, FormulaText:=
```

```
    SolverOptions AssumeNonNeg:=True
    SolverSolve UserFinish:=True
End Sub
```

The final procedure to be outlined is related to displaying the solution on the output sheet. If there is a chart, you may need to update the source data. If there was a simulation, you may want to create some histograms. In any case, you want to put the solution values in some report table on the output sheet. The procedure to create the output may be called from the calculation procedures or from another functional or navigational button on the calculation spreadsheet. Consider the following example.

```
Sub CreateReport()
        'place solutions in report table
        'update chart source data
        ActiveSheet.ChartObjects(1).Select
        ActiveChart.SetSourceData Source:=
        'create histogram
        Application.Run ``ATPVBAEN.XLA!Histogram," Input, Output, Bin, Labels,
        Pareto, Cumulative, Chart
        Worksheets(``Output").Visible = True
End Sub
```

These procedures should outline the overall flow of the application from user input to calculations to output. Aside from these, there should also be any needed navigational procedures for "End" buttons or "Next," "Back," or "View" buttons. Consider the following example.

```
Sub EndProgram()
        Worksheets(``Welcome").Visible = True
```

```
        ActiveSheet.Visible = False
End Sub
```

Also ensure that all variables are declared and that any variables used in multiple procedures are declared as Public variables at the top of the module.

Table 2–4: Summary: Procedures

Main	Call ClearPrevious procedure. Show input form or take user to input sheet.
Clear Previous	Clear previous ranges of input or solution values. Initialize variables.
Receive Input	Store values from form controls or input cells to corresponding variables. Record these values to appropriate cells in calculation sheet.
Perform Calculations	Perform calculations using function procedures, simulations loops, or Solver commands.
Generate Output	Display solution values to report table, update chart source data, or create histograms.
Navigational	Change Visible property of worksheets for "End," "Next," "Back," or "View" button functionality.
Variables	Make sure all variables are declared and that variables used in more than one procedure are declared as Public variables at the top of the module.

2.6 Resolve Options

The last but most important step in developing a DSS application is to ensure that it has all of the components of a complete decision support system. There should be some input taken from the user via some GUI, and there should be some calculations made based on some model base, database, or knowledge base. We confirm the input interface while outlining the user interface, and we confirm the calculations and model in the procedure outline. The other important DSS feature that we should now check is the resolve options.

Can the user easily modify the input to resolve the problem without having to re-enter all input from scratch? We should ensure that this is possible by making sure the user's initial input values are preserved when re-displaying a user form

or input sheet. Make sure you do not call a ClearPrevious procedure unless the user has indeed restarted the entire application. Also ensure that default values do not overwrite the user's last input values when re-showing a user form. This allows users to quickly modify one or several parts of the input and resolve the calculations to compare results.

Can the user change other parts of the calculations or model when resolving? That is, we do not want the user to be limited to only modifying input values when resolving. The user should be able to change some constraints or objectives as well. Try to keep your application dynamic so that a user can experiment with different problem dimensions. This may not be possible or applicable for every DSS, but if it is, it should be made available to the user. If some dynamic options are not available to the user, state your assumptions clearly on the "Welcome" sheet to explain this.

With resolve options, you may want to provide the user with a way to compare various results or scenarios. You may want to store multiple solutions for this comparison or sensitivity analysis. Ask yourself what the user is really interested in learning from the DSS. Remember that a DSS is designed to aid a decision maker in making a decision. Check that the results of the application are indeed helpful to this decision making process.

We will give a few examples from our case studies; a detailed description of the DSS components can be found in each case study chapter in this part of the book. Let us first consider the Reliability Analysis case study. In this study, a user is analyzing a parallel series system of three machine types. After providing the necessary input, a simulation is run to determine the mean failure time of the system and how often a particular machine type caused the system failure. Figure 2.16 shows the output sheet for this study.

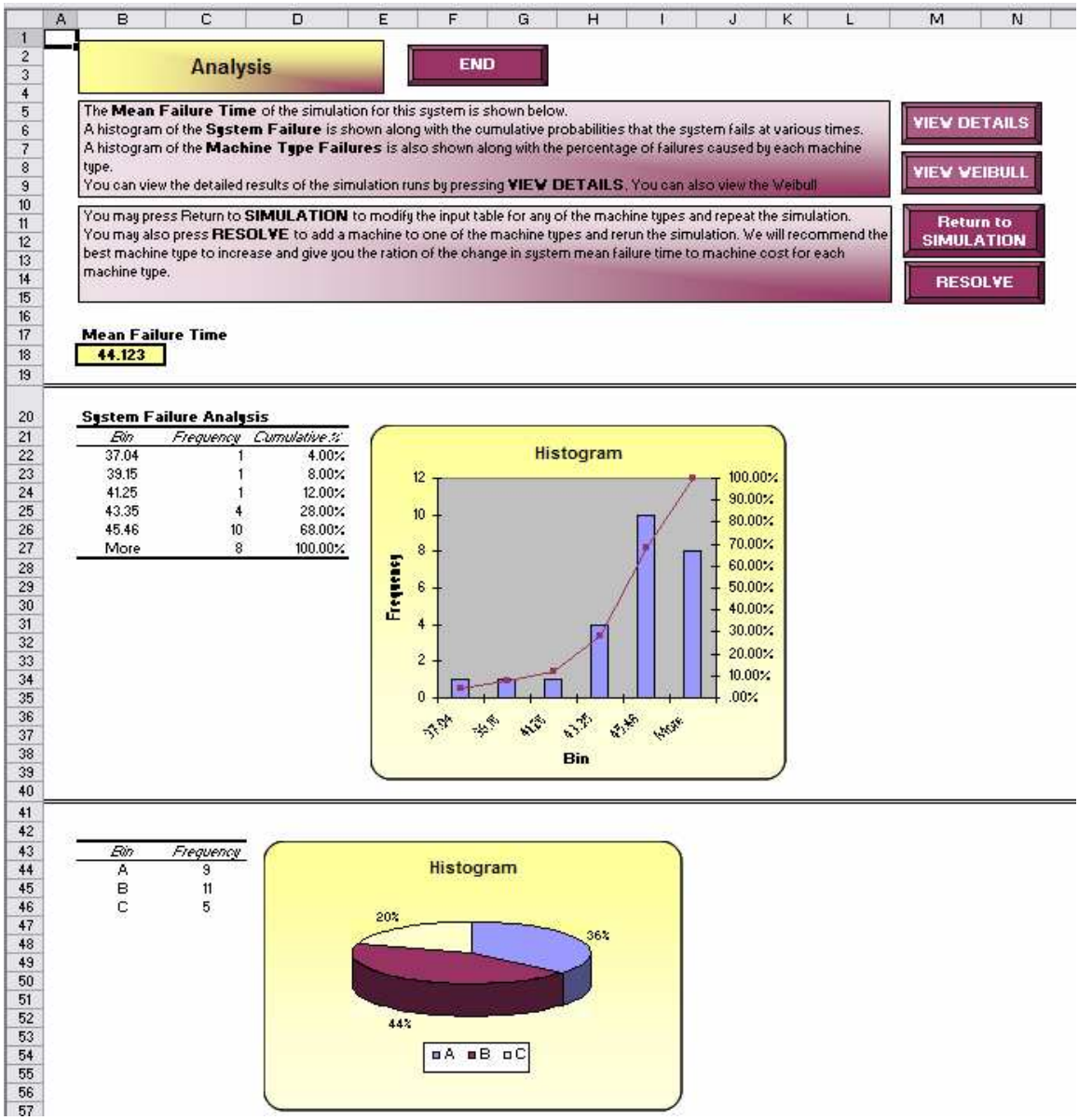


Figure 2–16: The output sheet for the Reliability Analysis case study.

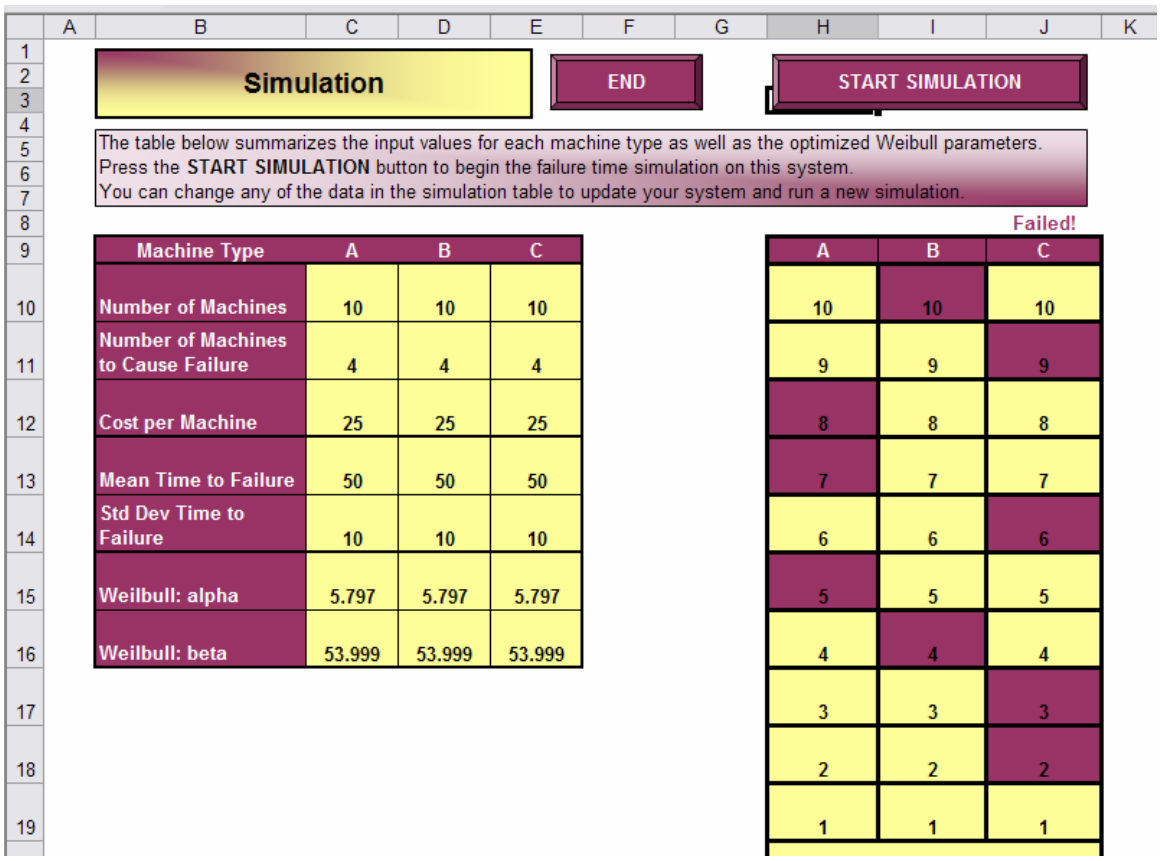


Figure 2–17: The first resolve option: modify input in table and rerun simulation.

In this case, we have two resolve options for the user. The first option is for the user to return to the simulation sheet and modify the initial input values in a given table (see Figure 2.17). They can then re-run the simulation and view the updated results.

The second option is for the user to improve the system by adding one machine of a particular machine type. To aid the user, or decision maker, in deciding which machine type they should add a machine to, we first run an optimization in the background and suggest to them the optimal choice. We do not enforce this decision, but instead try to aid the decision maker. This information is presented to the user on a user form (see Figure 2.18).

After a machine type is selected, one machine is added to this type and the simulation is rerun. The updated results are then shown.

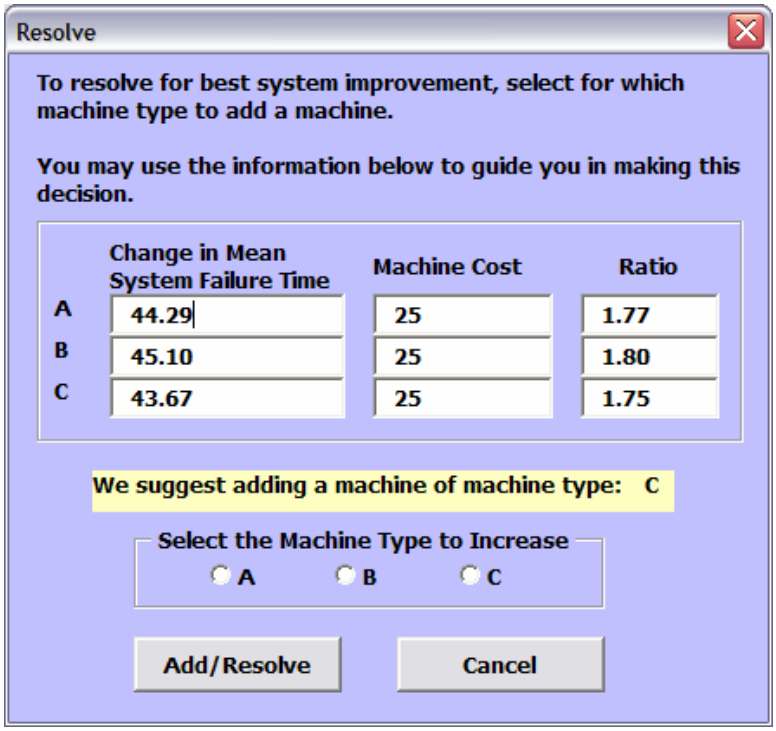


Figure 2–18: The second resolve option: suggestion is made to aid decision maker.

Another example is from the Inventory Management case study (refer to Figure 2.12). In this case, the user can actually change the model base along with the input each time the application is resolved. The user can decide which inventory model to use: Standard EOQ, Backorders, or Reorder Point. There is also an input table which can be modified on the same sheet.

Another example is from the Portfolio Management case study (refer to Figure 2.13). In this case, after the user has created their portfolio, they can optimize their investment strategy by minimizing risk (see Figure 2.19).

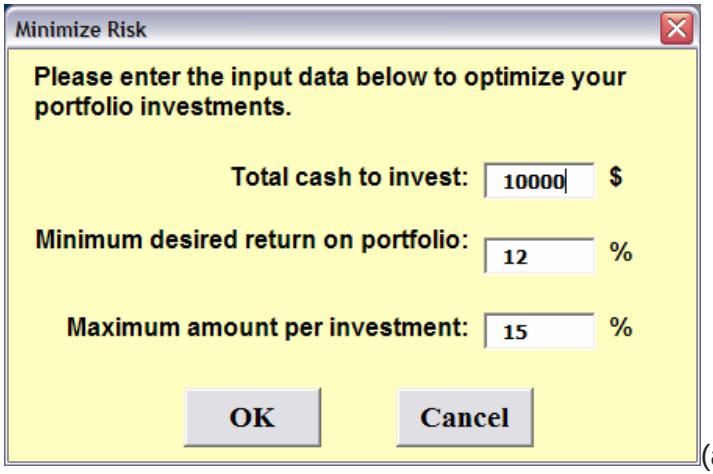
After filling the input in the user form for the optimization (Figure 2.19(a)), the resulting optimized investment strategy is displayed on an output sheet (Figure 2.19(b)). However, if the optimization was infeasible, or if the user wants to experiment with different values, they can either return to the input form to experiment with different values (by pressing the “Modify Input” button), or return to the portfolio sheet to modify their stock selection (by pressing the “Modify

Portfolio" button). An extension to this case study may be to allow the user to modify their objective in optimizing their investment strategy; currently we assume that we minimize risk, but the user may also want to maximize returns.

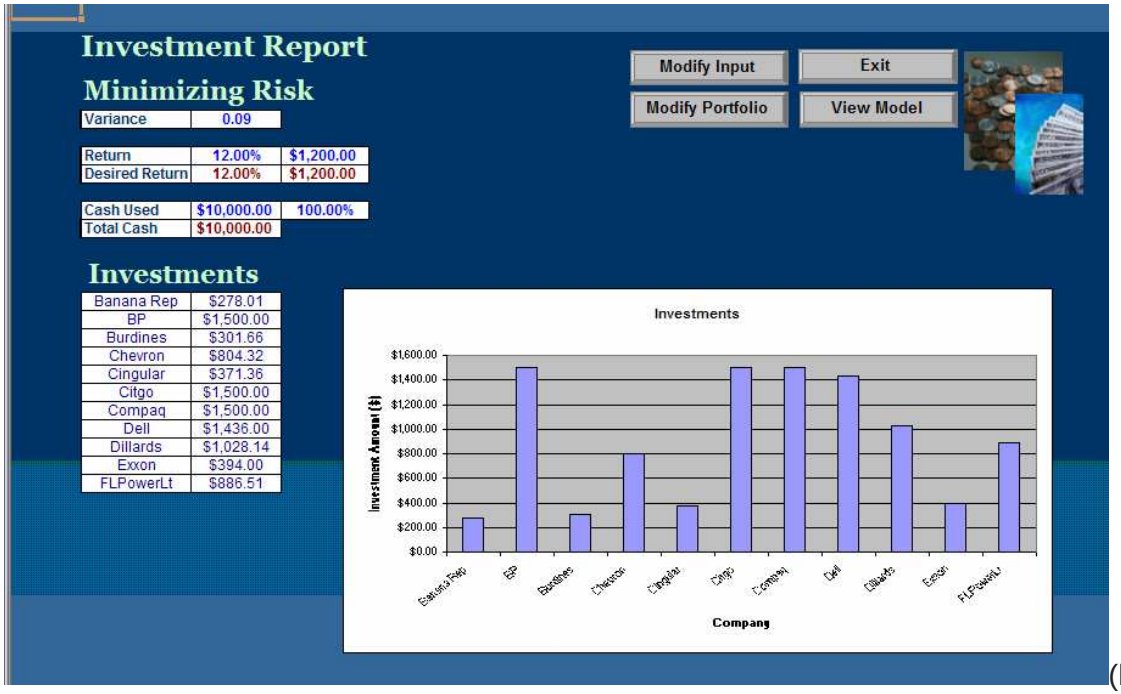
Resolve options are an important DSS component. Ensure that the DSS is aiding the decision maker by allowing the user to modify inputs or calculation options.

Table 2–5: Summary: Resolve Options

Resolve Options	Modify inputs, calculation options, constraints, objectives; aid decision maker in making the best decision.



(a)



(b)

Figure 2–19: Two "Modify" buttons give the user different resolve options.

CHAPTER 3
GUI DESIGN AND PROGRAMMING PRINCIPLES

3.1 GUI Design

A graphical user interface (GUI) is the "graphical representation of, and interaction with, programs, data, and objects on a computer screen." (Mandel [2]) It presents a visual display of information and objects which can present visual feedback to a user. Part of the definition of a DSS is: A DSS is designed to be easy to use; user friendliness, graphical capabilities, and an interactive human-machine interface greatly increase the effectiveness of a DSS (refer to Chapter 1). Thus, it is very important to design the user interface such that it is easy for the user to understand and use. If the user interface is not designed well, then the application's functionality will not be appreciated. In this section, we will discuss some theory behind good GUI design and give some examples of good and bad user interfaces.

3.1.1 The Theory Behind Good GUI Design

There are many GUI design books which lists several different principles and guidelines for good GUI design. We present here a summarized version of what we feel are the most important theoretical points for good GUI design in spreadsheet-based DSS applications. These are: knowing the user, the user's tasks and goals; maintaining clarity, and staying consistent.

3.1.1.1 Users, tasks, and goals

It is important to know who the users of your application will be. Are they managers? If so, how deep is their understanding of the problem? Do they know the model or algorithms being used to perform the calculations? What terminology do they use to discuss the problem? If the user does not have a highly technical understanding of the topic of the application, then try to avoid describing the

details of the model or calculations. This would be a case when the calculation sheet may remain hidden. Try also to give instructions and label input without using technical terminology. For example, instead of labeling input as C or D, give meaningful descriptions such as “Annual Cost” or “Annual Demand.” In the case that your users do have a more technical understanding, you should show and explain the calculations and assumptions. You may also want to give more details using the terminology they are familiar with.

Keep in mind that the user is using this application to complete some tasks and achieve a goal. It is important to ensure that the user interface is an aid to the user in completing these tasks so that the user feels that the DSS has indeed become a helpful tool in increasing the efficiency of achieving their goal. The user’s task domain includes “the data that users manipulate, the manner in which that data is divided , and the nature of the manipulation that users perform on the data.” (Johnson [3]) Remember that the user’s tasks are already necessary without the help of a DSS; therefore, ensure that your DSS application aids them in completing these tasks in the same domain they are familiar with. These tasks should be organized on some priority or hierarchy base in order to create a flow for the application. This flow influences the outline of the entire application as we discussed in the first section. Your interface should guide the user so that they can work with the data in their task domain in the order in which it needs to be completed.

For example, let us suppose that the user’s task domain involves looking at some historical data, then computing a mean and standard deviation of this data, and then entering these values into a forecasting model. Based on the result of the model, the user has to take the forecast demand for the next month and place an order of that size. When constructing the interface for a forecasting DSS, ensure that these tasks are presented to the user in the same order. First, ask

them to enter the historical data. If they usually get this data as a text file from a coworker, then do not ask them to enter it manually, instead prompt them to import the text file. You can then automatically calculate the mean and standard deviation to display for them. Afterwards you may ask for some extra input for the forecasting model, but try not to get to technical. You may then display clearly to them what their order amount should be based on this forecast. Do not try to reorganize their tasks as they will find the DSS hard to learn. Keep the presentation of the tasks simple so that there is an element of familiarity for them.

Table 3–1: Summary: Users, Tasks, and Goals

What is the user's knowledge of the problem and technical understanding of the model calculations?
What terminology is the user familiar with?
Define the user's task domain to determine the application flow.

3.1.1.2 Clarity

A user interface is the communication between the user and the application; therefore, if you want the user to use the application correctly, you must communicate clearly to them what they should do to use it. First and foremost, make sure there is a clear description of what is involved on every spreadsheet and every form. For example, in Figure 3.1, we show the calculation sheet from a Sales Force Allocation case study. We ask the user to enter some bound values for the optimization constraints. We then give them two calculation options. We explain the user's tasks in a text box at the top of the sheet. We have bolded the button names and column names in the text to help the user quickly identify the location of the tasks on the sheet.

The functionality of any button or control should be clear to the user. On spreadsheets, try to make some separation between navigational buttons and functional buttons. For example, if on an input sheet you have the buttons "End,"

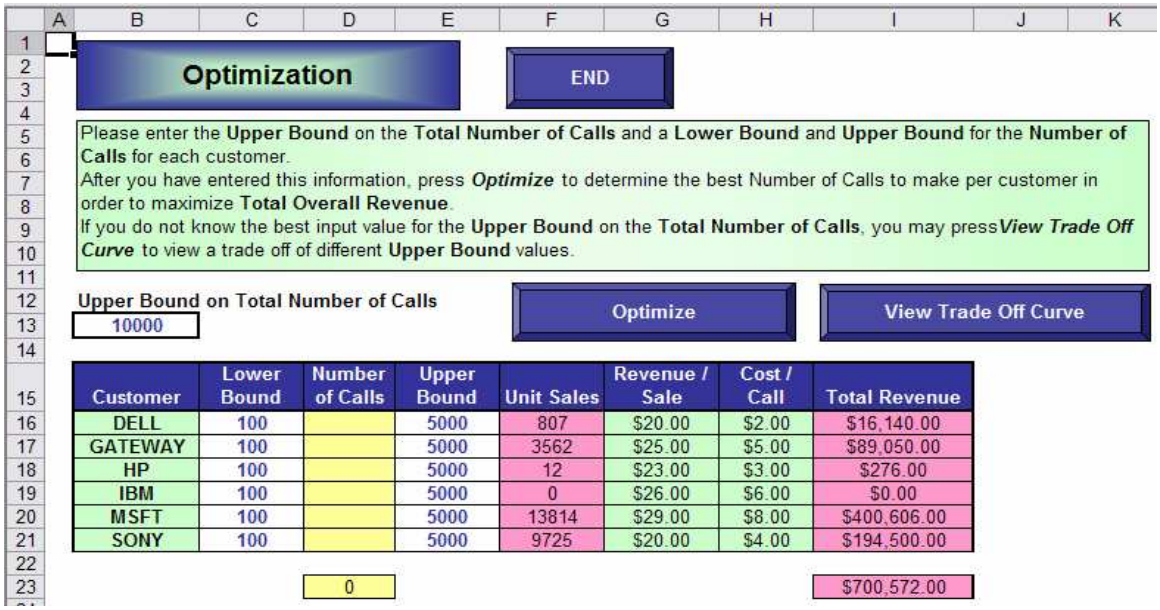


Figure 3–1: Clear instructions and descriptions on each sheet and form.

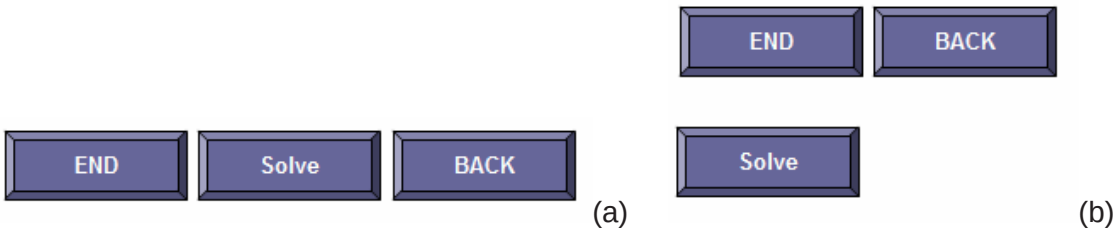


Figure 3–2: Buttons are clearly separated into navigation and calculation groups.

"Back" and "Solve," it is better to keep the navigational buttons "End" and "Back" together and place the "Solve" button somewhere else on the sheet.

Likewise, on user forms, ensure that functional buttons are separate from the "OK" and "Cancel" buttons.

Aside from buttons and command button controls, all other controls should also be clearly labeled so that their functionality is understood. Never let a text box be unlabeled and assume the user knows what to enter. Also ensure that list boxes and combo boxes are labeled so that the user knows what the list contains. Frames containing grouped items should also be labeled to signify the grouping. The clearer the controls are, the quicker the user can learn their functionality and

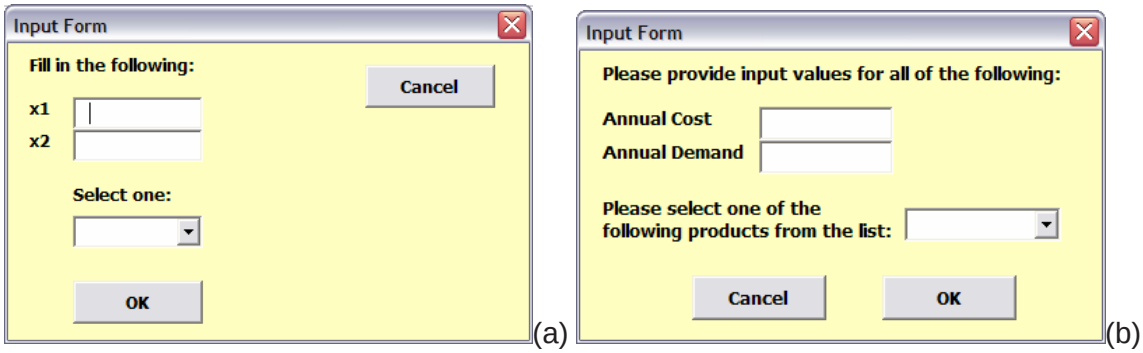


Figure 3–3: Labels clearly designate functionality of controls.

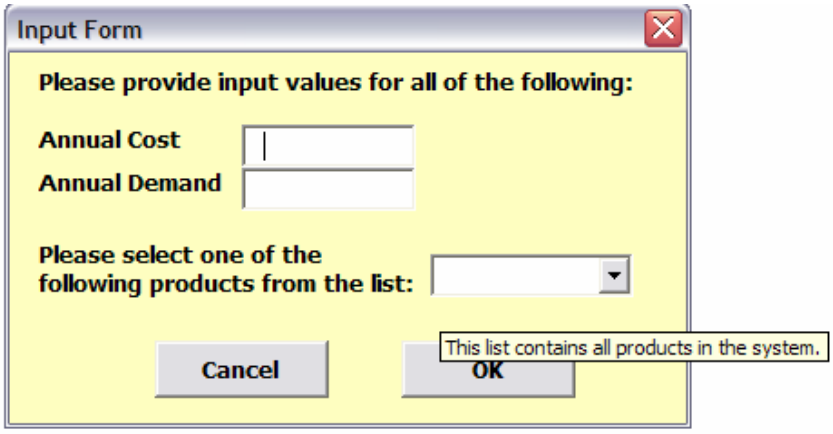


Figure 3–4: Control tips clarify control functionality.

