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Use of Financial Planning Languages for the Optimization of Generated Networks for Equipment Replacement

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USE OF FINANCIAL PLANNING LANGUAGES FOR THE OPTIMIZATION OF GENERATED NETWORKS FOR EQUIPMENT REPLACEMENT

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USE OF FINANCIAL PLANNING LANGUAGES FOR THE OPTIMIZATION
OF GENERATED NETWORKS FOR EQUIPMENT REPLACEMENT

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ABSTRACT

We discuss the use of a financial planning modeling language for scientific programming. The electronic tablet data organization, commands, functions, input/output methods, and other factors built into systems for financial planning purposes turn out to be uniquely useful for scientific applications. Because of these factors, it is possible to design, develop and implement models in a financial planning language much faster than in traditional scientific programming languages such as FORTRAN, BASIC, PASCAL, etc.

When it is possible to organize a problem where a financial planning system is suitable, answers can be obtained orders of magnitude faster than with say, FORTRAN or BASIC even though the execution time may be significantly longer. The design and implementation processes are expedited with financial planning languages. If only a few scenarios of a model are to be tested, they can be done with the financial planning language model. Once the model is running, a faster, scientific programming implementation can be developed if justified by the cost.

Using the IFPS (Interactive Financial Planning System) modeling language, we implemented an integrated Decision Support System for equipment replacement. The optimization subsystem is a special structure version of the Dijkstra shortest path labeling algorithm in IFPS. In order to develop an integrated Decision Support System, the optimization is performed in IFPS. The models are generated from a kernel (or base case) network in IFPS as well.
Using the "What If" capability of IFPS, different scenarios can be generated and solved. A specific example is given to illustrate the method.
1. Introduction

Over the past 35 years steady progress has been made in developing equipment replacement methods. As pointed out by Dean [7], equipment is normally replaced for two reasons. First, degradation or deterioration occurs or obsolescence takes place and the equipment is subject to replacement because newer equipment offers improved, faster, or cheaper return on planned investment. Second, complete or partial failure may occur in the original unit or units which in turn forces the decision of immediate replacement or repair of single or group units.

In this paper we are concerned with the first type of planned replacement. The problem involves 1) determining the optimum point in time or cumulative usage to replace all or part of the existing units and 2) choosing the best of the available equipment to be purchased for replacement or to cope with a forecasted future demand.

Consider the equipment replacement problem faced by a production shop which must keep a machine or facility operating over a finite time horizon. As the machine ages, its costs of operation and maintenance increase, while its salvage value decreases. At some point in time, it may be replaced by a new machine. The process repeats for this new machine. As a result, a chain of replacement decisions are made [20], [21], [22], [23], [26].

The problem then is to determine the optimal time to replace the machines in sequence. The replacement decisions are based on machine prices, maintenance and operation costs, and salvage functions as well as forecasted new technologies ([2], [6]). It is perhaps useful to classify the methods into

Equipment replacement approaches are reviewed briefly in [1]. For a comprehensive review of the literature see the survey articles by Pierskalla and Voelker [20] and Rapp [21].

In this paper, we discuss the use of financial planning modeling languages for scientific purposes. We illustrate our techniques with models written in IFPS (Interactive Financial Planning System) [10], [13]. We discuss the optimization, finding of a longest path, of the network equipment replacement model, for which the generation of its arc values is presented in a companion paper. We propose that electronic tablet and other advanced financial planning modeling languages should be modified, or even specifically designed for scientific programming purposes. This may be the next step in designing compilers capable of understanding English or natural language statements.

In Section 2, we present a brief summary of the network equipment replacement model discussed in [1]. We discuss the applicability of financial planning models to scientific programming in Section 3. In Section 4, we discuss an IFPS model for optimizing the equipment replacement model of Section 2. In Section 5, we present an example to illustrate the model. Finally, we offer a summary and conclusions in Section 6.

