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A mathematical model for decision-making of a non-potable water system in residential buildings: decentralized in clusters or individual decentralized?

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Summary

1. Introduction
2. Objective and methodology
3. Results and discussions
4. Final considerations

Introduction

- The research work related to the use of non-potable water systems focuses, in general, the quality of the water on the economic feasibility only in the **first year of operation**.

- However, other variables must be taken into account at the decision-making as to which non-potable-water system will be employed in dwelling buildings.

- The decision-making in the use of non-potable water in building systems **must include all the risks** involved in its adoption.

- Not only is it important the costs of acquiring and implementing the system, but also, and equally important, is the analysis of operating and maintenance expenses.

Introduction

- Oliveira *et al.* presented during CIB 2013 a model, based on the **nearest-neighborhood algorithm**.

- The results of which indicated that the centralized non-potable water system is more feasible economically than the decentralized one, **but without considering how much the total cost is at the end of a given period of time, such as 20-year service life**.

Objective

- Formulate a mathematical model for decision making to afford the choice for the optimum solution for a **condominium with ten buildings**, but from the principles of Integer Programming.

Methodology

Survey of data in the literature that may characterize and compare individual decentralized systems with decentralized-in-cluster systems

Based on the data and with Integer Programming, it was formulated a mathematical **decision-making model**, using the LINDO™ software

General formulation of the decision-making model

Case study

Results

Methodology

This model was formulated based on the principles of **Integer Programming** with variables **0** and **1** and with data from Literature.

Objective function: $$(\text{MIN}) \quad Z = \sum_{i=1}^{n} \sum_{j=1}^{m} A_{ij} X_{ij}$$

$\boldsymbol{A_{ij}}$**:** represents the costs

(implementation, operation, maintenance...)

Restrictions
$$\begin{cases} \sum_{i=1}^{n} X_{ij} = 1, & j = 1,2, \dots m \\ X_{ij+1} - X_{ij} \leq 0, & i = 1,2, \dots , n \; and \; j = 1,2, \dots m \cdot \\ X_{ij} \in \{0, 1\} & \forall \; i, j \end{cases}$$

$\boldsymbol{X}$ $\boldsymbol{i}$ $\boldsymbol{j}$ → Type of cost

↓

Type of system

$\boldsymbol{X_{ij} = 1}$ **Possibility of instalation**

(centralized or descentralized?)

$\boldsymbol{X_{ij} = 0}$ **No possibility of instalation**

Case study

- The model was formulated in order to compare the **total costs** of individual decentralized systems with decentralized-in-cluster systems involving **different types of treatment** implemented in a **hypothetical** residential condominium with population of 1700 dwellers.
- The deployment, maintenance and operating costs were taken into account.

Case study: Characteristics of the systems used in the study

Population, costs and energy consumption in each system indicated in the literature in the year of the systems' operation.

System	Type of Treatment	Maximum Population Served	Implementation Cost (US$)	Maintenance Cost (US$/year)	Operating Cost (US$/year)
1	Rotating Biological Contactor (**RBC**)	170	43,486	16,780	0
2	Physical-Chemical	360	60,642	23,824	656
3	**UASB** Reactor with Aerated Submerged Biological Filter (**ASBF**)	1,719	305,229	7,640	5,809

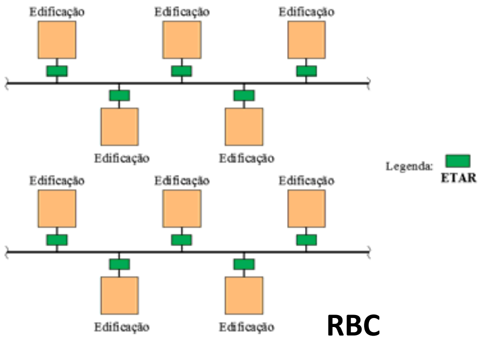
It is considered that the **maintenance costs** of the three systems of analysis have a symbolic increase of **1% per year**.

Case study

- **Aim:** to **compare** a decentralized-in-cluster system with individual decentralized system.
- **Ten 14-storey residential** buildings with **four** apartments per floor, and with an average population of 170 persons/ building, thus **1,700 dwellers**.

