AutoMan

DECISION SUPPORT SOFTWARE FOR AUTOMATED MANUFACTURING INVESTMENTS

USER MANUAL

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PREFACE

AutoMan is a microcomputer program designed to support multi-criteria decisions about automated manufacturing investments. It was developed at the Center for Computing and Applied Mathematics of the National Institute of Standards and Technology (NIST). The project was conducted in collaboration with the NIST Automated Manufacturing Research Facility, the United States Navy, and Computer Aided Manufacturing -- International (CAM-I), a consortium of manufacturing firms.

The authors wish to thank all those who contributed excellent ideas and suggestions incorporated into this version of AutoMan. Christoph J. Witzgall of NIST verified some of the mathematical algorithms for computing weights and ratings from pairwise comparison judgments. The comments of NIST reviewers Belinda L. Collins, Sieglinde K. Fuller, Harold E. Marshall, and Rosalie T. Ruegg inspired many useful improvements to the documentation and software. Volunteer beta testers from corporations, universities, professional associations, and the CAM-I Cost Management System program suggested other significant enhancements and revisions. The authors are particularly indebted to Robert Bennett of the Accountancy Department of Northern Illinois University and Steven Neises of Woodward Governor for their very careful review and testing of AutoMan and their extensive written and oral suggestions for making the product more useful to practicing managers, accountants, and engineers.

ABSTRACT

This manual documents AutoMan, a microcomputer program designed to support multi-criteria decisions about automated manufacturing investments. The program permits users to combine quantitative and qualitative criteria in evaluating investment alternatives. Quantitative criteria could include such traditional financial measures as Life-Cycle Cost and Net Present Value as well as such engineering performance measures as throughput and setup time. Qualitative criteria could include flexibility and product quality. First, the user specifies the evaluation criteria and the investment alternatives to be evaluated. Second, the user makes pairwise comparisons between criteria to establish their weights. Third, the user rates each investment alternative with respect to the criteria. The pairwise comparison process helps the user rate the qualitative criteria, while measured performance data, such as cost, setup time, or throughput, can be entered for quantitative criteria. AutoMan combines ratings with criteria weights into an overall rating for each investment alternative and then ranks alternatives. AutoMan comes with sample decision models and a manual that includes a detailed tutorial, a glossary of evaluation criteria, a bibliography, and an index.

Key Words: Analytic hierarchy process; automation; automated manufacturing; decision support software; economic evaluation; microcomputer software; multi-criteria decisions; performance measures; qualitative data.

HOW TO INSTALL AND START AUTOMAN

AutoMan runs on an MS-DOS[tm] microcomputer with at least 512 kilobytes of RAM and a floppy diskette drive. It may be started directly from a 360 kilobyte floppy drive or it may be first installed on a hard drive and then started from there.

To start from a 360k floppy drive [Do NOT run AutoMan from a 1.2 Mb drive]:

Insert the diskette into the drive (for example, drive A), type **A:** and press ENTER to go to the A drive. To start the program type **AUTOMAN** and press ENTER, or **AUTOMAN M** for Monographic systems like the Compaq[tm] Portable II or III. If you have a hard drive, AutoMan will run much faster if you install it on the hard drive.

To install AutoMan on a hard drive:

Insert the diskette into drive A and type **A:** and press ENTER to go to the A drive. Then type **INSTALL** to install it on the C drive. Press ENTER and the installation will begin. All of the AutoMan program and data files will be automatically copied to a directory called \AUTOMAN on the hard drive.

If you prefer to install AutoMan on a drive other than the C drive or in a different directory, simply create the directory and then copy all of the files on the diskette to that directory.

To start from a hard drive:

Go to the directory in which AutoMan is installed by typing **CD\AUTOMAN** and pressing ENTER, then type **AUTOMAN** and press ENTER, or **AUTOMAN M** for Monographic systems like the Compaq[tm] Portable II or III.

The AutoMan distribution disk contains these files:

    AUTOMAN.EXE -   Executable program.
    MODELIST.DBF - Data file of model names.
    *.DBF   - Several data files containing sample models.
    INSTALL.BAT - Batch file to install AutoMan on a hard disk.

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LIST OF EXHIBITS

1. INTRODUCTION

Most capital investment decisions are made using such traditional measures of financial worth as net present value, life-cycle cost, and return on investment. These measures incorporate the stream of costs and benefits of an investment over time into a single measure. The measures are either denominated in dollars or derived from dollar-denominated data. Financial worth measures are often applied to reduce costs such as labor, materials, inventory, and rework. They tend to focus more on cost reduction than revenue creation because the former is usually easier to quantify.

Measures of financial worth are often inadequate to evaluate investments in automated manufacturing. The shortcomings of relying solely on these measures when evaluating automated manufacturing investments are discussed throughout the literature.[1] The most pervasive complaint is that measures of financial worth fail to account fully for the nonfinancial impacts of these investments. Nonfinancial impacts may be either quantitative or qualitative. Nonfinancial quantitative impacts can be measured, but not easily converted to dollars. They may consist of non-monetary measures of performance such as throughput, cycle time, and schedule attainment. Qualitative impacts cannot be measured at all. They typically involve issues that affect the long-term or strategic position of the firm, such as technology advancement, plant modernization, product quality, flexibility, competitive position, and even the survival of the firm.

Although industry recognizes the need for analytical techniques that account for nonfinancial impacts, there has been little change in the way most automated manufacturing investment decisions are made. Indeed, in a 1984 survey of the National Electrical Manufacturers Association, 91 percent of business executives reported using traditional measures of financial worth as the major criteria for automation investment decisions (Sullivan, 1986, pp. 42-50).

Approaches that include more than one measure of performance in the evaluation process are multi-attribute or multi-criteria decision methods.[2] The advantage of these methods is that they can account for both financial and nonfinancial impacts. The Analytic Hierarchy Process (AHP) is one multi-criteria decision method that has recently gained in popularity and been applied to a wide variety of complex decision problems. The AHP technique was developed in the 1970's by Thomas L. Saaty at the Wharton School of the University of Pennsylvania.[3]

The AHP structures a complex decision into a hierarchy of its elements. It then establishes shares of influence, or relative weights, among the elements through a sequential process of pairwise comparisons. Pairwise comparisons are based on judgments about relative differences between comparable elements. The relative weights are combined to derive a single overall rating for each decision alternative.

One of the major strengths of the AHP is that it permits inconsistencies among the pairwise comparison judgments. For example, A need not be four times as important as C just because

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[1]For example, see Fred Choobineh, "Justification of Flexible Manufacturing Systems," in Choobineh (1986, pp. 269-281), Computer Aided Manufacturing-International, Inc. (1988), Jelinek (1986), Sullivan (1986), and Canada and Sullivan (1989).

[2]For more information on multi-criteria decision methods, see Zeleny (1982), Goicoechea et al. (1982), and Canada and Sullivan (1989).

[3]For information on the AHP, see Saaty (1988) and Gass (1985).

A is twice as important as B and B is twice as important as C. In technical terms, this means that the user is not forced to preserve cardinal transitivity among comparisons. The AHP even provides an explicit measure of inconsistency that indicates how far the pairwise judgments deviate from perfect cardinal transitivity.

Several shortcomings of the AHP are discussed in the literature. The major criticisms question the lack of a theoretical framework for modeling decision problems into a hierarchy (Zahedi, 1986, p. 102), the use of subjective judgments in making pairwise comparisons (Reeve, 1988, pp. 26-27), the use of the eigenvector method for estimating relative weights (Zahedi, 1986, p. 103), and the lack of a formal treatment of risk (Harker, 1988).

Despite its limitations, the AHP appears ideally suited for economic decisions on automated manufacturing investments. It incorporates into a unified analytic framework a wide variety of normally incommensurable impact criteria, some of which may be financial, some nonfinancial yet quantifiable, and some qualitative. It appeals to decision makers because they directly participate in the process and can generally understand how results are produced. Furthermore, it has the advantage of dealing formally with inconsistency in human judgments. Some researchers have already begun applying the AHP to automated manufacturing investment decisions.[1]

This manual describes the microcomputer program AutoMan, a special-purpose adaptation of the AHP designed to support investment decisions about automated manufacturing equipment. AutoMan is useful for selecting the best investment in automated manufacturing equipment and for ranking a set of investment alternatives. AutoMan requires that the investment alternatives be identified and well specified beforehand. If financial worth measures are to be factors in the decision, AutoMan requires that these measures have been separately estimated. Similarly, actual performance data or qualitative judgments must be available on the merits of each alternative with respect to nonfinancial evaluation criteria to be used in the decision.

AutoMan evaluates up to seven investment alternatives simultaneously. If there are more than seven alternatives, you can evaluate them in groups of seven, and then reevaluate those that rank high in each group against one another. The outcome of this procedure, however, is sensitive to the way alternatives are initially grouped. AutoMan evaluates either (1) mutually exclusive alternatives (i.e., select only one) or (2) non-mutually exclusive alternatives (i.e., select more than one) as long as the alternatives are independent of each other (i.e., their impacts are not affected by acceptance of other alternatives).

AutoMan may be used to arrive at a team decision requiring input from senior managers, accountants, financial analysts, and engineers. Senior managers could structure the decision into a hierarchy of its elements and establish priorities among the elements; accountants and financial analysts could develop financial data for the investment alternatives; and engineers could provide the nonfinancial data and judgments on the performance of alternatives.

Although AutoMan is designed for selecting investments in automated manufacturing equipment, it is applicable to a wide variety of decision problems. AutoMan is appropriate for supporting any multi-criteria decision involving both quantitative and qualitative evaluation criteria.

