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A COMPUTERIZED ROBOT SELECTION SYSTEM

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ABSTRACT

Attributes which should be considered when selecting a specific robot model are identified. Some of the attributes are specifications necessary to determine a set of feasible robots which are capable of performing a particular task. Other attributes pertain to the selection of a single robot model from the set of feasible robots. However, some attributes fall into both categories.

The robot selection model was implemented on an IBM PC using the R:BASE (a relational database management system by Microrim, Inc.) coupled with a BASIC program. The database consists of forty-nine robot models representing twenty vendors. The software consists of three phases. In the first phase, a feasible set of robot models is determined. The user is presented with a list of forty-five attributes and permitted to enter specifications for any or all attributes.

In the second phase, the user is presented with a list of twenty-nine attributes which are possible selection criteria. The user is then allowed to specify (up to a maximum of fifteen) attributes judged most important. The final phase of the software uses a BASIC program to interrogate the user regarding preferences and priorities with respect to the attributes being used as selection criteria. The information obtained from the interrogation is entered into the decision model and the most preferred robot model in the feasible set is determined.

A COMPUTERIZED ROBOT SELECTION SYSTEM

A. INTRODUCTION

The purpose of this paper is to describe an aid for using software which has been designed for the selection of the preferred robot model from a set of commercially available robots. This software was developed with funding from SHAME SP-10, who is responsible for its distribution.

The software includes an implementation of the relational database management system, R:BASE™, and the use of a BASIC program called JONES. Only the features of R:BASE™ which are necessary for this particular application are discussed. The hardware required is an IBM PC with 256 kilobytes of memory and 2 disk drives. Printer capability is optional. To use this software the user must have some basic knowledge of the operation of the hardware.

The robot model selection software is implemented in three phases. The first phase allows the user to define his requirements or specifications for any or all appropriate attributes. In the second phase, the user selects the set of attributes which will be used as decision criteria to determine the most preferred robot in the feasible set. The third phase uses the BASIC program JONES and interrogates the user regarding his preferences for the attributes being used as decision criteria. The program then presents the robots in the feasible set, ranked from most preferred to least preferred.

The complete software package consists of the following diskettes: R:BASE™ Diskette I, R:BASE™ Diskette II, Database, and JONES. Tables 1-3 give a descriptive analysis of the database.

To begin, place R:BASE™ Diskette I in Drive A and load the operating system from ths diskette. Place the Database diskette in Drive B. When the operating system has been loaded, then R:BASE™ is entered by typing RBASE and pressing [RETURN]. The screen should appear as shown in Screen 1 below.

```
**********************************************************************
*  Current date is Tue ~ 1-01-1980                                   *
*  Enter new date:  5-25-84                                          *
*  Current time is  0:00:23.17                                       *
*  Enter new time:  8:00                                             *
*                                                                    *
*                                                                    *
*  The IBM Personal Computer DOS                                     *
*  Version 2.10 (C) Copyright IBM Corp. 1981, 1982, 1983             *
*                                                                    *
*  A>rbase                                                           *
**********************************************************************
```

Screen 1

Then, press [RETURN]. Screen 2 should then appear.

Follow the instructions on Screen 2: remove the R:BASE™ Diskette I from Drive A and replace it with R:BASE™ Diskette II.

The first step in R:BASE™ is to open the database named ROBOTS, which is stored on the Database diskette in Drive B. The command is OPEN B:ROBOTS. B:ROBOTS. Then, hit [RETURN]. The screen should appear as shown in Screen 3.

```
**********************************************************
* Begin R:base 4000 Version 1.01 MSDOS Serial # ######   *
* For the IBM Personal Computer                          *
* Copyright 1983 by Microrim, Inc.                       *
*                                                        *
* For assistance type "HELP", for Prompt mode type "PKOMPT"
* R>open b:robots                                        *
*  Database exists                                       *
*R>                                                      *
**********************************************************
```