the easier it is for them to use the application. For example, compare Figure 3.3(a) and Figure 3.3(b); without clear control labels, users will have to hesitate and guess what information you are asking for.

Another way to clarify control functionality is by creating control tip messages. This is a good way to provide more detailed instructions to the user without cluttering the form. For example, in Figure 3.4, there is a control tip for the combo box. When the user places the cursor over the combo box, the text "This list contains all products in the system" appears.

Another benefit to clarifying your user interface functionality is that it may reduce the errors encountered by the user. The most frequent user errors involve inputting values in an incorrect format or of an incorrect type or choosing a

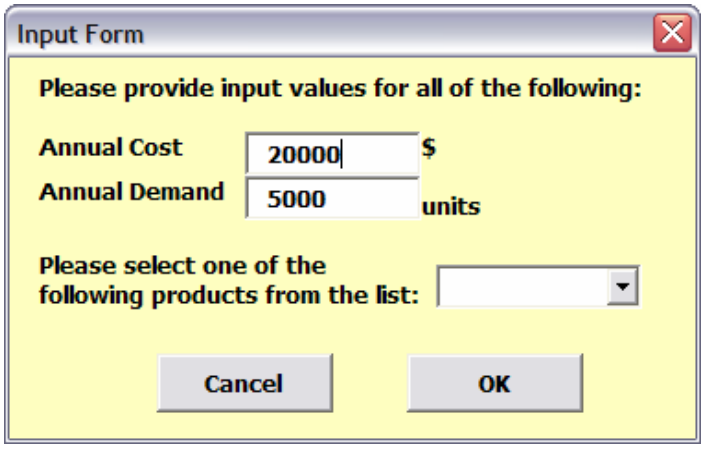


Figure 3–5: Formatting guidelines.

selection or command button at an inappropriate time. Even though error checking can be done, as discussed in Chapter 22, having a better-designed user interface can reduce this extra coding. Aside from clearly labeling controls, you may also give default values as an example of the input the user should enter. You may also guide the user for proper formatting issues.

For example, referring to Figure 3.3(b), if the user is supposed to enter a cost, they may enter "$20,000" or "20,000" or "20000." If you do not want the user to enter "$" or "," punctuation marks, then you should clarify this to them on the interface design. Either write more specific instructions, or guide them with default values; otherwise, you will have to do some error checking in your code to ensure that a data type error does not occur when you try to perform an operation on their input value (see Figure 3.5).

Some other common formatting examples are for numerical input such as social security numbers or telephone numbers. In Figure 3.6(a) we show that the user may input these values with various formatting. This may cause errors when storing, searching for, or performing operations with the data. Figure 3.6(b) has clarified the formatting issues so that the user is only entering numerical values without extra punctuation.

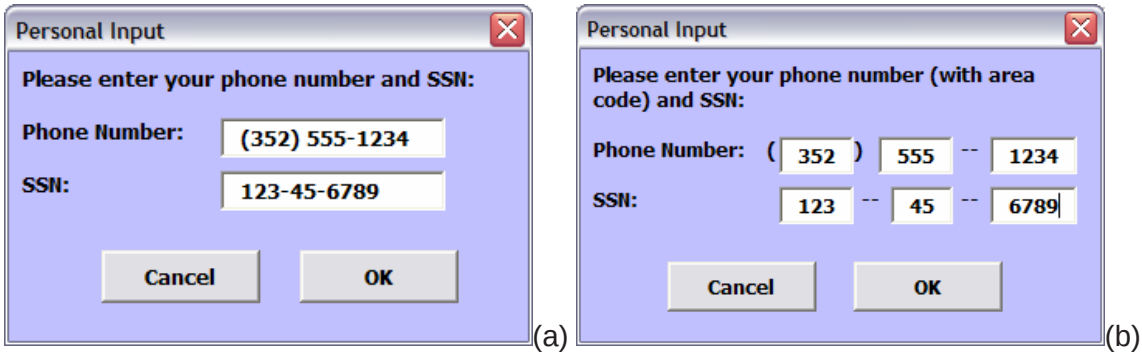


Figure 3–6: Clear formatting and default values.

If there is still a user error while using an input interface, make sure that a clear error message is given to the user. The user should understand what they did wrong and what they need to do to correct the problem. For example, the error message "Incorrect input!" is not helpful to a user. However, a message such as "You may not enter negative numbers. Please enter a positive number." redirects the user to correct the error. Errors should be hard to make and easy to correct.

Overall, clarity is very important in good GUI design. It is important to check sheet and form instructions, control labels, and data input guidelines to ensure that the user can clearly understand what to do.

Table 3–2: Summary: Clarity

Give clear instructions at the top of each spreadsheet and each form.
Label controls clearly so that their functionality is understood.
Control tips can be used to add detail to functionality descriptions without cluttering the form.
Give default values to clarify how data should be input.
Make formatting issues clear.
Clear GUI design can help the user avoid making errors.
If user errors are made, give clear error messages to redirect the user to correct their error.

3.1.1.3 Consistency

The third theoretical point for good GUI design is consistency. A user will be inclined to interact with an interface according to how they are expecting

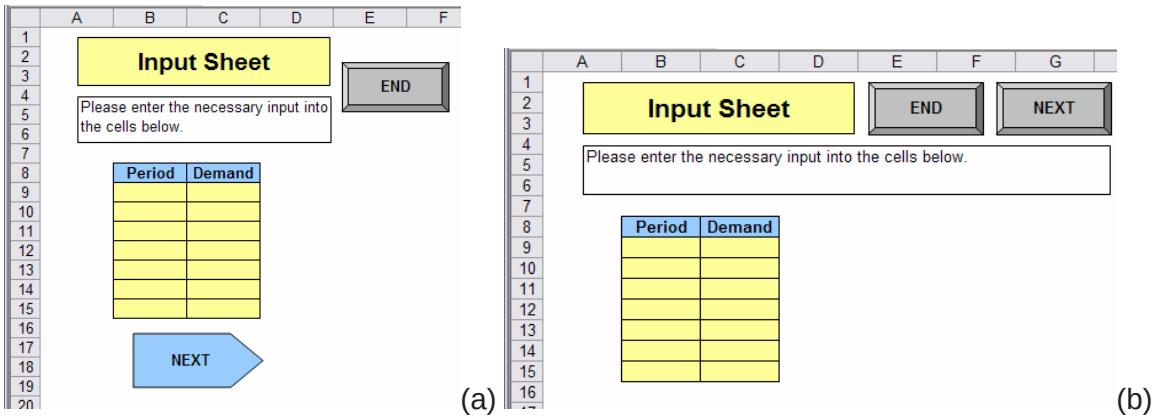


Figure 3–7: The navigational buttons are together and consistent in the sheet.

it to be. That is, they may expect some input prompt, button locations, and viewable options based on their familiarity with working with the problem or with other interfaces. It is important that within your application, or across similar applications, some features of the user interface are consistent.

The first place there should be consistency is on the spreadsheets. Try to keep the title and sheet description and instructions in the same location for each sheet in the application. This way, if the user is looking for an explanation of what is included on a particular sheet, they can always look at the same location on the sheet. We tend to keep sheet titles and descriptions at the top left of each sheet layout. Also ensure that the navigational buttons, especially the "End" button, is in the same location on each sheet. The user should not have to search through the sheet to try to exit the application. Compare the forms presented in Figure 3.7. You should also consider consistency in the sheet layout for input cells and charts. For example, if you have multiple output sheets, each with a chart, the charts should all be in the same position on each sheet.

In designing user forms, consistency can be enforced in several ways. First of all, as with sheets, ensure that some description label is always at the top of the form. Also keep navigational command buttons, like "OK" and "Cancel," in the same position on all forms. If "OK" is on the bottom right of a form and "Cancel"

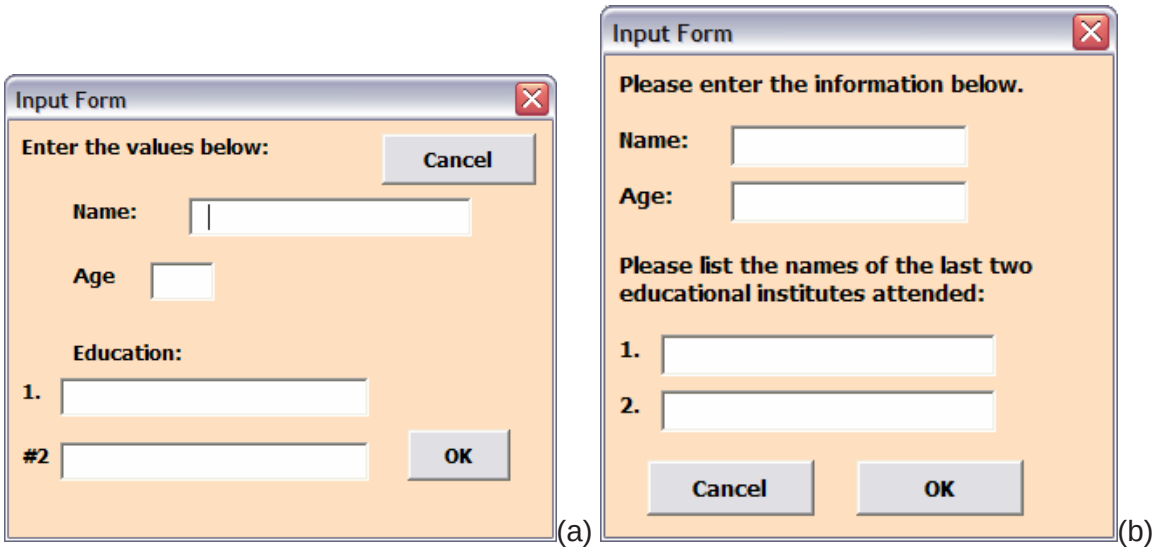


Figure 3–8: Consistent formatting and clear constructions.

is on the bottom left, do not switch them for subsequent forms. The user should not feel tricked into pressing the wrong button.

Regarding form controls, using the alignment and size features can also improve the form layout. Try to keep text box sizes the same throughout the form; they should also all be aligned equally. Keep all buttons the same size as well. Try to also be consistent with punctuation, such as the use of semicolons. Compare the forms presented in Figure 3.8.

If your form instruction label and command buttons are consistent for the forms in your application, you can save interface development time by saving the first form you create and importing it multiple times. (Refer to Chapter 18 for detailed instructions on how this is done.)

Another feature of form consistency that can aid the user in moving quickly through the interface is the tab order of the form. Ensure that the tab order take the user from the top of the form down to the "OK" button and finally the "Cancel" button. Again, the idea is to help the user feel that the user interface

is easy to learn and easy to use. Keeping the forms consistent throughout your application will help the user accomplish their tasks more quickly and efficiently.

Table 3–3: Summary: Consistency

Consistency is important in helping the user move quickly through the user interface.
Keep sheet titles and instructions in the same location.
Keep navigational buttons, especially the "End" button, in the same location per sheet.
Keep input cells and charts in the same locations for similar sheets.
Keep form instructions and command buttons in the same location for each form.
Make controls consistent by using align and same size features.
Set tab order to take user from top of form to "OK" and "Cancel" buttons.

3.1.2 Good and Bad GUI Designs

We would now like to provide several examples of good and bad GUI designs. We have grouped these examples by different control types and a few more general categories which apply to the entire user form.

3.1.2.1 Buttons

Buttons should always be of the same size and shape. Try to also keep buttons the same color unless highlighting a particular function button to guide the user. Group functional buttons together and navigational buttons together. We have seen examples of this in Figures 2.21 and 2.26

3.1.2.2 Text boxes versus list boxes and combo boxes

Reduce the memorization requirements of the user by replacing text boxes with list boxes or combo boxes when possible. This also reduces possibility of errors. For example, if user is asked to enter a student name for their class grades, using a combo box would prevent the user from entering the name of a student which is not in their class, or misspelling the student's name. Compare the forms in Figure 3.9.

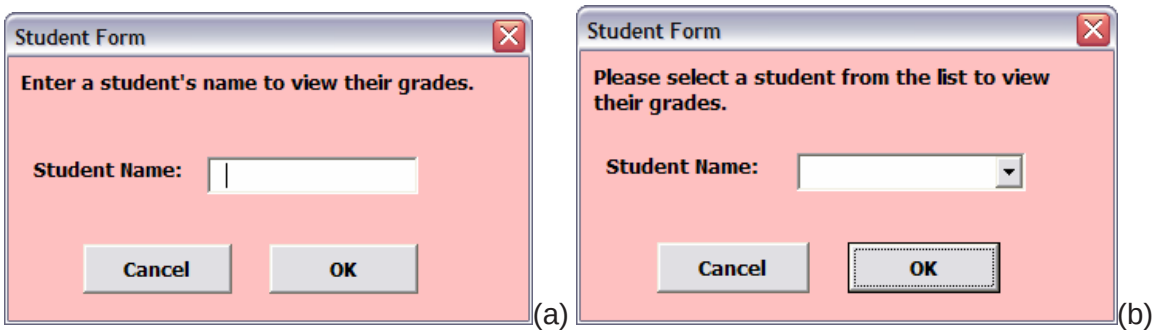


Figure 3–9: Combo boxes reduce user memorization and chance for errors.

3.1.2.3 Tab strips and multi pages

When using tab strips or multi pages, try to minimize the number of tabs. Too many tabs can cause tab positions to shift when clicked; the user may not see all of the tabs and leave some input blank. Try to reorganize your input needs so that you can use multiple forms or combine tab information to reduce the number of tabs. Compare the forms in Figure 3.10.

3.1.2.4 Check boxes versus option buttons

Only option buttons should be used for mutually exclusive input. Even though option buttons can also be used for non-mutually exclusive input if they are not grouped in a frame, we recommend using check boxes for this purpose instead. Be consistent in your use of check boxes and option buttons for these respective purposes. Compare the forms in Figure 3.11.

For option buttons, you should always have more than one grouped in a frame. If there is only one option, then treat it as an "on/off" option and use a check box. Another way to modify only one option is to create another option with an opposite value. For example, instead of just giving the user an "on/off" option for "Assume non-negative values," you could create another option such as "Do not assume non-negative values" or "Allow positive values."

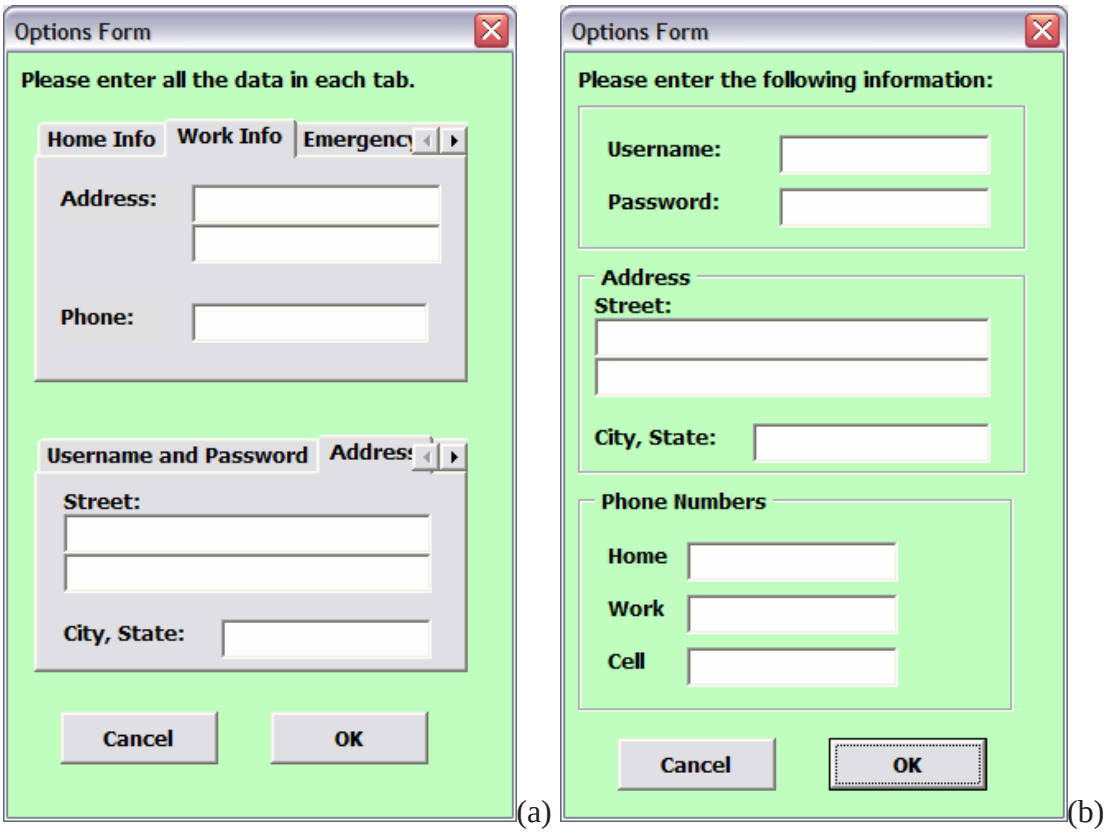


Figure 3–10: Tab strips and multi pages can be replaced if too many tabs are needed.

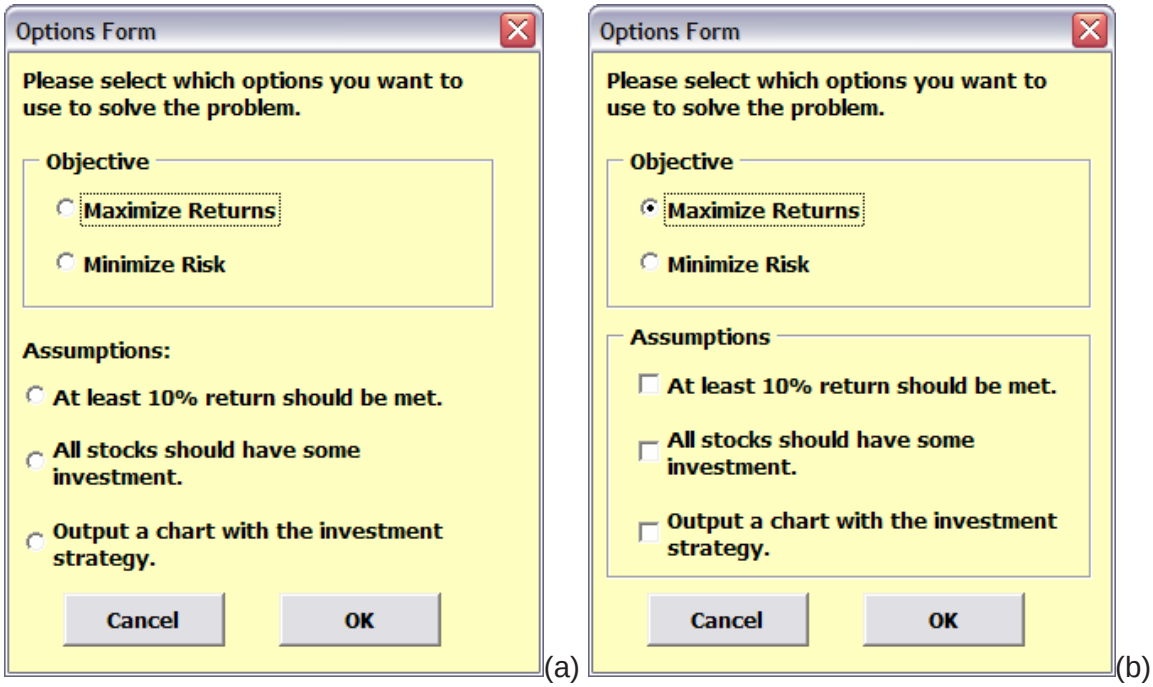


Figure 3–11: Option buttons are used for mutually exclusive options and check boxes are used for other options.

3.1.2.5 Frames

Frames can be used to group similar items. You should therefore always have at least two controls in a frame. However, if you have more than one frame on a form or sheet to separate different groups of controls, you may end up with only one control in one of the frames. You should still avoid having all frames with only one control or only one frame with only one control. Compare the forms in Figure 3.12. To use frames with controls on the spreadsheet, you can use shape boxes.

3.1.2.6 Labels versus text boxes

Labels should be used for read-only information. Do not use a text box to present information to a user when they should not be able to modify it. For example, suppose we have a form to receive input for three machine types in a production system. We may use a loop to show the same form to the user three times to receive the input for each machine type. We may display the machine type

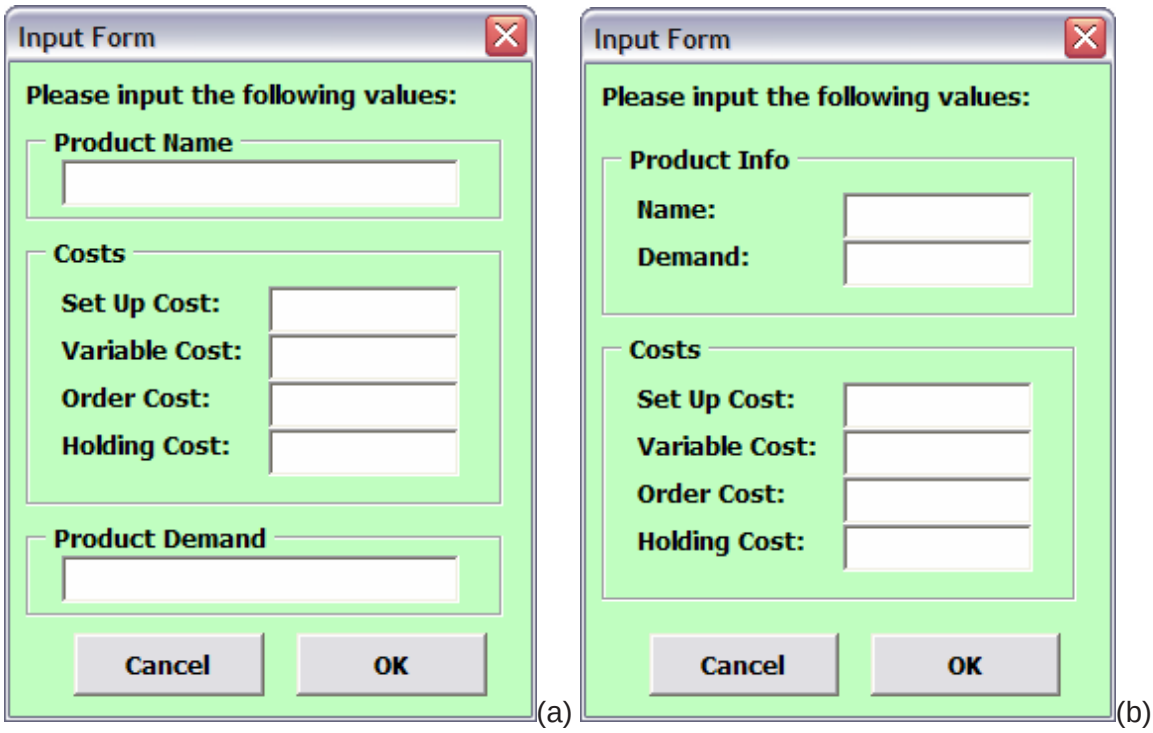


Figure 3–12: Frames have more than one control each.

number to the user, but we do not want them to modify it; therefore, we should use a label not a text box (see Figure 3.13)

3.1.2.7 Dynamic controls

For dynamic controls, you may be making some controls visible or not visible or you may keep them visible but make them inactive. To make a control inactive, you must gray it out to an extent that there is no confusion from the user on whether or not they can change the value in the inactive control (see Figure 3.14). You should also lock inactive controls so that they cannot be modified. If a control becomes inactive, you should also set the Tab Stop property to False.

3.1.2.8 Multiple forms

When using multiple forms, make sure to hide or unload sequential forms so that there is not a layering on the screen. The only time a layering may occur is if there is a sub form which must be filled before a main form can be completed. However, try to avoid such situations.

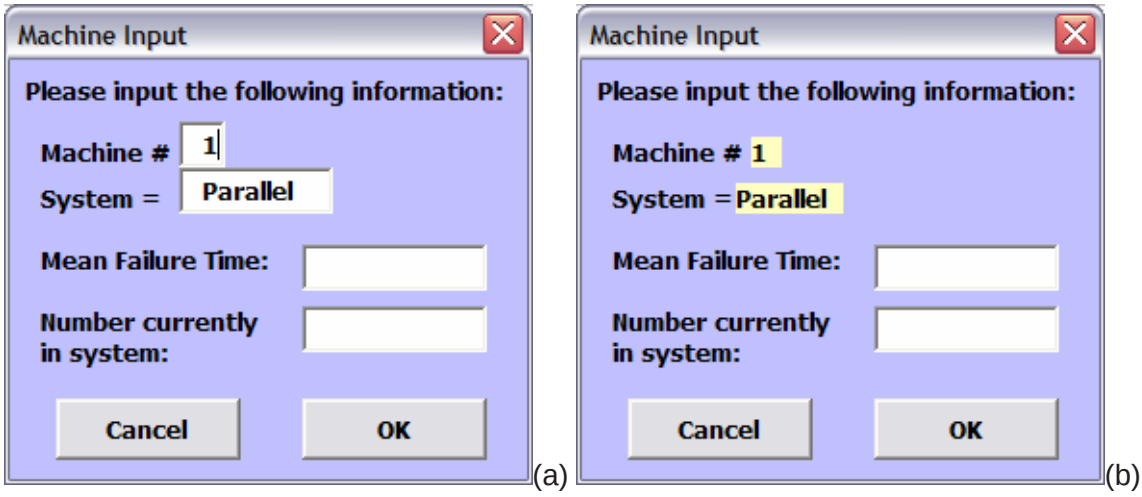


Figure 3–13: Labels are used for non-changeable values.

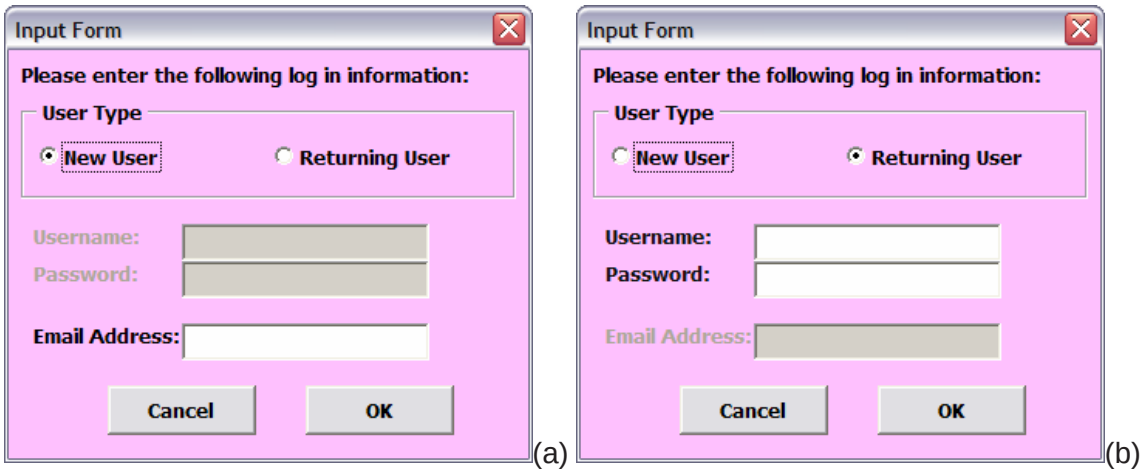


Figure 3–14: Some functions are active and some are inactive.

3.1.2.9 Event procedures

Associating actions with some event procedures can be confusing to the user. For example, when using command buttons, it is better to use the Click event rather than the MouseDown event. The user may press the mouse down and not see a result thinking that the form is not working.

For text boxes, it is better to use the AfterUpdate event rather than the Change event. The Change event may cause errors if some formatting or values have been enforced. For example, suppose there is an error check to ensure that a number has been entered in a text box. If the user is deleting a previous value to enter a new one, when the text box changes from one value to empty, the error will be caused. Instead use the AfterUpdate event so that you only check the value of the text box once the new value is completely entered.

For check boxes, we recommend that you use the Change event instead of the Click event. However, be aware that with mutually exclusive option buttons, the Change event may be over-triggered, and so the Click event may be better.

3.2 Programming Practices

There are many books on programming practices and coding standards. We summarize here what we feel are some important issues when coding in VBA for spreadsheet-based DSS development. We categorize these issues as follows: coding with a consistent style, using naming standards, having clear comments, and increasing coding efficiency.

3.2.1 Consistent Style

Your code should reflect a consistent style; that is, it should appear that the same person has developed all of the code. Spacing, indenting, line length and other formatting should be consistent. We would recommend keeping procedures and functions spaced apart enough so that it is easy to scan through the code.

Table 3–4: Summary: GUI Design

Command Buttons	Similar shapes, sizes, colors, and locations. Separate functional and navigational buttons.
Text Boxes versus List Boxes and Combo Boxes	Minimize user memorization by using list boxes or combo boxes instead of text boxes. This may also minimize user error.
Tab Strips and Multi Pages	Only use a few tabs. Avoid hiding some tabs.
Check Boxes versus Option Buttons	Option buttons should be used for mutually exclusive options; use check boxes otherwise. Use check boxes for "on/off" options or create an opposite option to use option buttons.
Frames	Try to have more than one control per frame and more than one frame per form.
Labels versus Text Boxes	Labels should be used for read-only information.
Dynamic Controls	Make inactive controls grayed and locked. Also change their tab order.
Multiple Forms	Make sure to close sequential forms. Avoid layering if possible.
Event Procedures	Command buttons: Click better than MouseDown; Text boxes: AfterUpdate better than Change; Check boxes: Change better than Click; Option buttons: Click better than Change

We also recommend using indenting to signify the beginning and end of a loop or logical structure. For example, consider the two examples below.