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[1]See for example Arbel and Seidmann (1984), Varney et al. (1985), Sullivan (1986), and Wabalickis (1988).

2. OVERVIEW OF AUTOMAN

The overview of AutoMan summarizes the general procedures and guiding principles to follow when building and applying decision models. The details and mechanics of using the program are illustrated in the Tutorial that follows in Section 3.

Using AutoMan to support a decision regarding automated manufacturing investment alternatives involves four steps. First, identify evaluation criteria, group them into logical categories, and name the investment alternatives for evaluation. Second, make pairwise comparisons to establish the relative importance of categories as well as of evaluation criteria within each category. Third, rate alternatives with respect to each criterion. For measurable criteria, use actual performance data for rating. For qualitative criteria, use the pairwise comparison method. Fourth, let AutoMan combine the ratings for each investment alternative with the criteria weights and rank alternatives by their overall ratings.

2.1 Build a Model

In the first step you select an existing decision model or build a new one. The model structure is a three-tier hierarchy consisting of a topmost tier of "categories," a middle tier of "criteria," and a bottom tier of investment "alternatives." A new model is built by identifying the evaluation criteria to be considered in the decision, grouping similar criteria into categories, and labeling the investment alternatives to be evaluated.

The evaluation criteria comprising the middle tier are the expected impacts of the investment alternatives, both quantitative and qualitative. All significant impacts should be fully reflected in the choice of evaluation criteria. The criteria should be selected and defined to avoid ambiguity and redundancy.

Similar evaluation criteria are grouped into categories, defining the topmost tier of the model. The three basic types of impacts discussed in Section 1 -- financial, nonfinancial quantitative, and qualitative -- are helpful in grouping evaluation criteria into categories.

Models will not necessarily group criteria into categories exactly matching the three basic types of impacts. For example, one model may group cost-related financial criteria in one category, benefit-related financial criteria in another, nonfinancial quantitative criteria in a third, and qualitative criteria in a fourth. Combining different types of criteria (e.g., financial and qualitative) in a single category is not recommended because of the potential difficulty in comparing the criteria. Keep in mind, however, that AutoMan lets you create any grouping. The only limits are no more than seven categories of evaluation criteria with up to seven criteria per category, for a total of 49 criteria.

In building models, the evaluation criteria within each category must be reasonably comparable -- no criterion should be more than ten times as important as any other criterion in that category. If a criterion is more than ten times as important as another, it should be reclassified into another category or redefined and decomposed into several criteria. On the other hand, if a criterion is less than one tenth as important as any other, it probably is not significant enough to warrant inclusion in the analysis. Similarly, the categories themselves must be reasonably comparable.

Once the categories and criteria have been developed, the investment alternatives are identified. The investment alternatives should be sufficiently specified so that you can at least make reasonable judgments as to relative performance with respect to all the criteria. Further, since retaining the existing manufacturing system may possibly be preferred to all new investment alternatives, the existing system should be included in the list of investment alternatives. The alternatives may be either mutually exclusive (i.e., select only one) or non-mutually exclusive alternatives (i.e., select more than one) as long as the alternatives are independent of each other. Seven alternatives may be evaluated simultaneously. For more than seven alternatives, evaluate them in groups of seven, and then re-evaluate those that rank high in each group against one another. The initial grouping, however, may influence the outcome of this procedure.

Building the decision model is one of the most important and difficult steps in AutoMan. To help you get started, the program offers three sample models, any one of which may be used as a template from which to develop a more suitable model. These models are provided only to illustrate different structures; such generic models are unlikely to articulate a particular organization's goals and strategies. All the sample models contain categories and criteria but only the model EXAMPLE contains data on weights or ratings. The data in EXAMPLE are by definition purely hypothetical because weights and ratings need to be specific to a particular decision-making environment.

To further help you build models, the Glossary in the back of the manual defines those criteria for evaluating automated manufacturing investments that are used in the sample models of AutoMan. Refer to the Glossary for criteria to consider when building a new model and revise and add to the definitions to meet the needs of your organization.

2.2 Weight Categories and Criteria

The second step derives weights for categories and then for the individual criteria in each category. The weights are critical because they establish the relative importance of each criterion to the overall decision. The importance of each criterion to the overall decision depends on its "share," which is the product of the criterion weight and the weight for the category to which the criterion belongs. The criteria shares all sum to unity. In general, the more criteria in a model, the less important is each criterion to the overall decision.

The weights are based on your judgments about the relative importance of criteria when compared in a pairwise fashion. If there are n elements (categories in the model or criteria within a category) to be weighted, then there are only n(n-1)/2 pairwise comparisons to be made. Thus, 4 evaluation criteria require 6 (= 4x3/2) comparisons. This is because of two assumptions: (1) each criterion is of equal importance to itself; and (2) if A is twice as important as B, then B is half as important as A. The procedure for comparing criteria is the same as that for comparing categories. When all the pairwise comparisons are entered, AutoMan derives a system of weights that sum to unity by computing the normalized eigenvector of the largest eigenvalue of the matrix of pairwise comparison values.[1] This approach establishes the relative importance of categories as well as criteria within each category.

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[1]AutoMan computes the normalized eigenvector by raising the matrix of pairwise comparisons to powers that are successively squared each time. This is the computational method suggested by Saaty (1988, p. 179).

In addition to the weights, AutoMan reports an Inconsistency Ratio. As indicated in Section 1, the pairwise comparison method lets you reveal their inconsistencies of judgment. Perfect consistency results when A is always judged to be four times as important as C if A is twice as important as B and B is twice as important as C. The Inconsistency Ratio measures how far all the pairwise judgments deviate from perfect consistency among all comparisons. If the Inconsistency Ratio exceeds 0.10, it is advisable to redo the pairwise comparisons. Otherwise, the overall ratings may be distorted. The Tutorial illustrates a convenient method to force any comparison value to be perfectly consistent. The best way to improve consistency, however, is to make better informed comparisons based on more information gathered either through research or expert judgment of others.

2.3 Rate Alternatives

The third step in AutoMan is to rate each investment alternative with respect to every criterion in the model. There are two rating methods: pairwise comparison and direct entry of performance data. The pairwise comparison method is the same as that used in Step 2 for establishing the relative importance of criteria. The only difference is that, rather than being asked to compare the importance of criteria, you are asked to compare the desirability of investment alternatives with respect to each criterion. The pairwise comparison method must be used for rating if there are no reliable performance data on the alternatives for the criterion.

The performance data method requires actual data on the performance of each alternative with respect to the criterion. The data must be either **directly** or **inversely** proportional to the desirability of each alternative. For example, revenue is directly proportional if $200 of revenue is considered twice as desirable as $100 of revenue. Scrap costs are inversely proportional if $200 of cost is considered half as desirable (twice as bad) as $100 of cost. Negative and zero values have no meaning and are ignored in deriving ratings since performance data must be proportional to desirability. The units in which the data are entered do not matter as long as the same units are used for each alternative within the criterion being evaluated by the performance data method.

Once the performance data are entered, AutoMan computes a set of ratings for the alternatives that sum to unity. For directly proportional data, the rating for each alternative is the ratio of its performance data value to the sum of the performance data values for all alternatives. For inversely proportional data, the rating is the ratio of the inverse of the alternative's performance data value to the sum of the inverses of the data values for all alternatives. This approach establishes the relative desirability of the alternatives with respect to each criterion.

2.4 Compute Overall Ratings

The final step in the process is carried out by AutoMan. All weights developed for the criteria are combined with ratings to compute a single, weighted-average rating for each alternative. The overall ratings are displayed, and all alternatives are ranked by them. The alternative with the highest overall rating is the best choice taking into account the relative importance of each criterion established by the user in Step 2 as well as the relative desirability of the alternatives with respect to each criterion in Step 3.

If the decision involves non-mutually exclusive alternatives (i.e., more than one may be selected), then the ranking by overall rating can be used to select the top set of alternatives. If there are more than seven alternatives to evaluate, then a copy of the model may be made

to cover the other alternatives. The user may then redefine the set of investment alternatives and keep the same categories and criteria. The new copy of the model will start out with the same pairwise comparison data and resulting weights as the original model. The new model will have a new set of alternatives which will require new ratings to be established for the alternatives with respect to each criterion. Provided the alternatives are grouped so that the better ones are not all clustered into the same model, the overall ratings could be used to establish an approximate ranking of all the alternatives.

3. TUTORIAL

The Tutorial shows how to use AutoMan to evaluate alternative investments in automated manufacturing equipment. The four major steps outlined in Section 2 are illustrated in detail.

The instructions throughout the Tutorial and at the bottom of each screen in the program use a common set of symbols to represent keystrokes that perform specific actions. The symbols, keystrokes, and resulting actions are as follows:

Symbol	Keystroke	Resulting Action
↵	Enter key	Enter data or redo comparisons
→ ←	Right and left arrow keys	Move within an element
↑ ↓	Up and down arrow keys	Move between elements
Del	Delete key	Delete a character or delete a model
Ctrl-Y	Hold down the Control key and press Y	Delete an element
Ctrl-Home	Hold down the Control key and press Home	View the criteria or view the ratings
Ctrl-End	Hold down the Control key and press End	View Inconsistency Ratios and shares
Esc	Escape key	Cancel current action or retreat to previous level

To start AutoMan:
- Type **CD\AUTOMAN** and press ↵.
- Type **AUTOMAN** and press ↵.
- When the opening screen appears, press ↵.