2. The Model

The capital budgeting formulation of the equipment replacement problem can be stated as a network problem [19], [29]. For instance consider the example shown in Figure 1 for a company planning its equipment replacement over a 5 year planning horizon. Let
\[ V_{ij} = \text{Net present value of the benefit of a machine purchased at the start of period } i \text{ and sold at the beginning of period } j. \]

In order to transform this problem into a shortest route network, let 
\[ d_{ij} = -V_{ij} \] and refer to the directed network of Figure 1. Nodes 1 and 6 represent the start and end of the planning period and each intermediate node \( j = 2, 3, 4, 5 \) represents the beginning of year \( j \) or the end of year \( j-1 \). From inspection of Figure 1, from every node \( i \) there is a directed arc to all nodes \( j \) only if \( j > i \).

The determination of the shortest path from node 1 to 6 determines the period or periods when equipment replacement takes place.

The arc values, \( V_{ij} \), of the network can be generated from a kernel (or base case) network as required, rather than inputted and stored explicitly. See Figure 2. If the price of the machine in period \( t > 1 \) is defined in terms of the period 1 price, then an open-ended network can be generated in the sense that a \( T + 1, T + 2, \ldots \) period network can be generated by functions identical to those used in generating a \( T \) period problem. This technique, an IFPS model for network generation, and a special structure algorithm are described in a companion paper [1].

Because of the special structure of the network model, we developed the following labeling algorithm [1] based on [8] which eliminates the expensive scanning operations and network data structures required by other methods. The variable \( \text{Label}(k) \) is the value of the longest path from node 1 to node \( k \); \( \text{Pred}(k) \) is the predecessor of \( k \), or previous node, along the longest path.
Special Structure Longest Path Algorithm:

1. Initialization
   Set $\text{Label}(1) = 0$
   $\text{Pred}(1) = 0$
   Compute $\text{CF}_{ij}$ for $j=2,\ldots,T$
   $\text{V}_{ij}$ for $j=2,\ldots,T+1$
   Set $\text{Label}(j) = \text{V}_{ij}$ for $2,\ldots,T+1$
   $\text{Pred}(j) = 1$ for $j = 2,\ldots,T+1$

2. For $i = 2$ to $T$
   For $j = i+1$ to $T+1$
     Find $\text{CF}_{ij}$ by (3) in terms of $\text{CF}_{(j-i+1)}$.
     Find $\text{V}_{ij}$ by (2).
     Set $\text{Pred}(j) = 1$, if $\text{Label}(i) + \text{V}_{ij} > \text{Label}(j)$
     Set $\text{Label}(j) = \text{Maximum}\{\text{Label}(j), \text{Label}(i) + \text{V}_{ij}\}$

The algorithm permanently labels the nodes starting from node 1 through $T+1$ in numerical sequence. Because the permanently labeled set is predictably augmented, only the label and predecessor node functions need be stored. The algorithm requires $T$ iterations. The solution time is on the order of $T^2$. In IFPS, we use the GENERATE statement to generate the actual statements which define the model from the kernel.

3. Relationship Between Financial Planning Model Languages and Scientific Programming

Over the past decade, software systems have emerged under the general name of financial planning systems [4], [10], [15], [18]. For example, see [3], [13] and [24]. Such languages have remained in the domain of financial planning applications. Their inherent characteristics make them useful for scientific programming problems as well, as indicated below.
3.1 System Design of Electronic Tablet Type Financial Planning Modeling Languages.

Important features of electronic tablet type financial planning modeling languages are:

1. Electronic Tablet Organization.
2. Command Driven.
3. Command Files.
5. What If Capability.

The data of financial planning models are typically organized in an electronic tablet format. Usually, the rows represent variables; the columns represent time. By manipulating variable expressions, the entries in the tablet change value. The languages are command driven in that specific commands are necessary to enter, modify, store and solve the models. These commands, as well as model statements tend to be machine independent at a much higher level than is traditionally attributed to so-called standard compilers and systems. Commands can be stored in files so that models which use the same sequence of commands can be solved without reentering the commands each time. These languages use data files, sometimes from data bases, for storing and retrieving information. Data files can be used also for compositing tablets from segments of other tablets, and as a means for models to communicate with each other and with external executable codes. Such capabilities were useful in developing an IFPS implementation of INTERAX [11], an interactive world economy simulation.

The "What if" capability allows for testing variations of a model for scenario evaluation. These can be run interactively, without the formal
mechanism of recompiling and executing a program. The last capability, report writing, is important so that model results can be printed in a meaningful format for a manager.

