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A Netform System for Resource Planning in the U.S. Bureau of Land Management

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We report an effective model and solution procedure for a major resource management problem of the U.S. Bureau of Land Management (B.L.M.), enabling large practical applications to be solved 20–300 times faster than previously possible. The resulting system has proved a useful analysis tool, providing model interaction capabilities that are employed routinely by the B.L.M. an average of 700 times a month throughout the U.S.

INTRODUCTION

THIS PAPER documents the development of an effective model and solution procedure for a major resource management problem faced by the U.S. Bureau of Land Management (B.L.M.). The development involved three principal stages: (1) a preliminary linear programming formulation; (2) a tailored netform (network-related) model; (3) a specialized solution algorithm. The initial L.P. formulation provided a starting framework, refined and extended through the network-related model, which led in turn to the advances provided by the specialized algorithm: specifically, the ability to solve large-scale B.L.M. resource allocation problems from 20 to 300 times faster than previously possible. The resulting system provides real time analysis and model interaction on a routine basis, and is now used throughout the U.S. an average of 700 times per month. Concrete examples of the interactive options available with the system are provided.

The scope and background of the problem may be described as follows. The B.L.M. manages 173 million acres of public rangelands. While minerals management is an ever-increasing problem, the larger problem by far is allocation of vegetation to various uses or user groups. Demand for vegetation by livestock, wildlife, watershed and other uses often exceeds the supply.

The rangelands managed by the B.L.M. are divided into reporting areas called 'site write-up areas' (S.W.A.s). The B.L.M. maintains vegetation inventory data for each S.W.A. Using the Bureau's soil and vegetation inventory method,[1] the Bureau determines how many units (lbs or tons) of each type of vegetation in a S.W.A. are available for use by animals (both wild and domestic).

A key goal for the B.L.M. is to determine the optimum number of animals of different types that can be supported, given the vegetation inventory information and the dietary requirements of the different animal types to be considered at the different S.W.A.s. The dietary information for the different animals also varies by S.W.A., as an animal's dietary intake varies by geographic location, owing to climate, altitude and other factors.

Prior to the development of an analytical model for this problem, conflicts that arose over the use of public lands for grazing and supporting wildlife were resolved by educated guess and personal bias. Overgrazing was a common problem, and ranchers constantly questioned B.L.M. decisions which they felt were arbitrary. Urgently needed was a model framework which the B.L.M. could draw upon to prepare grazing enviromnetal impact statements more easily and authoritatively.

The initial L.P. model, whose details are summarized by Martinson,[2] demonstrated that a rigorous conceptual framework for achieving these ends was indeed possible. This model also disclosed the magnitude of the problem the B.L.M. faced. Even in the regions involving a relatively small number of S.W.A. groups, the interrelationships among vegetation, availabilities, animal dietary needs, geographic variational factors and other such items presented a complexity far beyond the capacity to analyze without a computer-based support system.

Equally important, the initial model made it possible to think in terms of unified problem aspects that had previously been treated only on a piecemeal basis, and to contemplate exploring the effects of environmental and policy variations previously deemed impossible to characterize.

At the same time, however, the linear programming model proved susceptible to serious limitations and pointed to the need for an alternative analytical approach in order to realize the goals it brought into focus. The most significant limitation was the excessive demand on computer facilites to solve the problem.

The difficulty was accentuated as the B.L.M. began considering multiple S.W.A.s simultaneously and sought to determine the effect of limiting various animal populations. Some of the larger allotments (groups of S.W.A.s) were entirely beyond the ability of the linear programming code to handle effectively, and the sheer number of smaller problems were tying up the computer to such an extent that the detailed analyses were inordinately time-consuming and costly to run.

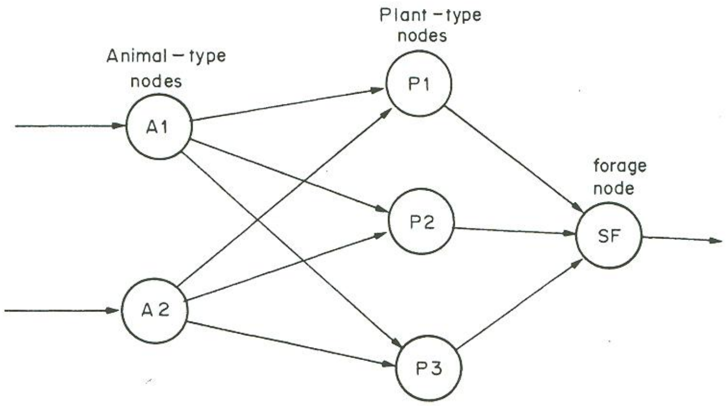
The alternative model and solution procedure we have developed for this problem achieves 95–99% of optimality (usually 98% or better) in a small fraction of the time required by linear programming. The relative speed advantage of the solution procedure increases with the problem size. Average problems solve about 100 times faster, and problems that formerly required 2 hours now solve in 1–2 minutes.