Screen 3

Table 1. Summary of Numeric Attribute Values in the Robot Database

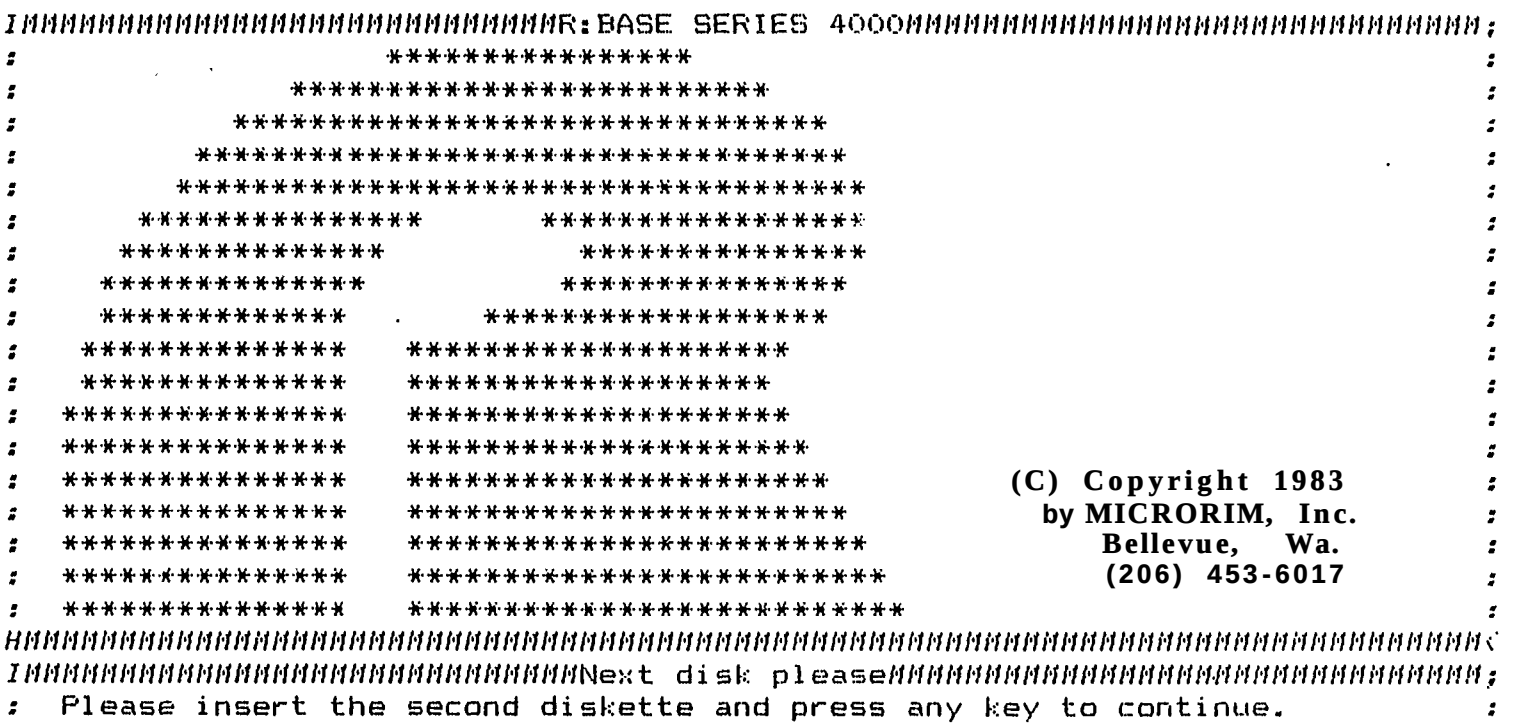
Attribute	Minimum	Average	Maximum
Resolution (in.)	0.0008	0.045	0 . 3 0 0
Accuracy (in.)	0.0004	0.037	0.400
Repeatability (in.)	0.0004	0.030	0.300
Wrist Roll (degrees)	180	330	900
Wrist Yaw (degrees)	90	221	370
Wrist Pitch (degrees)	90	197	270
Numoer of Axes	4	5	12
Maximum Reach (in.)	16	66	131
Maximum Velocity (in./sec.)	4	56	315
Load Capaciy (lbs.)	2	152	2000
Steps	99	2169	38000
Memory Size (kb)	1	44	256
Weight of Robot (lbs.)	35	2128	12000
Floor Space ($ft.^2$)	1	19	110
Min. Environ. Temp. (F°)	22	38	50
Flax. Environ. Temp. (F°)	104	116	140
Cost (initial)	$ 5500	$69936	$225000
Number Installed	10	403	2000
Delivery Time (days)	30	106	270
Length of Warranty (days)	90	347	365
Service Cost ($/day)	350	486	600