The AutoMan Menu appears with four options corresponding to four steps required to evaluate alternative investments (Exhibit 1).

```
        AUTOMAN

┌─────────────────────────────────────┐
│                                      │
│   Select or Build a Model            │
│                                      │
│   Weight Categories & Criteria       │
│                                      │
│   Rate Alternatives                  │
│                                      │
│   Compute Overall Ratings            │
│                                      │
│   Quit AutoMan                       │
│                                      │
└─────────────────────────────────────┘
        Model Selected:   NONE


    F1 for Help    ↓ ↑ to Move    ↵ to Select
```

Exhibit 1.   AutoMan Menu.

Press **F1** at the AutoMan Menu for a summary of the four major steps or modules (Exhibit 2). Throughout AutoMan press **F1** to see help screens that explain the current procedures.

```
┌──────────────────────────────────────────────────────────────────┐
│                     Main Modules of AutoMan                        │
├──────────────────────────────────────────────────────────────────┤
│                                                                    │
│   Select or Build a Model                                          │
│      Identify evaluation criteria, group them into logical         │
│      categories, and specify investment alternatives to be         │
│      evaluated.                                                     │
│                                                                    │
│   Weight Categories & Criteria                                     │
│      Enter pairwise comparisons into judgment matrices to          │
│      establish the relative importance of categories as well as    │
│      of evaluation criteria within each category.                  │
│                                                                    │
│   Rate Alternatives                                                │
│      Rate alternatives with respect to each criterion.  For        │
│      measurable criteria, use actual performance data.  For        │
│      qualitative criteria, use the pairwise comparison method      │
│      as in Weight Categories & Criteria.                           │
│                                                                    │
│   Compute Overall Ratings                                          │
│      AutoMan combines ratings for each investment alternative      │
│      with criteria weights and ranks alternatives by their         │
│      overall ratings.                                              │
│                                                                    │
│                                                                    │
│                              Press ◄┘ to Select Module . . .       │
└──────────────────────────────────────────────────────────────────┘
```

Exhibit 2.   Help Screen Explaining the AutoMan Menu.

3.1 Select or Build a Model

There are two ways to make a selection from the AutoMan Menu:
- Move the highlighted bar to the desired option and press ◄┘; or
- Type the initial letter of the option.

To choose Select or Build a Model:
- Press ◄┘ (since the first option is already highlighted).

This option displays a list of sample models included with AutoMan, along with a brief description, the date created, and the number of evaluation criteria in each (Exhibit 3). The two top models, SMALL and LARGE, are sample models to illustrate the general pattern by which models may be structured. They contain no data on the weights or ratings. The third sample model, EXAMPLE, has both a structure and hypothetical data on the weights and ratings. Press the **F1** key for a brief description of the options listed at the bottom of the screen.

To view the structure of any model:
- Move the highlighted bar to the model.
- Press **F3**.
- Press **Esc** to return to the Model Selection and Building screen.

The EXAMPLE model has the same structure as the model you are about to build, but all the data have already been entered. If you do not want to practice building a model and entering data in the Tutorial, you may select EXAMPLE and go directly to Section 3.2, Weight Categories and Criteria, and review each step in the process with a complete set of data already entered. To select EXAMPLE, use ↓ to highlight it and press ◄┘.

```
                    Model Selection and Building
                       Model Selected:  NONE

    NAME       DESCRIPTOR                            DATE      CRITERIA

    SMALL      Two Categories                        08/01/89         5
    LARGE      Four Categories                       08/01/89        16
    EXAMPLE    Practice Model with TUTORIAL Data     08/01/89         9




    Use ↓ ↑ to highlight Model and press:    F1 for Help   Esc to Exit
    ↵ to Select    F3 to Edit    F4 to Build  F5 to Copy   Del to Delete
```

Exhibit 3.   List of the Decision Models.

To build a new model:
- Press the **F4** key at the Model Selection and Building screen. AutoMan then asks for three entries at the bottom of the screen (Exhibit 4).
- A new model will be built from scratch so you do not want to pattern the model after the template model. Hold the **Ctrl** key down and press **Y** to delete everything to the right of the cursor, erasing the default name of the template model.
  (If you do not erase the name of the template model, then the categories, criteria, and alternatives of the template model will appear on the screen for building the new model. You may then add, delete, or edit any of these model elements.)
- Press ↵.
- Type the new model name, **TUTORIAL.**
- Type its descriptor, **Practice Model**, and press ↵.

```
                    Model Selection and Building
                       Model Selected:  NONE

    NAME       DESCRIPTOR                            DATE      CRITERIA

    SMALL      Two Categories                        08/01/89         5
    LARGE      Four Categories                       08/01/89        16
    EXAMPLE    Practice Model with TUTORIAL Data     08/01/89         9




    Template Model:  SMALL              New Model:
    Descriptor:                                       Esc to Cancel
```

Exhibit 4.   Building a Model: Enter Name and Descriptor.

- 9 -

You must now specify the structure of the new model, TUTORIAL. TUTORIAL will have three impact categories: Monetary, Performance Measures, and Strategic. See the Glossary for further definition of the categories, their criteria, and abbreviations of the categories and criteria. Press **F1** for help in building a model. To move within an element use → and — , and to move between elements use ↑ and ↓.

To enter these category labels:
- Type **Monetary**, **PerfMeas**, and **Strategc**, the abbreviated forms of the category labels to fit the eight character limit for labels in AutoMan (Exhibit 5).
- After checking that the category labels are all correct, press **PgDn** to leave the four remaining category entries blank.
  (Be sure to enter all categories in succession from left to right; any categories entered beyond a blank entry will be ignored.)

```
┌──────────────────────────────────────────────────────────────┐
│                     Building a New Model                       │
│                     Model:  TUTORIAL                           │
├──────────────────────────────────────────────────────────────┤
│  Enter at least 1 and no more than 7 Categories of Evaluation Criteria: │
│                                                                │
│      Monetary  PerfMeas  Strategc                              │
│                                                                │
│                                                                │
│                                                                │
│                                                                │
│                                                                │
│                                                                │
│                                                                │
│                                                                │
│                                                                │
├──────────────────────────────────────────────────────────────┤
│   F1 for Help   ↓ ↑ for Next/Prior Label  PgDn to Save  Esc to Cancel │
└──────────────────────────────────────────────────────────────┘
```

Exhibit 5.   Building a Model: Enter Categories.

For each category, you may enter up to seven evaluation criteria. Exhibit 6 depicts the screen once all criteria are entered. One criterion for the Monetary category is Initial Cost of the investment alternative, which may include currently needed repairs of an existing system. Another Monetary criterion is Revenue. If no criteria are entered, AutoMan automatically adds a single default criterion to the model, using the same label as the category itself. This provides a way to have a category that serves as its own criterion.

Enter the Monetary criteria:
- Type **InitCost** and **Revenue** as criteria under the Monetary category.
- Press ↵ six times to skip through the five remaining undefined criteria (since there are only two criteria for this category).

The next category to specify is Performance Measures, abbreviated as PerfMeas. It includes non-monetary measures of performance. In this example criteria are: Cycle Time, Schedule Attainment, Throughput, and Yield.

Enter Performance Measures criteria:
- ◦ Type **CycleTim**, **Schedule**, **Thruput**, and **Yield**, the abbreviated forms of the criteria labels.
- ◦ Press ↵ four times.

```
┌─────────────────────────────────────────────────────────────────────┐
│                       Building a New Model                          │
│                       Model:  TUTORIAL                              │
├─────────────────────────────────────────────────────────────────────┤
│ Enter at least 1 and no more than 7 Categories of Evaluation Criteria:│
│                                                                     │
│     Monetary  PerfMeas  Strategc                                    │
│                                                                     │
│ Enter up to 7 Evaluation Criteria for each Category:                │
│                                                                     │
│  1. InitCost  CycleTim  Flexity                                     │
│  2. Revenue   Schedule  Quality                                     │
│  3.           Thruput   Risk                                        │
│  4.           Yield                                                 │
│  5.                                                                 │
│  6.                                                                 │
│  7.                                                                 │
│                                                                     │
│ Enter at least 2 and no more than 7 ALTERNATIVES to be evaluated:   │
│                                                                     │
│     Existing  New                                                   │
│                                                                     │
├─────────────────────────────────────────────────────────────────────┤
│    F1 for Help   ↓ ↑ for Next/Prior Label  PgDn to Save  Esc to Cancel│
└─────────────────────────────────────────────────────────────────────┘
```

Exhibit 6.   Building a Model: Enter Criteria and Alternatives.

The last category is abbreviated Strategc and is meant to include the evaluation criteria often associated with a company's strategic plan. For the model TUTORIAL, this category consists of three evaluation criteria: Flexibility, Quality, and Risk.

Enter the Strategic criteria:
- ◦ Type **Flexity**, **Quality**, and **Risk**, the abbreviated forms of the criteria labels.
- ◦ Press ↵ five times.

Once the criteria for all categories have been entered, you must enter at least two and up to seven investment alternatives. These alternatives will be evaluated with respect to each criterion entered above. The TUTORIAL model has two investment alternatives: Existing and New (Exhibit 6). Existing is the current system, and New represents a specific level of investment in automated manufacturing equipment.

Enter the alternatives:
- ◦ Type **Existing** and **New**.
- ◦ Press **PgDn**.