THE PROBLEM STRUCTURE

In the following problem description we describe the structure of the basic site write-up area (S.W.A.) problem and then show how the separate S.W.A. problems are joined into the full B.L.M. problem, the allotment problem. (An allotment is a collection of S.W.A.s.) We cast the problem as a network with a large number of side constraints.

For ease of understanding, we initially disregard the side constraints, and show a network diagram of a simple S.W.A. The overall diagram is described in general terms. Next, each component of the problem is discussed as we build on the basic diagram and introduce the constraining side conditions. When the complete S.W.A. problem has been revealed, we combine S.W.A.s to arrive at the complete B.L.M. allotment problem.

The simplest component of the problem may be depicted as follows:



In this rudimentary diagram, the arc into node A1 represents the total amount of forage consumed by animal type A1. The arcs from A1 to P1, P2 and P3 represent, respectively, the amounts of plant types P1, P2 and P3 consumed by animal type A1.

Following standard network conventions, this part of the diagram says mathematically that the total amount of forage consumed by animal type A1 is equal to the sum of the amounts of plant types P1, P2 and P3 that it consumes. The arcs touching node A2 likewise indicate that the total amount of forage consumed by animal type A2 is equal to the sum of the amounts of plant types P1, P2 and P3 that animal type A2 consumes.

The arc from P1 to SF represents the total amount of plant type P1 that is consumed. Since arc (A1, P1) represents the amount of P1 consumed by A1, and arc (A2, P1) represents the amount of P1 consumed by A2, the arcs touching node P1 express the fact that the total amount of plant type P1 consumed is equal to the amount of plant type P1 consumed by animal type A1 plus the amount of plant type P1 consumed by animal type A2 (i.e. total flow into the node equals total flow out). Corresponding equations hold at nodes P2 and P3.

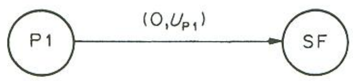
The arc out of node SF represents the total S.W.A. forage of all plant types. The arcs touching node SF show that the S.W.A. forage of all plant types is equal to the sum of the consumption of plant types P1, P2 and P3.

Viewing the diagram as a whole, note that the only arcs in are at nodes A1 and A2, and the only arc out is at node SF. Consequently, the diagram also indicates that the total S.W.A. forage of all plant types (the flow on the arc leaving node SF) is equal to the sum of the total forage consumed by animal types A1 and A2 (the flows on the arcs into nodes A1 and A2).

Upper bound on plant availability

There is an upper limit on the amount of each plant type that is available in each site write-up area (S.W.A.). This upper bound on each plant type's availability is determined by what the B.L.M. calls the 'allowable use factor' (A.U.F.). The A.U.F. is the maximum fraction of the annual plant production that can be removed by grazing from the plant without reducing its vigour. Historical records, professional judgement and literature searches are used to determine A.U.F.s for each plant.

The product, by plant type in each S.W.A., of the annual plant production times its allowable use factor is introduced to the network as U_P, the upper bound on the availability of plant P. With the introduction of the upper bound U_P, for plant type one, the arc from P1 to SF appears as follows:



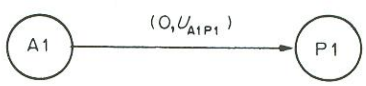
(We follow the convention whereby a lower bound of L and an upper bound of U on the flow across an arc is represented by attaching a parenthetical notation (L, U) to the arc. An arc without this notation is assumed to have a lower bound of zero and an upper bound of infinity.)

Upper bound on plant availability by animal type

The B.L.M. determines what it calls 'proper use factors' (P.U.F.s) of a given plant species by a given animal type. These factors affect the amount of each plant type available to each animal.

The P.U.F. is the fraction of total annual plant production, by type, that a given animal type may consume without overutilizing the surrounding plant community. P.U.F.s reflect the animal's forage preference on a particular range, given that all present plant species are sufficiently abundant. Like A.U.F.s, P.U.F.s are determined by historical records, professional judgement and literature searches.