Table 2. Tally of Features Available on Robots in the Database.

	Available	Unavailable	Information Missing
Programmable Velocity	40	9	0
Synchronized with Surrounding Equipment	47	1	1
Diagnostic Software	42	6	1
Service Contract	39	10	0
Mass Storage System	38	10	1
Additional Memory	13	0	36

Table 3. Summary of Actuator Types on Robots in the Database.

Actuator Type	Number	Max. Load Capacity (lbs.)	Min. Cost	Max. Cost	Minimum Repeatability (in.)	Maximum Velocity (in./sec.)
Electric	19	150	$28,500	$140,000	0.0010	315
Hydraulic	19	2000	$28,000	$225,000	0.0050	79
Pneumatic	11	33	$ 5,500	$ 45,000	0.0004	24


R:BASE SERIES 4000
(C) Copyright 1983
by MICRORIM, Inc.
Bellevue, Wa.
(206) 453-6017
Next disk please
Please insert the second diskette and press any key to continue.

Screen 2

B. ROBOT MODEL SELECTION

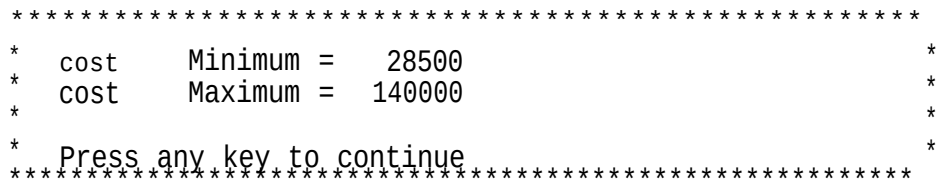
1. Determine the Feasible Set

To begin the selection process, type PROM␣FEAS, and then press [RETURN]. Then, Screen 4 should appear with the cursor making the appropriate space for the entry. As explained in Screen 4, the next screen to appear (Screen 5) will show a list of attributes and their two digit codes. To get the list of attributes and their code, enter CODE on Screen 4. Then, Screen 5 should appear. If a code number is preceded by an asterisk (*), then some data regarding what is available for that attribute in the current feasible set will be displayed prior to the user being required to enter his specification(s). If these attribute entries are text (string), then a tally of what possibilities are in the current feasible set is shown. Screen 6 is an example of what would be displayed if 28 (for actuator type) were entered on Screen 5.

```
**********************************************************
*     actuat                    Number of Occurrences    *
*                                                        *
*     electric a.c.                      2               *
*     electric d.c. servo               16               *
*     electric d.c. steppe               1               *
*     hydraulic                         19               *
*     pneumatic                         10               *
*                                                        *
* Press any key to continue                              *
**********************************************************
```

Screen 2

If the attribute entries are numeric values, then the minimum and/or maximum (depending on the specific attribute) attribute value for the current feasible set will be displayed. Screen 7 is an example of what would be displayed if 40 (for cost) was entered on Screen 5.



Screen 7

After the information regarding attribute values in the current feasible set have been displayed, the next screen will allow the user to input his specification for that attribute. For example, Screens 8 and 9 are the ones which would follow Screens 6 and 7, respectively. If the information displayed indicates to the user there are no models which will meet his requirement, he should press [Esc] and the [Q] (to quit) when the screen for entering values is presented. After the user specifies an attribute value, he is returned to the list of attributes and codes to continue the inputting of attribute specifications, one at a time.