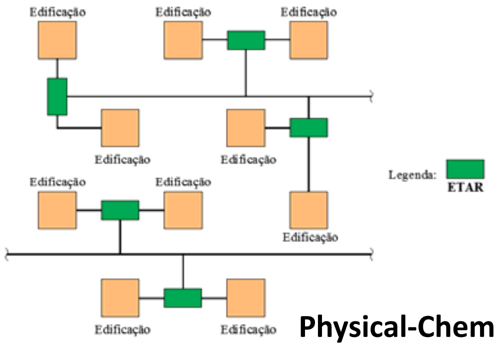
According to maximum populations served, the options to distribute the systems in order to cater to the demand of the condominium are the following:

Option 1: 10 x 170 = 1,700 dwellers



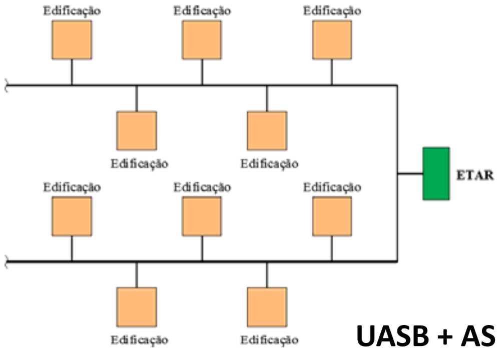
RBC

Option 2: 5 x 180 = 1,800 dwellers



Physical-Chemical

Option 3: 1 x 1,719 dwellers



UASB + ASBF

Case study: Decision-making

- The model formulated aims to answer what the **lowest total cumulative cost** is among the **three options** of system distribution available to the designer, with the data obtained in the consulted references serving as a basis.

- Taking into account the **implementation, maintenance and operating costs**, the following decision-making model is attained for each operation **quinquennium** of the systems:

Case study

Costs of each option for the **first year of operation**, considering the characteristics of the systems.

Option	Type of System	Number of Systems	Implementation Cost (US$)	Maintenance Cost (US$/ano)	Operating Cost (US$/ano)
1	Individual Decentralized	**10**	434,860	167,800	0
2	Decentralized in Cluster	**5**	303,210	119,120	3,280
3	Decentralized in Cluster	**1**	305,229	7,640	5,809

Case study

Considering that the maintenance costs of the systems have an adjustment rate of **1% per year**, Table shows the cumulative maintenance costs of each option in **each quinquennium** of analysis.

Option	**Cumulative Maintenance Cost (US$)**				
	1st year	5th year	10th year	15th year	20th year
1	167,800	855,780	1,753,510	2,693,190	3,674,820
2	119,120	607,512	1,244,804	1,911,876	2,608,728
3	7,640	38,964	79,838	122,622	167,316

Case study

- The rate of adjustment of the operating cost was regarded as **10.35% a year** (rate of annual adjustment in the charge of electric energy).

Summary of the cumulative **operating costs** of the options at **every five years** of operation

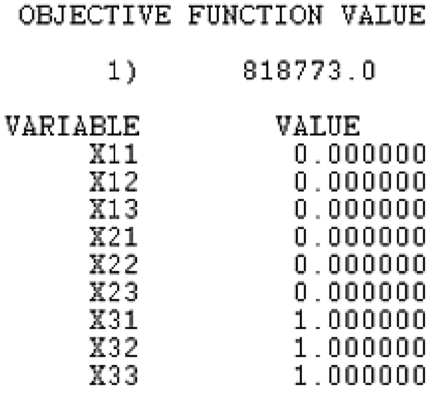
Option	Cumulative Operating Cost (US$)				
	1st year	5th year	10th year	15th year	20th year
1	0	0	0	0	0
2	3,280	20,165	53,160	107,150	195,494
3	5,809	35,712	94,149	189,767	346,228

Case study

Therefore, based on the data of Tables, the decision-making model in the **twentieth year** is given by:

$$(\text{MIN}) \quad Z = 434{,}860X_{11} + 3{,}674.820\, X_{12} + 0X_{13} + 303{,}210X_{21} + 2{,}608.728\, X_{22} + 195{,}494X_{23} + 305{,}229X_{31} + 167{,}316\, X_{32} + 346{,}228X_{33}$$

$$s.a. \begin{cases} X_{11} + X_{21} + X_{31} = 1 \\ X_{12} + X_{22} + X_{32} = 1 \\ X_{13} + X_{23} + X_{33} = 1 \\ X_{12} - X_{11} \leq 0 \\ X_{13} - X_{12} \leq 0 \\ X_{22} - X_{21} \leq 0 \\ X_{23} - X_{22} \leq 0 \\ X_{32} - X_{31} \leq 0 \\ X_{33} - X_{32} \leq 0 \\ X_{ij} \in \{0, 1\} \end{cases}$$



```
OBJECTIVE FUNCTION VALUE

        1)       818773.0

 VARIABLE           VALUE
      X11        0.000000
      X12        0.000000
      X13        0.000000
      X21        0.000000
      X22        0.000000
      X23        0.000000
      X31        1.000000
      X32        1.000000
      X33        1.000000
```