Exhibit 7 displays the revised list of decision models now in the system. Note that TUTORIAL, the model you just built, has been added at the bottom of this list, indicating that the TUTORIAL model has been saved. Since TUTORIAL is the model currently selected it is shown at the top of the screen.

```
┌─────────────────────────────────────────────────────────────────┐
│                  Model Selection and Building                     │
│                  Model Selected:   TUTORIAL                       │
│                                                                   │
│   NAME        DESCRIPTOR                          DATE    CRITERIA │
│   ══════════════════════════════════════════════════════════════ │
│   SMALL   │ Two Categories                    │ 08/01/89 │    5    │
│   LARGE   │ Four Categories                   │ 08/01/89 │   16    │
│   EXAMPLE │ Practice Model with TUTORIAL Data │ 08/01/89 │    9    │
│   TUTORIAL│ Practice Model                    │ 08/02/89 │    9    │
│           │                                   │          │         │
│           │                                   │          │         │
│           │                                   │          │         │
│           │                                   │          │         │
│           │                                   │          │         │
│           │                                   │          │         │
│           │                                   │          │         │
│   ──────────────────────────────────────────────────────────────│
│   Use ↓ ↑ to highlight Model and press:    F1 for Help  Esc to Exit│
│   ↵  to Select    F3 to Edit    F4 to Build  F5 to Copy  Del to Delete│
└─────────────────────────────────────────────────────────────────┘
```

Exhibit 7.   New List of Decision Models Including TUTORIAL.

To view the model structure (Exhibit 8):
- ° Highlight the TUTORIAL model.
- ° Press **F3**.
- ° Press **Esc** to return to the Model Selection and Building screen.


```
┌─────────────────────────────────────────────────────────────────┐
│              Edit Labels of Hierarchical Structure                │
│                      Model:   TUTORIAL                            │
│   ══════════════════════════════════════════════════════════════ │
│                                                                   │
│        Descriptor:   Practice Model                               │
│                                                                   │
│                 Categories of Evaluation Criteria                 │
│                   Monetary  PerfMeas  Strategc                    │
│                                                                   │
│                       Evaluation Criteria                         │
│                 InitCost  CycleTim  Flexity                       │
│                 Revenue   Schedule  Quality                       │
│                           Thruput   Risk                          │
│                           Yield                                   │
│                                                                   │
│                                                                   │
│                                                                   │
│                 Alternatives to be Evaluated                      │
│                       Existing  New                               │
│                                                                   │
│   ──────────────────────────────────────────────────────────────│
│     F1 for Help   ↓ ↑ for Next/Prior Label   PgDn to Save  Esc to Cancel│
└─────────────────────────────────────────────────────────────────┘
```
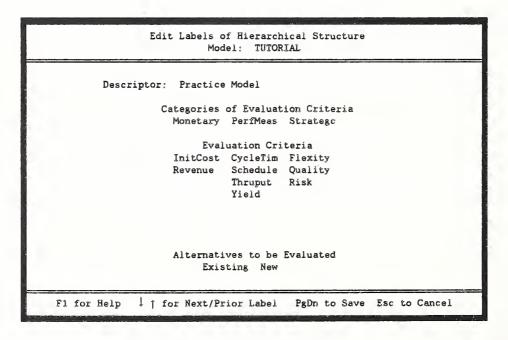
Exhibit 8.   Structure of the TUTORIAL Model.

Now you could modify the model. By pressing F3 to edit, you could change any of the labels for categories, criteria, and alternatives, but not the structure of the model. By pressing F5 to copy, you could enter a new set of alternatives but keep the structure the same. By pressing F4 to build, you could completely modify the structure by changing the number of criteria, categories, and alternatives. With F4 the data on weights and ratings from the original model are no longer relevant to the new structure and so are not transferred to the new model. Now press ↵ to select the TUTORIAL model and return to the AutoMan Menu.

3.2 Weight Categories and Criteria

At the AutoMan Menu, type **W** to select Weight Categories and Criteria.

Press the **F1** key to display a screen of instructions describing how to weight categories. Categories are weighted by using a scale of 0.100 to 9.900 to indicate how many times as important the category of each row is compared with the category of each column. If the two are equally important, enter a **1.0**. If the row category is MORE important than the column category, enter the value (greater than one) comparing row to column. If the row category is LESS important than the column category, either directly enter the value (between zero and one) comparing row to column, or enter the value (greater than one) comparing column to row and then press **F2**. Pressing F2 automatically reverses the comparison by inverting the value. To change any comparison value, use the ↑ and ↓ keys to move to the desired field and enter the correct value.

To record comparison judgments between each pair of the three categories (Exhibit 9):
- ° The Monetary category is judged to be one and a half times as important as (or 50 percent more important than) Performance Measures, so type the value **1.5** in the first field and press ↵.
- ° The Strategic category is judged to be twice as important as Monetary. But, since you are asked for the reverse comparison:
  - ° Type the value **2**.
  - ° Press **F2** while still in the second field to reverse the order of the comparison and invert the value to 0.500.
  - ° Press ↵.

```
              Recording Pairwise Comparisons between Categories
                            Model:  TUTORIAL


           Monetary  PerfMeas  Strategc
Monetary             1.500     0.500
PerfMeas                       0.250
Strategc

For the overall decision,
PerfMeas is how many times as IMPORTANT as Strategc?    [Use 0.100 to 9.900]




    F1 for Help      F2 to REVERSE Comparison    ↓ ↑ for Next/Prior Pair
                  PgDn to compute Weights    Esc to Cancel
```

Exhibit 9.   Weighting Categories: Enter Pairwise Comparisons.

○ The Strategic category is judged to be four times as important as Performance Measures, so in the third field:
  ○ Type the value **4**.
  ○ Press **F2** to reverse the comparison and invert the value to 0.250.
  ○ Press ↵ or **PgDn** to compute the category weights and the Inconsistency Ratio.

The category weights displayed in Exhibit 10 represent the relative importance that will be assigned to each category in determining the overall ratings of the alternatives. The weights are derived from the pairwise comparisons you just entered.

Note that the Inconsistency Ratio is less than 0.100, so there is no need to redo the comparisons. For an explanation of the Inconsistency Ratio, press the **F1** key now to display the help screen or refer to Section 2.
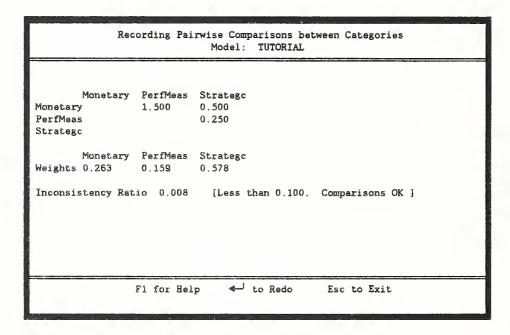
```
┌─────────────────────────────────────────────────────────────────┐
│          Recording Pairwise Comparisons between Categories        │
│                      Model:  TUTORIAL                             │
├───────────────────────────────────────────────────────────────────┤
│                                                                   │
│          Monetary  PerfMeas  Strategc                             │
│  Monetary          1.500     0.500                                │
│  PerfMeas                    0.250                                │
│  Strategc                                                         │
│                                                                   │
│          Monetary  PerfMeas  Strategc                             │
│  Weights 0.263     0.159     0.578                                │
│                                                                   │
│  Inconsistency Ratio  0.008    [Less than 0.100.  Comparisons OK ]│
│                                                                   │
│                                                                   │
│                                                                   │
├───────────────────────────────────────────────────────────────────┤
│          F1 for Help      ↵ to Redo      Esc to Exit              │
└─────────────────────────────────────────────────────────────────┘
```

Exhibit 10.   **Weighting Categories: Computed Weights and Inconsistency Ratio.**

○ Press **Esc** to display the Selection of Category for Pairwise Comparisons screen.

Once the categories have been compared with each other, you must weight the criteria within each category. The procedure for comparing criteria is the same as that for comparing categories. Comparisons must be entered for the criteria in each of the three categories listed in Exhibit 11. Here the procedure is illustrated in detail for the Performance Measures category.
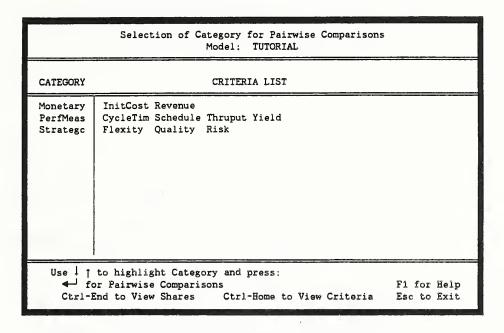
```
┌─────────────────────────────────────────────────────────────┐
│            Selection of Category for Pairwise Comparisons     │
│                    Model:   TUTORIAL                          │
├─────────────────────────────────────────────────────────────┤
│                                                               │
│  CATEGORY                       CRITERIA LIST                 │
├─────────────────────────────────────────────────────────────┤
│  Monetary   │ InitCost Revenue                                │
│  PerfMeas   │ CycleTim Schedule Thruput Yield                 │
│  Strategc   │ Flexity  Quality  Risk                          │
│             │                                                 │
│             │                                                 │
│             │                                                 │
│             │                                                 │
│             │                                                 │
│             │                                                 │
├─────────────────────────────────────────────────────────────┤
│  Use ↓ ↑ to highlight Category and press:                     │
│      ↵  for Pairwise Comparisons               F1 for Help    │
│    Ctrl-End to View Shares    Ctrl-Home to View Criteria      │
│                                                Esc to Exit    │
└─────────────────────────────────────────────────────────────┘
```

Exhibit 11.   Weighting Criteria: Select Category.

To compare the four evaluation criteria in the Performance Measures category:
- Press ↓ once to highlight PerfMeas, the abbreviation for Performance Measures.
- Press ↵ to display the Pairwise Comparisons between Criteria screen.