The user does not have to specify attribute values for each attribute. Rather, he may specify values only for those judged important to him. he may also specify more than one value for those attributes which have several choices available. However, the specifications must be made one at a time. For example, assume the user wants a robot which is capable of performing welding and spray painting. He would enter code 10), enter WELD (see Table 4) on the screen that follows, and be returned to the list of attribute codes. Then he would enter code 10 again, enter SPR PNT (see Table 4) on the next screen and return to the list of codes. His current feasible set of robot models would contain only models which are capable of performing both tasks. The attributes which allow the user to enter more than

```
Push [ESC] when done with this data
IMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMPROMPTSMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM;
: You are now in the section that will allow you to specify certain features :
: or specificatios that a robot must have to be considered feasible for      :
: purchase.                                                                  :
:                                                                            :
: The next screen will show the attributes (and their respective codes) that :
: have been identified as possible selection criteria. You will be allowed to:
: enter specifications for any or all of the attributes. To be able to spe-  :
: cify an attribute value, type its code number where you see the cursor at  :
: the bottom of the list. If an attribute is marked with an * , you will be  :
: shown some information on what is available before you have to input       :
: your requirement. After you have input your requirement for an attribute,  :
: you will be returned to the list to select another. When you have speci-   :
: fied all the attributes you wish to, input 99 to move the program to the   :
: next section.                                                              :
:                                                                            :
: If you have questions, please refer to the User's Manual for a more        :
: thorough explanation.                                                      :
:                                                                            :
: When you are ready to review the list, type CODE:code                      :
:                                                                            :
: After CODE is typed correctly, press [Esc]; then [G].                      :
HMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM<
```

Screen 4

```
Push [ESC] when done with this data
I########################################PROMPTS#########################################;
:  10 Applications            *26 No. of axes            *42 Reputation          :
:  11 Sensors                 *27 Coordinate system      *43 Load Capacity       :
:  12 End effectors           *28 Actuator type          *44 Max. velocity       :
:  13 Power requirement       *29 Motion control         *45 Warranty length     :
:  14 Operating cost          *30 Control system         *46 Service cost        :
:  15 Memory technology       *31 Reach                  *47 Min. envir. temp.   :
:  16 Oper. control inputs    *32 Resolution             *48 Max. envir. temp.   :
:  17 Std. input devices      *33 Accuracy               *49 Programmable vel.   :
:  18 Operation language      *34 Repeatability          *50 Synchronization     :
:  19 Control language        *35 Roll                   *51 Diag. software      :
:  20 Manuals supplied        *36 Pitch                  *52 Mass stor. system   :
:  21 Training courses        *37 Yaw                    *53 Service contract    :
:  22 Number installed        *38 Memory size            *54 Additional memory   :
: *23 Floor space             *39 Steps                                          :
: *24 Weight of robot         *40 Cost                   99 GO TO NEXT SECTION   :
: *25 Training location       *41 Lead time                                      :
:                                                                                :
: To specify an attribute value, enter the number given beside it:               :
:                                                                                :
: When the number has been entered correctly, press [Esc]; then [G].             :
H################################################################################
```

Screen 5

```
Push [ESC] when done with this data
I=========================PROMPTS==========================;
:                                                          :
:                    ACTUATOR TYPE                         :
:                                                          :
:    Enter the type of actuator your robot must have from the :
:    possibilities shown on the previos screen.            :
:                                                          :
:    ACTUATOR TYPE:                                        :
:                                                          :
:    When the type of actuator required has been entered correctly, :
:    press [Esc]; then [G].                                :
H==========================================================<
```

Screen 8

```
Push [ESC] when done with this data
I=========================PROMPTS=========================;
:                                                        :
:                        COST                            :
:                                                        :
:  Enter your budget constaint or the maximum amount you are willing  :
:  to pay for the robot.                                 :
:                                                        :
:  COST LIMITATION:                                      :
:                                                        :
:  When the maximum amount you are willing to pay for a robot has  :
:  been entered correctly, press [Esc]; then [G].        :
H========================================================<
```

Screen 9

one specification are: end effectors, sensors, applications, memory technology, operator control inputs, standard input devices, manuals supplied, and training courses.