The product, by plant type in each S.W.A., of the available annual plant production times each animal's P.U.F. for that plant type is introduced to the network as U_{AP}, the upper bound on the availability of plant P to animal type A. With the incorporation of this type of upper bound for animal type one and plant type one, the arc from A1 to P1 appears as follows:



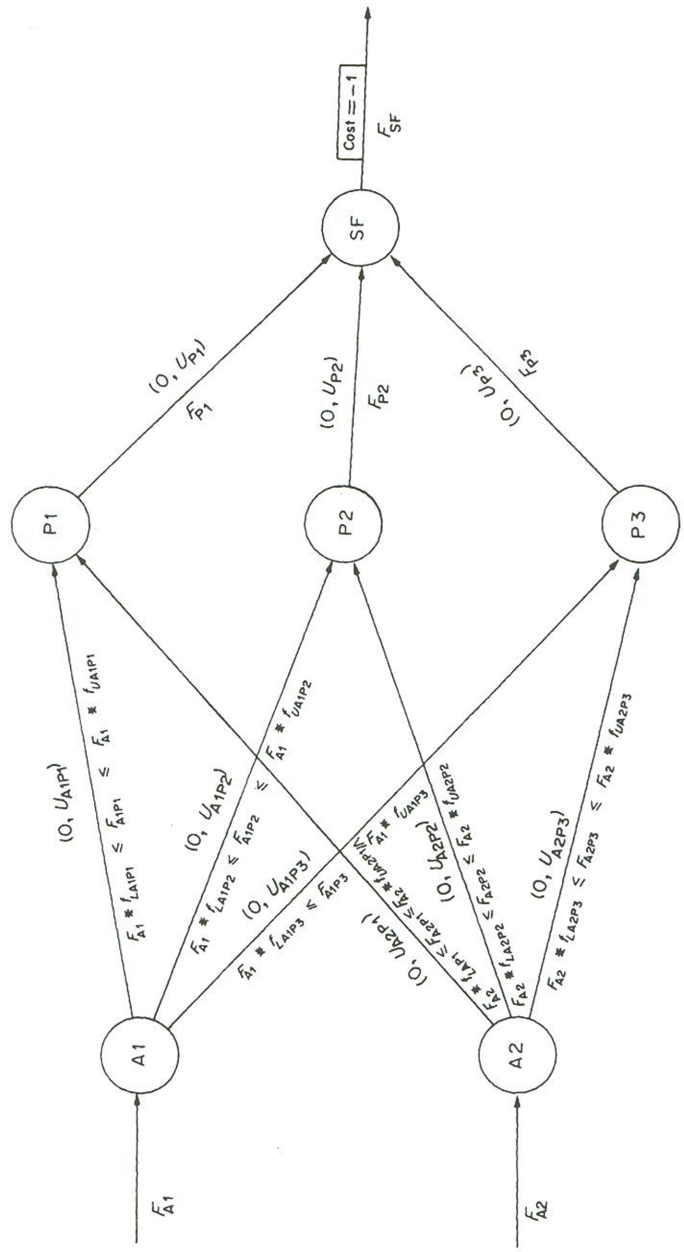

SF
Cost = −1
F_SF
P1
P2
P3
(O, U_P1)
F_P1
(O, U_P2)
F_P2
(O, U_P3)
F_P3
A1
A2
F_A1
F_A2
(O, U_A1P1)
F_A1 * f_LA1P1 ≤ F_A1P1 ≤ F_A1 * f_UA1P1
(O, U_A1P2)
F_A1 * f_LA1P2 ≤ F_A1P2 ≤ F_A1 * f_UA1P2
(O, U_A1P3)
F_A1 * f_LA1P3 ≤ F_A1P3 ≤ F_A1 * f_UA1P3
(O, U_A2P2)
F_A2 * f_LA2P2 ≤ F_A2P2 ≤ F_A2 * f_UA2P2
(O, U_A2P3)
F_A2 * f_LA2P3 ≤ F_A2P3 ≤ F_A2 * f_UA2P3

FIG. 1

Dietary requirements of each animal

Dietary requirement estimates are determined from fecal analysis and scientific literature. The portion of a particular plant type in an animal's diet is termed the 'relative preference value' (R.P.V.) of that plant type for that animal type. The R.P.V.s are determined either from dietary sources or by normalizing the weighted P.U.F.s. Site-specific dietary estimates are scarce but are used where available.

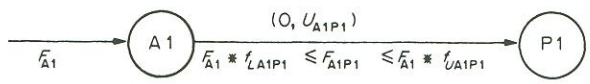
Because of the uncertainty associated with diet estimates, an animal's dietary requirement for a particular plant type is best expressed as an allowable range. Rather than stating, for example, that animal type A1's diet must include exactly 20% plant type P1, animal A1's dietary requirement for plant P1 would more likely be expressed as between 15 and 25% of animal A1's total intake (in pounds of forage).