```
Indenting not clear:
        If A is True Then
        'actions 1
        ElseIf B is True Then
        'actions 2
        End If


Clearer indenting style:
        If A is True Then
                'actions 1
        ElseIf B is True Then
                'actions 2
        End If
```

We also recommend being consistent with the line length of your code. It is better not to have to scroll back and forth through your module to read various lines of code. Try to break lines at logical places, but be as consistent in line length as possible. Coding style can also be observed in the naming standards and commenting style, which we discuss in later sections.

Another area where style should be consistent is in error checking. Ensure that error checking is done consistently. That is, do not check input from one form but not another; or do not check input from a Message Box but not a form. Whatever methods you use for error checking, try to use them in all of your error checking routines if possible. In general, when you are outlining your procedures, ensure that there is some consistency to your coding approach.

3.2.2 Naming

Naming standards should be applied to both variables and procedures. Avoid redundancies in these two different areas. That is, if you have a procedure named "MinProfit," try not to define a variable named "MinProf." It is good to use abbreviations in names, but make sure they are clear and not confusable with multiple meanings. For example, the variable name "NumFac" may represent "number of facilities," "number of faculty," or "number of factories." When using more than one word in a name, we suggest capitalizing the beginning of each word. Try to make names descriptive but not to lengthy; for example: "MinVal," "SumProfit," "MaxPrice." Variable used for loops, aside from "i" or "j" or other small indices, may be descriptive of the loop count. For example, you may use "iter" to count the number of iterations in a loop; or "run" to count the number of runs in a simulation.

Some other common naming standards refer to control names. We give a list of the starting name values for various controls in Chapter 18. For example, the name of a text box should begin with "txt"; the name of a form should begin with "frm." For Boolean variables, we recommend starting the variable name with "Is" or "Do." For example, "IsDone" or "DoAnimation." For constants, we recommend writing the names in all uppercase, such as: "PI" or "INFINITY."

For procedure names, try not to make them to vague. For example, instead of "Calc," use a more descriptive name such as "CalcReturn." For function procedures, you may also use names which signify the returned value. For example, "FindMinCost" or "GetUserInfo." In general, use names which will not be easily confused. This will help avoid coding errors and ease debugging.

3.2.3 Comments

Commenting is a good habit to have as a coder. Comments help clarify what you have done and why you have done it. They would also benefit another

programmer who may look through your code later. Keep your comments up to date as you make changes or updates to your code.

You should have a comment at the beginning of each procedure to give an overview of what the sub or function will do. Avoid abbreviations in these comments as you want to ensure that they are clear. You should also have comments before loops or logical checks to explain the flow of the code.

Use comments to organize your code and make it easier to read. Do not overdo it though as you do not want to have unnecessary comments which only add length to your code.

3.2.4 Efficiency

The most important programming issue is code efficiency. You should constantly be trying to improve your code by reducing the complexity of the logic or time required. If you have several nested loops, see if you can simplify this structure; maybe a Select, Case structure would be better than multiple levels of If, Then. Check if you are repeating some actions unnecessarily. Are you clearing values before overwriting them? Are you reformatting a range unnecessarily? Are you repeating a calculation that has previously been computed? As you are writing comments to explain your code, check if you could improve it first.

Another way to improve code efficiency is to ensure that extra memory is not being used. For example, there is no need to declare a counting variable "i" as a Double, it only requires the memory of an Integer data type. Ensure that arrays are also dimensioned for the needed storage space. You can use the ReDim Preserve statement to do this.

You should also write your code to be dynamic for future extensions or updates. For example, for bound variables, array sizes, or range values, you may want to use variables instead of values. Consider the following examples.

```
Static structure:
```

```
    For i = 1 to 10
        'do actions
    Next i
```

Dynamic structure:

```
    For i = 1 to NumProducts
        'do actions
    Next i
```

Static structure:

```
    Dim CostArray(10) as Double
```

Dynamic structure:

```
    Dim CostArray() As Double, CostSize As Integer
    ReDim CostArray(CostSize)
```

Static structure:

```
    'paste in output table
    Range(``A1").PasteSpecial
```

Dynamic structure:

```
    Dim OutputTable As Range
    Set OutputTable = Range(``A1")
```

```
OutputTable.PasteSpecial
```

In the dynamic structures in the above examples, it is easy to modify the code by assigning a new value to the extra variable; otherwise, modifications would have to be made multiple times throughout the code.

For spreadsheet-based DSS applications, you can also improve code efficiency by balancing what needs to be done in code with what can be done in the spreadsheet. For example, some calculations can be prepared on a spreadsheet using Excel functions rather than computing them with a function procedure or loop in the code. Likewise, much formatting can be done in the spreadsheet instead of in the code. There will be a tradeoff between functionality and fanciness of the program; it is more important that the application model performs correctly. The better the coding, the better the quality and performance of the application.

Table 3–5: Summary: Programming Principles

Consistent Style	Use a consistent style for formatting, organizing, and commenting your code.
Naming	Use naming standards for variables and procedures. Naming standards also apply to control names and specific data types, such as Boolean.
Comments	Make comments clear throughout the code. Describe procedure functionality and loop and logical flow.
Efficiency	Always look for ways to improve your coding efficiency. Avoid redundancies and unnecessary code.

CHAPTER 4
WAREHOUSE LAYOUT

4.1 Application Overview

This case study is a DSS application of the warehouse layout problem. The warehouse layout problem is to subdivide the floor area of a warehouse into storage areas for several product types so that the total material handling cost between the storage areas and the warehouse docks is minimum.

4.1.1 Model Definition and Assumptions

For simplicity, we discretize the warehouse floor area into A unit grids, called bays; here A represents the total warehouse area. We are seeking to allocate these bays to various products types. We will now describe this problem in greater detail. However, we will present some notations first for the three entities in the problem: the warehouse bays, docks, and product types.

Bays: We decompose the warehouse floor area into A bays, indexed by $k = 1$, 2, , A.

Docks: The warehouse has n docks indexed by $j = 1, 2, \ , n$. Products are brought into the warehouse and travel out of the warehouse through these docks. We represent the distance between each bay and each dock as d_{kj}.

Product types: The warehouse layout problem as m product types indexed by $i = 1, 2, , m$. A product i requires an area of A_i bays in the warehouse. We assume that the warehouse has enough floor area to store all of the product types.

$$\sum_{i=1}^{m} A_i = A \tag{4.1}$$

In Figure 4.1 we construct an example with five product types and two docks.

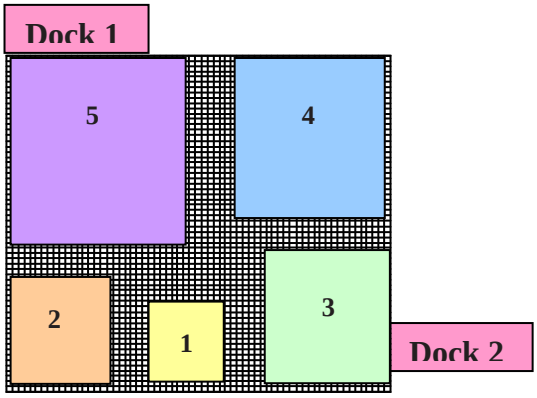


Figure 4–1: An example warehouse layout.

Each product type i has a demand D_i. We assume that the demand for each product type i is uniformly divided over the entire storage area required by for the product type. Since product type i is stored on A_i bays, the total demand of product i per storage bay is D_i/A_i.

Each product type also interacts with the docks with a different frequency. The frequency is defined as the fraction of the demand that will travel in or out of the warehouse through a particular dock. We define these frequencies as F_{ij}. The sum of the frequencies over all docks for each product type should be 1; that is.

$$\sum_{j=1}^{n} F_{ij} = 1 \quad \forall i \tag{4.2}$$

We are seeking to assign product types to the warehouse area such that the product types with the highest demand per storage bay are situated closest to the docks with which they have the highest frequency. To enforce this policy during assignment, we define a weight W_{ij} to represent the amount of a particular product type i per storage bay that travels to and from a particular dock j. These weights are defined as follows.

$$W_{ij} = F_{ij} * \frac{D_i}{A_i} \tag{4.3}$$

Therefore, if product type i is stored at bay k, then the total material handling cost with dock j due to this storage is $d_{ki} * W_{ij}$. We define the assignment decision variables x_{ki} as binary variables to represent whether or not product type i is assigned to bay k.

$$x_{ki} = \begin{cases} 1, & \text{if assignment was made;} \\ 0, & \text{if no assignment was made.} \end{cases} \tag{4.4}$$

The warehouse layout problem can now be formulated as the following integer programming (IP) problem.

$$\min \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{A} x_{ki} * d_{kj} * W_{ij} \tag{4.5}$$

$$\text{Subject to:} \tag{4.6}$$

$$\sum_{k=1}^{A} x_{ki} = A_i \quad \forall i \tag{4.7}$$

$$\sum_{i=1}^{m} x_{ki} = 1 \quad \forall k \tag{4.8}$$

$$x_{ki} \in \{0, 1\} \quad \forall i, k \tag{4.9}$$

This objective seeks to minimize the material handling cost between the assigned storage areas and the warehouse docks over all product types. The constraint 4.7 states that only A_i bays are assigned for each product type i. Constraint 4.8 states that only one product type can be assigned per bay.

This formulation is an IP problem and can be solved by an IP algorithm. (For more details, see Francis [4]) In this application, however, we will consider a special case of the objective function 4.5 that can be solved very efficiently using a greedy method.

Recall that W_{ij} represent the amount of a particular product type i per storage bay that travels to and from a particular dock j. We assume that the m by n matrix $W = \{W_{ij}\}$ factors; that is, there exist numbers α_i and β_j such that.

$$W_{ij} = \alpha_i * \beta_j \quad \forall i, j \tag{4.10}$$

We may point out that not every matrix W factors, only some do. When a matrix W factors, we can give an intuitive explanation to the factors α_i and β_j. Let α_i denote the total demand of product type i per storage bay over all docks, and β_j denote the frequency with which each dock j is used.

$$\alpha_i = \frac{D_i}{A_i} \tag{4.11}$$

$$\beta_j = F_j \tag{4.12}$$

We now have the following.

$$W_{ij} = \alpha_i * \beta_j = \frac{D_i}{A_i} * F_j \tag{4.13}$$

The factoring assumption implies that each product type will have the same dock frequency for a dock j as any other product type. This frequency, formerly noted as F_{ij}, is now noted as F_j or β_j. For example, if there are two docks with frequencies $\beta_1 = 0.3$ and $\beta_2 = 0.6$, then the factoring assumption implies that each product type will send 30% of its demand per storage area through dock 1 and 60% through dock 2.

In this case, when the matrix W factors, we can restate the objective function of the warehouse layout problem as follows.

$$\min \sum_{i=1}^{m} \sum_{k=1}^{A} x_{ki} * \alpha_i * (\sum_{j=1}^{n} d_{kj} * \beta_j) \tag{4.14}$$

We can now observe that since α_i denotes the total demand of product type i per storage bay over all docks, the greater the value of ai for any product type, the greater is the interaction this product will have with the docks. Therefore, we want to ensure that these product types with the highest ai values are assigned to the bays with the minimum distance to the docks.

We also observe that for any bay k, $\sum_{j=1}^{n} d_{kj} * \beta_j$ denotes the average distance traveled per unit demand for any product type stored at that bay; that is, with probability β_j the assigned product type will travel to dock j incurring the distance d_{kj} We now define the value γ_k to denote the weighted distances between each bay k and each dock j as follows.

$$\gamma_k = \sum_{j=1}^{n} d_{kj} * F_j \quad \forall k \tag{4.15}$$

It should now be intuitively clear that to minimize the total material handling cost, product types with high priority weight values should be assigned to bays with small distance weights. This intuition suggests the following greedy algorithm for the warehouse layout problem.

1. Sort the weighted distances γ_k in ascending order for each bay k.
2. Sort the product type weights α_i in descending order for each product type i.
3. Assign the highest weighted product type i to the first A_i bays from the sorted weighted distance list.

This algorithm ensures that the product types with the highest weight are assigned to the bays with the smallest distance weights. Thus, the overall distance traveled by each product type to each dock should be minimized.

Let us now illustrate this algorithm with a small numerical example. Consider a warehouse of area $A = 100$ and two docks (see Figure 4.2).

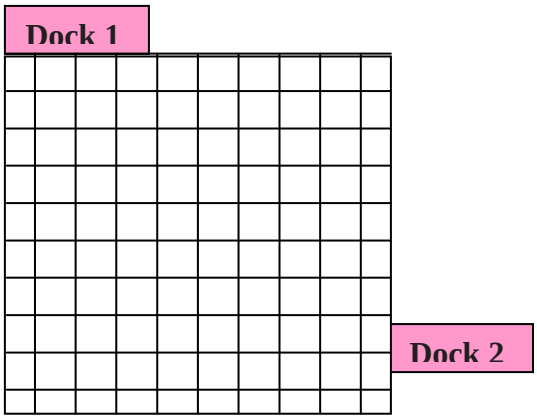


Figure 4–2: The warehouse area is discretized into bay areas of value 1.

We assume there are five product types. The product type area requirements and demands are as follows.

Product Type: i	Area: A_i	Demand: D_i
1	10	300
2	15	250
3	20	400
4	25	500
5	30	450

Assuming that dock frequencies are the same for all product types, we use the following frequency values for the two docks.

F1 = 35%	F2 = 65%

With these values, we can now calculate the α_i values for each product type i and the γ_k values for each bay k. If we sort the product types in descending order of their α_i values the bays in ascending order of their γ_k values, applying the greedy algorithm would yield the following bay assignments.

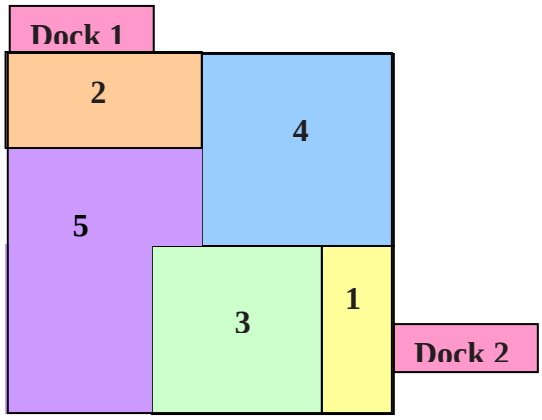


Figure 4–3: The final warehouse layout for five products and two docks.

i	α_i	γ_k for assigned bays k	A_i
1	300 / 10 = 30	2, 5, 7, 9, 12, 15, 18, 19, 23, 28	10
3	400 / 20 = 20	30, 32, 34, 36, 38, 39, 40, 43, 44, 46, 48, 49, 50, 54, 57, 59, 62, 64, 67, 68	20
4	500 / 25 = 20	73, 76, 78, 79, 80, 83, 85, 87, 88, 89, 92, 93, 95, 97, 101, 104, 107, 109, 111, 114, 115, 116, 118, 119, 122	25
5	450 / 25 = 18	125, 127, 129, 131, 135, 137, 138, 139, 142, 143, 145, 147, 148, 152, 156, 157, 159, 160, 163, 164, 167, 168, 169, 173, 178, 179, 182, 184, 187, 189	30
2	250 / 15 = 16.67	191, 193, 194, 197, 198, 201, 204, 205, 206, 208, 210, 214, 215, 217, 218	15

Notice that the total number of bays assigned to each product type is equal to the product type areas A_i. See Figure 25.3 for the final layout for this example.

Table 4–1: Algorithm

1. Sort the weighted distances in ascending order for each bay.
2. Sort the product type weights in descending order for each product type.
3. Assign the highest weighted product type to the first bays from the sorted weighted distance list until the product type area requirement is satisfied.

4.1.2 Input

Using the model described in the above section, we can define the following input.

- Area of the warehouse
- Number of docks
- Dock locations
- Dock frequencies
- Number of product types
- Area required per product type
- Demand per product type

We consider the area of the warehouse as the total number of bays available for assignment. The area required per product type is basically the number of bays to assign per product type.

We use one user form and two input sheets in this application to receive these input values from the user. We do not place any bounds on these inputs. We do give default values for a warehouse area of 30, 3 product types, and 2 docks; however these values may be changed by the user.

4.1.3 Output

Our main output is the warehouse layout. We present this output to the user using different color cells to represent the different product types. The product type color representation is summarized in a legend next to the warehouse grid. The docks are also shown in their specified locations adjacent to the grid. We have

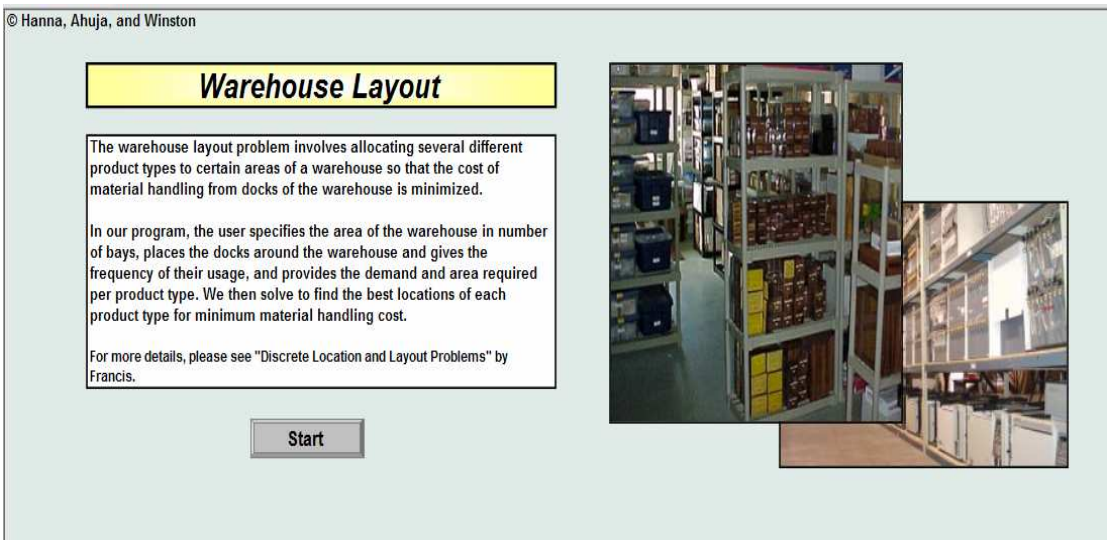


Figure 4–4: The welcome sheet.

several navigational buttons as well as some resolve options; we discuss these in more detail later.

4.2 Spreadsheets

We use four spreadsheets in this application: a welcome sheet, two input sheets, and an output sheet. In the welcome sheet we describe the warehouse layout problem and give an overview of what the user will input and what output they will see displayed (see Figure 4.4). We have some images of a warehouse and a "Start" button. The "Start" button is assigned to our Main sub procedure which we will discuss later.

The next spreadsheet the user sees is the first of two input sheets. Before the user arrives to this sheet, they will complete a user form with the area of the warehouse, number of product types, and number of docks (we discuss the form in more detail in the next section). From this information, we create a grid representing the warehouse area on the first input sheet. The first input sheet allows the user to place the docks adjacent to the warehouse grid. There are some event procedures associated with the spreadsheet which allows the user to simply

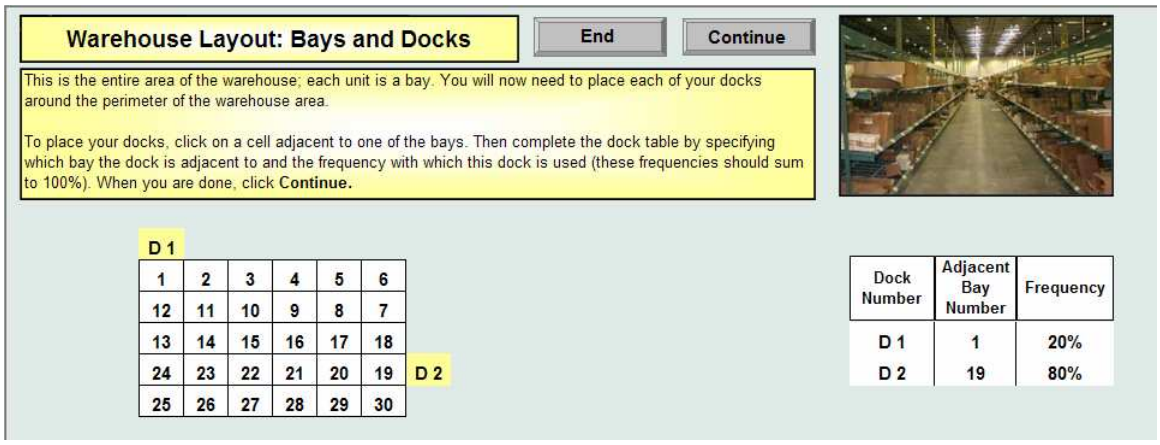


Figure 4–5: The first input sheet for dock information.

click on the location of a dock in order for the dock number and formatting to appear. We will discuss the details of these procedures later.

We also create a table for the dock information which the user must complete. Based on the placement of the docks adjacent to the warehouse grid, the user must enter the number of the bay each dock is adjacent to. This will help us determine the distance from each bay to each dock. The user must also enter the dock frequencies at this point. The frequencies should sum to 1. In Figure 4.5, we show an example with two docks located near bays 1 and 19 with frequencies 20% and 80% respectively.

The user then presses the "Continue" button to navigate to the next input sheet. The second input sheet is for information on the product types (see Figure 4.6). We create a table where the user enters the area requirement (number of bays) and demand for each product type. The sum of the number of bays required over all product types must be less than or equal to the available number of bays in the warehouse.

In Figure 4.6, we continue the example shown in Figure 4.5. Here we have three product types with area requirements of 2, 4, and 7 bays respectively. The product type demands are 300, 500, and 600 respectively. We may note here

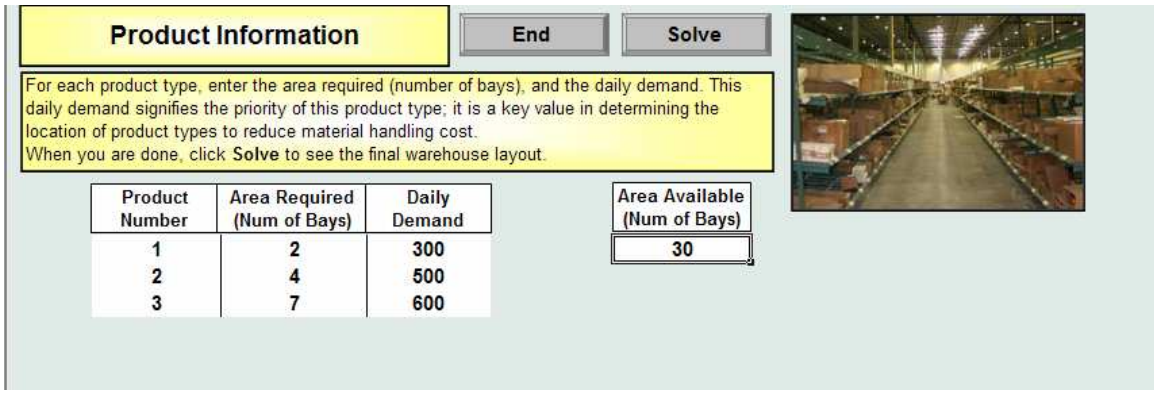


Figure 4–6: The second input sheet for product information.

that the weights for each product type would be 150, 125, and 85.7 respectively ($\alpha_i = D_i/A_i$). Therefore, product type 1 has the highest priority, then product type 2, then product type 3.

The user then presses the "Solve" button to run the main calculation procedures and perform the greedy algorithm. The output sheet will then appear (see Figure 4.7). The output sheet shows the final layout for all of the product types in the warehouse area. We color each product type differently and give a legend for this representation. In Figure 4.7, we can observe that product type 1 (which had the highest priority) was assigned to the bays closes to the second dock (which had the highest frequency).

There are some resolve options and navigational buttons here also. We will discuss these in more detail in a later section.

Table 4–2: Summary: Spreadsheets

Welcome sheet	Problem description and "Start" button.
First input sheet	Dock input table, initial layout for dock placements, "End" and "Continue" buttons.
Second input sheet	Product type input table, "End" and "Solve" buttons.
Output sheet	Final layout with product type bay assignment, legend for product type colors, resolve layout area, "End," "Resolve," "View Product Info" and "View Dock Info" buttons.

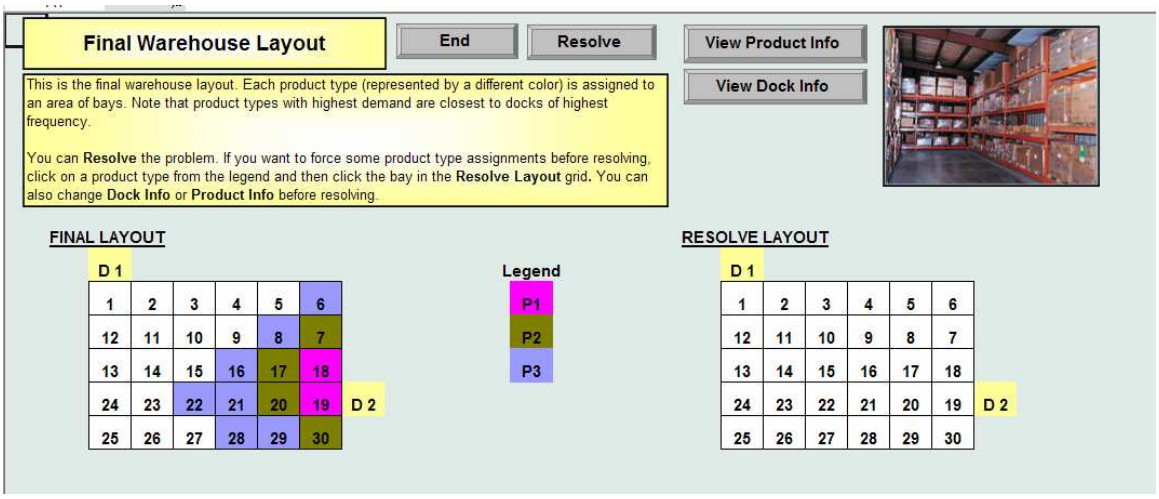


Figure 4–7: The output sheet with its navigational buttons and resolve options.

4.3 User Interface

For this application, we have several navigational buttons, some functional buttons, one user form, and two input sheets. We begin the application by displaying the user form after the "Start" button is pressed from the welcome sheet. The form prompts the user for the number of product types, number of docks, and area of the warehouse. We ask the user to define the area of the warehouse by its dimensions; that is, by the number of rows and columns needed to construct the warehouse area assuming each bay is represented by one row by one column. The form is shown in Figure 4.8.

We use two frames to group similar text boxes together. The first frame contains the text boxes for the number of product types and number of docks. The second frame contains the warehouse dimensions values: number of rows and number of columns. We have entered default values for three product types, two docks, and a warehouse area of 30 bays. The "Cancel" button simply unloads the form, leaving the user at the welcome sheet. The "OK" button performs some error checking and assigns the input values to corresponding variables. It then takes the user to the first input sheet.

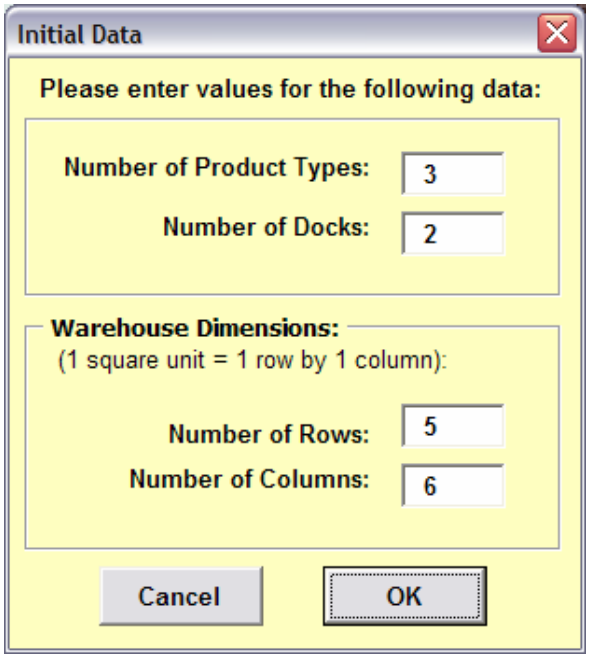


Figure 4–8: The user form asks for the first input values.

The first input sheet, discussed in the previous section, has two buttons: "End" and "Continue" (see Figure 4.5). The "End" button closes the sheet and returns the user to the welcome sheet. The "Continue" button performs some error checking, records the dock information the user has entered in the table, closes the sheet, and takes the user to the next input sheet.

On the second input sheet, also discussed in the previous section, there are also two buttons. "End" and "Solve" (see Figure 4.6). The "End" button has the same functionality here as in the previous sheet. The "Solve" button performs some error checking, records the product type information entered by the user in the table, and then calls the main procedures to perform the greedy algorithm. It then closes the sheet and takes the user to the output sheet.

On the output sheet has a few more buttons (see Figure 4.7). The "End" button is again the same as the others. There are then two navigational buttons which allow the user to revisit the input sheets: "View Product Info" and "View Dock Info." These buttons simply close the output sheet and take the user to the

respective input sheet. When the user revisits an input sheet, a new button will appear to "Go Back" to the output sheet. This "Go Back" button replaces the "Continue" and "Solve" buttons.

There is also a "Resolve" button on the output sheet. This button is used to record any changes the user has made to either of the input sheets or the "Resolve Layout" and then resolves the problem. We will discuss the meaning of the "Resolve Layout" and other resolve functions in a later section.

Table 4–3: Summary: User Interface

Input Form	Number of products, number of docks, warehouse dimensions in number of rows and columns.
First input sheet	Dock location in terms of adjacent bay, dock frequencies.
Second input sheet	Required area and demand per product type.
Navigational buttons	"End," "View Product Info," "View Dock Info," "Go Back."
Functional buttons	"Start," "Continue," "Solve," "Resolve."

4.4 Procedures

We will now outline the procedures for this application. We begin with the Main sub procedure and variable definitions (see Figure 4.8). We define several variables as public variables since they will be used in multiple procedures. We have variables to represent the problem dimensions, such as the number of product types and number of docks, some counting variables for loops, several arrays to be used in the preparation calculations, and several variables to be used in the algorithm.

The Main procedure begins by calling the ClearPrevious procedure (see Figure 4.9). The ClearPrevious procedure clears the cell values and formatting of all of the sheets in the application. It also ensures that the original buttons on the input sheets are visible and hides the "Go Back" buttons. Lastly, it initializes some variables.

```
Option Explicit
Option Base 1

Public NProds As Integer, NRows As Integer, NCols As Integer, NDocks As Integer, NBays As Integer, _
i As Integer, j As Integer, k As Integer, _
XCoord() As Integer, YCoord() As Integer, ACoord() As Integer, BCoord() As Integer, _
Area() As Integer, Demand() As Integer, DFreq() As Double, WtDist() As Double, _
ItemOrder() As Integer, BayOrder() As Integer, _
Sum As Double, DockCount As Integer, ProdColor() As Integer, _
PColor As Integer, PIndex As Integer, _
UserReady1 As Boolean, UserReady2 As Boolean, _
ResolveCalled As Boolean, FixedProd() As Integer, FixedBay() As Boolean

Sub MAIN()
'Assigned to the "Start" button on the "Welcome" sheet

    Call ClearPrevious
    frmInitialData.Show

    'reset any previous resolve conditions (no assignements are enforced)
    NBays = NRows * NCols
    ReDim FixedProd(NProds), FixedBay(NBays)
    For i = 1 To NProds
        FixedProd(i) = 0
    Next i
    For k = 1 To NBays
        FixedBay(k) = False
    Next k

    'assign product colors
    Dim BayCol As Integer
    ReDim ProdColor(NProds)
    BayCol = 7
    For i = 1 To NProds
        ProdColor(i) = BayCol
        BayCol = BayCol + 5
    Next i

    Call NumberingBay
    UserReady1 = True

    Worksheets("Layout").Visible = True
    Worksheets("Welcome").Visible = False
    Worksheets("Layout").Activate
    Range("A1").Select
End Sub
```

Figure 4–9: The Main procedure and public variable declarations.

```
Sub ClearPrevious()
'Called from the Main procedure; clears previous values, resets formatting,
'and initializes some variables

    Application.ScreenUpdating = False
    Dim ws As Worksheet
    For Each ws In ActiveWorkbook.Sheets
        If ws.Name <> "Welcome" Then
            ws.Cells.ClearContents
            ws.Cells.Borders.LineStyle = xlNone
            ws.Cells.Interior.ColorIndex = xlNone
        End If
    Next

    Worksheets("Layout").Shapes("ReturnLayout").Visible = False
    Worksheets("Layout").Shapes("ContLay").Visible = True

    Worksheets("ProductInfo").Shapes("ReturnLayout").Visible = False
    Worksheets("ProductInfo").Shapes("ContProd").Visible = True

    ResolveCalled = False
    UserReady1 = False
    UserReady2 = False
    DockCount = 1

    Application.ScreenUpdating = True
End Sub
```

Figure 4–10: The ClearPrevious procedure clears values and formatting on all sheets; it also initializes some variables.

The Main procedure then shows the input form (refer to Figure 4.8). The main code associated with this form is in the Click event procedure of the "OK" button (see Figure 4.10). This procedure performs some error checking to ensure that all of the input values have been given. It then assigns the input values to their corresponding variables. At this point we now know the number of product types, number of docks, and area of the warehouse. We refer to the area of the warehouse by the number of bays, which is equal to the number of rows multiplied by the number of columns provided by the user.

The Main procedure continues by resetting some arrays used for the resolve options and then assigning colors to the product types. Then, the NumberingBay procedure is called. This procedure numbers the warehouse grid and computes the X and Y coordinates of each bay (see Figures 4.12 and 4.13).

```
Sub cmdCancel_Click()
'close the form

    Unload Me
    End
End Sub

Sub cmdOK_Click()
'error checking that all input given;
'record values to corresponding variables

    Dim ctl As Control
    For Each ctl In Me.Controls
        If TypeName(ctl) = "TextBox" Then
            If ctl.Value = "" Then
                MsgBox "Please make sure all textboxes are filled in."
                ctl.SetFocus
                Exit Sub
            End If
        End If
    Next

    NProds = txtNumProd.Value
    NRows = txtNumRows.Value
    NCols = txtNumCols.Value
    NDocks = txtNumDocks.Value

    Unload Me
End Sub
```

Figure 4–11: The cmdOK_Click procedure assigns the input values to their corresponding variables.

The procedure begins by creating the initial warehouse layout. We move from row 1 to the number of rows and from column 1 to the number of columns and then back to column 1 and so forth, labeling each bay in the warehouse area. We set the X and Y coordinates equal to the row and column value of each created bay. These coordinates are stored in two arrays.

The NumberingBay procedure continues by preparing the input tables for the docks and product types based on the input provided by the user in the input form. The dock table is created on the first input sheet. The product type table is created on the second input sheet. The total number of bay areas is also recorded on the second input sheet. Returning to the Main procedure, we now simply take the user to the first input sheet.

On this sheet the user is able to place the docks around the warehouse area simply by clicking on a cell. To enable this feature, we have written an event procedure for the SelectionChange event of the worksheet (see Figure 4.14). We first check if the active cell is in a range where the docks are allowed to be placed. This range can be defined as the intersection of the warehouse area with an additional one unit circumference and all other cells. We define this intersection by using a logical check and two Union worksheet functions.

Once we ensure that the user has clicked a cell in the allowable dock location area, we check that they have not already placed all of the docks. If this condition is false, then we label the cell with "D" and the current dock number.

The next procedure is the DockInfo procedure (see Figure 4.15). This procedure is assigned to the "Continue" button on the first input sheet. The procedure begins with two error checks: to ensure that the dock table has been completely filled and to check that the dock frequencies sum to zero. We then determine the X and Y coordinates for each dock.

```
Sub NumberingBay()
'Called from the Main procedure; creates the warehouse area Bay;
'computes X and Y coord for each bay; creates dock table, creates product information table

    Application.ScreenUpdating = False
    ReDim XCoord(NBays), YCoord(NBays)
    Dim u As Integer, v As Integer, increment As Integer

    u = 1
    v = 1
    increment = 1

    'number bays and calculate x and y coordinates
    For k = 1 To NBays
        XCoord(k) = u
        YCoord(k) = v
        With Range("Layout").Offset(v, u)
            .Value = k
            .Interior.ColorIndex = 2
            .BorderAround Weight:=xlThin
        End With

        u = u + increment
        'ensure that dimensions of warehouse area are honored
        If u > NCols Then
            u = NCols
            v = v + 1
            increment = -increment
        ElseIf u = 0 Then
            u = 1
            v = v + 1
            increment = -increment
        End If
    Next k

    'ranges named for interface on first input sheet
    Range(Range("Layout").Offset(1, 1), Range("Layout").Offset(NRows, NCols)).Name = "BayArea"
    Range(Range("Layout"), Range("Layout").Offset(NRows + 1, NCols + 1)).Name = "DockArea"
```

Figure 4–12: The beginning of the NumberingBay procedure.

```
    'tables are created
    For j = 1 To NDocks
        With Range(Range("Docks").Offset(j, 0), Range("Docks").Offset(j, 2))
            .Interior.ColorIndex = 2
            .Borders(xlInsideVertical).Weight = xlThin
        End With
        Range("Docks").Offset(j, 0).Value = "D " & j
    Next j

    For i = 1 To NProds
        With Range(Range("Products").Offset(i, 0), Range("Products").Offset(i, 2))
            .Interior.ColorIndex = 2
            .Borders(xlInsideVertical).Weight = xlThin
        End With
        Range("Products").Offset(i, 0).Value = i
    Next i

    With Range("ProdArea")
        .Value = NBays
        .Interior.ColorIndex = 2
        .BorderAround Weight:=xlThin
    End With

    Application.ScreenUpdating = True
End Sub
```

Figure 4–13: The end of the NumberingBay procedure.

Knowing that the docks are placed adjacent to the warehouse area and given the bay numbers to which each dock is adjacent, we can determine the dock coordinates by determining which border the adjacent bay is on. If the adjacent bay is on the top or bottom border of the warehouse area (that is, on the first or last row), then the X coordinate should be zero or one more than the number of rows, respectively. The Y coordinate will be the same as the Y coordinate of the adjacent bay. If the adjacent bay is on the left or right border of the warehouse area (that is, on the first or last column), then the Y coordinate will be zero or one more than the number of columns, respectively. The X coordinate will be the same as that of the adjacent bay.

We also record the dock frequencies into an array. Finally, we take the user to the second input sheet.

