CropPlanWP – A decision support system for multiannual crop farm planning under probabilistic water availability

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Abstract
This paper presents a decision support system, running under Microsoft Windows, and implementing a linear programming model for solving planning problems for crop farms. The planning includes permanent and annual crops, and covers many years. Manager's goal is to determine how much land should be planted in each permanent crop, and how much land should be planted in each annual crop each year in order to maximize its net cash income. The model includes constraints referring to available land and water, as well as the number of hydrologic events. The program is part of the LINMOD package.

Key words: decision support system, linear programming, simplex method, computer package, multiannual crop farm planning.

Introduction
There is no single universally accepted definition of a decision support system (DSS). For example, Turban ([12] and [13]), gives, among others, the following two: (1) A DSS is a form of computer software, designed and operated to model or otherwise represent the structure of a decision problem, and thus allow the user(s) to identify and select a preferred strategy or other course of action from two or more alternatives against a pre-determined set of criteria, and (2) A DSS is a set of systematically organised procedures whereby a decision maker can be assisted in capturing and analysing information relevant to a decision task. Such a process can be used repeatedly if required, and can assist any decision maker to anticipate the probable outcome of any given choice or strategy.

Some decision problems are optimization problems, which can be solved using well-known mathematical models. This paper presents CropPlanWP program – part of the LINMOD computer package, containing several software systems dedicated to solve decision problems that can be modeled using linear programming techniques.

Mathematical background
The linear programming model
The general mathematical programming problem is stated as follows:

maximize (minimize) the function:  \( f(x) = f(x_1, x_2, ..., x_n) \)

where \( x = (x_1, x_2, ..., x_n) \) is subject to:

\[ g_i(x) = g_i(x_1, x_2, ..., x_n) \leq 0, \quad i = 1, 2, ..., m. \]

The variables \( x = (x_1, x_2, ..., x_n) \) are known as decision variables, the function \( f \) is called objective function, and \( g_i \) (i = 1, 2, ..., m) are constraints.
When the objective function and the constraints are linear, the problem becomes the linear programming problem:

maximize (minimize) the function: \( f(x) = cx = \sum_{k=1}^{n} c_k x_k \)

subject to:

\( g_i(x) = \sum_{k=1}^{n} a_{ik} x_k - b_i \leq 0, \ i = 1, 2, ..., m. \)

The well-known method for solving linear programming problems is the SIMPLEX algorithm (see [1] and [2]).

Multiannual crop farm planning under probabilistic water availability

The farm planning problem (see, for example, [2] and [4]) is one of the most studied optimization problems in agriculture. It involves the establishment of a farm plan for a current production year. The paper [11] discusses a DSS designed to solve this problem.

A more realistic situation, taken from [3], considers a planning horizon of several years. In order to keep things simpler, we consider a crop farm growing permanent and annual crops, under land and water availability constraints only.

I. Problem statement. A crop farm owns \( L \) ha of land and grows \( n \) permanent crops and \( m \) annual crops over a planning horizon of \( T \) years. The water available comes from a number of hydrologic events, and the probability of having a hydrologic event in the year \( j \) is \( p_j \). The farm has no irrigation system, so all the water comes from natural sources, i.e. rain.

The farmer wants to know how much land should be planted in each crop (permanent and annual, latter for each year \( j \) of the planning horizon) in order to maximize its net expected value benefit.