The B.L.M. calls the spread covered by the diet specification the 'dietary range factor' (D.R.F.) The D.R.F. sets a range about the R.P.V.s used. It attempts to capture in an objective way the subjective knowledge that animals will change their food habits as the forage pool changes, and the degree of uncertainty that the decision maker attaches to the estimate of the diet. This factor may vary to such an extent as to cause the D.R.F. to specify an exact percentage for one plant type, while permitting a range of 0–100% for another plant type.

Side constraints for the site write-up area

We are now in a position to characterize mathematically the relationships, expressed as side constraints in our formulation, that take the problem beyond the realm of 'pure' networks and classify it as a netform (network-related formulation). These relationships constitute the essential complicating feature of the problem that must be handled by a tailored solution procedure.

Specifically, let F_{AP} represent the flow from animal A to plant P (hence the amount of plant P consumed by animal A), and let F_{A} represent the total forage consumption for animal A. Also let $f_{L\mathrm{AP}}$ be the lower fraction of animal Å's diet that must consist of plant P, and f_{UAP} be the upper fraction of animal A's diet that may consist of plant P. The F_{AP}, the flow on the arc from animal A to plant P, must be between $F_{\mathrm{A}} * f_{L\mathrm{AP}}$ and $F_{\mathrm{A}} * f_{U\mathrm{AP}}$, i.e. $F_{\mathrm{A}} * f_{L\mathrm{AP}} \leq F_{\mathrm{AP}} \leq F_{\mathrm{A}} * f_{U\mathrm{AP}}$. In terms of our netform, this requirement dictates that the flow on each arc leaving a given (animal) node must be bounded above and below by specified fractions of the flow that enters this node. This non-network restriction, for animal type A1 and plant type P1, is appended to the diagram as follows:



Completed formulation for a single site write-up area

Upon including an objective component, the formulation for single S.W.A. is complete. The B.L.M. objective is to utilize the total forage available to the fullest extent possible, subject to dietary requirements of the various animal species. This is accomplished by placing a negative cost (i.e. a profit) on the arc leaving the S.W.A. forage node and using a cost-minimizing algorithm to solve the problem. The single S.W.A. diagram, updated to include the characteristics described so far, is shown in Figure 1.

The larger 'allotment' problem

An allotment is a collection of a number of S.W.A.s. Two additional features characterize the allotment problem (which is the complete problem). First is the ability to refer to the flow on the arcs into the animal-type nodes in number of animals rather than pounds of forage. Second is the ability to specify bounds, both upper and lower, on the number of animals of each animal type over the entire allotment.

The objective of handling flows in number of animals is achieved by placing multipliers on arcs that lead into the S.W.A. animal-type nodes. In network terminology, these arcs

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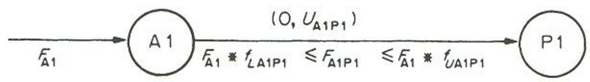

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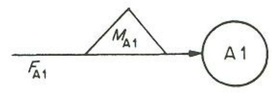
The objective of handling flows in number of animals is achieved by placing multipliers on arcs that lead into the S.W.A. animal-type nodes. In network terminology, these arcs are called generalized arcs. Enclosing the applicable multiplier in a triangle, the revised diagram of the arc into animal-type node A1 is:



The multiplier M_{A1} operates by literally multiplying the flow F_{A1} on the indicated arc to produce the flow $F_{A1} * M_{A1}$ entering the node A1. The value of the multiplier is the pounds of forage consumed annually by one type-A1 animal. For example, if animal type A1 consumes 700 lbs of forage annually, the value of M_{A1} would be 700. Thus, a flow of one animal (F_{A1}) along the arc into A1 is, in effect, converted to 700 lbs of forage at node A1. All flows to the left of the multipliers in the diagrams that follow are in units of whole animals, while all flows to the right of the multipliers are in units of pounds of forage. The use of multipliers to convert to different units of measure is a common netform application.

To prescribe or limit the number of animals of each animal type over an entire allotment, additional animal-type nodes are introduced at the allotment level. These additional nodes and their associated arcs join numerous S.W.A. problems into a unified allotment problem. Each S.W.A.'s total forage is similarly collected into an overall allotment forage node. The negative cost (profit) arc is then moved to the output side of the allotment forage node to maximize total allotment forage. Figure 2 is a diagram of a 2-S.W.A. allotment with all allotment arcs and nodes.

System development

By the foregoing characterization, the B.L.M. allotment problem is a netform composed of a generalized network problem with side constraints. Special compact basis and L.P. partitioning methods can be applied to problems of this type (see, for example, Glover and Klingman[3]), but in practice, these methods prove successful (i.e. more efficient than standard L.P.) only where the number of side constraints is a relatively small fraction (e.g. not more than 20%) of the total. In the B.L.M. problem, side constraints typically account for *85%* of the total number of constraints.

