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Interactive Computer-based Game for Decision-making in Ecology

Abstract: This paper describes a prototype Ecology Decision Game which has been developed for experimental use within IBM. The paper is directed to those in ecology desiring to use similar techniques in developing programs that interrelate computing, management science, mathematics, and APL for training and educational purposes. The game is implemented in two modes: an *author* mode, which permits an author to write his own scenario; and a *player* mode, which enables a person to play the game. Features of the game exploit interactive capabilities for both modes. The particular scenario written for the game treats decision-making in the environmental area of solid-waste management. Three submodules explore progressively more complicated situations that give rise to management science problems: shortest route, transportation, and maximal flow. By active and passive role-playing, and controlled and uncontrolled learning, the player is given the opportunity to use quantitative tools to refine his subjective judgments.

Introduction

Administrators, planners, and those generally involved in ecology face admittedly complex problems, and are avidly seeking tools that can aid in solving these problems. This paper is concerned in part with solutions, particularly of the management science type. More central, however, is the elucidation of an approach, hopefully an easy, interesting, and challenging approach, for training and education through the device of an interactive computer-based game, designated the Ecology Decision Game.

• *Gaming*

Games are a natural adjunct to our way of life. Huizinga[1] has even argued that, Thomas Aquinas not withstanding, man is not only a "reasoning animal" but a "playing animal." Games of the serious class can also be interesting, as evidenced by the unusual popularity of management games. The American Management Association first made available their widely accepted game in 1956, and since that time the number of such games has grown prodigiously[2]. This is not to say that games cannot be made challenging, particularly for the player who wants to have a greater understanding of the areas that the game treats. In fact, Coleman[3] has suggested that the challenge lies not only with the player, but also with the observer of the player.

• *Ecology*

In this paper the particular area of ecology selected for gaming is one that is attracting increased attention, the more so because it absorbs the largest expenditures in pollution control: solid-waste management. Nevertheless, although federal legislation regulating water pollution originated in 1899 and laws governing air pollution date back to 1955, the first Solid Waste Disposal Act did not come into existence until 1965. In recognition of the burgeoning problem, the federal government has moved to enact laws and establish agencies in an area that traditionally has been the function of local government[4].

A few statistics indicate the dimensions of the problem[5]. In 1966 the cost of refuse collection and disposal was reported to exceed three billion dollars annually, third among public services only to expenditures for schools and roads. By 1970 the cost had reached at least four billion dollars, and this outlay is expected to triple by 1980. In 1966 refuse production averaged about 4.5 pounds daily per person, a rate which by 1970 had risen to more than five, and which is projected to increase possibly to eight by 1980. Collection, as contrasted with disposal, accounts for 75 to 85 percent of the total cost, which is continuing to rise rapidly, primarily as a result of increased labor charges.

• *Management science*

From a management science standpoint, routing-problem solutions have been identified as the possible key to improved planning and more economic collection operations[6]. In fact, Klee[7] has described a simulation game developed by the Bureau of Solid Waste Management in which players attempt to optimize solid-waste management costs by assigning different routings.

Gaming

A "scenario" has been written that involves players in routing problems associated with collection operations and planning in solid-waste management. Before examining the game in detail, an outline of its salient features is presented.

- *Interactive gaming*

The game is, first of all, a prototype intended for experimental use as a demonstration of capabilities not usually found in a single game. It is interactive with provision for multi-accessing. One consequence is that each player at a terminal has the impression that he has his own computer at all times. This capability is provided by the APL system[8]. A further implication of interaction is that there is a "dialogue" established between the player and the computer via the terminal. The player sees natural language text and answers in constructed responses, stylized where necessary to avoid the pitfalls of full natural language processing. He can, of course, command the full capabilities of the APL system and is given the opportunity to do so at various points in the game.

- *Instructional gaming*

Another facet of the game attempts to bridge the gap that often exists when a player sees only input and output, and wonders about the intervening process. The "black-box" approach is appropriate in simulation games in which the attempt is to create the real world through an approximation model. One disadvantage, however, is that the player usually has no knowledge of the model except by inference. As a complement to such games, instructional gaming[9] can lead the player to an understanding of the model that constitutes the black box and to problem solutions that can be obtained with the model.