IFPS has all of the characteristics described above. In addition, an important feature which makes IFPS useful for the companion study [1] is the ability to generate model lines automatically by using a model statement. This also makes IFPS useful for developing scientific models for which iterative calculations are based on variables in a previous period.

3.2 Using Financial Planning Languages for Scientific Programming

The commands and functions built into systems for financial planning purposes turn out to be uniquely useful for scientific applications. Such functions perform moving averages, summations, minimization, maximization, absolute value, powers, logarithms, etc. There are variable assignments and conditional statements. In addition, the languages are designed to automatically displace variables through time. By model generation, as in IFPS, it is possible to displace variables forward and backward spatially as well. It is possible to address the rows and columns of the electronic tablet directly or indirectly. The following list summarizes the factors that make financial planning languages useful for scientific programming:

1. Commands.
2. Functions.
3. Dynamic Data Dimensioning.
4. Direct and Indirect Addressing.
5. Easy Input/Output.
Because of these factors, it is possible to design, develop and implement models in a financial planning language much faster than in traditional scientific programming languages such as FORTRAN, BASIC, PASCAL, etc. It is easy to visualize the data structures in the electronic tablet format. By specifying more columns, all arrays are dynamically redimensioned without a formal compilation. The input and output is easily implemented using the data file interface structure.

If it is possible to organize a problem where a financial planning system is suitable, answers can be obtained orders of magnitude faster than with say, FORTRAN or BASIC. However, the execution time will be significantly longer than that of an implementation in FORTRAN or compiled BASIC. Because the design and implementation processes are expedited with financial planning languages, we recommend that these languages be used at least as a first attempt at design for testing and debugging methods. If only a few scenarios of a model are to be tested, they can be done with the financial planning language model. Once the model is running, a faster, scientific programming implementation can be developed if justified by the cost.

There have been two diametrically opposite approaches to electronic tablet software. The first consists of languages like IFPS which were initially implemented on mainframe computers. Now such languages are being implemented on mini and personal computers [28]. The second view consists of personal computer spreadsheet languages such as VisiCalc [5], which are becoming more sophisticated in the direction of IFPS capabilities (for example, see [14], [17], [27]). See [25] for a recent survey of financial languages and spreadsheets implemented on mini and personal computers.

The driving force of the evolution of financial planning languages is the advent of personal computers having the capability to solve moderately sized
problems interactively. Because of the nature of time-sharing environments on large mainframes and minicomputers, the elapsed time of an interactive job may be equal to the computation time (= elapsed time) of the same job on a personal computer. This fact makes the personal computer an ideal candidate for such languages. We can exploit the capabilities of IFPS-type financial planning languages to solve scientific problems. We also propose that a general purpose, easy to use financial planning type language be developed for scientific programming. Versions of such a language could be developed for both mainframe and personal computers.

In the next section, we describe an IFPS model for network optimization. It gives insight on how to design an IFPS-type language for network optimization. Although progress has been made along those lines [9], [16] for developing some specific network languages, IFPS is more general as is demonstrated below.

4. Optimization of Generated Networks for Equipment Replacement

The reasons IFPS was chosen to implement the optimization model were that it exhibited all the necessary properties described earlier. In addition, we had already developed an IFPS model to generate the arc values of the network. Rather than feed the arc value data into a FORTRAN optimization code, or critical path code [12], we developed an integrated IFPS model to solve the problem.

Such an approach comprises an integrated Decision Support System (DSS) [4], [15], [18]. We show a flow diagram of the system in Figure 3. First, the equipment replacement problem data are formulated into the network model. Using the network arc generation model, the arc values are generated. By using a STORENT (STORE No Tag) command, the network data are stored in a data
file for input to the IFPS optimization model described in this section. The optimization model is solved, and a chain of replacement decisions are reported. The model can then be modified and re-solved to check the sensitivity of the solution to various model parameters, or to test other possible scenarios. Of course, the model and solutions can be saved for updating at the next time period, when the model parameters may have changed.

The IFPS optimization model is shown in Figure 4. The variables (rows) PRESENT VALUE 1 through PRESENT VALUE 10 correspond to the arc values $V_{1j}$, for $j = 2, \ldots, T+1$ through $V_{T,T+1}$. See [1] for their computation. A full description of the IFPS model and the functions and key words used is given in the Appendix.