Moreover, to prepare grazing environmental impact statements, the B.L.M. needs the ability to solve hundreds of allotment problems having an average of over 100 S.W.A.s per allotment. It must be possible to handle up to 20 animal types per allotment, and as many as 12 animal types and 75 plant types in each of 200 S.W.A.s. These dimensions produce a generalized network component of 17,621 constraints and 197,621 variables, with additional upper and lower limiting side constraints on each of 180,000 of the variables (not counting non-negativity side constraints). This is an exceedingly large problem, and the necessity for repeated solution makes the requirement for a highly efficient solution procedure imperative.

The tailored method we have developed involves the integration of several algorithmic components plus relaxation/restriction interfaces (see Lasdon[4]). Following the philosophy of standard L.P. decomposition approaches (which, however, are poorly suited to the B.L.M. problem structure), we undertook to converge within a target percentage of global optimality. This target was settled upon to be 95%, though in fact the procedure generally achieves 98% or better before termination.

This type of strategy implies a 'primal' type of procedure. However, the first phase of the method is essentially a dual phase, in that it solves a collection of relaxations, disregarding side constraints.

Subsequently, the relaxationss are refined. In principle, successive relaxations consist of solving the generalized network previously indicated, with side constraints replaced by exact arc bounds. These bounds are obtained by plugging the relaxed solution on the preceding pass into the side constraints, and then loosening the result by making upper bounds a few percent larger and lower bounds a few percent smaller. As the number of passes grows, this percentage is reduced.