The Ecology Decision Game is primarily concerned with instructional gaming. Teaching is based on the Socratic method and the use of tutorial dialogue. The player is given learner control over his individualized instruction in that he can branch around parts of the game. He can also cause the computer to perform tedious chores for him. He has at his service, for example, a desk calculator, a plotter, a message sender and receiver, and a note taker and report generator, in addition to a problem solver for well posed problems.

In this type of instructional gaming the player may want to take a passive role and compete, say, only against nature as represented by the computer. On the other hand, he might enjoy vying with other players in a more active role. He might at some points in the game want to be controlled as to the method of learning. At other times, he might want to explore various possibilities that suggest themselves in an uncontrolled setting. The Ecology Decision Game exhibits these features. It leaves open considerations that are often closed in simulation gaming, such as the number of players and the roles that the players adopt.

- *Game authoring*

No matter how well conceived and executed a game may be, players and authors find deficiencies, especially during the validation and evaluation phase of game development. The literature reflects the diverse approaches taken to gaming[10]. For this reason, and for others such as currency of content, a game should be readily modifiable, even to the point of extensive rewriting.

The Ecology Decision Game, as described thus far, is a particular scenario treating a given area of ecology. The game, however, also provides an author with the capability of writing his own scenarios to treat other areas of ecology. To do so he uses an interactive and conversational mode, coupled with prompting, so that his need for computing expertise is minimized. In this sense the game resembles computer-aided instruction systems such as COURSEWRITER and PLANIT[11].

Frames are constructed by means of a restricted natural language. Dialogue is established between the computer and the author, who provides his script as input. The author can also link to pre-established APL functions to augment features of the game. As in conventional text processing, he is given editing and composition capabilities so that he can revise and format the game to his requirements.

Ecology Decision Game

- *Objectives*

The Ecology Decision Game has been developed to assist both the author in writing scenarios for a game and the player who wants to learn by playing the game. More particularly, the game is directed to authors with limited knowledge of computing and to players largely unfamiliar with computing, mathematics, management science, and APL. With this target population in mind, the objectives of the game are summarized in Table 1.

- *Strategy*

The game is intended to be used either alone or as a complement to a total gaming environment. Alone, it is a terminal-oriented, self-contained package requiring minimal instructor interaction. As a complement it can serve, for example, to reinforce lectures and demonstrations in any of the areas outlined under objectives, or to introduce other topics in ecology. Emphasis is placed on

Table 1 Overall objectives of the Ecology Decision Game.

Enable authors to write scenarios in
- Natural language insofar as possible
- Prompting method to minimize need for computing expertise

Expose players to the application of computing in ecology through
- Management science techniques
- Decisions resting in part on these techniques
- Mathematical concepts
- APL system capabilities

Table 2 System features in the *author* mode.

Questions
- Merge questions
- Right-justify text

Answers
- Single or multiple
- Expected or unexpected
- Full or partial
- Ordered or unordered
- Scored or unscored

Branches
- To questions:
    - Global
    - Local
- To APL functions:
    - Numeric
    - Non-numeric

Scenario
- Edit
- Print
- Logic map

Table 3 System features in the *player* mode.

Linkage to game
- Entry to beginning, intermediate points
- End linkage, resume linkage

Game functions
- Access full use of APL system
- Form tables
- Plot graphs
- Right-justify text
- Provide "help"
- Deliver "mail"

Table 4 Submodule objectives.

Sub-module	*Management science technique*	*Decision-making area*	*Mathematical concepts*	*APL capabilities*
MOD1A	Shortest route problem	Number of sites	Scalars Vectors	Numeric processing
MOD1B	Transportation problem (also linear regression)	Cost-planning	Vectors Matrices	Numeric processing Tables, graphs, reports Messages
MOD1C	Maximal flow problem	Truck fleet size	Matrices Heuristics Simulation	Numeric processing Non-numeric processing

developing cognitive skills and strategies rather than on creating win-lose situations.

- *Author mode*

Features of the *author* mode are shown in Table 2. The author is prompted to write the scenario as a question followed by an answer followed by a branch to another question. This basic sequence is elaborated upon to give added flexibility for modifying paradigms. A "question" can in fact be a question, but it can also be a statement or even a blank line. Similarly, an "answer" can be an expected answer in which the whole character string is matched, or only part of the character string, or it can be an unexpected answer. In fact, a sequence of answers can be formed, but the sequence ends when the author indicates that he has made provision for an unexpected answer. The branch to each answer must be satisfied as the answer is constructed.