Table 1: Problem data

<table>
<thead>
<tr>
<th>Resource</th>
<th>1</th>
<th>2</th>
<th>( n )</th>
<th>( n+1 )</th>
<th>( n+2 )</th>
<th>( n+m )</th>
<th>Amount of water available</th>
<th>Probability of an hydrologic event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>( q_{11} )</td>
<td>( q_{12} )</td>
<td>( q_{1n1} )</td>
<td>( q_{211} )</td>
<td>( q_{221} )</td>
<td>( q_{2m1} )</td>
<td>( a_1 )</td>
<td>( p_1 )</td>
</tr>
<tr>
<td>Year 2</td>
<td>( q_{112} )</td>
<td>( q_{122} )</td>
<td>( q_{1n2} )</td>
<td>( q_{212} )</td>
<td>( q_{222} )</td>
<td>( q_{2m2} )</td>
<td>( a_2 )</td>
<td>( p_2 )</td>
</tr>
<tr>
<td>Year ( T )</td>
<td>( q_{11T} )</td>
<td>( q_{12T} )</td>
<td>( q_{1nT} )</td>
<td>( q_{21T} )</td>
<td>( q_{22T} )</td>
<td>( q_{2mT} )</td>
<td>( a_T )</td>
<td>( p_T )</td>
</tr>
<tr>
<td>Net income</td>
<td>( c_{11} )</td>
<td>( c_{12} )</td>
<td>( c_{1n} )</td>
<td>( c_{21} )</td>
<td>( c_{22} )</td>
<td>( c_{2m} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All the needed input data are shown in Table 1, as follows:

- \( n \) – the number of permanent crops; \( i \) is the index \( (i = 1, 2, ..., n) \);
- \( m \) – the number of annual crops; \( l \) is the index \( (l = 1, 2, ..., m) \);
- \( T \) – the number of years included in the planning horizon; \( j \) is the index \( (j = 1, 2, ..., T) \);
- \( q_{1ij} \) – annual unit water use per ha of permanent crop \( i \) in the year \( j \) \( (i = 1, 2, ..., n) \);
- \( q_{2jl} \) – annual unit water use per ha of annual crop \( l \) in the year \( j \) \( (l = 1, 2, ..., m) \);
- \( c_{1i} \) – net average annual revenue from permanent crop \( i \) per ha \( (i = 1, 2, ..., n) \);
- \( c_{2l} \) – net average annual revenue from annual crop \( l \) per ha \( (l = 1, 2, ..., m) \);
- \( L \) – total amount of land available (ha).
II. Notations. Let $x_{ij}$ be the number of land units (ha) grown for permanent crop $i$ ($i = 1, 2, \ldots, n$) and $x_{jl}$ be the number of land units (ha) grown for annual crop $l$ ($l = 1, 2, \ldots, m$) in the year $j$ ($j = 1, 2, \ldots, T$). These are the problem variables (unknowns).

III. Constraints refer to:
- availability of land: the land used in each year $j$ should not exceed the amount $L$ of available land:
  \[ x_{11} + x_{12} + \ldots + x_{1n} + x_{211} + x_{221} + \ldots + x_{2m1} \leq L \]
  \[ x_{11} + x_{12} + \ldots + x_{1n} + x_{212} + x_{222} + \ldots + x_{2m2} \leq L \]
  \[ \ldots \]
  \[ x_{11} + x_{12} + \ldots + x_{1n} + x_{21T} + x_{22T} + \ldots + x_{2mT} \leq L \]
- availability of water: the water consumption in each year $j$ should not exceed the amount $a_j$ of available water:
  \[ q_{111} \cdot x_{11} + q_{111} \cdot x_{12} + \ldots + q_{11n} \cdot x_{1n} + q_{211} \cdot x_{211} + q_{212} \cdot x_{221} + \ldots + q_{2m1} \cdot x_{2m1} \leq a_1 \]
  \[ q_{112} \cdot x_{11} + q_{112} \cdot x_{12} + \ldots + q_{11n} \cdot x_{1n} + q_{212} \cdot x_{212} + q_{212} \cdot x_{222} + \ldots + q_{2m2} \cdot x_{2m2} \leq a_2 \]
  \[ \ldots \]
  \[ q_{11T} \cdot x_{11} + q_{11T} \cdot x_{12} + \ldots + q_{11n} \cdot x_{1n} + q_{21T} \cdot x_{21T} + q_{22T} \cdot x_{22T} + \ldots + q_{2mT} \cdot x_{2mT} \leq a_T \]
- nonnegativity restrictions for all problem variables:
  \[ x_{ij} \geq 0, \quad x_{jl} \geq 0, \quad (i = 1, 2, \ldots, n; \quad j = 1, 2, \ldots, T; \quad l = 1, 2, \ldots, m). \]