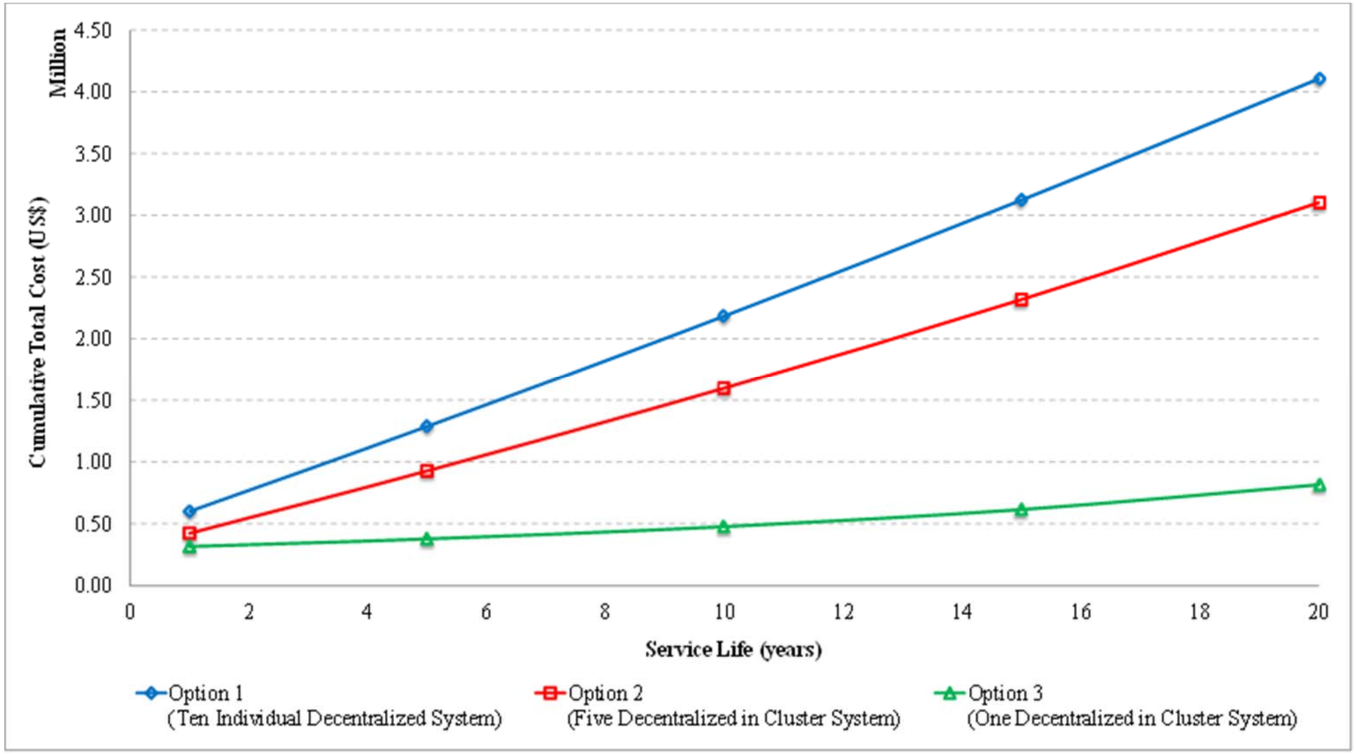
Results and discussions

Synthesis of the results obtained for **each quinquennium**

Service Life (year)	Objective Function Result (US$)	Option	Type of System	Type of Treatment
01	318,678	**3**	Decentralized in cluster (one system)	**UASB** Reactor with Aerated Submerged Biological Filter
05	379,905	**3**	Decentralized in cluster (one system)	**UASB** Reactor with Aerated Submerged Biological Filter
10	479,216	**3**	Decentralized in cluster (one system)	**UASB** Reactor with Aerated Submerged Biological Filter
15	617,618	**3**	Decentralized in cluster (one system)	**UASB** Reactor with Aerated Submerged Biological Filter
20	**818,773**	**3**	Decentralized in cluster (one system)	**UASB** Reactor with Aerated Submerged Biological Filter

Results and discussions

Total cumulative cost during the service life of the options available for a condominium with **1,700 dwellers**



Final considerations

- The principles of Integer Programming afforded a decision-making mathematical model:
  - it is possible to **indicate which type of system offers the lowest total cumulative cost** and**;**
  - what the value of this **cost is at the end of a given period of time** to cater to a specific demand.

- The results obtained pointed out:
  - the importance of analyzing cost performance throughout the **service life of the systems**;
  - the relevance that all the variables have, because the type of treatment or system that seems competitive at first may prove to have a higher total cumulative cost as compared to other options available.

Final considerations

- The formulated model can be improved should it consider **different maintenance frequencies for each type of treatment**.

- The **influence of a scale** effect on maintenance costs, resulting from the increase of population and from the number of systems implemented for each option.

Dank u wel!

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