A global request can be permitted by the author so that the player may at any time ask, for example, to quit, restart, or use the full capabilities of the APL system. Also, branching can lead to an APL function for numeric or non-numeric processing. Additionally, the author can merge successive questions into one question, score answers, accept unordered answers, right-justify text, edit any portion of the scenario (which includes both text and logic), and print the scenario or an abbreviated "logic map."

- *Player mode*

The *player* mode, features of which are listed in Table 3, is initiated by the player or anyone acting that role. The player can start at the beginning or at some intermediate point in the game. He can use the APL system to send and receive messages, or use global game functions such as those for plotting graphs, forming tables, and composing reports. At specific points in the game he can also call for local game commands such as HELP or MAIL. Of course, he always has available the APL system should he want to construct his own functions or use any of the library functions.

- *Scenario features*

The scenario for the game is divided into modules. Each module in turn consists of submodules, which progressively increase in complexity with respect to the stated objectives. In general, the player is presented with a situation requiring attention and action and he uses management science tools as aids in the decision-making process.

The major module, MOD1 Collection, is directed to the environmental area of solid-waste collection operations and planning. This module consists of three submodules, each of which relates to the objectives outlined for the player as indicated in Table 4.

MOD1A Shortest route problem

The player is confronted with a situation involving a shortest route solution[12, 13]. A dialogue is established between him and the computer as illustrated in Fig. 1. The case stems from a request by a municipal agency to improve environmental conditions and at the same time upgrade operating efficiency. A simplified map is provided at the terminal which shows collection points and disposal sites, distances between these points, and allowable routings. The problem is to find the shortest allowable route between each collection point and a disposal site so that the sum of these distances is a minimum. All routes are assumed to be two-way for simplicity of exposition.

From a management science standpoint, the problem reduces to that of finding shortest paths between pairs of nodes of the Fig. 1 network. We are given a set of $N = 8$ nodes and the $N \times N$ matrix D, whose elements d_{ij} represent the distances between nodes i and j (d_{ij} can differ from d_{ji} in real problems). We assume $d_{ii} = 0$ and $d_{ij} > 0$ for all i and j ($i, j = 1, 2, \cdots, N$). If there is no route (arc) from node i to node j, then $d_{ij} = \infty$ or, for computational purposes, d_{ij} can be assumed to be arbitrarily large.

Mathematically, the problem can be stated as

$$\text{Minimize } d_{ij} \text{ for all } i \text{ and } j,$$

$$d_{ij} \geq 0 \text{ and } i, j = 1, 2, \cdots, N. \qquad (1)$$

To solve this problem, any of several algorithms can be used; in this game, that of Hu[13] has been adopted. Figures 2(a) and 2(b) illustrate how the player is introduced to the correct answer.

Figure 1 Initial problem statement and presentation of map.

```
THE MAYOR'S ENVIRONMENTAL PROTECTION
AGENCY (EPA) HAS ASKED FOR A REVIEW OF REF-
USE COLLECTION. IT PARTICULARLY WANTS TO
KNOW IF THE CITY CAN BE MADE CLEANER BY BET-
TER USE OF COLLECTION TRUCKS AND TEAMS.
TO GET SOME FEELING FOR THE PROBLEM, YOU
HAVE DECIDED TO CONSIDER A VERY SIMPLIFIED
SITUATION: REFUSE PICKED UP BY COLLECTION
TRUCKS AT SPECIFIC POINTS AND TRANSPORTED
TO DUMP SITES.
                     .
                     .
                     .
LOOK AT THE FOLLOWING MAP. WE SHOW COL-
LECTION POINTS BY o AND DISPOSAL POINTS BY
*. WE ALSO SHOW A TYPICAL DISTANCE (=6) FROM
POINT [3] TO POINT [4] WHICH WE LABEL, WITH
SOME FORESIGHT, D[3;4] ← 6.

          D[3;4] ← 6
       *[3]---------o[4]

           o[2]
 o[6]
              o[1]
o[8]
               *[5]

                      *[7]

HERE ARE THE ALLOWED ROUTES AND DISTANCES
SO YOU CAN FILL IN THE REST OF THE MAP BY
HAND. HIT CR.

  D[1; 2] ← 3    D[2; 4] ← 4    D[6; 7] ← 13
  D[1; 5] ← 1    D[3; 6] ← 5    D[6; 8] ← 2
  D[2; 3] ← 3    D[5; 6] ← 10   D[7; 8] ← 14
```

The number of points, eight in all, is not unlike the construct described by Klee[7]. This number is intentionally small so that the player can solve the shortest route problem by inspection. In a tutorial dialogue he verifies that he has analyzed the problem correctly. He then asks for the computer solution. The player is encouraged to analyze a similar situation of his own choosing and is guided to provide input data [Fig. 2(c)]. Following this opportunity for individualized exploration he is introduced to costs associated with the various routes.