Model lines 5000-5180 determine the node labels. Each label, LABEL 2 through LABEL 10 is defined in terms of the previous one. INDEX 1 through INDEX 10 are used to offset the columns for indirect addressing with the VMATRIX function. The INDEX $k$ variable is equal to $k-1$, for $k = 1$ through 10. These are set in the network generating model described in [1]. The FROM 1 through FROM 10 in lines 6000-6180 represent the node predecessors. In Lines 7000 through 7080, the longest path is determined from the predecessor labels. They invert the PREDECESSOR labels (7050), perform a forward recursive scan to find the REVERSE PATH (7060), and invert the REVERSE PATH to find the actual PATH (7080).

5. Example

In Table 1, we show the arc values, $V_{1j}$, generated for the 10 year example model of [1]. The $V_{1j}$ of Table 1 correspond to the variables PRESENT VALUE 1 through PRESENT VALUE 10 of the IFPS model shown in Figure 4. These
values are generated from a kernel network specified by the following characteristics:

1. The price of a new machine at the beginning of year 1 is $1000. The price increases at the rate of 5% per year.
2. The salvage value of a machine decreases exponentially at the rate of 15% per year.
3. The annual cash flow = revenue - cost is $300 at the end of year 1. It increases by 15% per year for 3 years, 5% for 1 year, then decreases by 10% for 2 years, and decreases by 40% for the remaining 3 years.
4. The cash flow escalation rate is 6.6% per year. That is, the cash flow for a new machine purchased at the start of year 1 equals the cash flow of a new machine purchased at the start of year 1 multiplied by $(1.06)^i$. This is how the kernel network is used to generate arc values for equipment purchased in year $i$, for $i$ greater than 1.
5. The discount rate is 12% per year.

The output from the IFPS optimization model is shown in Figure 5. The variable LABEL indicates the node labels for nodes 1 through 11 of the network model in columns 1 through 11, respectively. The variable PREDECESSOR consists of the predecessor nodes for the columns. For example, the LABEL and PREDECESSOR of column 10 are 8 and 1040 respectively. The longest path to node 10 has the value 1040. The last arc in the path is from node 8 to node 10. If the problem were truncated to 9 periods, the machine would be replaced in year 8.

The optimal solution for the 10 period problem indicates that the machine should be replaced at the start of year 6 and retained until the start of year
11. The total value of this solution is that of the LABEL, which is 1180 in column 11. This can be found by a backward recursion of the PREDECESSOR from 11 to 6 to 1. In IFPS, this recursion is implemented by reversing the path and performing a forward recursion. The path is 1-6-11, as shown by the variable PATH = 1, 1, 1, 1, 6, 6, 6, 6, 6, 11.

6. Summary and Conclusions

We have presented an IFPS network optimization model for equipment replacement. We have succeeded in developing a method for solving longest path optimization problems within the framework of the financial planning language IFPS. The significance of our approach is that it permits effective utilization of the Decision Support System shown in the flow diagram of Figure 3. It strongly supports the notion that a financial planning language can be used for decision support when an optimization module is required.

We have demonstrated that the features of financial planning languages can be used for scientific programming applications. There are other nonnetwork scientific models which it is possible to solve in IFPS. These include thermodynamic differential equation systems and world economy simulations. Financial planning languages are easy to use, and their inherent characteristics make them ideal candidates for scientific programming. In practice, an IFPS model can be developed and implemented much more quickly than a program in a traditional computer language.

In a financial planning language, scientific users can solve some problems more quickly, because of the unique data structures and ease of Input and Output. As long as the data of a problem can be set up in a matrix structure, the implementation is straightforward.
For the example equipment replacement optimization model, it is not immediately apparent as how to organize the data structures for solving the problem. However, with some thought, this originally nonmatrix problem was solved in IFPS. Conceptually, it is easy to develop such a model, but in this case, it is also possible to solve large network problems.