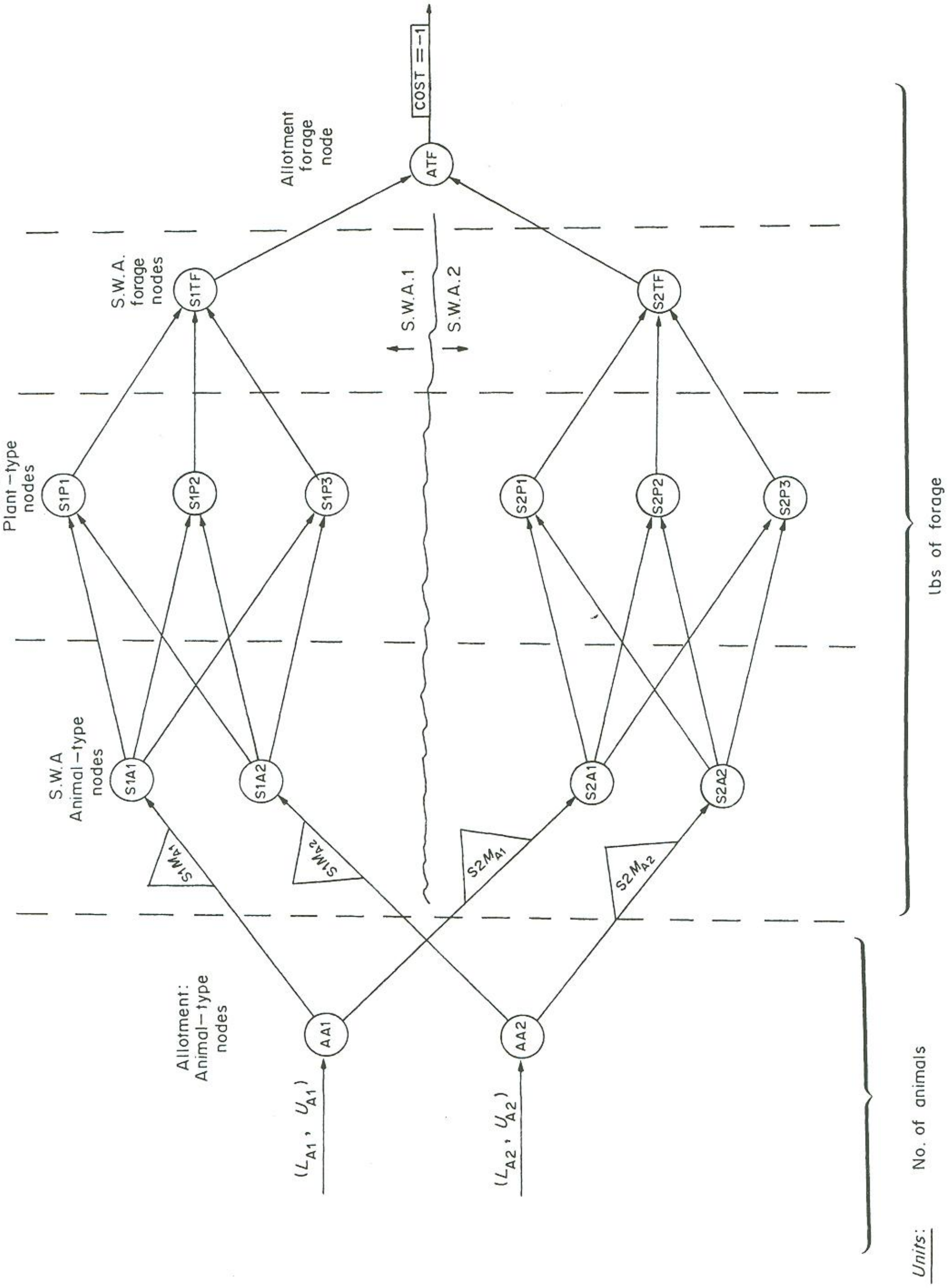

Allotment forage node
ATF
COST = −1
S.W.A. forage nodes
S1TF
S2TF
S.W.A.1
S.W.A.2
S.W.A Plant-type nodes
S1P1
S1P2
S1P3
S2P1
S2P2
S2P3
S.W.A Animal-type nodes
S1A1
S1A2
S2A1
S2A2
$S1M_{A1}$
$S1M_{A2}$
$S2M_{A1}$
$S2M_{A2}$
Allotment: Animal-type nodes
AA1
AA2
(L_{A1}, U_{A1})
(L_{A2}, U_{A2})
Units:
lbs of forage
No. of animals

FIG. 2

The process is complicated, however, by the fact that the bounds obtained in this fashion create infeasibilities, often radical, for the solution just generated. If this fact is ignored, successive passes throw the solution values haphazardly about, sending the process out of control. To handle this, intermediate solution steps are introduced which identify violated constraints and then undertake to adjust both flows and bounds to reduce violations. These intermediate steps apply staged penalties to arcs with violations, thus permitting primal network iterations to be employed. Extreme violations are penalized more heavily, so that as the flows and bounds move toward a compromise position (from which the next pass is initiated), a balanced configuration is achieved in which no flows lie greatly outside their targeted limits.

By alternating between these dual and primal strategies, the procedure eventually moves into a region on the feasible side close to the global optimum.

The ability of this approach to obtain solutions on the average 100 times faster than the L.P. approach has established the overall model design as a highly effective analytical tool. The usefulness of this tool to B.L.M. decision makers has been further enhanced by imbedding it in an interactive query-response system with a variety of special options. The nature of these options, and concrete illustrations of their use in an interactive environment, are provided in the next section.

Model implementation

The B.L.M. vegetation allocation system offers an array of alternatives for the handling and manipulation of the soil vegetation inventory method (S.V.I.M.) data. It has been designed to operate exclusively in a man-machine interactive mode. The vegetation allocation system is being used extensively by the B.L.M. to prepare grazing environmental impact statements.

The decision maker needs only to enter the name of the allotment data file to begin the allocation session. The interactive steps that follow can be grouped into three categories: (a) aggregation of plant species into plant groupings; (b) change of selected data items; (c) initialization of selective parameters.

Category (a) (aggregation of plant species into plant groupings) allows the decision maker to select the most abundant plants or to single out certain plant species and to agglomerate the rest into annual and perennial grasses and forbs, and shrubs. The allowable use factors (A.U.F.s) and proper use factors (P.U.F.s) of these resulting plant groupings are composition-weighted to reflect their individual make-up. Aggregation (or 'crunching') reduces the size of the problem and shortens the execution time. More importantly, it brings down the number of plants in each S.W.A. to a manageable level and makes it easier for the decision maker to analyze the final results.

Category (b) (selected data items) enables the decision maker to examine the impact of data changes on the final results. A.U.F.s, P.U.F.s, suitabilities, forage intake rates and seasons of use can be individually changed on a S.W.A.-by-S.W.A. basis. A.U.F.s, P.U.F.s, forage intake rates and seasons of use can be changed for the whole allotment at one fell swoop.

Category (c) (parameter initialization) gives the decision maker the capability to select the weighting function for the relative preference values (R.P.V.s) and the dietary range factor. The decision maker also has the choice between strata or S.W.A.s as the basic data units in the allotment. Other parameter initialization options include the merging of S.W.A.s by common use and suitability, and the selection of the plant production level to modify the 'normal' year production. Merging of S.W.A.s further reduces the size of the problem and its time of execution, and gives the decision maker a quick, approximate answer which he can use as the starting point for a more elaborate run. Modification of 'normal' year production can be used to study the impact of changes in production on the carrying capacities of the allotment.