Solution of this shortest route problem suggests abandoning one of the disposal sites. The player is alerted through newspaper articles to consider other factors:

Figure 2 Instructional gaming: (a) tutorial dialogue; (b) function evaluation; (c) opportunity to initiate data.

```
YOU NOW HAVE ENOUGH INFORMATION TO FIND
THE SHORTEST ROUTE. FOR EXAMPLE, CONSIDER
COLLECTION POINT [1]. ITS CLOSEST DISPOSAL
POINT IS [5]. YOU'D THEN ROUTE [1] TO [5], NOT
TO [3] OR [7].
SO, LET'S SEE. [1] GOES TO ? (THE ANSWER IS 5—
JUST PUT IN THAT NUMBER).
                    .
                    .
                    .
FINALLY, [8] WOULD GO TO ? (CAREFUL)
7
THE CORRECT ROUTING IS TO [3]. WE TOLD YOU
TO BE CAREFUL. HIT CR AND WE'LL GO ON.
```

(a)

```
WE CAN ALSO ASK THE COMPUTER TO TYPE OUT
THE SHORTEST PATH FROM [8] TO [3]. TO DO SO,
TYPE IN '8 3', LEAVING AT LEAST ONE BLANK BE-
TWEEN THE NUMBERS TO SEPARATE THEM; OTHER-
WISE HIT CR.
8  3
8  6  3
AGREED THAT THE PATH FROM [8] TO [3] IS [8] TO
[6] TO [3]? OK, HIT CR.
```

(b)

```
BEFORE WE LOOK AT THE SITUATION MORE CRITI-
CALLY, MAYBE YOU'D LIKE TO CONSIDER THE SAME
TYPE OF PROBLEM IN YOUR OWN CITY OR REGION.
IF SO, YOU'LL HAVE TO GIVE DISTANCES BETWEEN
POINTS THAT CAN BE CONNECTED, JUST AS WE'VE
DONE BEFORE. DO YOU WANT TO ENTER YOUR
OWN DATA? TYPE Y OR N.
```

(c)

Figure 3 Decision-making: (a) request for decision; (b) advice on factors in decision.

```
BRR . . INN . . GGG. MAIL FOR YOU. TYPE 'MAIL'.
MAIL
THE EPA ADMINISTRATOR HAS JUST CALLED.
WANTS YOUR PRELIMINARY THOUGHTS ABOUT IM-
PROVING COLLECTION OPERATIONS. WHAT ARE
YOU GOING TO TELL HIM? EVEN THOUGH THIS IS A
PRELIMINARY REPORT, YOU SHOULD TAKE INTO
CONSIDERATION OTHER POSSIBLE FACTORS. RE-
MEMBER ALSO THAT AS A PLAYER YOU HAVE
ADOPTED A CERTAIN ROLE, SO YOU SHOULD PRE-
SENT THAT VIEWPOINT.
```

(a)

```
BEFORE YOU DECIDE ON WHETHER TO REPORT
NOW AND WHETHER TO ABANDON DUMP SITE [7],
YOU MIGHT LIKE TO REFER TO A PARTICULAR SITU-
ATION REPORTED IN THE NEWSPAPER THAT AT-
TRACTED YOUR ATTENTION. TYPE 'MAIL' IF YOU
WANT TO SEE EXCERPTS THAT YOUR SECRETARY
RECORDED FOR YOU. OTHERWISE HIT CR TO
GO ON.
MAIL

UNHAPPY SAUGUS SEEKS TRASH DISPOSAL SOLU-
TION

THE TRUCKS KEEP ROLLING INTO SAUGUS AND NO
ONE KNOWS HOW TO STOP THEM.
THE TRUCKS—300 A DAY—ALL HAVE SLOGANS ON
THEIR SIDES: 'KEEP EVERETT CLEAN.' 'HELP KEEP
OUR CITY CLEAN' ON MELROSE TRUCKS, AND SIMI-
LAR MESSAGES FROM 14 OTHER NORTH SHORE
CITIES AND TOWNS.
```

(b)

diminishing available space, rising costs, and the political and social implications associated with solid-waste collection and disposal (Fig. 3). The decision that confronts the player, who adopts a particular role, is whether he should surrender the disposal site.