```
Private Sub Worksheet_SelectionChange(ByVal Target As Range)
'allows user to place docks adjacent to warehouse area

    If UserReady1 Then
        'check that selected cell is in the possible dock placement area
        If Application.Union(ActiveCell, Range("DockArea")).Address = Range("DockArea").Address And _
            Application.Union(ActiveCell, Range("BayArea")).Address <> Range("BayArea").Address Then

            'check that number of docks placed is less than or equal to total number of docks
            If ActiveCell.Value = "" And DockCount <= NDocks Then
                ActiveCell.Value = "D " & DockCount
                DockCount = DockCount + 1
                ActiveCell.Interior.ColorIndex = 36
            ElseIf ActiveCell.Value <> "" Then
                ActiveCell.ClearContents
                ActiveCell.Interior.ColorIndex = xlNone
                DockCount = DockCount - 1
            End If
        End If
    End If

End Sub
```

Figure 4–14: The SelectionChange event procedure enables the user to click on the sheet to place the docks.

The next procedure performs the main calculations and calls the procedures which execute the algorithm. This is the FinalSteps procedure (see Figure 4.16). This procedure is assigned to the “Solve” button on the second input sheet. The procedure begins with two error checks to ensure that the product type table has been completely filled and that the sum of the required bays is less than or equal to the total number of bays in the warehouse.

Next, the ComputeF procedure is called (see Figure 4.17). This procedure computes the weighted distances using the recorded dock frequencies. These distance weights are equivalent to the ?k values described in the model. We define $\gamma_k = \sum_{j=1}^{n} d_{kj} * F_j$ and so compute these values using a loop over each bay with their respective X and Y coordinates and a sub loop over each dock with their respective frequency values and X and Y coordinates.

```
Sub DockInfo()
'Assigned to the "Continue" button on the first input sheet;
'records the dock locations; computes dock X and Y coord; records dock frequenc

    Application.ScreenUpdating = False
    ReDim ACoord(NDocks), BCoord(NDocks), DFreq(NDocks)

    'error checking that dock table was filled
    If Range("Docks").Offset(1, 0).Value = "" Or Range("Docks").Offset(1, 1).Va
        MsgBox "You have not completely filled out this sheet."
        Exit Sub
    End If

    'error checking that sum of frequencies is 100 percent
    Sum = 0
    For j = 1 To NDocks
        Sum = Sum + Range("Docks").Offset(j, 2)
    Next j
    If Sum > 1 Then
        MsgBox "The sum of dock frequencies is more than 100 percent." & _
                "Please correct your data and press Next again."
        Exit Sub
    End If

    'X and Y coord of docks calculated based on adjacent bays
    For j = 1 To NDocks
       k = Range("Docks").Offset(j, 1).Value
       If XCoord(k) = NCols Then
            ACoord(j) = NCols + 1
            BCoord(j) = YCoord(k)
        ElseIf XCoord(k) = 1 Then
            ACoord(j) = 0
            BCoord(j) = YCoord(k)
        ElseIf YCoord(k) = NRows Then
            BCoord(j) = NRows + 1
            ACoord(j) = XCoord(k)
        ElseIf YCoord(k) = 1 Then
            BCoord(j) = 0
            ACoord(j) = XCoord(k)
        End If

        DFreq(j) = Range("Docks").Offset(j, 2).Value
    Next j

    Range("A1").Select
    Worksheets("ProductInfo").Visible = True
    Worksheets("Layout").Visible = False
    Application.ScreenUpdating = True
End Sub
```

Figure 4–15: The DockInfo procedure records the dock information.

```
Sub FinalSteps()
'Assigned to "Solve" button on second input sheet
'records product type information; calls other calcuation procedures

    Application.ScreenUpdating = False
    'error checking that product table was filled
    If Range("Products").Offset(1, 1).Value = "" Or Range("Products").Offset(1, 2).Value = "" Then
        MsgBox "You have not completely filled out this sheet."
        Exit Sub
    End If

    'error checking that total bay area does not exceed total number of bays
    Sum = 0
    For i = 1 To NProds
        Sum = Sum + Range("Products").Offset(i, 1)
    Next i
    If Sum > NBays Then
        MsgBox "The sum of product areas exceeds the total number of bays in the warehouse." & _
                "Please correct your area data and press Solve again."
        Exit Sub
    End If

    'record product type info
    ReDim Area(NProds), Demand(NProds)
    For i = 1 To NProds
        Area(i) = Range("Products").Offset(i, 1).Value
        Demand(i) = Range("Products").Offset(i, 2).Value
    Next i

    'begin algorithm
    Call ComputeF
    Call SortItems
    Call SortBays
    Call Assign

    Worksheets("FinalLayout").Visible = True
    Worksheets("ProductInfo").Visible = False
    Range("A1").Select
    UserReady2 = True
    Application.ScreenUpdating = True
End Sub
```

Figure 4–16: The FinalSteps procedure performs the main calculations and call the procedures which execute the algorithm.

```
Sub ComputeF()
'called from Final Steps procedure;
'computes the weighted distances for each bay (gamma-k values)

    ReDim WtDist(NBays)
    For k = 1 To NBays
        Sum = 0
        For j = 1 To NDocks
            Sum = Sum + DFreq(j) * (Abs(XCoord(k) - ACoord(j)) + Abs(YCoord(k) - BCoord(j)))
        Next j
        WtDist(k) = Sum
    Next k
End Sub
```

Figure 4–17: The ComputeF procedure computes the weighted distances based on the dock frequencies.

The next procedure called from the FinalSteps procedure is the SortItems procedure (see Figure 4.18). This is the first step of the algorithm. This procedure will calculate the product type weights use these values to sort the product types in descending order of importance. The product type weights are equivalent to the ai values described in the model. We define $\alpha_i = D_i/A_i$ and so compute these values using the recorded demand and area values; the weights are stored in a Ratio array.

We then sort the product types according to these Ratio values. We perform the sort on an array called ItemOrder. We initialize this array such that each product type i as an ItemOrder value i. We then search for the largest Ratio value and move this product type to the front of the list; that is, we exchange its ItemOrder value with the product type which has ItemOrder value equal to 1. We continue this process but examine one less value each time. Eventually, the ItemOrder array will signify the sorted order of the product types.

The next procedure called is the SortBays procedure (see Figure 4.19). This is the second step of the algorithm. This procedure sorts the bays in descending order of their distance weights computed in the ComputeF procedure. The sorting is done in the same manner in which the product types were sorted. This time

```
Sub SortItems()
'called from Final Steps procedure; first step of algorithm;
'calculates product type weights (alpha-i values); sorts in descending order using arrays

    Dim q As Integer, Ratio() As Integer, _
    Max As Double, MaxIndex As Integer, MaxOrder As Integer

    ReDim ItemOrder(NProds), Ratio(NProds)
    'ratio = alpha-i values
    For i = 1 To NProds
        ItemOrder(i) = i
        Ratio(i) = Demand(i) / Area(i)
    Next i

    'sort arrays by moving max to beginning and shifting beginning by one
    Max = 0
    For i = 1 To (NProds - 1)
        For q = i To NProds
            If Ratio(ItemOrder(q)) > Max Then
                Max = Ratio(ItemOrder(q))
                MaxIndex = q
                MaxOrder = ItemOrder(q)
            End If
        Next q

        ItemOrder(MaxIndex) = ItemOrder(i)
        ItemOrder(i) = MaxOrder
        Max = 0
    Next i
End Sub
```

Figure 4–18: The SortItems procedure calculates the product type weights and sorts them.

```
Sub SortBays()
'called from Final Steps procedure; second step of algorithm;
'sorts bays in ascending order of weighted distances

    Dim q As Integer, Min As Double, MinIndex As Integer, MinOrder As Integer
    ReDim BayOrder(NBays)

    For k = 1 To NBays
        BayOrder(k) = k
    Next k

    'sort arrays by moving min to beginning and shifting beginning by one
    Min = 100000
    For k = 1 To (NBays - 1)
        For q = k To NBays
            If WtDist(BayOrder(q)) < Min Then
                Min = WtDist(BayOrder(q))
                MinIndex = q
                MinOrder = BayOrder(q)
            End If
        Next q

        BayOrder(MinIndex) = BayOrder(k)
        BayOrder(k) = MinOrder
        Min = 100000
    Next k
End Sub
```

Figure 4–19: The SortBays algorithm sorts the bays in ascending order of their distance weights.

however, we search for the minimum weight value in each pass. We use an array called BayOrder to store the bay order.

The final procedure called from the FinalSteps procedure is the Assign procedure (see Figure 4.20). This is the last step of the algorithm. This procedure completes the assignment of bays to each product type and creates the final layout.

The procedure begins with some formatting for the final layout. There is then a small section of code which is related to the resolve options; we will discuss this in more detail in the next section. The assignment loop then begins. We loop through the sorted list of product types in the descending order of their weight values found in the SortItems procedure. We then assign bays to each product by

looping through the list of sorted bays until the area requirement for the product type has been met. To reflect that an assignment has been made, we format the assigned bay with the color of the product type. When the assignment is finished for the product type, we also update our legend with the product type's color and index.

The last part of this procedure simply formats the resulting layout and creates a "Resolve Layout" which we discuss in the next section. We now return to the FinalSteps procedure which takes the user to the output sheet.

The only remaining procedures are for the navigational buttons (see 4.22). These include the "End" button, "View Product Info" button, "View Dock Info" button, and "Go Back" buttons. Each procedure simply hides and shows the appropriate sheets.

4.5 Resolve Options

There are two main resolve options for this DSS. The first option allows the user to revisit the input sheets and change previously entered values. For this option, the user would use the navigational buttons on the output sheet to return to either of the input sheets. Suppose, for example, that the user returns to the first input sheet (see Figure 4.23). Here they may change the location of the docks or the frequencies of the docks. In Figure 4.23, we have changed the frequencies from 20% and 80% to 50% and 50% respectively. The user can then press the "Go Back" button to return to the output sheet.

At this point, the user can press the "Resolve" button to see the new layout with the changed dock information, or they can choose the other navigational button to revisit the second input sheet. Let us suppose the user also revisits the second input sheet to modify the product type information. In Figure 4.24, we have changed the area requirements for the product types from 2, 4, and 7 to 4, 10, and

```
Sub Assign()
'called from Final Steps procedure; final step of algorithm

    Dim AssignedBay As Integer, AssignStart As Integer, AssignedProd As Integer, Assigned As Integer
    'copy layout to output sheet
    Range(Range("Layout"), Range("Layout").Offset(NRows + 1, NCols + 1)).Copy
    Range("A1").Select
    Range("FinalLayout").PasteSpecial xlPasteAll
    Range("FinalLayout").Offset(-1, 0).Value = "FINAL LAYOUT"
    Range("FinalLayout").Offset(-1, 0).HorizontalAlignment = xlLeft

    For i = 1 To NProds
        Area(i) = Area(i) - FixedProd(i)
    Next i

    AssignStart = 1
    k = AssignStart

    'assign bays with lowest weight to products of highest weight
    For i = 1 To NProds
        AssignedProd = ItemOrder(i)
        Assigned = 0

        'assign bays until the area requirement has been satisfied
        Do While Assigned < Area(AssignedProd)
            If FixedBay(BayOrder(k)) = False Then
                AssignedBay = BayOrder(k)
                With Range("FinalLayout").Offset(YCoord(AssignedBay), XCoord(AssignedBay))
                    .Interior.ColorIndex = ProdColor(AssignedProd)
                End With
                Assigned = Assigned + 1
            End If
            k = k + 1
        Loop

        With Range("FinalLayout").Offset(i, NCols + 5)
            .Value = "P" & AssignedProd
            .Interior.ColorIndex = ProdColor(AssignedProd)
        End With
        AssignStart = k
    Next i
```

Figure 4–20: The beginning of the Assign procedure.

```
    Range("FinalLayout").Offset(0, NCols + 5).Name = "Legend"
    Range("Legend").Value = "Legend"
    Range(Range("Legend").Offset(1, 0), Range("Legend").End(xlDown)).Name = "LegendArea"

    Range(Range("FinalLayout"), Range("FinalLayout").Offset(NRows + 1, NCols + 1)).Copy
    Range("Legend").Offset(0, 4).Name = "ResolveLayout"
    Range("ResolveLayout").PasteSpecial
    Range("ResolveLayout").Offset(-1, 0).Value = "RESOLVE LAYOUT"
    Range("ResolveLayout").Offset(-1, 0).HorizontalAlignment = xlLeft
    Range(Range("ResolveLayout").Offset(1, 1), Range("ResolveLayout").Offset(NRows, NCols)).Name = "ResolveArea"
    Range("ResolveArea").Interior.ColorIndex = 2
    Application.CutCopyMode = False
End Sub
```

Figure 4–21: The end of the Assign procedure.

```
Sub ExitProg()
'assigned to "End" button on all sheets
    Worksheets("Welcome").Visible = True
    ActiveSheet.Visible = False
End Sub

Sub ViewProd()
'assigned to "View Product Info" button on output sheet
    Worksheets("ProductInfo").Visible = True
    Worksheets("ProductInfo").Shapes("ReturnLayout").Visible = True
    Worksheets("ProductInfo").Shapes("ContProd").Visible = False
    ActiveSheet.Visible = False
End Sub

Sub ViewDock()
'assigned to "View Dock Info" button on output sheet
    Worksheets("Layout").Visible = True
    Worksheets("Layout").Shapes("ReturnLayout").Visible = True
    Worksheets("Layout").Shapes("ContLay").Visible = False
    ActiveSheet.Visible = False
    Range("A1").Select
End Sub

Sub FinLayout()
'assigned to "Go Back" buttons on both input sheets
    Worksheets("FinalLayout").Visible = True
    ActiveSheet.Visible = False
End Sub
```

Figure 4–22: The navigational procedures.

Table 4–4: Summary: Procedures

Main	Initializes application, displays input form, calls ClearPrevious and NumberingBays, takes user to first input sheet.
ClearPrevious	Clears values and formatting on all sheet, initializes variables.
cmdOK_Click	Does some error checking, assigns input values to corresponding variables.
NumberingBays	Creates initial layout, determines X and Y coordinates for all bays, creates dock and product type tables.
Worksheet_ SelectionChange	Allows user to place docks adjacent to warehouse area, keeps track of number of docks added.
DockInfo	Does some error checking, determines X and Y coordinates for the docks based on adjacent bays, records dock frequencies.
FinalSteps	Does some error checking, records product type areas and demands, calls ComputeF, SortItems, SortBays, and Assign, takes user to output sheet.
ComputeF	Computes bay distance weights based on dock frequencies and bay X and Y coordinates.
SortItems	Computes product type weights based on the ratio between their demands and areas, sorts the product types in descending order of these weights.
SortBays	Sorts the bays in ascending order of their distance weights.
Assign	Creates final layout by assigning products to bays in their sorted orders until all product type area requirements are satisfied.

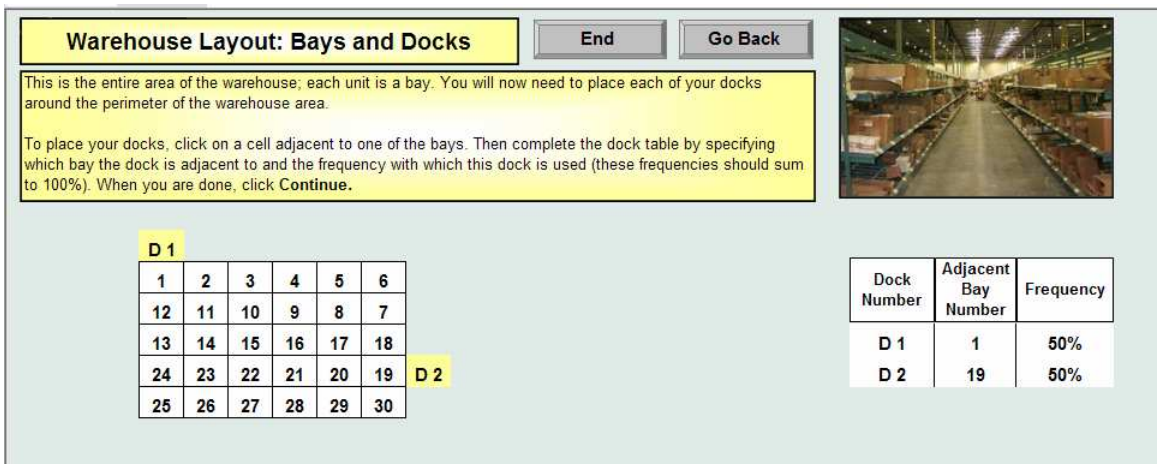


Figure 4–23: The first input sheet is revisited and some of the dock information is changed.

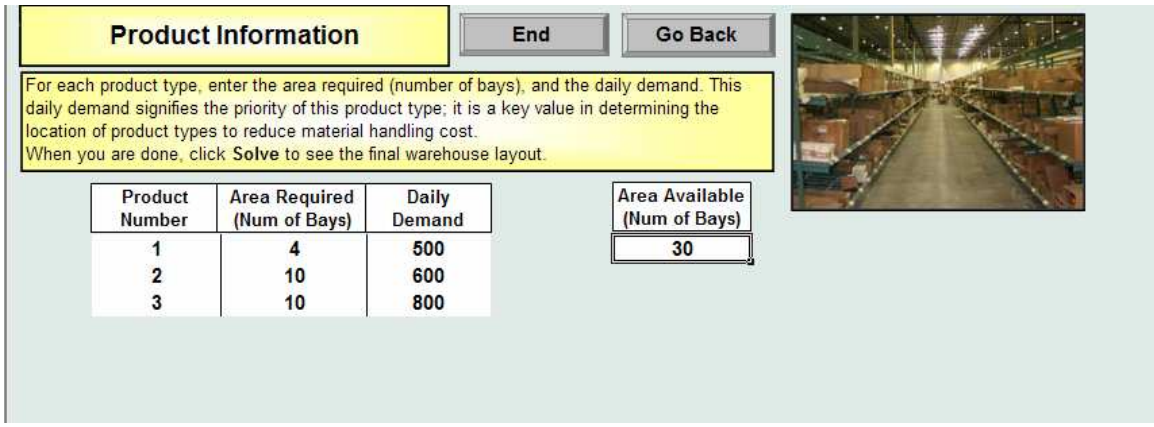


Figure 4–24: The second input sheet is revisited and the product type information is changed.

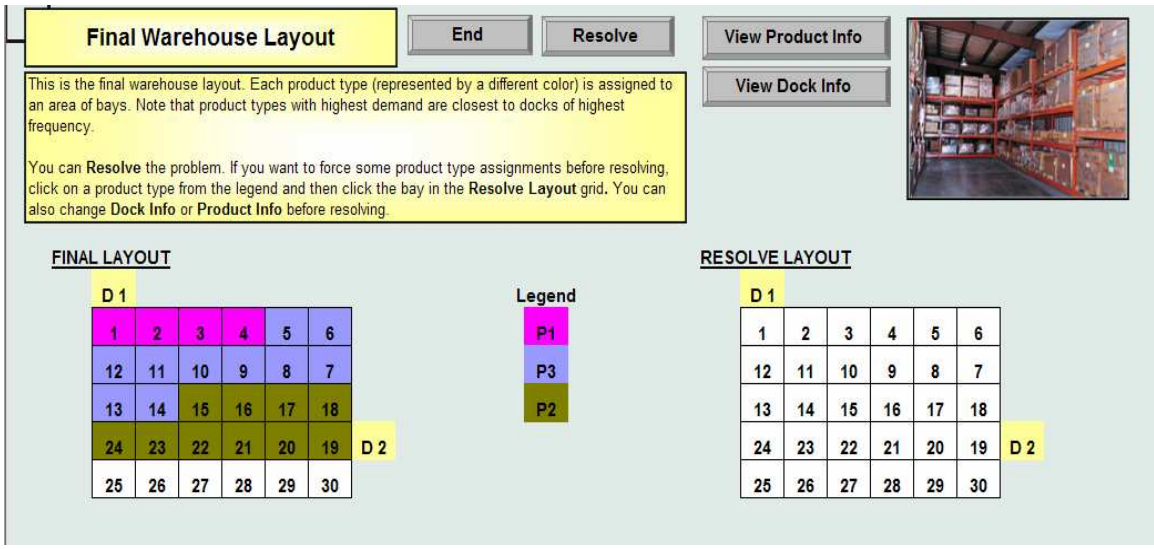


Figure 4–25: The new layout is displayed after pressing the "Resolve" button.

10 respectively. We have also changed the demand values from 300, 500, and 600 to 500, 600, and 800 respectively. The user can again use the "Go Back" button to return to the output sheet.

If the user now presses the "Resolve" button, the main procedures will be rerun and a new layout will be displayed. In Figure 4.25, we show the result of the resolved layout after making the above changes to the dock and product type information.

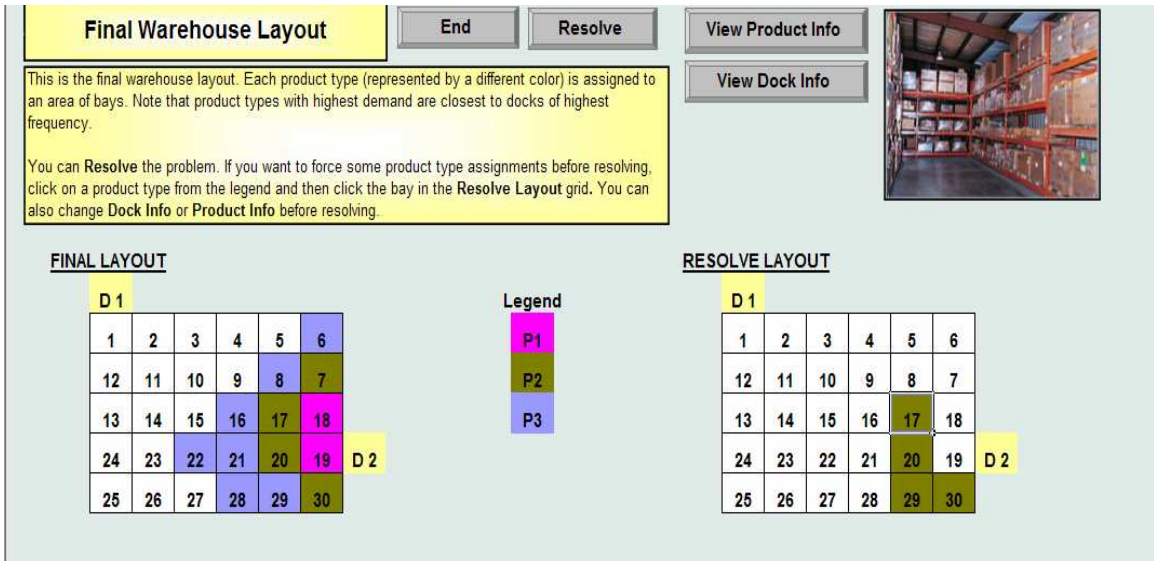


Figure 4–26: The resolve options allow the user to specify a particular product's layout on the Resolve Layout grid.

The second resolve option allows the user to enforce bay assignments for any of the product types. To do this, the user should select the product type they wish to enforce from the legend. They can then click on the desired bay assignments in the "Resolve Layout." For example, suppose the user wants to enforce the bay assignments for all of the bays required for product type 2. The user would click on the "P2" cell in the legend and then click on the desired assignment bays in the "Resolve Layout" (see Figure 4.26).

The user can then press the "Resolve" button to see the updated layout with these enforced assignments. In Figure 4.27, we show the modified layout after enforcing the bay assignments for product type 2. The other assignments are now made given that product type 2 will be assigned to the specified bays.

Not all of the required bays for any product type need to be enforced. For example, instead of enforcing all four of the required bays for product 2, the user could have only enforced the assignment of two of the bays. Multiple product types can also be enforced at once. In Figure 4.28, we enforce the same bay assignments for product type 2 as well as six of the seven required bays for product type 3.

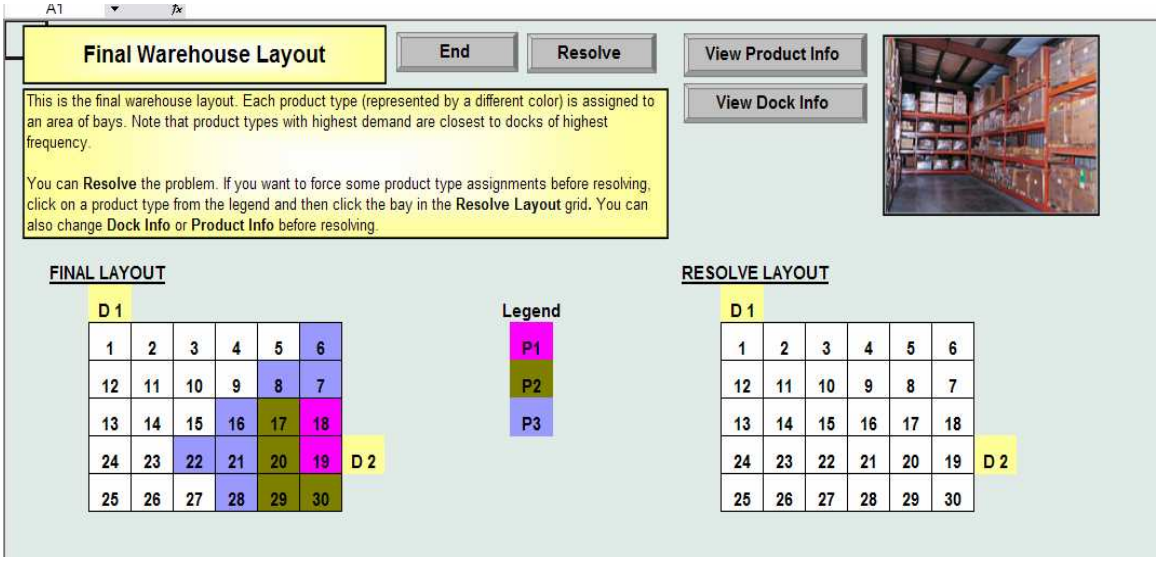


Figure 4–27: The layout has been resolved with the user's specifications enforced.

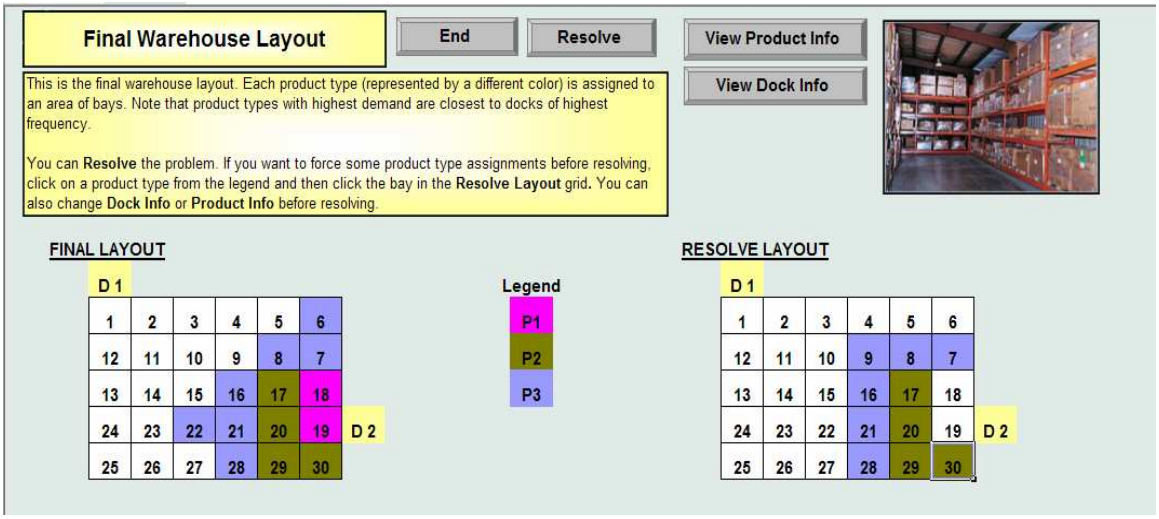


Figure 4–28: Bay assignments for multiple product types can be enforced.

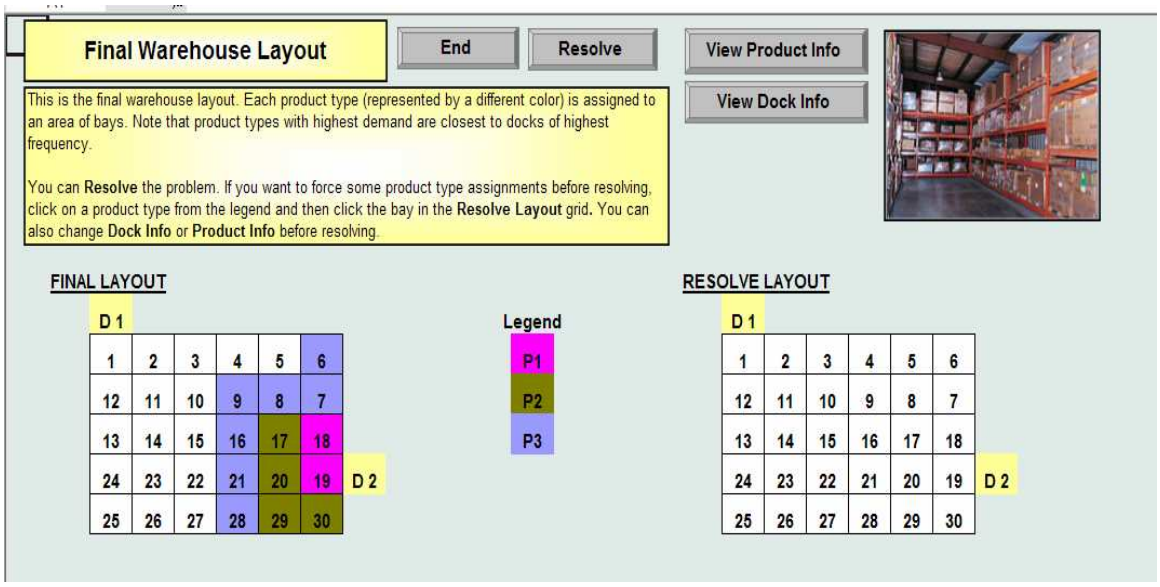


Figure 4–29: The final layout is modified to honor the enforced bay assignments.

The resulting layout is shown in Figure 4.29 after the "Resolve" button has been pressed.

To allow the user to enforce bay assignments with this interface, we have written a SelectChange event procedure associated with the output sheet (see Figure 4.30). This procedure is similar to the SelectChange event procedure associated with the first input sheet in that we have to first check the location of the selected cell using Union functions.

We first check if the user has clicked in the legend area. If so, then we record which product type has been selected. Once a product type is selected, the user may click in the "Resolve Layout" area to specify the enforced assignments. We check that the next cell clicked is indeed in this layout area and reformat the selected cell with the product type's color.

We also record that the selected bay has been fixed; this is recorded in a Boolean array called FixedBay. We must also ensure that the user does not specify more bay assignments than the required number of bays for the selected product

type. We do this by keeping track of the number of bays which have been assigned for the selected product type in a FixedProd array.

We can now discuss the Resolve procedure which re-performs the calculations and re-runs the algorithm for either of these two resolve options (see Figure 4.31). Since we have stored which bay assignments are fixed, we will skip those bays when we reach the Assign procedure. Therefore, we begin the procedure by copying the "Resolve Layout" to capture the assignments made by the user.

We then clear the output sheet and recall the DockInfo and FinalSteps procedures. These procedures will re-record the information from the dock table and product type table on the input sheets to capture any changes made by the user to the input values. The assignment algorithm will then be executed, this time ignoring the bays which have already been fixed. The resulting layout will reflect the user's enforced assignments. We then reset the FixedProd and FixedBay arrays.

Table 4–5: Summary: Resolve Options

First resolve option	Use view buttons to return to input sheets and modify values; then press "Resolve" button to see new layout.
Second resolve option	Enforce some product type bay assignments by clicking on a product type from the legend and specifying enforced assignments on "Resolve Layout"; then press "Resolve" button to see new layout.
Worksheet_ SelectionChange	Event procedure to allow user to make assignment enforcements; it records which bays are fixed and how many bays have been fixed for each product type.
Resolve	Copies the "Resolve Layout" and recalls the DockInfo and FinalSteps procedures; reassigns bays ignoring those that were fixed by the user.