Implementing each of these options in a man-machine interactive framework provides the decision maker with a chance to examine the results, make the necessary changes and run the model again until the answers can be regarded as satisfactory. It is easy to examine the results and determine what constraints are limiting, and whether or not the assumptions used in postulating the R.P.V.s have led to a diet that can withstand professional scrutiny. The next section examines a few examples of this interactivity.

Actual examples

The following interactive run illustrates the process that a field decision maker may go through when using the forage allocation model. Prior to making the run, the user has decided on: which aggregation criteria to use, whether to use stratum or S.W.A. as the basic data unit, whether or not to merge S.W.A.s, which weighting function to use for the R.P.V.s, the value of the dietary range factor, and the value of the yearly production factor. An example of an interactive session in which these variables are assigned specific values follows. For a more detailed account of the capabilities of the model, the reader is referred to the *S.V.I.M. Forage Allocation Users Manual.*[5]

INTERACTIVE INPUT

```
ENTER NAME OF ALLOTMENT DATA FILE
=TESTFILE
DO YOU WANT TO AGGREGATE PLANT SPECIES INTO PLANT GROUPS?
=YES
CRUNCH BY COMPOSITION OR SPECIES (ENTER C OR S)
=C
ENTER NO. OF MAJOR PLANT SPECIES (LESS THAN 20)
=0
DO YOU WANT TO SEE THE CRUNCH BREAKDOWN?
=YES

SWA NO. D073        % COMP
  PGRASS
    AGCR             80.18
    STCO4            12.81
    ORHY              4.07
    SIHY              1.87
    BOGR2             1.06
  PFORBS
    ERIOG            59.03
    SPHAE            40.97
  T-S
    ARTR2            89.80
    CHVI8            10.20

SWA NO. D074        % COMP
  PGRASS
    SIHY            100.00
  PFORBS
    ERIOG            62.60
    ASTER            26.16
    SPHAE            11.24
  T-S
    EULA5            90.56
    ARTR2             9.09
    CHVI8             0.28
    GUSA2             0.08

SWA NO. D074        % COMP
  PGRASS
    SIHY            100.00
  PFORBS
    ERIOG            62.44
    ASTER            26.24
    SPHAE            11.31
  T-S
    EULA5            90.56
    ARTR2             9.09
    CHVI8             0.28
    GUSA2             0.08

SWA NO. D076        % COMP
  PGRASS
    ORHY             45.00
    SIHY             42.33
    BOGR2             7.09
    STCO4             3.84
```

```
    AGCR              1.74
  PFORBS
    PFORBS
    ASTER            75.72
    PHLOX            22.22
    SPHAE             1.09
    ASTRA             0.97
  AFORBS
    ACHIL           100.00
  T-S
    ARTR2            89.69
    CHVI8            10.31

DO YOU WANT TO MAKE ANY CHANGES TO THE RAW DATA?
=YES
DO YOU WANT TO ENTER A NEW ANIMAL?
=NO
DO YOU WANT TO MAKE ANY SWEEPING DATA CHANGES?
=YES
DO YOU WANT TO MAKE SWEEPING FORAGE INTAKE CHANGES?
=NO
DO YOU WANT TO MAKE SWEEPING SEASONS OF USE CHANGES?
=NO.
DO YOU WANT TO MAKE SWEEPING AUF CHANGES?
=YES
ENTER PLANT NAME AND AUF VALUES
=PGRASS,.45,.45,.50,.50
    4 AUF CHANGES MADE FOR PLANT PGRASS
DO YOU WANT TO MAKE ANY MORE AUF CHANGES?
=NO
DO YOU WANT TO MAKE SWEEPING PUF CHANGES?
=NO
DO YOU WANT TO SAVE THE DATA CHANGES?
=NO
DO YOU WANT TO SEE OR CHANGE ANY OF THE RAW DATA, BY SWAS?
=NO
ENTER GROUPING DISCIPLINE FOR RAW DATA
(UNG)UNGROUPED,(STR)STRATUM,(SWA)SWA
=SWA

INPUT DATA ARE GROUPED IN 3 GROUPS


SWA NO.          NO. OF STRATA                    STRATUM NO.
D073                          1
                                                     0499
SWA NO.          NO. OF STRATA                    STRATUM NO.
D074                          2
                                                     0500
                                                     0511
SWA NO.          NO. OF STRATA                    STRATUM NO.
D076                          1
                                                     0501
ENTER COMPOSITION WEIGHTING PREFERENCES FOR RPVS
(UNW)UNWEIGHTED, (LOG)LOG-WEIGHTED, (FUL)FULLY WEIGHTED
=FUL
ENTER DIETARY RANGE FACTOR, IN FRACTIONAL FORM
=.25
ENTER NORMAL YEAR PRODUCTION FACTOR, IN FRACTIONAL FORM
=1.0

GRP ENTRIES
D073
D074
D076

HAVE YOU PREVIOUSLY EXAMINED THE TARGET DIET?
=NO

TARGET DIET

SWA NUMBER D073
PLANT        CA     HO     SH
PGRASS       1.00   0.97   1.00
PFORBS       0.00   0.00   0.00
T-S          0.     0.03   0.

SWA NUMBER D074
PLANT        CA     HO     SH
T-S          1.00   1.00   1.00
MISC         0.00   0.00   0.00
```