Press **F1** to see the help screen on comparing criteria. Since there are four Performance Measures criteria, a total of 6 (= 4 x(4-1) / 2) pairwise comparisons are needed. To correct an entry, use the ↑ and ↓ keys to move to the desired field and enter the correct value.

Enter the six comparison values as follows:
- Schedule is twice as important as CycleTim, so type the value **2** in the first field and then press **F2** to reverse the comparison. Press ↵.
- CycleTim is twice as important as Thruput, so in the second field type the value **2** and press ↵.
- CycleTim is three times as important as Yield, so in the third field type the value **3** and press ↵.
- Schedule is twice as important as Thruput, so type **2** in the fourth field and press ↵.
- Schedule is twice as important as Yield, so type **2** in the fifth field and press ↵.
- Thruput is four times as important as Yield, so type **4** in the last field and press ↵.

Exhibit 12 shows the screen after the numbers have all been entered and the weights and Inconsistency Ratio have been computed. The Inconsistency Ratio is greater than 0.100, so the comparison values should be reviewed.

There is a convenient method to force consistency by using the comparison values in the first row to derive the perfectly consistent values for the remaining comparisons. The method assumes the user has the most confidence in the first row comparisons. The consistent comparison value is the ratio of the first row value for the current column criterion to the first row value for the current row criterion. For example, the consistent value for comparing Schedule to Yield would be 6.000 (= 3.000/0.500), the value for comparing CycleTim to Yield divided by the value for comparing CycleTim to Schedule.

```
              Recording Pairwise Comparisons between Criteria
                 Model:   TUTORIAL          Category:  PerfMeas


           CycleTim  Schedule   Thruput    Yield
CycleTim             0.500      2.000      3.000
Schedule                        2.000      2.000
Thruput                                    4.000
Yield

           CycleTim  Schedule   Thruput    Yield
Weights 0.290        0.378      0.228      0.104

Inconsistency Ratio  0.109     [Exceeds 0.100.  Redo Comparisons ]




                 F1 for Help      ←┘ to Redo      Esc to Exit
```

Exhibit 12.   Weighting Criteria: Pairwise Comparisons Cause Excessive Inconsistency

To edit the comparison values:
- Press ←┘ to redo.
- Press ↓ four times to edit the field comparing Schedule to Yield where 2.000 is entered.
- Type **6** to replace the value 2.000 and press **PgDn** to recompute the weights and the Inconsistency Ratio. The Inconsistency Ratio is now much lower as shown in Exhibit 13.

```
              Recording Pairwise Comparisons between Criteria
                 Model:   TUTORIAL          Category:  PerfMeas


           CycleTim  Schedule   Thruput    Yield
CycleTim             0.500      2.000      3.000
Schedule                        2.000      6.000
Thruput                                    4.000
Yield

           CycleTim  Schedule   Thruput    Yield
Weights 0.274        0.448      0.208      0.070

Inconsistency Ratio  0.036     [Less than 0.100.  Comparisons OK ]




                 F1 for Help      ←┘ to Redo      Esc to Exit
```
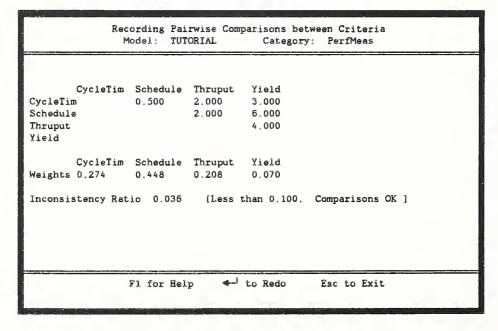
Exhibit 13.   Weighting   Criteria: Revised   Comparisons   Improve Inconsistency Ratio.

Now press **Esc** to return to the Selection of Category for Pairwise Comparisons screen. At this screen (Exhibit 11), the Inconsistency Ratios for the categories already selected can be displayed. You can also review the share of the overall rating controlled by each category. Just hold down the **Ctrl** key and press **End** (Ctrl-End) to see the Inconsistency Ratios and shares. To restore the screen with the criteria lists, hold down the **Ctrl** key and press **Home** (Ctrl-Home).

To compare the importance of the two evaluation criteria in the Monetary category:
- Highlight the Monetary category.
- Press ↵.
- Type **3** to indicate that InitCost is three times as important as Revenue.
- Press ↵ or **PgDn** to compute the weights and the Inconsistency Ratio.
- Press **Esc** to return to the Selection of Category screen.

To compare the importance of the three evaluation criteria in the Strategic category:
- Highlight the Strategic category.
- Press ↵.
- Type the first two comparison values pressing ↵ after each one: **1.5** and **1**.
- For the third field type **1.5** then **F2** to reverse the comparison and invert the value to 0.667.
- Press ↵ or **PgDn** to compute the weights and the Inconsistency Ratio.
- Press **Esc** to return to the Selection of Category screen.
- Press **Esc** to return to the AutoMan Menu.

3.3 Rate Alternatives

The third step in AutoMan is to rate investment alternatives with respect to each criterion.
- Type **R** to select the Rate Alternatives option from the AutoMan Menu and display the Selection of Rating Criterion screen (Exhibit 14).

```
┌─────────────────────────────────────────────────────────────────────┐
│                  Selection of Rating Criterion                       │
│                      Model:  TUTORIAL                                │
├─────────────────────────────────────────────────────────────────────┤
│                                   CURRENT RATINGS                     │
│       CRITERION   Existing New                                       │
├─────────────────────────────────────────────────────────────────────┤
│       InitCost                                                       │
│       Revenue                                                        │
│       CycleTim                                                       │
│       Schedule                                                       │
│       Thruput                                                        │
│       Yield                                                          │
│       Flexity                                                        │
│       Quality                                                        │
│       Risk                                                           │
│                                                                      │
│                                                                      │
│                                                                      │
├─────────────────────────────────────────────────────────────────────┤
│    Use ↓ ↑ to highlight Criterion and press:                         │
│       ↵ for Pairwise Comparisons    D  for Performance Data   F1 for Help │
│       Ctrl-End to View Shares       Ctrl-Home to View Ratings  Esc to Exit │
└─────────────────────────────────────────────────────────────────────┘
```

Exhibit 14.   Rating Alternatives: Select Criterion.

At this step, each alternative is rated with respect to the nine criteria in the TUTORIAL model. Either of the two rating methods may be used: pairwise comparison or performance data. The pairwise comparison method is the same as that used in Step 2 for weighting categories and criteria. The performance data method requires actual data on the performance of each alternative with respect to the criterion. Press F1 for help on deciding which rating method is appropriate to a given criterion.

Note that the performance data used for a criterion should be either directly or inversely proportional to the desirability of alternatives. Consequently, negative or zero values cannot be used for performance data. In such cases, the pairwise comparison method should be used for rating alternatives with respect to that criterion. Note also that all of the performance data for a given criterion must be entered in the same units. For example, use thousands of dollars valued at 1989 price levels. Similarly, if cash flows occur at different times, use discounting to convert all values for that criterion to the same time period.

Use ↓ and ↑ to highlight the criterion to be rated. You can also use the PgDn and PgUp keys to move to the bottom and top of the list of criteria.

To enter performance data for Revenue:
 ° Press ↓ once to highlight Revenue.
 ° Press D to enter performance data on the Revenue expected from the Existing and New alternatives.
 ° Type **900** for Existing and **1200** for New, pressing ↵ after each (Exhibit 15). Ignore commas that appear as you begin to enter data. Once you press ↵, commas will automatically align based on the size of the number.
   These two entries assume the Existing system results in $900,000/year in Revenue and the New system results in $1.2 million/year. The units in which the data are entered must be the same for all alternatives within the criterion being evaluated.

 ° Press Y for Yes at the question: "Are HIGHER Performance Values BETTER?"
   Answering Yes indicates that you prefer more rather than less Revenue.

```
          Rating Alternatives by Performance Data
          Model:  TUTORIAL   Criterion:  Revenue


            ALTERNATIVE      PERFORMANCE      RATING

            Existing              900
            New                 1,200








          Are HIGHER Performance Values BETTER [Y/N]?   Y




          F1 for Help    PgDn to Compute Ratings    Esc to Cancel
```

Exhibit 15.   Rating Alternatives: Enter Performance Data.

The Revenue ratings for the Existing and New systems will then appear to the right of the performance data (Exhibit 16). Note that New, with higher revenue, is given a proportionally higher rating for this criterion because higher values are better.

```
┌──────────────────────────────────────────────────────────────────┐
│          Rating Alternatives by Performance Data                  │
│          Model:  TUTORIAL   Criterion:  Revenue                   │
├──────────────────────────────────────────────────────────────────┤
│                                                                    │
│       ALTERNATIVE        PERFORMANCE        RATING                 │
│                                                                    │
│       Existing                 900          0.429                  │
│       New                    1,200          0.571                  │
│                                                                    │
│                                                                    │
│                                                                    │
│                                                                    │
│                                                                    │
│       Are HIGHER Performance Values BETTER [Y/N]?   Y              │
│                                                                    │
│                                                                    │
│                                                                    │
├──────────────────────────────────────────────────────────────────┤
│       F1 for Help        ←┘ to Redo         Esc to Exit           │
└──────────────────────────────────────────────────────────────────┘
```

Exhibit 16.   Rating Alternatives: Computed Ratings for Performance Data.