Table 4 shows the attributes for which the user must enter a choice from a set, but receives no information from the software as to what is available. It should be noted that the list of choices is from the complete database set of robot models, and it is possible that there are no models in the current feasible set which contain that value.

When all the user's specification have been entered, a code of 99 is input to move' the software to the next section. This section will allow the user to specify which attributes he wishes to use as decision criteria.

2. Specify the Decision Criteria

After the number 99 is enterd on Screen 7, Screen 10 will appear. After LIST has been entered on Screen 10, Screen 11 will appear. The user then specifies the attributes to be used as selection criteria by entering the attribute codes one at a time. Note that the codes on Screen 7 are different from the codes on Screen 11.

The user is again reminded to limit the number of attributes selected to fifteen or less. There is no method in R:BASE™ to limit the number selected, but if it is greater than fifteen there will be a problem reading the data later in JONES.

3. Determine the Most Preferred Model

The program JONES first reads the data (from the previous use of R:BASE™). It then checks to see if any model(s) dominate, i.e., if

Table 4. Attribute Values Available.

Code	Attributes	*Possible Choices
10	Applications	die cast, forg, inv cast, MTLU, parts trans, spr pnt, sm pts asm, finish, plas mold, weld, mach, elect asm, inspec, pallet, other.
11	Sensors	tracking sensors, part detection, force feedback sensors, vision, priximity.
12	End effectors	welding torch, pickup gripper, custom, magnetic vacuum, gun mounts, hydraulic toggle, internal gripper.
15	Memory technology	cassette, cartridge, disc, wire memory, PROM, RAM EPROM, bubble, ROM, core.
16	Operator control inputs	teach pendant, CRT, editing terminal, CAD link PC programming.
17	Standard input devices	con closure, switch, floppy, key, tape, CAD, teletype, cassettes, pendant.
18	Operation language	modified NC, PASCAL, assembler, custom.
19	Control language	modified NC, assembler, machine, PASCAL, custom.
20	Manuals supplied	operations, maintenance, installation, programming, parts, elect draw.
12	Training courses	operations, maintenance, programming, application development.

```
Push [ESC] when done with this data
I=========================PROMPTS=========================;
: From the previous screens you have created a feasible set of robots :
: from the database of commercially available robots. The next step is :
: to determine which model from the feasible set is best suited for    :
: your present situation. Given on the next screen is the list of     :
: attributes which may be used as decision criteria. You are to choose :
: the ones you wish to use. It is suggested that you try to limit     :
: the number of attributes chosen to between 8 and 15.                :
:                                                                     :
: You will be asked to select the attributes one at a time. RBASE will :
: return you to the list after each selection. Then you will select the :
: next attribute. When you have selected all the attributes you wish to :
: use enter 100 and the program will advance to the next stage.       :
:                                                                     :
: To begin this stage input LIST:                                     :
:                                                                     :
: When you have entered LIST correctly, press [Esc]; then [G].        :
H=====================================================================<
```

Screen 10

```
Push [ESC] when done with this data
I=========================PROMPTS=========================;
: 70 Operating cost        80 Number installed     90 Max. envir. temp.      :
: 71 Weight                81 Number of axes       91 Max. velocity          :
: 72 Floor space           82 Reach                92 Reputation             :
: 73 Resolution            83 Roll                 93 Programmable velocity  :
: 74 Accuracy              84 Pitch                94 Synchronization        :
: 75 Repeatability         85 Yaw                  95 Diagnostic software    :
: 76 Cost                  86 Memory size          96 Mass storage system    :
: 77 Lead time             87 Steps                97 Service contract       :
: 78 Service cost          88 Load capacity        98 Additional memory      :
: 79 Min. envir. temp.     89 Warranty length   100 GO TO THE NEXT SECTION   :
:                                                                            :
: To specify an attribute as a selection criterion, enter the number given   :
: beside it. (Please note the attribute codes are different from the ones    :
: given on the previous list):100                                            :
:                                                                            :
: When the number has been entered correctly, press [Esc]; then [G].         :
=============================================================================<
```

Screen 11

any model(s) has the best possible value for all attributes. If it finds such a model(s) the user is informed and execution terminates.