In this portion of the scenario, the player is exposed to scalars and vectors through the desk calculator capability of the game. He uses black boxes, which are later shown to be APL functions, and other game commands when they are made available to him, as in printing the contents of his "mailbox." Further, he uses APL system commands that permit him to perform ancillary operations, for example, loading various parts of the scenario.

MOD1B Transportation problem

In the second submodule the situation previously presented is indicated to be an over-simplification, in that there are incinerators at two of the disposal locations. Capacity constraints are thus placed on nodes 3 and 5, while node 7, which is designated a sanitary landfill, has no capacity constraint.

In the game the player learns that collection points 1, 2, 4, 6, and 8 in Fig. 1 generate 10, 15, 5, 10, and 15 tons of refuse daily, respectively; that the refuse handling capacities of the incinerators at disposal sites 3 and 5 are 25 and 20 tons per day, respectively; and that the cost of transportation is assumed to be proportional to the distance traveled.

The total refuse generated is 55 tons per day, whereas the incinerators can handle only 45 tons per day. Since the incinerator sites are preferred by the shortest route solution, only the excess ten tons of refuse should be routed to site 7. The question arises, Which ten tons and at what extra cost? The player is encouraged to try a hand solution to convince himself that even in this restricted and small-size problem, an optimal solution is found only after substantial effort.

Formally, the problem can be regarded as a transportation problem[14] in which commodities are transported from sources to destinations with associated costs, subject to constraints on the capacities of the sources and the demands of the destinations. Let x_{ij} denote the amount transported from source i $(i = 1,2, \cdots, m)$ to destination j $(j = 1,2, \cdots, n)$ with associated unit cost c_{ij}. Let a_i denote the capacity of source i and b_j denote the demand of destination j. In the game, sources are collection points, destinations are disposal sites, costs are proportional to distances (found by the shortest route algorithm), and the sum of all a_i equals the sum of all b_j. We are interested in the values of x_{ij} that correspond to minimum cost.

Mathematically, the problem can be stated as

$$\text{Minimize} \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}\, x_{ij}$$

$$\text{such that} \sum_{j=1}^{n} x_{ij} = a_i \qquad \text{for } i = 1,2, \cdots, m;$$

$$\sum_{i=1}^{m} x_{ij} = b_j \qquad \text{for } j = 1,2, \cdots, n;$$

$$x_{ij} \geq 0 \qquad \text{for all } i \text{ and } j. \tag{2}$$

A discussion of transportation algorithms can be found in Ref. 14.

The matrix for this transportation problem is shown in Fig. 4. The transportation algorithm is readily available to the player at the terminal and he can obtain such a solution on request. The total cost in this example is 320, whereas the cost for an unconstrained shortest route would have been 240. The increase in cost, 80, is due to the capacity constraints on the incinerators. Clark and Helms[15] deal with a similar but more difficult (nonlinear) routing problem.

In the course of working toward the solution, the player is introduced to further manipulations with vectors and matrices, as well as to the construction of tables and graphs. He is also exposed to non-numeric processing in preparing composed reports. The decisions that he makes require that he use the message sending capability. He is encouraged to challenge other players to find the minimum cost of operations for reduced capacity of the incinerators. For example, the game decrees that a lower level of operation will be necessary because air pollution standards are projected as becoming more stringent. At this point the player is given the opportunity to use linear regression (curve fitting) analysis in the projection of quality standards.

Figure 4 Transportation problem matrix. The first number of each pair is the assigned unit cost c_{ij}; the second, in boldface, is the solution x_{ij} for the amount of material transported.

	DESTINATION			
SOURCE	3	5	7	*SUPPLY*
1	6, **0**	1, **10**	24, **0**	10
2	3, **5**	4, **10**	21, **0**	15
4	6, **5**	8, **0**	24, **0**	5
6	5, **10**	10, **0**	13, **0**	10
8	7, **5**	12, **0**	14, **10**	15
DEMAND	25	20	10	55
MINIMUM COST ← 320				

MODIC Maximal flow problem

In the third submodule an even more realistic situation is studied. Not only are the previously inroduced constraints present, but there is also a schedule that must be met and trucks that can handle only a fixed-size load. (The problem of determining a schedule is assumed to have been solved separately.) There are 22 loads (55 tons) of refuse to be handled and all trucks are assumed to be the same size, namely, 2.5 tons capacity. Other conditions are that truck travel time is assumed to be proportional to distance and that after a loaded trip to a disposal site, the truck is available for routing to any of the collection sites, subject to pickup time constraints.