```
Private Sub Worksheet_SelectionChange(ByVal Target As Range)
'allows user to enforce bay assignments for selected product types

  If UserReady2 = True Then
    'check if user has made selection from the legend
    If Application.Union(ActiveCell, Range("LegendArea")).Address = Range("LegendArea").Address Then
        'determine which product type was selected
        For i = 1 To NProds
            If ActiveCell.Value = "P" & i Then
                PIndex = i
                PColor = ProdColor(i)
            End If
        Next i

    'check that user is making bay assignment enforcements in "Resolve Layout"
    ElseIf Application.Union(ActiveCell, Range("ResolveArea")).Address = Range("ResolveArea").Address Then
        FixedBay(ActiveCell.Value) = True
        ActiveCell.Interior.ColorIndex = PColor
        'make sure user assigns less than or equal to the required number of bays for the selected product
        If FixedProd(PIndex) + 1 > Area(PIndex) Then
            MsgBox "You cannot fix more units than the available area for this product."
            Range("ResolveArea").Interior.ColorIndex = 2
            For i = 1 To NProds
                FixedProd(i) = 0
            Next i
            Exit Sub
        Else
            'note the number of bays that have been enforced
            FixedProd(PIndex) = FixedProd(PIndex) + 1
        End If
    End If
  End If
End Sub
```

Figure 4–30: The SelectChange event procedure allows the user to enforce particular bay assignments for selected product types.

```
Sub Resolve()
'assigned to "Resolve" button on output sheet;
'records any changes to dock or product info;
'recalculates layout by recalling algorithm steps

    ResolveCalled = True
    UserReady1 = False
    UserReady2 = False

    'copy "Resolve Layout" to first input sheet
    Range("ResolveArea").Copy
    Range("Layout").Offset(1, 1).PasteSpecial
    Range(Range("Layout").Offset(1, 1), Range("Layout").Offset(NRows, NCols)).Name = "BayArea"
    Range(Range("Layout"), Range("Layout").Offset(NRows + 1, NCols + 1)).Name = "DockArea"

    'clear previous solution
    With Worksheets("FinalLayout").Cells
        .ClearContents
        .Borders.LineStyle = xlNone
        .Interior.ColorIndex = xlNone
    End With