If no robot models dominate, then the user must define the functions ($v_j(x_{ij})$) which best describe his preferences for each attribute. See Screen 12. Some possible functions, their descriptions, and implications are provided in the User's Manual. If the user finds a curve that describes his preference for the particular attribute, then he enters the number (1-14) of the curve. If no curve adequately describes his preference for the attribute, a preference value function can be defined by the user. Examples are shown in Screen 13. In Screen 13, note that the program has read the attribute codes and knows whether a lower value for the attribute or a higher value for the attribute is more preferred.

```
**************************************************************************
*                                                                        *
* You will now be asked to pick a value function                         *
* curve for each attribute                                               *
* Please study the curves and their descriptions in the User's Manual    *
*                                                                        *
*                                                                        *
*                                                                        *
* For the attribute repeatability                                        *
* Do you want to use one of the standard curves or define your own?      *
* Enter the number of the curve which best describes your value          *
* function, or enter 0 to define your own curve? 2                       *
*                                                                        *
*                                                                        *
*                                                                        *
* For the attribute cost                                                 *
* Do you want to use one of the standard curves or define your own?      *
* Enter the number of the curve which best describes your value          *
* function, or enter 0 to define your own curve? 0                       *
*                                                                        *
**************************************************************************
```

Screen 12

```
**************************************************************
* The attribute is cost                                      *
* If the minimum value is  28500                             *
* and is assigned a value of 1                               *
* and if the maximum value is 75000                          *
* and is assigned a value of 0                               *
* What value would have a scale value of .25? 40000          *
* What value would have a scale value of .5? 55000           *
* What value would have a scale value of .75? 67000          *
**************************************************************
```

Screen 13

It should be noted that for the attribute, reputation, the following arbitrary preference values have been assigned: excellent = 1, good = .67, fair = .33, poor=0, and untested = 0. For the other discrete attributes, the preference value for a specific model is 1 if the attribute is available on a particular robot model, and 0 if the attribute is not available or the information was not given by the robot vendor.

After preference value functions have been defined for each of the numeric (continuous) attributes, the user is asked to select a decison model. See Screen 14. Model 1 will require the user to first rank the n continuous attributes from 1 to n. See Screen 15. If the rank entered is not a value between 1 and n, or another attribute has already been assigned that rank, the user will receive an error message.

The next section of Decision Model 1 interrogates the user regarding trade-offs of attribute values. An example is shown in Screen lb. In this example, number of axes has been ranked higher than repeatability. The user is given a hypothetical robot model with the best value for repeatability (the lowest value) and the worst value for the number of axes (the lowest value). This robot model is to be compared

against another model with the worst value for repeatability (the highest value). The user must decide how many axes the second robot model would need in order for him to be indifferent between the two robot models. The process begins with the best value of the second-ranked attribute being traded off to gain a better value for the first-ranked attribute. It continues with this pairwise trade-off interrogation, until the nth-ranked attribute is traded off for an improvement in the (n-l)th-ranked attribute. The value entered must be between the minimum and maximum values for the attribute in question. If it is not, the user will receive an error message, the appropriate range will be displayed, and the user will be requested to re-enter the value.