To enter performance data for Initial Cost (following the example for Revenue):
- Press **Esc** to return to the Selection of Rating Criterion screen depicted in Exhibit 14, which now shows the ratings just computed for Revenue.
- Press ↑ once to highlight InitCost, the abbreviation for the Initial Cost criterion.
- Press **D** to enter performance data on the initial costs of the Existing and New systems.
- Type **200** for Existing and **600** for New, pressing ←┘ after each.
  The Existing system will require an initial outlay of $200,000 in repair costs to continue in service, and the New system has an estimated initial cost of $600,000. If the initial cost of the existing system were absolutely zero, the pairwise comparison method should be used to rate the alternatives with respect to initial cost.

- Type **N** for No when asked, "Are HIGHER Performance Values BETTER?" since higher costs are not better.
- Press **Esc** to return to the Selection of Rating Criterion screen (Exhibit 14).

The InitCost ratings for the Existing and New systems now appear, with a higher rating for the lower-cost Existing system.

Use the pairwise comparison method to rate alternatives with respect to evaluation criteria for which: (1) no objective performance data exists; (2) some alternatives have zero or negative performance values; or (3) performance is measured by the presence or absence of a feature. The method is similar to that for weighting criteria. Instead of judging the importance of criteria, however, you judge the performance of alternatives with respect to each criterion.

To judge the performance of alternatives with respect to Flexibility (since Flexibility is a criterion for which objective data are difficult to obtain):

- Highlight Flexity.
- Press ↵ to display the Rating Alternatives by Pairwise Comparisons screen and press **F1** if you want to see the help screen on comparing alternatives.
- Type the value **3** then press **F2** to reverse the comparison, indicating that the New system will be three times as flexible as the Existing system.

  Since our example is evaluating just two alternatives, you only need to make one comparison.

- Press **PgDn** to compute the Flexibility ratings (Exhibit 17).

  Because there is no room for any inconsistency in judgment when comparing only two items, the Inconsistency Ratio is a perfect score of 0.000.

- Press **Esc** to return to the Selection of Rating Criterion screen.

```
┌──────────────────────────────────────────────────────────────────────┐
│                 Rating Alternatives by Pairwise Comparisons            │
│                 Model:  TUTORIAL         Criterion:  Flexity           │
├──────────────────────────────────────────────────────────────────────┤
│                                                                        │
│                                                                        │
│            Existing   New                                              │
│   Existing            0.333                                            │
│   New                                                                  │
│                                                                        │
│            Existing   New                                              │
│   Ratings  0.250     0.750                                             │
│                                                                        │
│   Inconsistency Ratio  0.000     [Less than 0.100.  Comparisons OK ]   │
│                                                                        │
│                                                                        │
│                                                                        │
├──────────────────────────────────────────────────────────────────────┤
│              F1 for Help      ↵  to Redo      Esc to Exit              │
└──────────────────────────────────────────────────────────────────────┘
```

Exhibit 17.   Rating Alternatives: Computed Ratings for Pairwise Comparisons.

You must enter performance data or make pairwise comparisons for each of the criteria listed on this screen or the computed overall ratings will be incomplete and inaccurate. To complete the rating process for the remaining criteria enter the rest of the pairwise comparison data following the procedure illustrated for Flexity. Highlight the criterion, press ↵ to select it, and enter the following data for each criterion in turn:

CycleTim	Schedule	Thruput	Yield	Quality	Risk
2 then F2	.75	3 then F2	2 then F2	2 then F2	2

Exhibit 18 shows the screen after all the ratings have been completed.

o   Press **Esc** to return to the AutoMan Menu.

```
┌─────────────────────────────────────────────────────────────────────┐
│                   Selection of Rating Criterion                     │
│                       Model:  TUTORIAL                              │
├─────────────────────────────────────────────────────────────────────┤
│                                    CURRENT RATINGS                  │
│      CRITERION    Existing New                                      │
│    ┌────────────────────────────────────────────────────────────┐  │
│    │ InitCost    0.750    0.250                                  │  │
│    │ Revenue     0.429    0.571                                  │  │
│    │ CycleTim    0.333    0.667                                  │  │
│    │ Schedule    0.429    0.571                                  │  │
│    │ Thruput     0.250    0.750                                  │  │
│    │ Yield       0.333    0.667                                  │  │
│    │ Flexity     0.250    0.750                                  │  │
│    │ Quality     0.333    0.667                                  │  │
│    │ Risk        0.667    0.333                                  │  │
│    │                                                            │  │
│    │                                                            │  │
│    │                                                            │  │
│    └────────────────────────────────────────────────────────────┘  │
├─────────────────────────────────────────────────────────────────────┤
│    Use ↓ ↑ to highlight Criterion and press:                        │
│       ◄┘ for Pairwise Comparisons    D  for Performance Data  F1 for Help │
│       Ctrl-End to View Shares        Ctrl-Home to View Ratings  Esc to Exit │
└─────────────────────────────────────────────────────────────────────┘
```

Exhibit 18.   Rating Alternatives: List of All Ratings.

3.4 Compute Overall Ratings

After the criteria have been weighted and the alternatives have been rated against all of the evaluation criteria, the Overall Ratings may be computed by AutoMan.

To compute the Overall Ratings:
o   Press **C** at the AutoMan Menu.

To produce the Overall Rating for each alternative, AutoMan combines the weights derived from comparing the criteria with the ratings of the alternative with respect to each criterion. The Overall Rating equals the sum of the products of the criteria shares times the criteria ratings. The results appear in a bar chart as shown in Exhibit 19. The alternatives are ranked in the order of their overall ratings. For each . alternative, the overall rating is displayed beside a horizontal bar proportional to the rating. Press **F1** to see the help screen explaining how the overall ratings are computed and describing the two types of printed reports available.

The Short Report includes:
   Table 1.   Ranking of Alternatives by Overall Rating
   Table 2.   Model Structure, Weights, Shares, and Inconsistency Ratios
   Table 3.   Ratings by Criterion and Overall Ratings of Alternatives

The Long Report includes all tables of the Short Report plus:
   Table 4.   Pairwise Comparison Data for Weighting Categories and Criteria
               and for Rating Alternatives
   Table 5.   Performance Data for Rating Alternatives

```
              Computation of Overall Ratings
                      Model:   TUTORIAL
  ────────────────────────────────────────────────────────────────

  RANK   ALTERNATIVE   RATING

  ⇒1     New           0.521   ▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓

   2     Existing      0.480   ▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓▓




  ────────────────────────────────────────────────────────────────
  F1 for Help    S to print Short Report    L to print Long Report    Esc to Exit
```

Exhibit 19.   Overall Ratings of the Alternatives.

The Long Report for the completed TUTORIAL model is shown in Exhibit 20.

- Press **Esc** to return to the AutoMan Menu.

If you did not enter a complete set of data during the Tutorial, you may choose Select or Build a Model from the AutoMan Menu to return to the list of models and then select the model called EXAMPLE, which contains a complete data set for the Tutorial.

This concludes the Tutorial.   If you want more practice with AutoMan, try using the F5 option under Select or Build a Model to add alternatives to your TUTORIAL model and then redo the ratings following the illustrations in Section 3.3.   You could also select either the SMALL or LARGE models and enter both weighting and rating data into them.   Finally, you could press the F4 key to build a new model of your own using the Glossary of Evaluation Criteria.

When you are finished practicing with AutoMan, press **Q** at the AutoMan Menu to quit and safely close the files containing your models.

Exhibit 20. Long Report for the TUTORIAL Model.

Model: TUTORIAL--Practice Model   08/02/89   Pg 1

Table 1. Ranking of Alternatives by Overall Rating

RANK ALTERNATIVE RATING

=>1   New   0.521 ||||||||||||||||||||||||||||||||||||||||||||||||||||||||

  2   Existing   0.480 |||||||||||||||||||||||||||||||||||||||||||||||||||||

Exhibit 20. Long Report for the TUTORIAL Model, cont.

```
Model:  TUTORIAL--Practice Model                      08/02/89   Pg  2

    Table 2.  Model Structure, Weights, Shares, and Inconsistency Ratios
                                                              RATING
CATEGORY                 | CRITERION    WEIGHT     SHARE   INCONSISTENCY
--------------------------------------------------------------------------
MONETARY                 | InitCost     0.750     0.197      0.000
                         | Revenue      0.250     0.066      0.000
Weight = 0.263           |
Inconsistency = 0.000    |
                         |
                         |

PERFMEAS                 ¯ CycleTim     0.274     0.044      0.000
                         | Schedule     0.448     0.071      0.000
Weight = 0.159           | Thruput      0.208     0.033      0.000
Inconsistency = 0.036    | Yield        0.070     0.011      0.000
                         |
                         |

STRATEGC                 ¯ Flexity      0.375     0.217      0.000
                         | Quality      0.250     0.145      0.000
Weight = 0.578           | Risk         0.375     0.217      0.000
Inconsistency = 0.000    |
                         |
                         |
                         ¯

   [Inconsistency of pairwise comparisons between categories = 0.008]
--------------------------------------------------------------------------
   *Pairwise comparisons with inconsistency values > 0.1 should be redone.
```

Exhibit 20. Long Report for the TUTORIAL Model, cont.

Model: TUTORIAL--Practice Model   08/02/89   Pg 3

   Table 3. Ratings by Criterion and Overall Ratings of Alternatives

CATEGORY: RATINGS
   CRITERION Existing New

1: InitCost 0.750   0.250
1: Revenue   0.429   0.571
2: CycleTim 0.333   0.667
2: Schedule 0.429   0.571
2: Thruput   0.250   0.750
2: Yield   0.333   0.667
3: Flexity   0.250   0.750
3: Quality   0.333   0.667
3: Risk   0.667   0.333

   OVERALL
   RATING   0.480   0.521

Exhibit 20. Long Report for the TUTORIAL Model, cont.