    Call DockInfo
    Call FinalSteps

    'reset any previous resolve conditions
    For i = 1 To NProds
        FixedProd(i) = 0
    Next i
    For k = 1 To NBays
        FixedBay(k) = False
    Next k
End Sub
```

Figure 4–31: The Resolve procedure records changes made to input values and honors enforced bay assignments.

CHAPTER 5
RELIABILITY ANALYSIS

5.1 Application Overview

This case study is a DSS application of the reliability analysis problem. The reliability analysis problem estimates the system failure time of a system of machines.

5.1.1 Model Definition and Assumptions

In this application, we consider a series parallel system of machines in which there are three machine types each working in parallel and connected serially (see Figure 5.1).

To determine failure, we consider each machine type to have a k *out of* n system. Given there are n machines in a machine type, any time k of these n machines fail, the entire machine type fails. We then consider the entire system of all machine types to also be a k *out of* n system. In this application, we assume $n = 3$ machine types and $k = 1$. That is, any time one machine type fails, the entire system fails.

We use the Weibull distribution to estimate the failure times of the machines in each machine type. Weibull random variables are the most common random variables used to model failure times of machines (For more details, see Winston [5]). The cumulative distribution function of the Weibull distribution is as follows.

$$F(t) = 1 - e^{((-t/\beta)^{\alpha})} \tag{5.1}$$

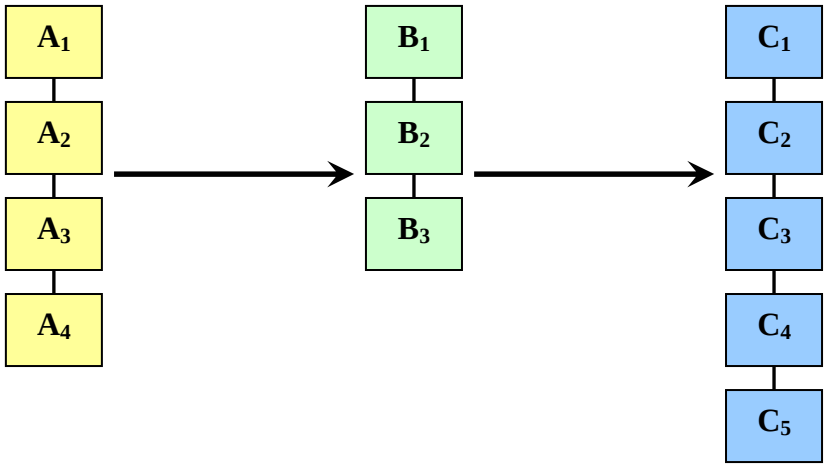


Figure 5–1: An example of a parallel serial system.

Thus, the inverse function for the Weibull distribution is.

$$X = \beta * (ln(1/1 - p)^{\alpha} \tag{5.2}$$

Where p is the probability that X is in the Weibull distribution, and X is the Weibull random variable. We will use this function to generate random Weibull values for the simulation. However, we first need to find the parameters α and β. We optimize the Weibull parameters for each machine type based on their given means and standard deviations of time to failure. We simulate the system failure time using these Weibull parameters.

For this application, we analyze the distribution of the system failure time. We also try to identify which machine type causes the most system failure. We wish to correct the bottleneck machine type and improve the overall performance of the system. The output sheet for this analysis includes a histogram of the system failure time with the mean system failure time as well as a histogram of the frequency with which a particular machine type caused the system failure.

5.1.2 Input

Using the model described in the above section, we can define the following input.

- Number of machines per machine type (n)
- Number of machine which cause failure per machine type (k)
- Cost per machine for each machine type
- Mean and standard deviation of time to failure for each machine type
- Number of runs to perform in the simulation

We use one user form to receive the first four input values from the user. We also use one Input Box to record the number of runs to perform. We keep the input values on a table in the simulation sheet to enable the user to modify them at any time.

5.1.3 Output

Our output can be defined as follows.

- Optimal Weibull parameters per machine type
- Mean system failure time
- Histogram of system failure times from simulation
- Histogram of frequency with which each machine type caused system failure from the simulation

The output is shown on the output sheet. There are also some important resolve options which we discuss in a later section.

5.2 Spreadsheets

We use six spreadsheets in this application: the welcome sheet, a calculation sheet for optimizing the Weibull parameters, a hidden calculation sheet for preparing the simulation data, a simulation sheet, another calculation sheet for recording the results of the simulation runs, and the output sheet. The welcome sheet gives a description of the application and has a “Start” button assigned to the Main procedure (see Figure 5.2).

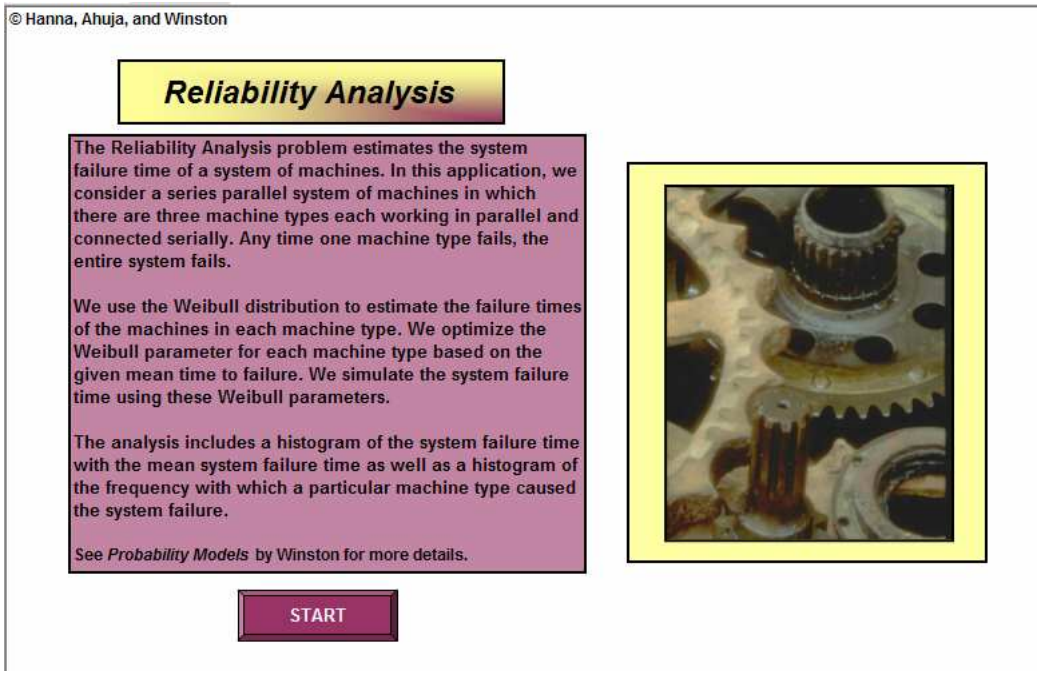
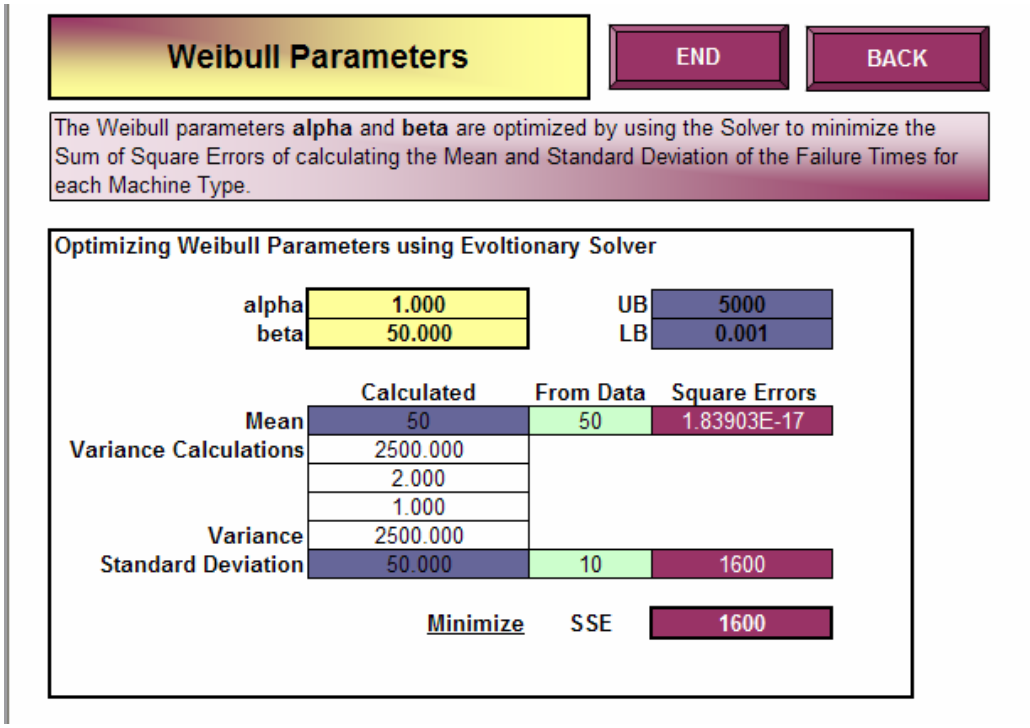


Figure 5–2: The welcome sheet.

The first calculation sheet is used to optimize the Weibull parameters for each machine type (see Figure 5.3). The optimization is performed using the Solver; therefore, the sheet is organized with ranges for the decision variables, constraints, and objective function. The input cells for this optimization are the mean and standard deviation for time to failure for each machine type. Each machine type's Weibull parameters are optimized one at a time.

The decision variables are the Weibull parameters alpha and beta. Both of these have the upper and lower bounds shown adjacent to their cells. These bounds are the only constraints. We then calculate a mean and standard deviation time to failure using these alpha and beta to find the square error compared to the user's input for these values. The objective function is therefore to minimize the sum of these square errors.

There are two buttons on this sheet: "End" and "Back." The "End" button returns the user to the welcome sheet and the "Back" button is used to return to the output sheet once the application is completed.



Weibull Parameters

END BACK

The Weibull parameters **alpha** and **beta** are optimized by using the Solver to minimize the Sum of Square Errors of calculating the Mean and Standard Deviation of the Failure Times for each Machine Type.

Optimizing Weibull Parameters using Evoltionary Solver

alpha	1.000	UB	5000
beta	50.000	LB	0.001

	Calculated	From Data	Square Errors
Mean	50	50	1.83903E-17
Variance Calculations	2500.000		
	2.000		
	1.000		
Variance	2500.000		
Standard Deviation	50.000	10	1600

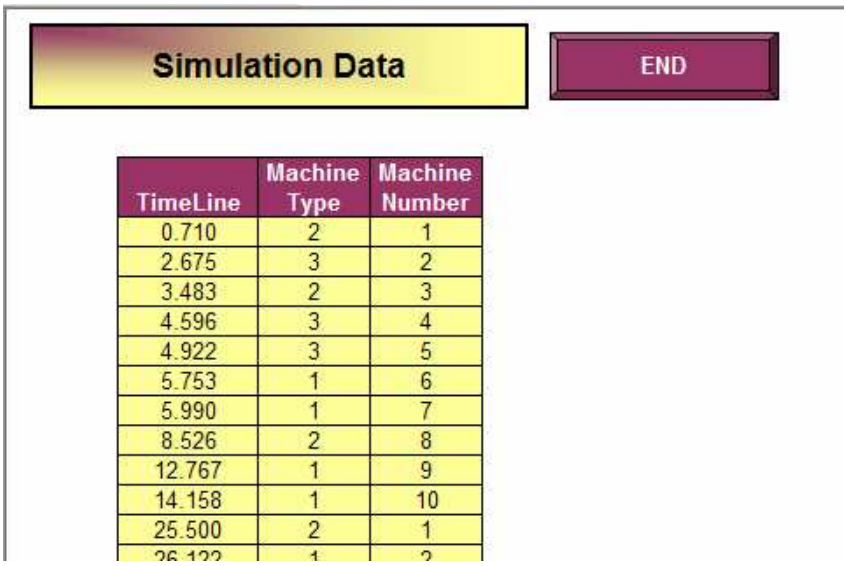
Minimize SSE 1600

Figure 5–3: The calculation sheet for optimizing the Weibull parameters.

We then use a hidden calculation sheet to create a timeline of failure times for each run of the simulation (see Figure 5.4). The time to failure for each machine on all machine types is recorded. The machine number and machine type will be used in the animation.

The next sheet the user sees is the simulation sheet. The simulation sheet contains an input table and the simulation animation layout (see Figure 5.5). The input table summarizes all of the input values given by the user in an initial input form. It also reports the Weibull parameters optimized in the previous sheet. The user can modify these values at any time and they will be recorded before the simulation is run.

The animation layout shows all of the machines for each machine type. As the simulation is run, a failed machine will change to red in the animation. If a particular machine type reaches its respective k number of failed machines, then a system failure occurs. The word “Failed” appears above the machine type which



TimeLine	Machine Type	Machine Number
0.710	2	1
2.675	3	2
3.483	2	3
4.596	3	4
4.922	3	5
5.753	1	6
5.990	1	7
8.526	2	8
12.767	1	9
14.158	1	10
25.500	2	1
26.122	1	2

Figure 5–4: The hidden calculation sheet for the simulation data.

caused the system failure. In Figure 5.4, machine type A has caused the system failure since six of its machines have failed; as you can see in the input table, six of the ten machines are required to cause a failure for machine type A.

There are two buttons plus a hidden button on this sheet. The "End" button brings the user to the welcome sheet and the "Start Simulation" button calls the procedure which begins the simulation. The hidden buttons is the "View Analysis" button which is made visible once the simulation has been completed. It takes the user to the output sheet.

The next sheet is another calculation sheet which contains the results of each run of the simulation (see Figure 5.6). The time until the system failed is recorded along with the machine type which caused the system failure. The table for bin values is used later in creating the histogram for the machine types.

There are two buttons on this sheet: "End" and "Back." They have the same functionalities as the buttons on the first calculation sheet.

The final sheet is the output sheet (see Figures 5.7 and 5.8). This sheet displays the mean system failure time, a histogram of the system time failures from

Simulation END

The table below summarizes the input values for each machine type as well as the optimized Weibull parameters.
Press the **START SIMULATION** button to begin the failure time simulation on this system.
You can change any of the data in the simulation table to update your system and run a new simulation.

Machine Type	A	B	C
Number of Machines	10	10	10
Number of Machines to Cause Failure	6	6	6
Cost per Machine	25	25	25
Mean Time to Failure	50	50	50
Std Dev Time to Failure	10	10	10
Weilbull: alpha	1.000	1.000	1.000
Weilbull: beta	50.000	50.000	50.000

Failed!

A	B	C
10	10	10
9	9	9
8	8	8
7	7	7
6	6	6
5	5	5
4	4	4
3	3	3
2	2	2
1	1	1

START SIMULATION

Figure 5–5: The simulation sheet with the animation layout and input table.

Simulation Results END BACK

The results of each run are recorded here. The time at which the system failure occurred and the machine type which caused the failure are recorded. The "Type Bins" table is used for the machine type histogram calculations.

	Time to Failure	Machine Type
1	14.186	1
2	67.025	2
3	34.487	3
4	29.196	2
5	25.407	2
6	38.998	1
7	21.375	2
8	23.574	1
9	30.712	2
10	30.026	2
11	38.679	1
12	26.483	2
13	29.957	1
14	38.069	3
15	31.652	3
16	26.015	3
17	9.898	1

Type Bins
1
2
3

Figure 5–6: The third calculation sheet for the results of the simulation runs.

the simulation, and a histogram of the frequencies with which each machine type caused the system failure. This is the most important information for the user to analyze to determine how the system is behaving.

There are several buttons on this sheet. The "End" button returns the user to the welcome sheet. The "View Details" button takes the user to the third calculation sheet in which the results of the simulation runs are recorded. The "View Weibull" button takes the user to the first calculation sheet in which the Weibull parameters were optimized. The last two buttons, "Return to Simulation" and "Resolve" are used with the resolve options which we discuss in a later section.

Table 5–1: Summary: Spreadsheets

Welcome sheet	Application description and "Start" button.
First calculation sheet	Optimizes the Weibull parameters using the Solver. "End" and "Back" buttons.
Hidden calculation sheet	Creates a timeline of failure times for the simulation animation.
Simulation sheet	Input table and animation layout. "End," "Start Simulation," and "View Analysis" buttons.
Third calculation sheet	Results of all simulation runs. "End" and "Back" buttons.
Output sheet	Mean system failure time, histogram for system failure times, and histogram for machine type failures. "End," "View Details," "View Weibull," "Return to Simulation" and "Resolve" buttons.

5.3 User Interface

For this application, we have one user form, one input table, several navigational buttons, and a few functional buttons. We also use one Input Box and one Message Box. The user form contains input for each machine type (see Figure 5.9). It prompts the user for the number of machines, number of machines which cause failure, cost per machine, and the mean and standard deviation of time to failure for the machine type. We use two frames to group similar text boxes. The "OK" button has an associated Click procedure which we describe later.

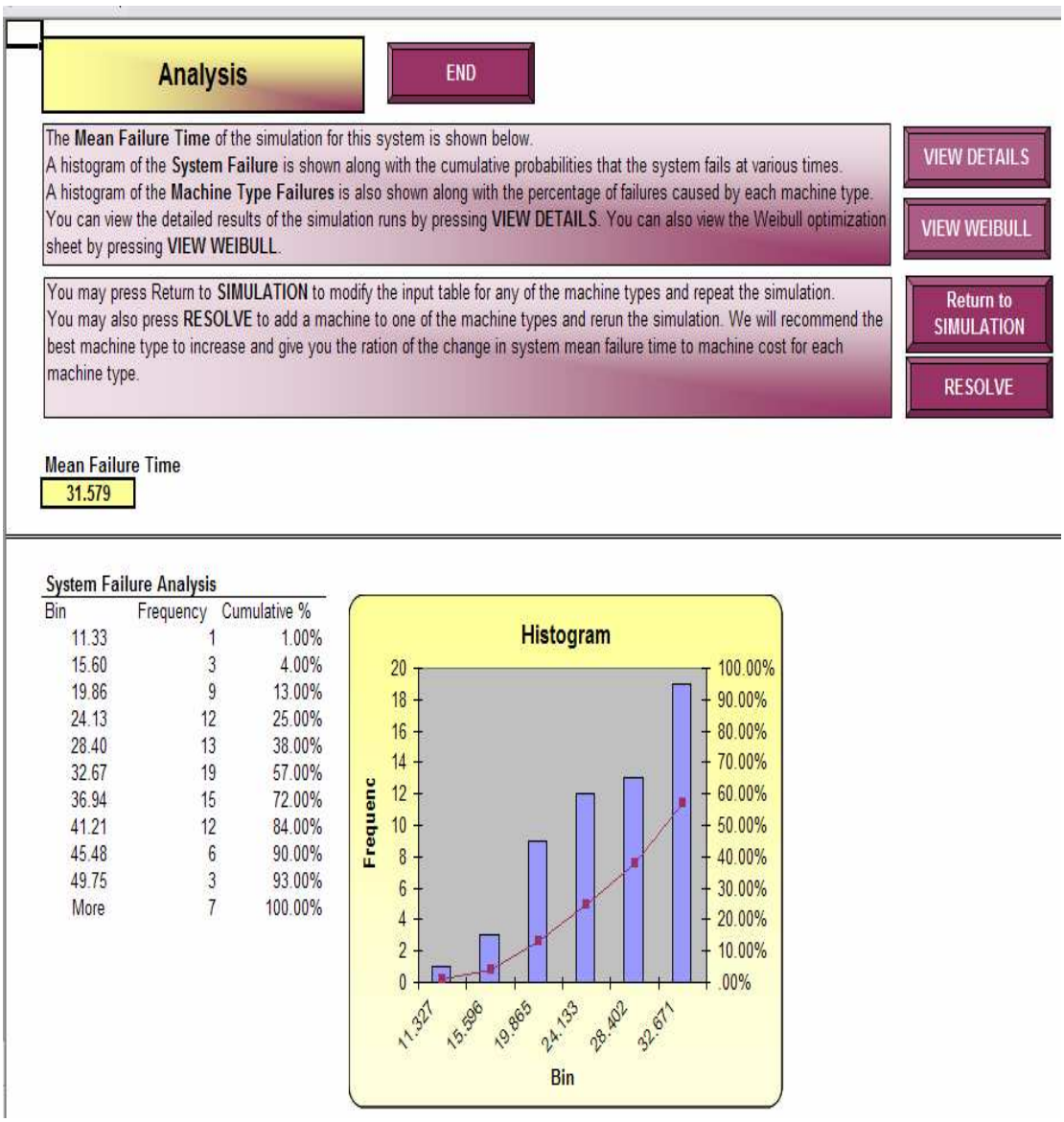


Figure 5–7: The top half of the output sheet.

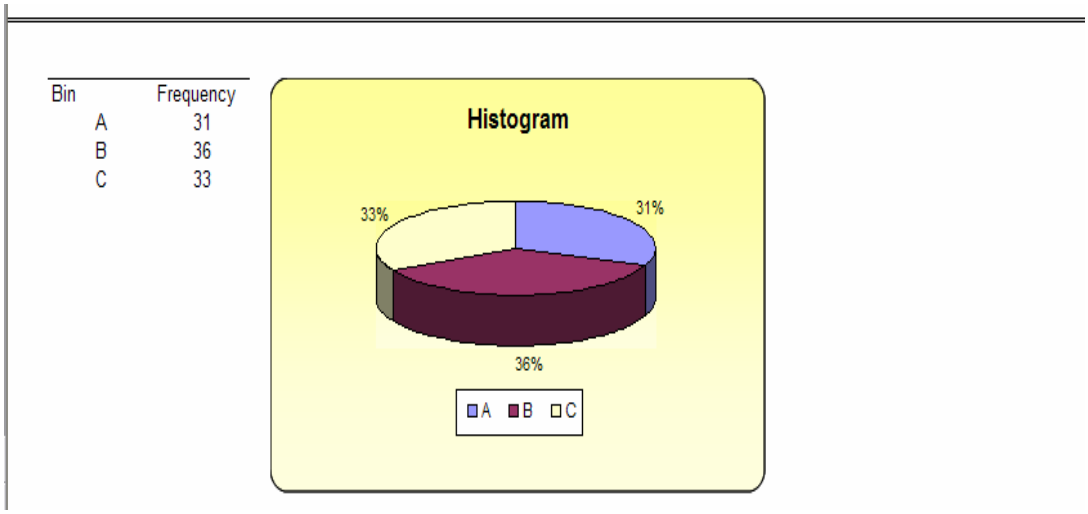


Figure 5–8: The bottom half of the output sheet.

This form is shown to the user three times in order to receive the input for each machine type. We have a dynamic label at the top of the sheet which shows the name of the current machine type the input will be associated with. Notice that we use a label and not a text box for this value since the user should never modify its value.

The input table on the simulation sheet has been described in the previous section. It simply summarizes the input provided by the user in the user form as well as the optimized Weibull parameters. The user can change this input before the simulation is run. The navigational buttons and functional buttons were also discussed in the previous section with each corresponding worksheet.

The Input Box is used to prompt the user for the number of runs for which the simulation should be run (see Figure 5.10). A title is given to the Input Box as well as a default value of 25 runs.

The Message Box is used to inform the reader that the Weibull parameter optimization has been completed (see Figure 5.11). The corresponding calculation sheet appears behind the Message Box. We take the user directly to the simulation sheet not allowing them to pause on the calculation sheet. They can however

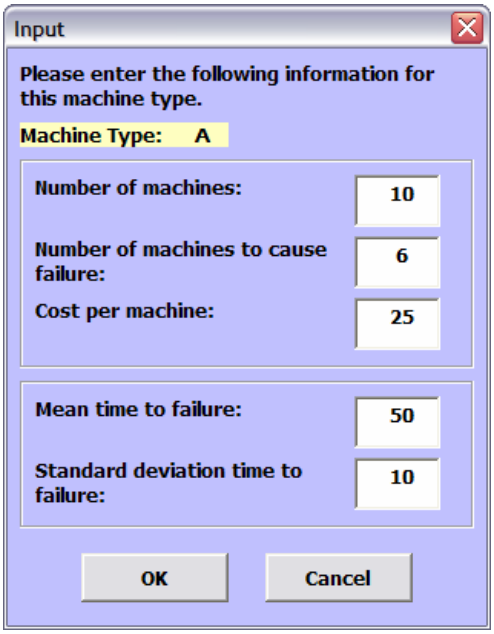


Figure 5–9: The input form with the dynamic label value for machine type "A."

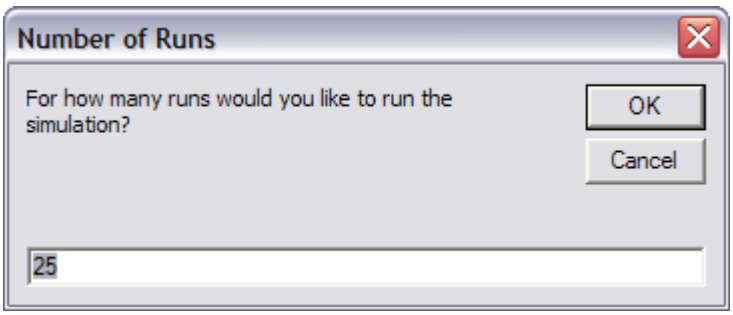


Figure 5–10: The Input Box.

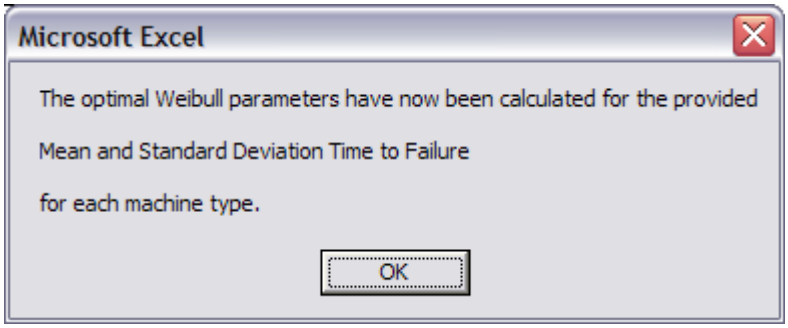


Figure 5–11: The Message Box.

revisit the Weibull parameter optimization calculations once the simulation is complete.

Table 5–2: Summary: User Interface

Input Form	Receives the initial input from the user.
Input table on simulation sheet	Summarizes the user input and displays the optimized Weibull parameters for each machine type.
Input Box	Prompts the user for the number of runs for the simulation.
Message Box	Informs the user that the Weibull parameters have been optimized.
Navigational Buttons	"End," "Back," "View Details," "View Weibull," "Return to Simulation"
Functional Buttons	"Start," "Start Simulation," "Resolve"

5.4 Procedures

We will now outline the procedures for this application. We begin with the Main sub procedure and variable definitions (see Figure 5.12). The variables shown defined as public variables are used in multiple procedures. All other variables are defined within the procedure they are used.

The Main procedure begins by calling the ClearPrev procedure. The ClearPrev procedure is used to initialize variables and clear previous worksheet values (see Figure 5.13). The formatting for the animation layout is also cleared.

Next, the Main procedure shows the user the input form. A loop is used to do this so that the input form can be shown for each machine type. The dynamic label

is adjusted before the form is shown to display the name of each machine type. The form values are recorded into arrays using the same index in the loop. The Click event procedure of the "OK" command button on the input form performs some error checking and then assigns the input values to the corresponding array variables (see Figure 5.14).

The Input Box for the number of runs is then shown. Some error checking is done to check if the user pressed the "Cancel" button on the Input Box.

The CalcWeibull procedure is then called. The CalcWeibull procedure uses the Solver commands to find the optimum Weibull parameters for each machine type (see Figure 5.15). The Solver is prepared by setting the objective function cells, decision variable cells, and constraints. Then a loop is used to change the input cells, which contain the mean and standard deviation of time to failure, for each machine type. Within this loop the Solver is executed and the decision variable cell values, the alpha and beta values, are recorded for each machine type.

Once we return to the Main procedure, the Message Box is then displayed to inform the user that the optimal Weibull parameters have been found for each machine type. The PrepSim procedure is then called. The PrepSim procedure rerecords the values from the input table on the simulation sheet and then prepares the animation layout (see Figure 5.16). The input values are rerecorded so that at a later time, if the user changes the input values, the simulation and animation will be updated. This feature becomes more relevant when the PrepSim procedure is called from the main simulation procedure.

The Main procedure then takes the user to the simulation sheet. On the simulation sheet, the "Start Simulation" button is used to call the StartSim procedure; this is the main simulation procedure. The StartSim procedure will initialize the animation, create the simulation data, and perform the simulation and

```
Option Explicit
Option Base 1

Public i As Integer, j As Integer, temp As Variant, runs As Integer, _
MachName(3) As String, NumMach(3) As Integer, NumToFail(3) As Integer, _
MachCost(3) As Double, MeanFail(3) As Double, StdFail(3) As Double, NumRuns As Integer, _
Alpha(3) As Double, Beta(3) As Double, Ratio(3) As Double, _
Resolving As Boolean, ChangeSysFail(3) As Double, BestChoice As Variant
```

```
Sub Main()
'Assigned to "Start" button on welcome sheet;
'initializes application

    Call ClearPrev

    'get input for all machine types
    For i = 1 To 3
        frmInput.lblType.Caption = MachName(i)
        frmInput.Show

        With Range("SimTable")
            .Offset(1, i).Value = NumMach(i)
            .Offset(2, i).Value = NumToFail(i)
            .Offset(3, i).Value = MachCost(i)
            .Offset(4, i).Value = MeanFail(i)
            .Offset(5, i).Value = StdFail(i)
        End With
    Next i

    'find number of runs
    temp = InputBox("For how many runs would you like to run the simulation?", "Number of Runs", 25)
    If temp = "" Then
        End
    Else
        NumRuns = temp
    End If

    'calc Weibull parameters for each machine type
    Worksheets("Weibull").Visible = True
    Worksheets("Welcome").Visible = False
    Call CalcWeibull
    MsgBox "The optimal Weibull parameters have now been calculated for the provided " _
    & vbCrLf & vbCrLf & "Mean and Standard Deviation Time to Failure " & vbCrLf & vbCrLf & _
    "for each machine type."

    Call PrepSim
    Worksheets("Simulation").Visible = True
    Worksheets("Weibull").Visible = False
End Sub
```

Figure 5–12: The Main procedure and variable declarations.

```
Sub ClearPrev()
'Called from Main procedure;
'initializes variables and clears previous values and formatting

    MachName(1) = "A"
    MachName(2) = "B"
    MachName(3) = "C"

    'clear simulation animation
    With Range(Range("SimAnim").Offset(1, 0), Range("SimAnim").Offset(50, 2))
        .Interior.ColorIndex = xlNone
        .Borders(xlInsideVertical).LineStyle = xlNone
        .Borders(xlInsideHorizontal).LineStyle = xlNone
        .ClearContents
    End With
    Worksheets("Simulation").Activate
    ActiveSheet.Shapes("ViewAnalysis").Visible = False

    'clear simulation data
    Range(Range("TimeLine").Offset(1, 0), Range("TimeLine").Offset(1, 2).End(xlDown)).ClearContents

    'clear simulation run results
    Range("TimeHist").ClearContents
    Range("TypeHist").ClearContents

    Resolving = False
End Sub
```

Figure 5–13: The ClearPrev procedure.

```
Private Sub cmdCancel_Click()
    Unload Me
    End
End Sub

Private Sub cmdOK_Click()
    Dim ctl As Control
    For Each ctl In Me.Controls
        If TypeName(ctl) = "TextBox" Then
            If IsNumeric(ctl) = False Or ctl.Value = "" Then
                MsgBox "Please enter a numeric value for all input."
                Exit Sub
                ctl.SetFocus
            End If
        End If
    Next

    NumMach(i) = txtNumMach.Value
    NumToFail(i) = txtNumToFail.Value
    MachCost(i) = txtCost.Value
    MeanFail(i) = txtMean.Value
    StdFail(i) = txtStd.Value

    Unload Me
End Sub
```

Figure 5–14: The cmdOK_Click event procedure.

animation (see Figures 5.17 and 5.18). The StartSim procedure begins by calling the PrepSim procedure as explained above.

It then begins a loop, for the number of runs given by the user, in which data is created, the animation is performed, and the results of the simulation run are recorded. To create the simulation data, the CreateData procedure is called. The CreateData procedure generates failure times for each machine in each machine type (see Figure 5.19). These values are generated using the WeibullInv function procedure (see Figure 5.20). This function procedure uses the inverse function given in the model description to produce a random Weibull variable value using a random probability value from the Rnd() function. The failure times are stored in the hidden calculation sheet with their corresponding machine number and machine type name. The values are then sorted based on the failure time to form the timeline that will be used to perform the animation.

```
Sub CalcWeibull()
'Called from Main procedure;
'uses mean failure time and standard deviation of failure time as input;
'uses Solver to optimize Weibull parameters

    Application.ScreenUpdating = False
    SolverReset
    SolverOk SetCell:=Range("ObjFunc"), MaxMinVal:=2, ByChange:=Range("DecVar")
    SolverAdd CellRef:=Range("DecVar"), Relation:=1, FormulaText:=Range("UB")
    SolverAdd CellRef:=Range("DecVar"), Relation:=3, FormulaText:=Range("LB")

    'for each machine type, enter mean and stdev fail time to Solver sheet
    For i = 1 To 3
        Range("UserMean").Value = MeanFail(i)
        Range("UserStd").Value = StdFail(i)

        'starting guess
        Range("Beta").Value = MeanFail(i)
        Range("Alpha").Value = StdFail(i) / 10

        'run solver --- do not need to reset changing cells, obj func, or constraints
        SolverSolve UserFinish:=True
        SolverFinish KeepFinal:=True

        Alpha(i) = Range("alpha").Value
        Beta(i) = Range("beta").Value
    Next i

    For i = 1 To 3
        'put resulting parameter values in simulation table
        Worksheets("Simulation").Range("SimTable").Offset(6, i).Value = Alpha(i)
        Worksheets("Simulation").Range("SimTable").Offset(7, i).Value = Beta(i)
    Next i

    Application.ScreenUpdating = True
End Sub
```

Figure 5–15: The CalcWeibull procedure.

```
Sub PrepSim()
'Called from StartSim procedure;
'records any changes made to input table on simulation sheet;
'prepares animation layout for current number of machines of each machine type

    Application.ScreenUpdating = False
    'record input from table to record any changes
    For i = 1 To 3
        With Range("SimTable")
            NumMach(i) = .Offset(1, i).Value
            NumToFail(i) = .Offset(2, i).Value
            MachCost(i) = .Offset(3, i).Value
            MeanFail(i) = .Offset(4, i).Value
            StdFail(i) = .Offset(5, i).Value
            Alpha(i) = .Offset(6, i).Value
            Beta(i) = .Offset(7, i).Value
        End With
    Next i

    'create animation layout
    With Range(Range("SimAnim").Offset(1, 0), Range("SimAnim").Offset(50, 2))
        .Interior.ColorIndex = xlNone
        .Borders(xlInsideVertical).LineStyle = xlNone
        .Borders(xlInsideHorizontal).LineStyle = xlNone
        .ClearContents
    End With

    For i = 1 To 3
        For j = 1 To NumMach(i)
            With Range("SimAnim").Offset(j, i - 1)
                .Interior.ColorIndex = 36
                .Value = NumMach(i) + 1 - j
                .BorderAround Weight:=xlThick
            End With
        Next j
    Next i

    Application.ScreenUpdating = True
End Sub
```

Figure 5–16: The PrepSim procedure.

```
Sub StartSim()
'Assigned to "Start Simulation" button on simulation sheet;
'runs simulation with animation

    Dim SysFail As Boolean, Failed(3) As Integer, FailType As Integer
    'record any changes to input in table on simulation sheet and
    'reflect changes in animation layout
    Call PrepSim

    For runs = 1 To NumRuns
        'generate failure times for the run
        Call CreateData

        For i = 1 To 3
            Failed(i) = 0
        Next i
        j = 1
        SysFail = False
```

Figure 5–17: The beginning of the StartSim procedure.

The StartSim procedure can then begin the animation process. It reads through the time values in the timeline just created and checks which machine number of which machine type has just failed. It then changes the formatting of the respective cell on the animation layout to reflect to the user that a machine has failed. It also checks whether or not enough machines of a particular machine type have failed to cause system failure. If so, then the word “Failed” is written over the appropriate machine type column in the animation layout. The time of the system failure is recorded to the third calculation sheet along with the machine type which caused the failure.

The animation is paused after each system failure using the Application.Wait function. The AnalysisPrep procedure is then called.

The AnalysisPrep procedure uses the results recorded for each run on the third calculation sheet to create the histograms for the system failure and machine type failures (see Figure 5.20). The mean system failure time is also reported.