SWA NUMBER D076

PLANT	AN	CA	SH
PGRASS	0.01	0.91	0.70
PFORBS	0.15	0.09	0.29
AFORBS	0.00	0.00	0.00
T-S	0.84	0.	0.

IS THE DIET OK?
= YES

ALLOTMENT ENTRIES

ENTER UPPER AND LOWER BOUNDS FOR CATTLE
= 9999,0
ENTER UPPER AND LOWER BOUNDS FOR HORSES
= 9999,0
ENTER UPPER AND LOWER BOUNDS FOR SHEEP
= 9999,0
ENTER UPPER AND LOWER BOUNDS FOR ANTELOPE
= 9999,0

RESULTS FOR ALLOTMENT AND FOR ONE S.W.A.

OPTIMAL ANIMAL TYPE MIXTURE	NO. ANIMALS	MAX. NO.	MIN. NO.
CATTLE	104.3	9999.0	0.0
HORSES	13.1	9999.0	0.0
SHEEP	7.7	9999.0	0.0
ANTELOPE	6.5	9999.0	0.0

FORAGE USED (LBS) 334971.

GRP NUMBER D073

	NO. ANIMALS	NO. OF MONTHS	SUITABILITY
CATTLE	26.37	2.03	1.00
HORSES	0.12	7.03	1.00
SHEEP	0.22	2.03	1.00

FORAGE USED (LBS) 43805.

FOR CATTLE	USED PUFS	UNUSED PUFS	GIVEN PUFS	TARGET PPVS	CALC. DIET
PGRASS	0.46	0.03	0.50	1.00	1.00
PFORBS	0.06	0.02	0.08	0.00	0.00
T-S	0.	0.	0.	0.	0.

FOR HORSES	USED PUFS	UNUSED PUFS	GIVEN PUFS	TARGET RPVS	CALC. DIET
PGRASS	0.01	0.44	0.45	0.97	0.98
PFORBS	0.	0.03	0.03	0.00	0.
T-S	0.00	0.01	0.01	0.03	0.02

FOR SHEEP	USED PUFS	UNUSED PUFS	GIVEN PUFS	TARGET RPVS	CALC. DIET
PGRASS	0.00	0.37	0.38	1.00	1.00
PFORBS	0.00	0.15	0.15	0.00	0.00
T-S	0.	0.	0.	0.	0.

FORAGE	USED AUFS	UNUSED AUFS	GIVEN AUFS	PLANT COMP.	PLANT PROD.
PGRASS	0.47	0.00	0.48	0.45	92453.0
PFORBS	0.06	0.39	0.44	0.00	515.0
T-S	0.00	0.38	0.38	0.55	111945.0

FORAGE REMAINING (LBS) 42592.

DIETARY RANGE FACTOR 0.25
NORMAL YEAR PRODUCTION FACTOR 1.00

Model specifics

The model is dimensioned to handle a maximum of 200 S.W.A.s and 20 animal types per allotment, and 75 plant species and 12 animal types per S.W.A. It is written in standard FORTRAN, and it is overlayed to run in less than 45K decimal, which is the current T/S ceiling on the B.L.M.s Honeywell 6680. As an added feature, the system also provides the option of using the Honeywell Mathematical Programming System (M.P.S.) linear programming package.[6]

CONCLUSION

The most significant problem faced by the B.L.M. in its management of 173 million acres of public rangelands—the allocation of vegetation to various users—has been captured in a large-scale analytical model. The number and complexity of the underlying relationships, however, made the solution of this model impractical even by state-of-the-art, linear programming computer methods. We have provided an alternative network-based formulation, involving generalized network components with a large number of side constraints, and a tailored solution procedure that has made the problem routinely solvable. Large problems that formerly required two hours of computer time to solve can now be solved in 1–2 minutes. Imbedding the result in a man–machine interactive system has provided the B.L.M. with a highly effective analytical tool that is used nationwide at a rate of several hundred times every month. From this use, decisions formerly made by educated guess and personal bias have been given a rational foundation, and grazing environmental impact statements are prepared with improved knowledge of the consequences of alternative courses of action.

REFERENCES

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