Table 4. Pairwise Comparison Data for Weighting Categories and Criteria
          and for Rating Alternatives

Comparisons between Categories

	Monetary	PerfMeas	Strategc
Monetary		1.500	0.500
PerfMeas			0.250
Strategc			

Comparisons between Criteria within Category: Monetary

	InitCost	Revenue
InitCost		3.000
Revenue		

Comparisons between Criteria within Category: PerfMeas

	CycleTim	Schedule	Thruput	Yield
CycleTim		0.500	2.000	3.000
Schedule			2.000	6.000
Thruput				4.000
Yield				

Comparisons between Criteria within Category: Strategc

	Flexity	Quality	Risk
Flexity		1.500	1.000
Quality			0.667
Risk			

Comparisons between Alternatives rated by Criterion: InitCost

[See Table 5 for Performance Data]

Comparisons between Alternatives rated by Criterion: Revenue

[See Table 5 for Performance Data]

Comparisons between Alternatives rated by Criterion: CycleTim

	Existing	New
Existing		0.500
New		

Comparisons between Alternatives rated by Criterion: Schedule

	Existing	New
Existing		0.750
New		

Comparisons between Alternatives rated by Criterion: Thruput

	Existing	New
Existing		0.333
New		

Exhibit 20. Long Report for the TUTORIAL Model, cont.

Model: TUTORIAL--Practice Model   08/02/89   Pg 5

    Table 4. Pairwise Comparison Data for Weighting Categories and Criteria
           and for Rating Alternatives

        Comparisons between Alternatives rated by Criterion: Yield
        Existing New
Existing   0.500
New

        Comparisons between Alternatives rated by Criterion: Flexity
        Existing New
Existing   0.333
New

        Comparisons between Alternatives rated by Criterion: Quality
        Existing New
Existing   0.500
New

        Comparisons between Alternatives rated by Criterion: Risk
        Existing New
Existing   2.000
New

Exhibit 20. Long Report for the TUTORIAL Model, cont.

Model: TUTORIAL--Practice Model   08/02/89   Pg 6

Table 5. Performance Data for Rating Alternatives

| CRITERIA | ALTERNATIVES | | IS HIGHER |
	Existing	New	BETTER?
InitCost	200	600	No
Revenue	900	1200	Yes
CycleTim	[See Table 4 for Pairwise Comparison Data]		
Schedule	[See Table 4 for Pairwise Comparison Data]		
Thruput	[See Table 4 for Pairwise Comparison Data]		
Yield	[See Table 4 for Pairwise Comparison Data]		
Flexity	[See Table 4 for Pairwise Comparison Data]		
Quality	[See Table 4 for Pairwise Comparison Data]		
Risk	[See Table 4 for Pairwise Comparison Data]		

GLOSSARY OF EVALUATION CRITERIA

This glossary defines criteria for evaluating automated manufacturing investments that are used in the sample models of AutoMan. Other criteria may be relevant to manufacturing investment decisions, since such investments may have many diverse impacts. The particular mix of impacts pertinent to each organization, however, depends upon the intensity of automation and the organization's priorities. The intensity of automation affects the magnitude of an impact and whether the impact is significant enough to be included in the analysis. For example, at relatively low levels of automation, improved flexibility may not be possible because the rest of the factory will retain its specialized, dedicated equipment. In this environment, flexibility is unaffected and, therefore, not needed as a criterion.

An organization's priorities also determine whether an impact is important enough to warrant inclusion. Priorities vary by industry and competitive strategies. Even a large impact may not be relevant to an organization or a particular decision. For example, machine utilization may significantly decrease with increased automation, but management may not wish to include this impact as a distinct evaluation criterion. Increased machine utilization may not be a desirable goal because it may lead to excess inventory; its effects may best be included as part of an inventory criterion.

The particular categories (groups of criteria) and criteria used in AutoMan's sample models are defined for illustrative purposes. The full name of each is given, followed by its abbreviated form to fit the eight character limit for labels in AutoMan. Categories are **bold-faced** and criteria are underlined. Some criteria, such as quality and risk, are often important to investment decisions, yet they involve complex issues that have not yet been resolved. The interpretation of such criteria may vary among organizations.

Refer to this glossary for criteria to consider when building a new model and revise and add to the definitions to meet the needs of your organization. In this way, a custom-made glossary can be developed to promote consistency in meaning among multiple users within the same organization.

Monetary Category (Monetary)

Evaluation criteria that can either be directly measured in dollars or derived from dollar-denominated data (e.g., financial ratios). Includes traditional measures of financial worth, all of which are derived from essentially the same data. Be aware of possible double counting if several of these measures are included in a model. This category may be further subdivided into a **Benefits Category (Benefit)**, composed of criteria for which higher values are better, and a **Costs Category (Cost)**, composed of criteria for which lower values are better.

Initial Cost (InitCost): The sum of design, purchase, installation, financing, and transition costs necessary to make new automated manufacturing equipment ready for use. For existing equipment, any immediate repair or replacement costs necessary to keep it in operation.

Internal Rate of Return (IRR): The compound rate of interest that equates the stream of dollar benefits or savings to dollar costs over some defined study period. When the return is measured solely on the original investment (which implicitly suggests the same

return on reinvestments as on the original investment), this measure is known as the unadjusted internal rate of return. When a combined return on the original investment and reinvested earnings is measured, it is known as the adjusted internal rate of return (American Society for Testing and Materials, 1987, pp. 1114, 1119).

Inventory Cost (Inventry): The sum of (1) the cost of ordering purchased parts for raw materials inventory, or the cost of machine setup for finished goods inventory, plus (2) inventory carrying costs. If there is a stockout problem, other factors to be considered are stockout cost per unit, demand during lead time, and the economic ordering quantity (Jordan, 1987, pp. 185-190). With automated manufacturing, combined operations, together with reductions in non-productive times, may reduce work-in-process inventory levels. Finished goods inventories may also be reduced as a result of smaller lot sizes and shorter cycle times.

Revenue (Revenue): Total dollar sales volume per time period.

Rework Losses (Rework): The cost of correcting defective work. Rework losses are also the cost of work performed to correct service-revealed difficulties when the work is performed before the part is delivered to the customer (Jordan, 1987, p. 130).

Scrap Losses (Scrap): The cost of any component which, due to defective work on the part of the machine operator, damage in handling, or other causes, makes the part unfit for use in the end product. Included also is the cost of parts that are made to predetermined specifications but that are scrapped due to service-revealed problems that cannot be corrected through rework (Jordan, 1987, p. 130).

Performance Measures Category (PerfMeas)

Evaluation criteria that can be measured, but not easily converted to dollars. Includes non-monetary measures of business and plant effectiveness in relation to the goals and objectives developed in the strategic planning process (Computer Aided Manufacturing-International, Inc., 1988, p. 159).

Cycle Time (CycleTim): The time between arrival at the factory of material for a product and shipping of the product (CAM-I, 1988, p. 239). Cycle time is dependent upon: (1) the number of machines through which a part is routed, (2) machine setup time, (3) batch size, (4) operation time (machine time, and workpart and tool handling times), and (5) non-operation time (transportation, delays, and inspections) (Salomon and Biegel, 1984, p. 89). Increased automation may affect all five of these components of cycle time.

Schedule Attainment (Schedule): The percentage of acceptable output to total scheduled output at the scheduled due date. Automation may improve schedule attainment by increasing the level of operational control and by allowing more accurate production forecasts derived from an integrated data base.

Setup Time (Setup): The time required to prepare a machine or work center for a manufacturing process (CAM-I, 1988, p. 244). Automation permits shorter setup times because any process that has been set up once, can be set up quickly again by reprogramming, compared with the retooling required in traditional manufacturing (Rhea, 1984, p. 50).

Throughput (Thruput): The amount of raw material processed within a given time period (Random House, Inc., 1973, p. 1370). Since automation is designed to improve material flow, it is likely to improve throughput of individual processes. When measuring the impact of automation on product throughput, however, total factory throughput is most important. An improvement in the modified area is offset somewhat by bottlenecks in others.

Yield (Yield): Actual output, expressed as the percentage of what is theoretically possible.

Strategic Category (Strategc)

Evaluation criteria that cannot easily be measured. Includes issues often associated with goals and objectives outlined in the long-term or strategic planning process.

Flexibility (Flexity): The ability to manufacture a wide variety of products with the same equipment. One type of flexibility permits changes of product mix within a product line and accommodates redesigns and engineering change notices. Another type of flexibility permits low-cost production of a large mix of low volume products across product lines. The latter is often called economies of scope (CAM-I, 1988, pp. 184-185). A traditional management goal is to lower unit costs by increasing volume to spread fixed costs. Automated manufacturing is reducing the importance of fixed cost, thus permitting greater product variety. Economies of scope enable a company to respond economically to the shorter product life cycles demanded by the marketplace.

Manufacturing Quality (Quality): The ability of a manufacturing process to produce acceptable output without defects being introduced during the production process. A goal of defect prevention is to build the product correctly the first time. Automated manufacturing improves manufacturing quality by using in-line, real-time, automated inspection, which flags potential problems before defective products emerge. The integrated database helps errors in the software that controls manufacturing to be detected and removed after the first run. Moreover, reduced direct labor content leads to fewer operator errors (CAM-I, 1988, pp. 82, 184).