The objective is to meet the schedule with the minimum number of trucks. The player readily observes that a trial and error solution to this problem is very time-consuming. Clearly, the maximum number of trucks required would be 22, one assigned to each pickup. To formulate the problem mathematically, we consider a directed graph $G(N,A)$, having N nodes (collection and disposal points) and A directed arcs (collection → disposal and disposal → collection routes), to which the following theorem of graph theory may be applied[12, 16].

Theorem: Let $G'(N,A')$ be a chain-decomposed acyclic graph of $G(N,A)$ (an equivalent bipartite graph) with C being the number of chains and D the set of arcs that are parts of the chains. Then $C + |D| = N$.

In this formulation, C is the number of trucks. We can minimize C by maximizing $|D|$. If we assign a flow ca-

Figure 5 Example of a maximal flow/routing solution of the collection-disposal problem. Such solutions are dependent on a predetermined schedule map for pickups.

```
      COLLECTION POINTS ← 5 (1, 2, 4, 6, 8)
      LOADS ← 22 (55 TONS)
      DISPOSAL SITES ← 3 (3, 5, 7)
      NODES N ← 36
      MAXIMAL FLOW |D| ← 28
      MINIMUM FLEET SIZE C ← 8

TRUCK              ROUTE ASSIGNED

  1     1 → 5 → 1 → 5 → 1 → 5 → 1 → 5 → 2 → 5
  2     2 → 5 → 2 → 3 → 6 → 3
  3     2 → 3 → 8 → 7
  4     8 → 3 → 2 → 5 → 4 → 3
  5     4 → 3 → 8 → 7
  6     6 → 3 → 6 → 3 → 2 → 5
  7     6 → 3 → 8 → 7
  8     8 → 3 → 8 → 7
```

pacity d_{ij} of one unit to each arc and define $x_{ij} = 1$ if nodes i and j belong to a chain, but $x_{ij} = 0$ otherwise, the maximum value of $|D|$ is equal to the maximal flow through the graph G' (N,A'). Thus, the problem may be restated as

$$\text{Maximize} \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij}, \quad x_{ij} = 0 \text{ or } 1, \quad 0 \leq x_{ij} \leq d_{ij}, \qquad (3)$$

for all i, j and flow conservation constraints.

The optimal fleet size is $N - |D|$. Hence, the solution may be obtained by determining the maximal flow through the network, for which the Ford-Fulkerson algorithm[16] is used in the game. The solution is printed at the terminal, along with the truck routings (Fig. 5). Effects on fleet size and routings (sensitivity analysis) are observed by the player, who is exposed to changes in the schedule map. Further work is fostered to familiarize the player with capabilities for both numeric and nonnumeric processing.

The player subsequently learns that the analytic techniques thus far presented are not the only management science methods available. Heuristic methods may be useful for more complex and larger problems. Clark and Helms[15], for example, have used heuristic procedures to find a solution to a solid-waste disposal problem formulated as a fixed-charge transportation problem. Simulation methods are similarly referenced in the game to identify their role in still more complex problems[17].

Summary

Systems analysis is introduced through modeling a situation in which the player participates from the outset. Where a hand solution is possible, his analysis and that of the computer are shown to be coincident. With progressive sophistication, he appeals to the computer when he cannot expect to find an optimal solution by hand. The strength of the computer is emphasized as being its ability to assist in the decision-making by implementing management science algorithms and to relieve the decision maker of burdensome tasks.

The management science solution, however, is identified as only part of the solution to the overall problem. The ultimate decision rests with the player. In this way, the player can accommodate the imprecision that the problem always poses.

The game has been developed to assist both an author, with a limited knowledge of computing, to write scenarios for a particular topical area, and a player, largely unfamiliar with computing, management science, and the APL system, to learn by playing the game.

Effectiveness of the Ecology Decision Game with respect to the stated objectives has been partially evaluated. Further evaluation as an adjunct to other methods of instruction is being developed as various groups use the game.

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