We support the application of financial planning languages for solving scientific problems and the development of special, machine independent, natural language scientific programming languages for mainframe and personal computers. Such a language should have the same structure as the best of the financial planning languages and for management optimization problems would be extremely helpful in developing stand alone Decision Support Systems that need not interface with external optimization code modules to perform their function.
APPENDIX: DESCRIPTION OF THE IFPS OPTIMIZATION MODEL

IFPS MODEL LINE DESCRIPTIONS

5000 - 6180 Network Longest Path Optimization Statements

5010 LABEL 2 - Node Labels for node 2, ..., 11 in columns 1, ... 10 for the arcs emanating from node 1.

5020 - 5190 LABEL 1 - LABEL 10 - Node labels updated from the previous one for nodes 2, ..., 10. The labels are updated according to the algorithm in Section *. LABEL 10 is the correct set of permanent node labels.

6000 - 6180 FROM 1 - FROM 10 - are the predecessor functions which correspond to the node labels LABEL 1 - LABEL 10 for nodes 2, ..., 10.

7000 - 7080 The Path Computation.

7010 LABEL - Shifts LABEL 10 to the right by one column to correspond to the correct node number.

7020 FROM - Shifts FROM 10 to the right by one column to correspond to the correct node number.

7030 - 7080 The PATH computation is performed by reversing the predecessor row to find a forward recursion. It is then reversed to define the PATH. This technique is used because IFPS Release 8.0 is not capable of defining the path with a backward recursion relationship due to the unavailability of FUTURE values.

IFPS FUNCTIONS and KEY WORDS USED

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>LINE FIRST USED</th>
<th>MEANING</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOR n</td>
<td>5020</td>
<td>Repeat this expression for n columns.</td>
</tr>
<tr>
<td>VMATRIX(a,b)</td>
<td>5020-5030</td>
<td>Use the value of variable a in the column addressed by the value of the variable b in this column. &quot;FUTURE a&quot; must be used (line 7050) if b references a FUTURE column.</td>
</tr>
<tr>
<td>MAXIMUM(a,b,)</td>
<td>5020</td>
<td>Use the maximum value of a and b.</td>
</tr>
<tr>
<td>IF a .GT. b THEN c ELSE d</td>
<td>6010</td>
<td>If the value of a is greater than b, use the value c, otherwise use the value d.</td>
</tr>
<tr>
<td>PREVIOUS</td>
<td>7010</td>
<td>Take the value from the previous column.</td>
</tr>
</tbody>
</table>
References


Table 1: The Arc Values, $V_{ij}$, from the Generated Network Equipment Replacement Example Problem [1]. These values correspond to variables PRESENT VALUE 1 Through PRESENT VALUE 10 of the IFPS Model. Columns 2-11 of the Table correspond to columns 1-10 of the IFPS model shown in Figure 4.

<table>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
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<td>262.4</td>
<td>447.0</td>
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<td>769.8</td>
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<td>862.0</td>
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DESCRIPTION OF THE FIGURES

Figure 1: Shortest Path Equipment Replacement Model over a five year planning horizon.

Figure 2: Kernel Network Representation of an Equipment Replacement Problem.
   The value of arc \((1,j)\) is \(V_{1j}\).

Figure 3: Flow Diagram of the Equipment Replacement Decision Support System.

Figure 4: The IFPS Optimization Model.

Figure 5: Output of the IFPS Optimization Model.
Figure 1: Shortest Path Equipment Replacement Model over a Five Year Planning Horizon.
Figure 2: Kernel Network Representation of an Equipment Replacement Problem. The value of arc \((1,j)\) is \(V_{1j}\).
Figure 3: Flow Diagram of the Equipment Replacement Decision Support System. The IFPS model is an integrated Decision Support System which can either perform steps 2 through 6 simultaneously or use data files to transfer information from one model segment to another. WHAT IF's can be run to test various scenarios.
Figure 4: The IFPS Optimization Model. LABEL 1 through LABEL 10 represent the node labels in iterations 1 through 10 of the algorithm. FROM 1 through FROM 10 are the predecessors for each iteration. LABEL and PREDECESSOR are the node labels and predecessors found at the completion of the algorithm. Lines 7000 through 7080 find the path by inverting it, using a forward recursion, and then invert it again. The variable INDEX \( k = k - 1 \) for \( k = 2, \ldots, 10 \).
Figure 5: Output of the IFPS Optimization Model. Because there are 11 periods, it is printed in two segments, periods 1-6, followed by periods 7-11. Before each segment, the columns are numbered. The Optimal Path is 1 - 6 - 11.
<table>
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