After this pairwise comparison for the numeric attributes, Decision Model 1 then addresses the discrete attributes. Screen 17 presents an example. The user is informed that a model with the best

```
************************************************************
* You must now consider the attribute dia. software        *
*                                                          *
* A model with the best value for all attributes           *
* is given a rating of 100.                                *
* A model with the worst value for all attributes is       *
* given a rating of 0.                                     *
*                                                          *
* What would be the rating of a model with the best        *
* value for all attributes except dia.' software           *
* but with dia. software not available on that model       *
*                                                          *
* Enter the rating for the model with dia. software missing *
* ??                                                       *
************************************************************
```

Screen 17

value for all attributes is given a rating of 100. A model with the worst value for all attributes is given a rating of 0. The user must decide what rating a robot model should be given which has the best

IF you feel Comfortable with your knowledge of robots and their associated attributes, you will be allowed to define the sealing constants through a decision model (Model 1) which will interrogate you regarding trade-offs of attribute values.

If your knowledge of robots is limited, or this is the first time you have selected a robot, a simpler model (Model 2) is available.

A description of each model is given in the User's Manual
Please enter the model you prefer ?

Screen 14

By this method of determining scaling constants you will be asked to 1) rank the attributes in order of least important to most important 2) given a fixed value of an attribute,input how much **you wou1d** be **willing** to give up in order to have more of another attribute

There are 3 attributes to rank. When an attribute name is given please input a value between 1 and 3 each rank should be different.

Enter the rank for no. of axes
Rank?

Screen 15

Given a robot model with a value of 28500 for cost
and a value of .06 for repeatability

If another model had a value of 75000 for cost
What approximate value would repeatability have to be for you to be
indifferent between the two models if all other attributes
were the same for both models

Enter the value here?

Screen 16

value for all attributes, except the attribute in question is not available. This is repeated for each discrete attribute which was chosen by the user as a selection criterion.

The final step in Decision Model 1 requires the user to enter the rating of importance of a robot model with the numeric attributes at their best, and the discrete attributes at their worst, i.e., when none of the discrete attributes are available. See Screen 18.

Decision Mode1 2 only requires that the user rate each attribute (numeric and discrete) on a scale of 1 to 10. A rating of 1 indicates the attribute is unimportant, and a rating of 10 indicates the attribute is very important. The ratings do not have to be unique. Screen 19 shows an example of the interrogation for Decision Model 2.

After the program JONES has interrogated the user to obtain the information necessary for the decision model being implemented, the results are displayed. Screen 20 shows the results for an example with a feasible set of 7 robot models being considered. The format of the results is a rank for each robot (according to most preferred to least preferred), the model name, the vendor name, and the preference value $(V_i(X),)$. The user is then given an option to re-run the program with different preference value functions and scaling constants to determine how sensitive the preference value is to these variations. That is, does a slightly different preference value curve result in a different robot model being the most preferred? When the user has run the program enough to feel satisfied with the preference value results to make a final selection, then he should enter NO as the last entry. After the screen returns an OK, the user may return to the command system (operating system) by simply typing SYSTEM.

What ratlng on a scale of 1 - l00) would a robot model have if none of the following attributes (features) were available, but all the other attributes were at their best.

die. software
service cont.

Enter the rating?

Screen 18

P, this method of determlning scaling constants you will only be asked to rate the importance of each attribute on a scale of 1 to 10 where 1 is unimportant and 10 is very important.

For the attribute repeatabılity what rating (1-10) .
would you gıve it? 6

For the attribute cost what rating (1-10)
would you give it? 3

For the attribute load capacity what rating (1_10)
would YOU give it?

Screen 19

Rank	Model	Vendor	Preference Value
1	RR650	Reis Machines Inc.	.9531402
2	RR625	Reis Machines	.8282857
3	IRb 6/2	ASEA	.7564738
4	GMF A-1	GMF	.7452723
5	P-5	General Electric	.7236279
6	Maker 100	United States Robots	.6840468
7	GMF M1-A	GMF	.5900141
8	7535	IBM	.550063
9	Apprentice	Unimation	5.468621E-02

This concludes the program. Do you wish to run it with other value functions and scaling constants as a sensitivity check? Enter 'yes' to re-run; 'no' to terminate?

Screen 20