IV. Objective function: maximize the income, i.e.
\[
p_1 \cdot (c_{11} \cdot x_{11} + c_{12} \cdot x_{12} + \ldots + c_{1n} \cdot x_{1n} + c_{21} \cdot x_{211} + c_{22} \cdot x_{221} + \ldots + c_{2m} \cdot x_{2m1}) + \\
p_2 \cdot (c_{11} \cdot x_{11} + c_{12} \cdot x_{12} + \ldots + c_{1n} \cdot x_{1n} + c_{21} \cdot x_{212} + c_{22} \cdot x_{222} + \ldots + c_{2m} \cdot x_{2m2}) + \ldots + \\
p_T \cdot (c_{11} \cdot x_{11} + c_{12} \cdot x_{12} + \ldots + c_{1n} \cdot x_{1n} + c_{21} \cdot x_{21T} + c_{22} \cdot x_{22T} + \ldots + c_{2m} \cdot x_{2mT}) \rightarrow \text{MAX} \]

All above quantities $L$, $a_j$, $p_i$, $q_{ij}$, $q_{ljk}$, $c_{li}$, and $c_{2l}$ ($i = 1, 2, \ldots, n; \quad j = 1, 2, \ldots, T; \quad l = 1, 2, \ldots, m$) are known.

The LINMOD package
The current version of LINMOD package contains six computer applications: ProdPlan, DietMix, Transport, Blending, FinPlan, FarmPlan and CropPlanWP (see, for details, [5]-[11]). The graphical user interface of each program is tailored to fit the problem being solved. All programs are implemented in Microsoft Visual Basic.

Common User Interface Features
The user interface of the programs is using English language. All programs in the package have some common features with respect to the user interface, as follows:
- input data from keyboard can be stored in a file, and can be reloaded later;
- the results are displayed in a separate window, and can be saved for later use.

The above features are implemented by the following elements in the main window (Figure 1):
- a table-like presentation of input data, with separate text boxes defining the number of rows/columns;
- intuitive/natural presentation of input data and results;
• six command buttons: Load and Save – loading and saving the current data in a file; Process – performing the computations and displaying the results; Display – activating the Results Window, which displays the results; Help and Close.

Figure 1. The main window of CropPlanWP program.

By pressing Process button, the programs automatically generate the corresponding mathematical programming model and then solve it, producing the results in natural language form, using notations specific to the problem being solved. By pressing the Help button, the user receives a short description of the problem and the corresponding linear programming model. The main window provides a range of display options, grouped in a frame under the title Display params.

The CropPlanWP Program
The user interface of the CropPlanWP program contains all the necessary information to define a farm planning problem. Its main window, shown in Figure 1, considers as parameters the number of years $T$, number of permanent crops $n$, the number of annual crops $m$, and the available land $L$; after this information is supplied by the user, the button Set table will configure the data table according to Table 1 layout. Then the user is asked to fill in the data table (in row or column order). During this process, entered data are validated – all the coefficients must be numbers. When the data table is completed, and the user is pressing the Process button, the program automatically builds the linear programming model of the farm planning problem described in 2.2 and then solve it by using the SIMPLEX algorithm. The results are automatically displayed in a separate window.
Conclusions
The above described program is easy to use and assists the manager in establishing different farm plans, according to different scenarios. By simply changing one or more input coefficients, the user can obtain another plan in no time. The graphical user interface enhances his/hers comfort and confidence. Finally, the manager will choose the desired variant. Additionally, the manager can play with different scenarios regarding the availability of water from rains, by setting different probabilities for hydrologic events in the years of the planning horizon.

Our future plans include the development of new computer programs as parts of the LINMOD package, for solving other decision problems in the agriculture. Of an immediate interest we will take into account complex models for water management, including irrigations, and a more sophisticated water balance.

References