Risk (Risk): The probability that an investment will result in an economic outcome different from what is desired or what is expected. This is properly called risk exposure. Risk attitude is the willingness of decision makers to undertake investments of uncertain outcome (Marshall, 1988, pp. ix-x). Risk attitude can be incorporated in the pairwise comparisons with the other criteria in the model. Three types of risk exposure criteria related to automated manufacturing investments follow (CAM-I, 1988, pp. 185-186).

Economic Risk (EconRisk): The probability that using a candidate technology will not achieve the projected economic benefits because of legislative trends, inflation rate changes, interest rate changes, competition from other companies, or time and resource constraints.

Technological Risk (TechRisk): The probability that a candidate technology will fail to achieve the desired manufacturing benefits. Higher risks are associated with leading edge applications. Technological risk factors include hardware failure, software failure, lack of vendor support, and communication facility failures.

Implementation Risk (ImplRisk): The probability that human resource factors will prevent successful implementation of the candidate technology. These factors include employee attitudes and skills, personnel education and training/retraining, employee reward system, organizational impact, and compatibility of the new technology with current operating procedures.

BIBLIOGRAPHY

A. Evaluation Methods for Automated Manufacturing Investments

Canada, John R., "Annotated Bibliography on Justification of Computer-Integrated Manufacturing Systems," The Engineering Economist, Vol. 31, No. 2, Winter 1986, pp. 137-150.

Canada, John R., and Sullivan, William G., Economic and Multiattribute Evaluation of Advanced Manufacturing Systems (Englewood Cliffs, NJ: Prentice Hall, 1989), 507 pp.

Choobineh, Fred, and Suri, Rajan (eds.), Flexible Manufacturing Systems: Current Issues and Models (Norcross, GA: Industrial Engineer and Management Press, 1986), 427 pp.

Frazelle, E., "Suggested Techniques Enable Multi-Criteria Evaluation of Material Handling Alternatives," Industrial Engineering, Vol. 17, No. 2, February 1985, pp. 42-48.

Goicoechea, Ambrose, Hansen, Don R., and Duckstein, Lucien, Multiobjective Decision Analysis with Engineering and Business Applications (New York, New York: John Wiley and Sons, 1982), 422 pp.

Gustavson, Richard E., "Choosing Manufacturing Systems Based on Unit Cost," Thirteenth ISIR/Robots 7 Conference, Chicago, IL, April 17-21, 1983, 19 pp.

Mecimore, Charles D., and Sullivan, William G., Cost Management Systems: A Digest of the Relevant Literature (Montvale, NJ: National Association of Accountants, and Arlington, TX: Computer Aided Manufacturing-International, Inc., 1987), 79 pp.

Meredith, Jack R. (ed.), Justifying New Manufacturing Technology (Norcross, Ga: Industrial Engineering and Management Press, 1986), 341 pp.

Meyer, Ronald J., "A Cookbook Approach to Robotics and Automation Justification," Robots VI Conference Proceedings, Detroit, Michigan, March 2-4, 1982, 29 pp.

Reeve, James M., and Sullivan, William G., "Strategic Evaluation of Interrelated Investment Projects in Manufacturing Companies," unpublished report to Computer Aided Manufacturing - International, Inc., February 1988, 55 pp.

Sullivan, William G., and Liu, Ming-Cheng, "Economic Analysis of a Proposed Industrial Robot," Industrial Engineering, Vol. 16, No. 10, October 1984, pp. 118-124.

Sullivan, William G., "Models IEs Can Use to Include Strategic, Non-Monetary Factors in Automation Decisions," Industrial Engineering, Vol. 18, No. 3, March 1986, pp. 42-50.

Wabalickis, Roger N., "Justification of FMS with the Analytic Hierarchy Process," Journal of Manufacturing Systems, Vol. 7, No. 3, 1988, pp. 175-182.

Zeleny, Milan, Multiple Criteria Decision Making (New York, NY: McGraw-Hill Inc., 1982), 497 pp.

B. The Analytic Hierarchy Process: Theory and Applications

Arbel, A., and Seidmann, A., "Performance Evaluation of Flexible Manufacturing Systems," IEEE Transactions on Systems, Man and Cybernetics, Vol. SMC-14, No. 4, July-August 1984, pp. 606-617.

Faddeeva, N. V., Computational Methods of Linear Algebra (New York, NY: Dover, 1959), 252 pp.

Gass, Saul I., "The Analytic Hierarchy Process," Chapter 24, Decision Making, Models, and Algorithms (New York, NY: John Wiley and Sons, 1985), pp. 355-397.

Harker, Patrick T., and Vargas, Luis G., "The Theory of Ratio Scale Estimation: Saaty's Analytic Hierarchy Process," Management Science, Vol. 33, No. 11, November 1987, pp. 1383-1403.

Harker, Patrick T., "The State of the Art in The Analytic Hierarchy Process," unpublished presentation at the TIMS/ORSA National Meeting (Washington D.C.: April 25, 1988).

Householder, Alston S., "Iterative Methods," Section 4.1, Principles of Numerical Analysis (New York, NY: McGraw-Hill, 1953), pp. 150-155.

Hwang, Ching-Lai, and Yoon, Kwangsun, Multiple Attribute Decision Making Methods and Applications: A State-of-the-Art Survey (New York, NY: Springer-Verlag, 1981), 259 pp.

Saaty, Thomas L., "A Scaling Method for Priorities in Hierarchical Structures," Journal of Mathematical Psychology, Vol. 15, No. 3, June 1977, pp. 234-281.

Saaty, Thomas L., "Axiomatic Foundation of the Analytic Hierarchy Process," Management Science, Vol. 32, No. 7, July 1986, pp. 841-855.

Saaty, Thomas L., "Exploring Optimization Through Hierarchies and Ratio Scales," Socio-Economic Planning Sciences, Vol. 20, No. 6, 1986, pp. 355-360.

Saaty, Thomas L., Multicriteria Decision Making: The Analytic Hierarchy Process (Pittsburgh, PA: University of Pittsburgh, 1988), 287 pp.

Saaty, Thomas L., The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation (New York: McGraw-Hill, 1980), 287 pp.

Varney, Mark S., Sullivan, William G., and Cochran, Jeffery K., "Justification of Flexible Manufacturing Systems with the Analytical Hierarchy Process," Annual International Industrial Engineering Conference Proceedings, 1985, pp.181-190.

Zahedi, Fatemeh, "The Analytic Hierarchy Process - A Survey of the Method and its Applications," Interfaces, Vol.16, No. 4, July-August 1986, pp. 96-108.

C. Criteria for Evaluating Automated Manufacturing Investments

American Society for Testing and Materials, "Standard Practice for Measuring Internal Rates of Return for Investments in Buildings and Building Systems," in 1987 Annual Book of ASTM Standards, Vol. 04.07 (Philadelphia, PA: ASTM, 1987), pp. 1114-1124.

Computer Aided Manufacturing-International, Inc., Cost Management for Today's Advanced Manufacturing: The CAM-I Conceptual Design, edited by Callie Berliner and James A. Brimson (Boston, MA: CAM-I, 1988), 253 pp.

Hutchinson, George K., "Flexibility is Key to Economic Feasibility of Automating Small Batch Manufacturing," Industrial Engineering, Vol. 16, No. 6, June 1984, pp. 77-86.

Jelinek, Mariann, and Goldhar, Joel D., "Economics in the Factory of the Future," CIM Review, Winter 1986, pp. 21-27.

Jordan, Raymond, Cost Accounting for Profit Improvement (American Management Association, 1987).

Marshall, Harold E., Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Building Investments, NIST Special Publication 757 (Washington, DC: U.S. Government Printing Office, 1988), 84 pp.

Muir, William T., "An Alternative for Evaluating CIM Investments - A Case Study," CIMCOM Conference, Washington, DC, March 13-15, 1984, 13 pp.

Potter, Ronald D., "Analyze Indirect Savings in Justifying Robots," Industrial Engineering, Vol. 15, No. 11, November 1983, pp.28-29, 94.

Random House, Inc., The Random House College Dictionary (New York, NY: Random House, Inc., 1973).

Rhea, Nolan W., "New Approaches to Justifying the Purchase of Robots," Material Handling Engineering, Vol. 39, No. 8, August 1984, pp. 47-50.

Rutledge, Arthur L., "Economies of Computer Integrated Manufacturing," International Industrial Engineering Conference Proceedings, Dallas, TX, May 11-14, 1986, pp. 247-253.

Salomon, Daniel P., and Biegel, John E., "Assessing Economic Attractiveness of FMS Applications in Small Batch Manufacturing," Industrial Engineering, Vol. 16, No. 6, June 1984, pp. 88-96.

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

This manual documents AutoMan, a microcomputer program designed to support multi-criteria decisions about automated manufacturing investments. The program permits users to combine quantitative and qualitative criteria in evaluating investment alternatives. Quantitative criteria could include such traditional financial measures as Life-Cycle Cost and Net Present Value as well as such engineering performance measures as throughput and setup time. Qualitative criteria could include flexibility and product quality. First, the user specifies the evaluation criteria and the investment alternatives to be evaluated. Second, the user makes pairwise comparisons between criteria to establish their weights. Third, the user rates each investment alternative with respect to the criteria. The pairwise comparison process helps the user rate the qualitative criteria, while measured performance data, such as cost, setup time, or throughput, can be entered for quantitative criteria. AutoMan combines ratings with criteria weights into an overall rating for each investment alternative and then ranks alternatives. AutoMan comes with sample decision models and a manual that includes a detailed tutorial, a glossary of evaluation criteria, a bibliography, and an index.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

analytic hierarchy process; automation; automated manufacturing; decision support software; economic evaluation; microcomputer software; multi-criteria decisions; performance measures; qualitative data.

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