MATHEMATICAL PROGRAMMING APPROACHES FOR PROCUREMENT IN WATER IRRIGATION SYSTEMS

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ALSIA – Agrobios
Metaponto, 11th July 2019
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1. Presentation
   i. Personal
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   iii. Research lines

2. Mathematical programming and optimization approaches

3. Water resources management problems


5. Open questions
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PRESENTATION

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PRESENTATION

Master's Degree in Organisational and Logistics Engineering
Information Systems
Quantitative Methods for Industrial Organization

Master's Degree in Business Administration
Technology And Operations Strategy
PRESENTATION

22 years
30 people
95 R+D projects
22 research lines
900 publications
125 contracts with companies
My research lines:
- Production and transport planning
- Approaches for planning under uncertain environments
- Multi-objective decision making
- Water resources and waste water plants management
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Operations research employs the scientific method as a basis to deal with decision making problems by designing and solving mathematical models. One of the most studied and developed is linear programming, which seeks to optimise a linear objective function that is subject to some constraints which are also linear.

Linear programming techniques are employed in a large number of problems:

- Production planning
- Financial planning
- Human resources management
- Transport problems and distribution
- Forest planning
- Scheduling flights
- etc
MATHEMATICAL PROGRAMMING

● Linear programming is a mathematical process to determine the optimum allocation of scarce resources. The Simplex Method is a widely used solution algorithm for solving linear programmes.

● Any linear programming problem consists in an objective function and a set of constraints which must satisfy the following conditions:
  ● The objective function must be linear.
  ● The objective must represent the decision maker’s goal and must be the maximization or the minimization of a linear function
  ● Constraints must also be linear.
A linear programming model consists of the following components: **decision variables**, **objective function** and **constraints**. These three model components are linked by mathematical relations.

- **Decision variables** are those factors among which the decision maker must choose and they are controllable variables. The aim of linear programming is to find the best values for these decision variables.

- The **objective function** represents the relation between decision variables and uncontrollable variables which represent the limitations imposed by the environment (interest rates, prices of raw materials, market demand, etc.).

- **Constraints** express the limitations imposed on management systems owing to the relations with the environment.
● Building a **linear programming model** consists in the following steps:

1) Defining decision variables
2) Defining the objective or goal in terms of the decision variables
3) Defining all the system constraints
4) Restricting all the variables so they are not negative.

● A **linear programming model** can be expressed canonically as:

\[
\begin{align*}
\text{ Maximise } & \quad c^T x \\
\text{subject to } & \quad Ax \leq b \\
\text{ and } & \quad x \geq 0
\end{align*}
\]
MATHEMATICAL PROGRAMMING APPROACHES

- Integer programming
- Quadratic programming
- Nonlinear programming
- Stochastic programming
- Robust programming
- Fuzzy mathematical programming
- Multi-objective optimization
- Heuristics and metaheuristics
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5. Open questions
Why are the water and energy terms related?

The water has a high weight...

1 m³ = 1000 kg = 1 ton
Why are the water and energy terms related?

The water has a high weight...

\[ 1 \ m^3 = 1000 \ \text{kg} = 1 \ \text{ton} \]

How many do kilogrammes consume each family?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity;</td>
<td>0 kg/year</td>
</tr>
<tr>
<td>Gas;</td>
<td>55 kg/year</td>
</tr>
<tr>
<td>Drinking water;</td>
<td>120000 kg/year</td>
</tr>
<tr>
<td>Irrigation water;</td>
<td>3500000 kg/year·ha</td>
</tr>
</tbody>
</table>
WATER RESOURCES MANAGEMENT PROBLEMS

Why are the water and energy terms related?

The water has a high weight...

\[ 1 \text{ m}^3 = 1000 \text{ kg} = 1 \text{ ton} \]

How many do kilogrammes consume each family?

- Electricity; 0 kg/year
- Gas; 55 kg/year
- Drinking water; 120000 kg/year
- Irrigation water; 3500000 kg/year·ha

100 trucks!!
Why are the water and energy terms related?

The water has a high weight...