```
        Application.ScreenUpdating = False
        'run through timeline created in CreateData procedure
        Do While SysFail = False
            Select Case Range("TimeLine").Offset(j, 1).Value
            'color failed machine in appropriate machine type column;
            'check if machine type failure / system failure has occured
                Case 1
                    Range("SimAnim").Offset(NumMach(1) - Range("TimeLine").Offset(j, 2).Value + 1, 0).Interior.ColorIndex = 54
                    Failed(1) = Failed(1) + 1
                    If Failed(1) = NumToFail(1) Then
                        SysFail = True
                        FailType = 1
                        Range("Failure").Cells(1).Value = "Failed!"
                    End If
                Case 2
                    Range("SimAnim").Offset(NumMach(2) - Range("TimeLine").Offset(j, 2).Value + 1, 1).Interior.ColorIndex = 54
                    Failed(2) = Failed(2) + 1
                    If Failed(2) = NumToFail(2) Then
                        SysFail = True
                        FailType = 2
                        Range("Failure").Cells(2).Value = "Failed!"
                    End If
                Case 3
                    Range("SimAnim").Offset(NumMach(3) - Range("TimeLine").Offset(j, 2).Value + 1, 2).Interior.ColorIndex = 54
                    Failed(3) = Failed(3) + 1
                    If Failed(3) = NumToFail(3) Then
                        SysFail = True
                        FailType = 3
                        Range("Failure").Cells(3).Value = "Failed!"
                    End If
            End Select
            j = j + 1
        Loop
        'record info when system fails = system failure time and machine type which caused failure
        Worksheets("SimRuns").Range("Runs").Offset(runs, 0).Value = Range("TimeLine").Offset(j, 0).Value
        Worksheets("SimRuns").Range("Runs").Offset(runs, 1).Value = FailType
        If Resolving = False Then
            'only animate if not resolving
            Application.ScreenUpdating = True
            Application.Wait (Now() + TimeValue("00:00:01"))
        End If
        Range(Range("SimAnim").Offset(1, 0), Range("SimAnim").Offset(50, 2)).Interior.ColorIndex = 36
        Range("Failure").ClearContents
    Next

    If Resolving = False Then
        'only update output sheet if not resolving
        Call AnalysisPrep
        Worksheets("Simulation").Activate
        ActiveSheet.Shapes("ViewAnalysis").Visible = True
    End If
End Sub
```

Figure 5–18: The end of the StartSim procedure.

```
Sub CreateData()
'Called from StartSim procedure;
'generates failure time values for all machines in each machine type based on Weibull parameters;
'generates a timeline of machine failures with associated machine type

    Dim last As Integer
    Application.ScreenUpdating = False
    Worksheets("SimData").Visible = True

    'create the timeline
    last = 1
    For i = 1 To 3
        For j = 1 To NumMach(i)
            'generate fail times for each machine
            Range("TimeLine").Offset(last, 0).Value = WeibullInv(Alpha(i), Beta(i))
            Range("TimeLine").Offset(last, 1).Value = i
            Range("TimeLine").Offset(last, 2).Value = j
            last = last + 1
        Next j
    Next i

    'sort the timeline
    Range(Range("Timeline").Offset(1, 0), Range("Timeline").Offset(1, 1).End(xlDown)).Name = "TimeLineData"
    Range("TimeLineData").Sort key1:=Range("Timeline"), order1:=xlAscending

    Worksheets("SimData").Visible = False
    Application.ScreenUpdating = True
End Sub
```

```
Function WeibullInv(Alpha, Beta)
'Function called from CreateData procedure;
'generates a random Weibull value

    Dim Prob As Double
    Prob = Rnd()
    WeibullInv = Beta * (Log(1 / (1 - Prob))) ^ (1 / Alpha)
End Function
```

Figure 5–19: The CreateData procedure and WeibullInv function.

```
Sub AnalysisPrep()
'Called from StartSim procedure;
'Creates histograms and displays mean system failure time

    Worksheets("Analysis").Activate
    Range(Range("Runs").Offset(1, 0), Range("Runs").Offset(runs, 0)).Name = "TimeHist"
    Range(Range("Runs").Offset(1, 1), Range("Runs").Offset(runs, 1)).Name = "TypeHist"

    'create histograms
    Range(Range("HistTime"), Range("HistTime").Offset(0, 2).End(xlDown)).ClearContents
    Range(Range("HistType"), Range("HistType").Offset(0, 1).End(xlDown)).ClearContents

    Application.DisplayAlerts = False
    Application.Run "ATPVBAEN.XLA!Histogram", Range("TimeHist"), Range("HistTime"), _
        , False, True, False, False
    With Range(Range("HistTime").Offset(1, 0), Range("HistTime").Offset(1, 0).End(xlDown))
        .NumberFormat = "##.00"
        .HorizontalAlignment = xlCenter
    End With

    Application.Run "ATPVBAEN.XLA!Histogram", Range("TypeHist"), Range("HistType"), _
        Range("TypeBins"), False, False, False, False
    Range(Range("HistType").Offset(4, 0), Range("HistType").Offset(4, 1)).Clear
    For i = 1 To 3
        Range("HistType").Offset(i, 0).Value = MachName(i)
    Next i
    Range(Range("HistType").Offset(1, 0), Range("HistType").Offset(3, 1)).HorizontalAlignment = xlCenter

    'report mean fail time
    Range("MeanSysFail").Value = Application.WorksheetFunction.Average(Range("TimeHist"))

    Worksheets("Analysis").Visible = True
    Worksheets("Simulation").Visible = False
    Range("A1").Select
End Sub
```

Figure 5–20: The AnalysisPrep procedure.

The StartSim procedure then displays the "View Analysis" button on the simulation sheet.

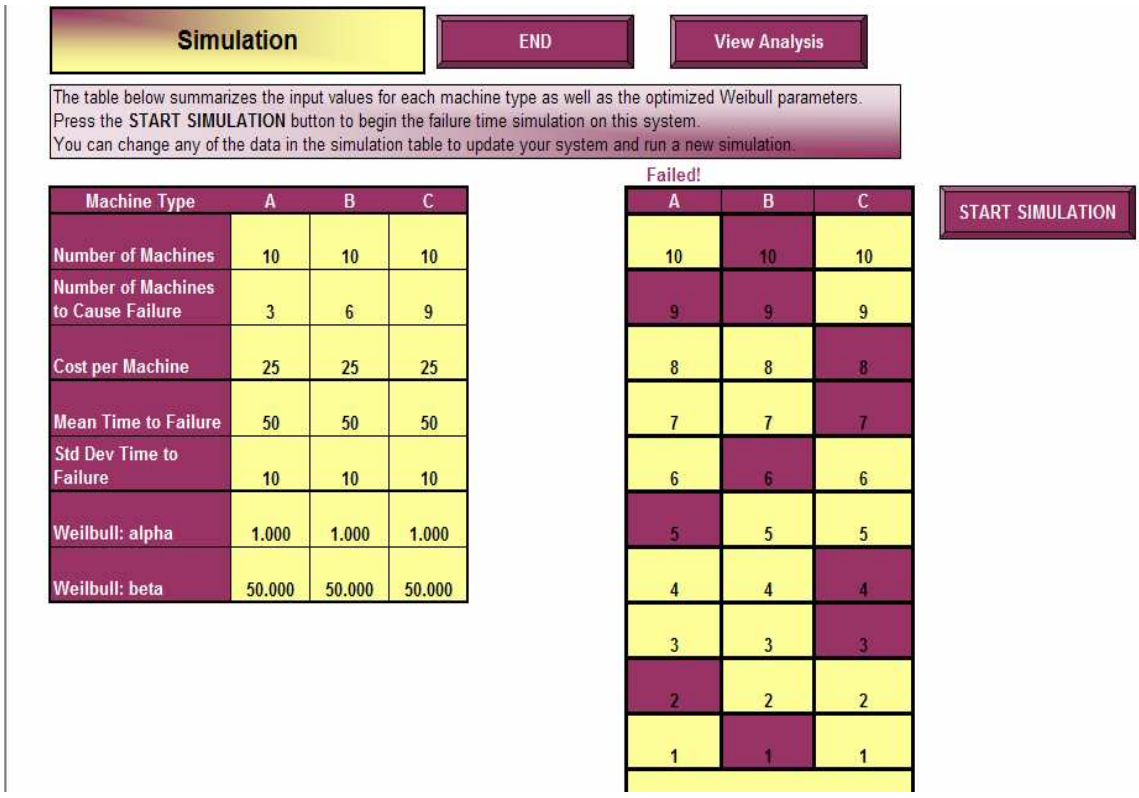
The only other procedures are the navigational procedures (see Figure 5.21). These are for the "End," "Back," "View Analysis," "View Details," "View Weibull," and "Return to Simulation" buttons.

```
'navigational procedures
Sub EndProg()
    Worksheets("Welcome").Visible = True
    ActiveSheet.Visible = False
End Sub

Sub ViewRuns()
    Worksheets("SimRuns").Visible = True
    ActiveSheet.Visible = False
End Sub

Sub GoBack()
    Worksheets("Analysis").Visible = True
    ActiveSheet.Visible = False
End Sub

Sub ViewWeibull()
    Worksheets("Weibull").Visible = True
    ActiveSheet.Visible = False
End Sub

Sub ReturnSim()
    Worksheets("Simulation").Visible = True
    ActiveSheet.Visible = False
End Sub
```

Figure 5–21: The navigational procedures.

Table 5–3: Summary: Procedures

Main	Initializes application and retrieves initial input from user.
ClearPrev	Initializes variables, clears previous values, and clears animation layout formatting.
cmdOK_Click	Error checking, assigns input values to corresponding array variables.
CalcWeibull	Envokes Solver to find optimal Weibull parameters for each machine type.
StartSim	Runs the simulation and performs the animation.
PrepSim	Rerecords input to capture any changes made by the user, prepares the animation layout.
CreateData	Creates a timeline of machine failures for all machines in each machine type.
WeibullInv	Generates Weibull random variable values.
PrepAnalysis	Creates histograms and displays mean system failure time. Navigational For navigational buttons.



Machine Type	A	B	C
Number of Machines	10	10	10
Number of Machines to Cause Failure	3	6	9
Cost per Machine	25	25	25
Mean Time to Failure	50	50	50
Std Dev Time to Failure	10	10	10
Weilbull: alpha	1.000	1.000	1.000
Weilbull: beta	50.000	50.000	50.000

A	B	C
10	10	10
9	9	9
8	8	8
7	7	7
6	6	6
5	5	5
4	4	4
3	3	3
2	2	2
1	1	1

Figure 5–22: An example of the first resolve option.

5.5 Resolve Options

There are two main resolve options for this DSS. The first option allows the user to return to the simulation sheet and modify the input table to rerun the simulation. This is done by pressing the "Return to Simulation" button on the output sheet.

For example, in Figure 5.22, we have returned to the simulation sheet after the initial simulation was run. We have changed the values for the "Number of Machines to Cause Failure" in the input table from 6 for each machine type to 3, 6, and 9. We then press the "Start Simulation" button again to restart the simulation. We can see that the new input has been recorded as the first machine type has caused the system failure when 3 of its machines failed.

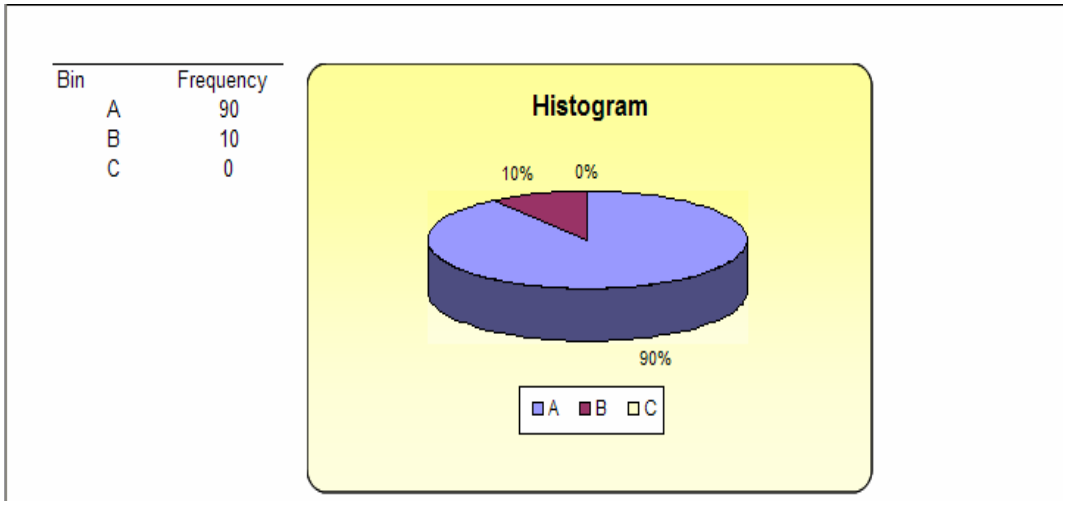


Figure 5–23: Updated analysis from the first resolve option.

We can then view the output sheet again by pressing the "View Analysis" button to see that indeed the first machine type has caused the majority of the system failures (see Figure 5.23).

The second resolve option enables the user to determine the system bottleneck machine type and add one machine to this machine type to improve system performance; that is, to increase the mean system failure time. This option is performed by a Resolve procedure that is called when the "Resolve" button on the output sheet is pressed (see Figure 5.24).

The Resolve procedure will show the user a resolve form in which they can choose which machine type to add a machine to. However, before doing that, we want to suggest to the user which machine type would be the best choice. To do that, the Resolve procedure begins by performing some trials to determine this best choice. For each machine type, one machine is added and the simulation is rerun. We then record the improvement in the mean system failure time. After that is done for all three machine types, we compute a ratio of these improvements to the machine cost for each machine type. The best choice will be the machine type with

the highest ratio; that is, it is most beneficial to add a machine which will cause the most improvement in system failure time at the least cost.

The resolve form is then shown (see Figure 5.25). When the form is initialized, we display the improvements in system failure time, machine costs, and ratio values for each machine on a table in the form (see Figure 5.26). We also update a dynamic label to display the best choice that we suggest to the user and select the corresponding option button.

A frame with these option buttons is used to retrieve the user's selection of which machine type they want to add a machine to. The "OK" button will record this selection and increase the number of machines for this machine type by one (see Figure 5.27). It will then update the input table and animation layout and recall the StartSim procedure.

The user can then observe the new simulation and animation. For example, in Figure 5.28, we have added one machine to the first machine type. Notice that this modification is reflected in the input table and the animation layout. The user can then review the analysis to see if the mean system time has indeed improved. This process may be repeated as many times as the user desires.

Table 5–4: Summary: Resolve Options

First resolve option	User presses the "Return to Simulation" button on output sheet to return to simulation sheet; they can modify the input table and rerun the simulation; the analysis is updated with the new simulation results.
Second resolve option	User presses the "Resolve" button on the output sheet to view the resolve form; the resolve form enables them to add one machine to one machine type; the best choice is suggested to the reader after running trial simulations in the Resolve procedure.

```
Sub Resolve()
'Assigned to "Resolve" button on output sheet;
'adds one machine to each machine time (sequentially) and
'reruns the simulation to record change in mean system failure time;
'compares ratio of this time change to the cost per machine of the machine type;
'suggests that the user adds one machine to the machine type with the largest ratio

    Dim MaxRatio As Double
    Resolving = True
    Application.ScreenUpdating = False

    For temp = 1 To 3
        'add 1 machine of type i
        NumMach(temp) = NumMach(temp) + 1

        'repeat simulation
        Call StartSim
        ChangeSysFail(temp) = Application.WorksheetFunction.Average(Range("TimeHist")) - Range("MeanSysFail").Value
        Ratio(temp) = ChangeSysFail(temp) / MachCost(temp)

        'reset values
        NumMach(temp) = NumMach(temp) - 1
    Next

    'find max ratio
    MaxRatio = 0
    For i = 1 To 3
        If Ratio(i) > MaxRatio Then
            MaxRatio = Ratio(i)
            BestChoice = MachName(i)
        End If
    Next i

    Application.ScreenUpdating = True
    frmResolve.Show
End Sub
```

Figure 5–24: The Resolve procedure.

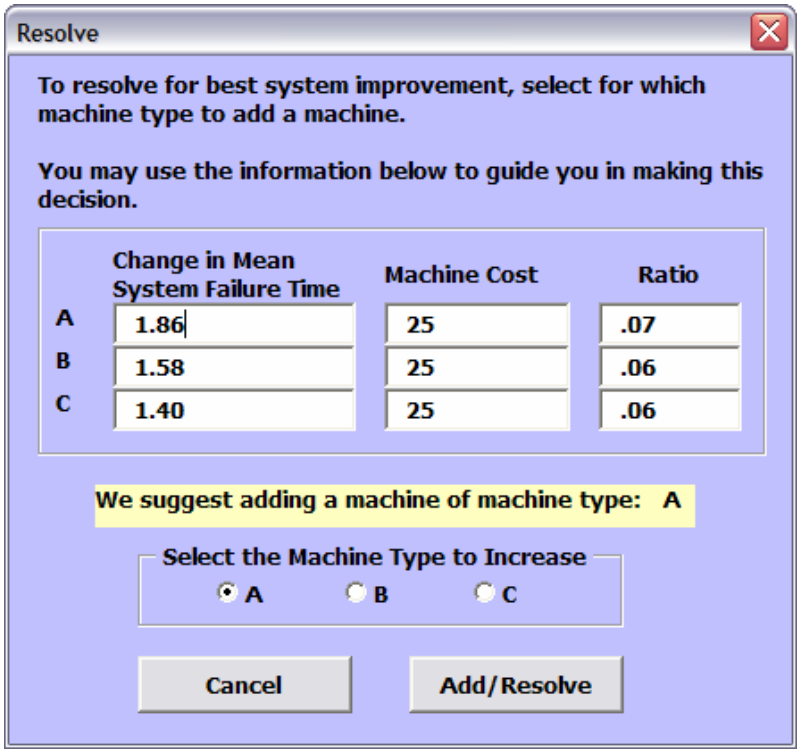


Figure 5–25: The resolve form.

```
Private Sub UserForm_Initialize()
'enters values found in Resolve procedure on form;
'displays suggested machine type

    txtChangeSysA.Value = Format(ChangeSysFail(1), "##.00")
    txtChangeSysB.Value = Format(ChangeSysFail(2), "##.00")
    txtChangeSysC.Value = Format(ChangeSysFail(3), "##.00")

    txtMachCostA.Value = MachCost(1)
    txtMachCostB.Value = MachCost(2)
    txtMachCostC.Value = MachCost(3)

    txtRatioA.Value = Format(Ratio(1), "##.00")
    txtRatioB.Value = Format(Ratio(2), "##.00")
    txtRatioC.Value = Format(Ratio(3), "##.00")

    lblBestChoice.Caption = BestChoice
    If BestChoice = "A" Then
        optA = True
    ElseIf BestChoice = "B" Then
        optB = True
    ElseIf BestChoice = "C" Then
        optC = True
    End If
End Sub
```

Figure 5–26: The initialization event procedure for the resolve form.

```
Private Sub cmdCancel_Click()
    Unload Me
    Worksheets("Welcome").Visible = True
    ActiveSheet.Visible = False
    End
End Sub

Private Sub cmdOK_Click()
'records user's selection on which machine type to increase;
'updates number of machines for this machine type;
'updates animation layout and input table on simulation sheet;
'Calls StartSim to rerun simulation

    If optA Then
        BestChoice = 1
    ElseIf optB Then
        BestChoice = 2
    ElseIf optC Then
        BestChoice = 3
    End If

    NumMach(BestChoice) = NumMach(BestChoice) + 1
    Range("SimTable").Offset(1, BestChoice).Value = NumMach(BestChoice)
    Range("SimAnim").Offset(2, BestChoice - 1).Cells.Insert shift:=xlDown
    Range("SimAnim").Offset(1, BestChoice - 1).Value = NumMach(BestChoice)
    Range("SimAnim").Offset(2, BestChoice - 1).Value = NumMach(BestChoice) - 1

    Unload Me
    Worksheets("Simulation").Visible = True
    ActiveSheet.Visible = False

    Resolving = False
    Call StartSim
End Sub
```

Figure 5–27: The Click event procedure for the "OK" button on the resolve form.

Simulation

END

View Analysis

The table below summarizes the input values for each machine type as well as the optimized Weibull parameters.
Press the **START SIMULATION** button to begin the failure time simulation on this system.
You can change any of the data in the simulation table to update your system and run a new simulation.

Machine Type	A	B	C
Number of Machines	11	10	10
Number of Machines to Cause Failure	6	6	6
Cost per Machine	25	25	25
Mean Time to Failure	50	50	50
Std Dev Time to Failure	10	10	10
Weilbull: alpha	1.000	1.000	1.000
Weilbull: beta	50.000	50.000	50.000

Failed!

A	B	C
11	10	10
10	9	9
9	8	8
8	7	7
7	6	6
6	5	5
5	4	4
4	3	3
3	2	2
2	1	1

START SIMULATION

Figure 5–28: An example of the second resolve option.

CHAPTER 6
CONCLUSION

6.1 The Importance of DSS

A decision support system (DSS) is a model-based or knowledge-based system intended to support managerial decision making. A DSS is not meant to replace a decision maker, but to extend his/her decision making capabilities. It uses data, provides a clear user interface, and can incorporate the decision maker's own insights.

OR graduates are frequently being employed in positions that require developing DSS which are gaining widespread popularity. Imparting DSS development skills, which combine OR skills with IT skills, will make graduates highly sought after in the modern workplace.

6.2 Spreadsheet-Based DSS

In the past few years, several platforms have become available which allows the integration of DSS development and IT skills into the OR curriculum. For spreadsheet-based DSS, we recommend using Excel since it is the most widely used spreadsheet package among managers and engineers, allows data storage and model building. Excel also has many built-in program as well as many add-on programs available that wallow optimization and simulation of various models built in Excel.

Excel also has a macro programming language, Visual Basic for Applications (VBA), which allows building GUIs and manipulating Excel objects. Thus, Excel provides a platform using which fairly sophisticated DSS applications can be built.

6.3 Developing a DSS

We propose five basic steps for developing a DSS: i) Application Overview: create a layout of the entire application to understand the flow from the user input

to the model calculations to the output, ii) Spreadsheets: determine how many spreadsheets you will need to best handle input, calculations, and output, iii) User Interface: outline what interface you will need to receive input from the user and navigate them through the application, iv) Procedures: outline what sub and/or function procedures you will need in your code to receive the input, perform the calculations, and display the output, v) DSS Components: decide what resolve options the user may have. These steps have been our guidelines to developing decision support systems.

6.4 Conclusion and Future Direction

Using good GUI design and programming principles along with a clear outline of the purpose and implementation of the application, a DSS can become a very powerful tool in aiding decision making. We focus here on spreadsheet-based DSS applications since spreadsheets are commonly used among decision makers in OR and business. We are making efforts to develop a textbook which can teach Excel skills, VBA programming, and DSS application development to industrial engineering, OR, and business students. [6] We feel that this will aid in better preparing graduates for real life problems.

DSS applications can be further developed to be applied on larger scale real world problems as well. The case studies we demonstrate here are simplified versions of such real world problems. Future work includes finding larger scale applications, related to research or industry topics in OR, and developing advanced DSS for them. These DSS may use more advanced object-oriented programming languages such as $C++$ or $C\#$, and may also reference other optimization software such as CPLEX. The development process we propose is still an important factor in developing a DSS with a friendly user interface and efficient implementation of models and algorithms so that the decision making process is indeed enhanced.

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BIOGRAPHICAL SKETCH

Michelle Hanna graduated from the University of Florida with a Bachelor of Science degree in industrial and systems engineering in May 2002. She then joined the doctoral program there in industrial and systems engineering in August 2002. After taking several doctoral level courses, Michelle decided to switch to the doctoral program in decision information sciences in the Warrington School of Business. She is now completing her master's degree in industrial and systems engineering.

Michelle is very interested in the development and application of decision support systems. She has written a textbook in *Developing Spreadsheet-Based Decision Support Systems* with coauthors Ravindra K. Ahuja and Wayne L. Winston. She has also given several lectures on this topic at international conferences and workshops. Michelle plans to continue to use her DSS development skills as she works on her doctoral research. Her dissertation will be focused on applying network theory and algorithms to logistics or scheduling problems.

Michelle plans to pursue an academic career in an operations management or information science department in a business school. She plans to work towards a tenured position as a professor in either of these areas.

Michelle is the daughter of Dr. Magdi Hanna and Mrs. Roblyn Hanna. She has one younger brother, Timothy. Her fiance is Onur Seref. She was born in Georgia, but has lived in Florida for the last 12 years. Her interests include languages, international cultures, and spirituality.