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Why are the water and energy terms related?
The water has a high weight: 
\[ 1 \text{ m}^3 = 1000 \text{ kg} = 1 \text{ ton} \]

How many kilogrammes do each family consume?
- Electricity: 0 kg/year
- Gas: 55 kg/year
- Drinking water: 120,000 kg/year
- Irrigation water: 3,500,000 kg/year·ha

100 trucks!!
WATER RESOURCES MANAGEMENT PROBLEMS

MATHEMATICAL PROGRAMMING APPROACHES FOR PROCUREMENT IN WATER IRRIGATION SYSTEMS

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What is the main objective currently?

The development of strategies to reduce the energy consumption along getting of water resource, distribution and recycle of the flows in the water cycle.

What could strategies be applied in the water systems?

- Strategies to reduce the energy consumption
  - Water resources
    - Origin
      - Genetic algorithms
      - Traditional methods
  - Water-Networks
    - Design stage
      - To reduce the leakages
    - Management stage
    - Design stage
      - To change the water management of the water system through energy audit
  - Waste-water treatment
    - Management stage
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4. **Mathematical Programming Model for Procurement Selection in Water Irrigation Systems. A Case Study**

5. Open questions
Mathematical Programming Model for Procurement Selection in Water Irrigation Systems. A Case Study

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Received 2 April 2016; Accepted 20 December 2017
The development tools that are used to improve the water management takes on special relevance, particularly, when the area presents a high deficit of the water resource.

Relevant in countries with increase of the population, the decrease of the water resources and the increase of the energy prices.

**SUSTAINABILITY**

Profits of farmers

Efficient use of water resources

**Contribution:** To introduce an optimization tool for addressing the replenishment process in a local irrigation network with the aim to decide what volume is procured (source, quantity and timetable) as well as what volume is stored while minimizing the involved total costs.
MATHEMATICAL PROGRAMMING MODEL FOR PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS

Fig. 1. Inputs to water manager’s decision
Problem statement

Given:
- A set of water procurement sources
- The possible procurement methods for each water source
- The water demand over the planning horizon
- The capacities for each source per period and method
- Initial inventory level at the tank
- Capacity of the tank for storing water and minimum safety stock
- Inventory water holding cost and procurement fixed and variable costs from each source and method
Problem statement

● To determine:
  ● The volume to procure from each source with each method per period
  ● The water inventory level in the tank in each period

● The main goal to meet is:
  ● To minimize total costs including procurement costs and inventory costs while meeting customers demand
MATHEMATICAL PROGRAMMING MODEL FOR PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS

Indexes

\[ i \in I \]  Procurement sources
\[ m \in M \]  Procurement methods
\[ t \in T \]  Time periods
\[ k \in K \]  Months in the year

Sets

\[ M^K_t \]  Set of time periods in month \( k \)

Parameters

\( d_t \)  Demand in period \( t \) (in m\(^3\))
\( CM_{it} \)  Maximum procurement level for source \( i \) in period \( t \) (in m\(^3\))
\( CMT_i \)  Monthly maximum procurement level for source \( i \) (in m\(^3\))
\( CH_{i,m} \)  Monthly available time for the procurement in source \( i \) with method \( m \) (in hours)
\( IMIN_t \)  Safet y stock level of stored water in period \( t \) (in m\(^3\))
\( IMAX_t \)  Maximum level of stored water in period \( t \) (in m\(^3\))
\( cpv_{imt} \)  Procurement variable cost for source \( i \) with method \( m \) in period \( t \) (in euros/m\(^3\))
\( cpf_{imt} \)  Procurement fixed cost for source \( i \) with method \( m \) in period \( t \) (in euros/m\(^3\))
\( ci_t \)  Storage cost in period (in euros/m\(^3\))
\( cf_{im} \)  Procurement fixed cost for source \( i \) with method \( m \) over the planning horizon (in euros/m\(^3\))
Decision variables

- $I_t$ Level of stored water in period $t$ (in $m^3$)
- $Q_{imt}$ Amount of procured water from source $i$ with method $m$ in period $t$ (in $m^3$)
- $Y_{imt}$ 1 if any amount of water is procured from source $i$ with method $m$ in period $t$ (in $m^3$), 0 otherwise
- $F_{im}$ 1 if any procurement from source $i$ with method $m$ is placed over the planning horizon, 0 otherwise
MATHEMATICAL PROGRAMMING MODEL FOR PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS

Objective function

\[
\text{Min } z = \sum_{i} c_i \cdot I_i + \sum_{m} \sum_{i} c_{pv_{imt}} \cdot Q_{imt} + \sum_{m} \sum_{i} c_{pf_{imt}} \cdot Y_{imt} + \sum_{m} c_{f_{im}} \cdot F_{im}
\]  \hspace{1cm} (1)

Subject to

\[I_t = I_{t-1} + \sum_{m} Q_{imt} - d_t\]  \hspace{1cm} \forall t  \hspace{1cm} (2)

\[I_t \leq I_{MAX_t}\]  \hspace{1cm} \forall t  \hspace{1cm} (3)

\[I_t \geq I_{MIN_t}\]  \hspace{1cm} \forall t  \hspace{1cm} (4)

\[\sum_{m} Q_{imt} \leq CM_{it}\]  \hspace{1cm} \forall i \forall t  \hspace{1cm} (5)

\[\sum_{m} Y_{imt} \leq 1\]  \hspace{1cm} \forall i \forall t  \hspace{1cm} (6)

\[Q_{imt} \leq CM_{it} \cdot Y_{imt}\]  \hspace{1cm} \forall i \forall m \forall t  \hspace{1cm} (7)

\[\sum_{m} \sum_{i \in M_t^f} Q_{imt} \leq CM_{it}\]  \hspace{1cm} \forall i  \hspace{1cm} (8)

\[\sum_{i \in M_t^f} Y_{imt} \leq CH_{im}\]  \hspace{1cm} \forall i \forall m  \hspace{1cm} (9)

\[I_t, Q_{imt} \in \mathbb{R}\]  \hspace{1cm} (10)

\[Y_{imt}, F_{im} \in \{0,1\}\]  \hspace{1cm} (11)

Minimization of total costs

Constraint maximum, minimum (safety) and inventory balance

Constraint maximum capacity of source per hourly period

Constraint unique method per hourly period

Constraint maximum capacity of source per month

Constraint maximum capacity (in available hours) of source per month
MATHEMATICAL PROGRAMMING MODEL FOR
PROCUREMENT SELECTION IN WATER IRRIGATION SYSTEMS

- Irrigation network that supplier 260 hectares
- Main crop is **vineyard** and some oil trees
- The topography varies between 590 m and 380 m above sea level
- The water is accumulated in a reservoir with a maximum capacity of **550000 m³**, located at 610 m above sea level
- 5 possible **sources** to get the water resource to meet the demand and 7 **procurement methods** depending the time period and corresponding energy prices
The manager and responsible of the procurement from the different sources used a **heuristic procedure** based on his experience and personal judgement supported by a spreadsheet.

**SUBOPTIMAL RESULTS:**

important errors that may involve substantial costs
The proposed model was implemented by using the **modelling language MPL** and the corresponding resolutions were carried out with **Gurobi** solver version 7.0.1 in a computer with a Inter Core i5 1.80 GHZ processor and 4 GB RAM memory.
Table 2. Results obtained by the current procedure and the proposed model

<table>
<thead>
<tr>
<th></th>
<th>Current heuristic procedure (€)</th>
<th>Proposed model (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total water management costs</td>
<td>128108.80</td>
<td>61181.31</td>
</tr>
<tr>
<td>Final inventory costs</td>
<td>52740.70</td>
<td>11203.75</td>
</tr>
<tr>
<td>Procurement variable costs</td>
<td>72168.09</td>
<td>46777.56</td>
</tr>
<tr>
<td>Procurement fixed costs</td>
<td>3200.00</td>
<td>3200.00</td>
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The proposed model reduces 52.2% the total water management costs when it is compared to the current heuristic procedure.
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Expansión

Los precios de la luz se disparan tras multiplicarse por tres la cotización del CO2
To transform the proposed model with deterministic input data into a new model with uncertain data related to energy costs
OPEN QUESTIONS

● Profits generated by current crops?
● Changes in weather conditions?
● Anticipation of water purchases and financing through loans?
Questions? Suggestions?

Thank you very much
MATHEMATICAL PROGRAMMING APPROACHES FOR PROCUREMENT IN WATER IRRIGATION SYSTEMS

Manuel Díaz-Madroñero
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Research Centre on Production Management and Engineering (CIGIP)

ALSIA – Agrobios
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