Theoretical and experimental researches on the operating costs of a wastewater treatment plant

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Abstract. Purpose of the work: The total cost of a sewage plants is often determined by the present value method. All of the annual operating costs for each process are converted to the value of today's correspondence and added to the costs of investment for each process, which leads to getting the current net value. The operating costs of the sewage plants are subdivided, in general, in the premises of the investment and operating costs. The latter can be stable (normal operation and maintenance, the establishment of power) or variables (chemical and power sludge treatment and disposal, of effluent charges). For the purpose of evaluating the preliminary costs so that an installation can choose between different alternatives in an incipient phase of a project, can be used cost functions. In this paper will be calculated the operational cost to make several scenarios in order to optimize its. Total operational cost (fixed and variable) is dependent global parameters of wastewater treatment plant. Research and methodology: The wastewater treatment plant costs are subdivided in investment and operating costs. We can use different cost functions to estimate fixed and variable operating costs. In this study we have used the statistical formulas for cost functions. The method which was applied to study the impact of the influent characteristics on the costs is economic analysis. Optimization of plant design consist in firstly, to assess the ability of the smallest design to treat the maximum loading rates to a given effluent quality and, secondly, to compare the cost of the two alternatives for average and maximum loading rates. Results: In this paper we obtained the statistical values for the investment cost functions, operational fixed costs and operational variable costs for wastewater treatment plant and its graphical representations. All costs were compared to the net values. Finally we observe that it is more economical to build a larger plant, especially if maximum loading rates are reached. The actual target of operational management is to directly implement the presented cost functions in a software tool, in which the design of a plant and the simulation of its behaviour are evaluated simultaneously.

1. Introduction
The total cost of a sewage plants is often determined by the present value method. All of the annual operating costs for each process are converted to the value of today's correspondence and added to the costs of investment for each process, which leads to getting the current net value. The operating costs of the sewage plants are subdivided, in general, in the premises of the investment and operating costs [1]. The costs can be stable or variables [2]. In this paper will be calculated the operational cost to make several scenarios in order to optimize its. Total operational cost (fixed and variable) is dependent global parameters of wastewater treatment plant [3].
2. Research and Methodology

2.1. Fully parametric product model with parameters and relations
These costs are subdivided in investment and operating costs [3]. The investment costs (table 1) for a wastewater treatment plant can be quantified in comparison with the size of the process (area, volume flow) by using the laws of power or polynomial functions [4]. We choose Constanta North’ waste water treatment plant (WWTP) for example. The functions for investment costs are depending on different parameters: flow rate (influent), capacity of oxygen (aeration system), volume of different equipments of each stage of WWTP (oxidation ditch, storage tank, thickener, aeration tank), area (settler), etc. We develop the cost functions for different scenarios (components of each stage of WWTP).

Example of investment cost (IC) functions may be found in the literature [5, 6]. Also, for mechanical stage of WWTP the investment costs functions (equation (1), equation (2), equation (3)) are:

\[ IC = 2334 \, Q^{0.637} \]
\[ IC = 2123 \, Q^{0.540} \]
\[ IC = 3090 \, Q^{0.349} \]

where, \( Q \) is the flow rate of influent, \([m^3/h]\). The values for these investment costs functions are presented in table 1:

| Name of equipments | Cost function IC [Eu] | Parameter Q \([m^3/h]\) | Range of parameter |
|--------------------|------------------------|--------------------------|-------------------|
| Intake pumps       | 2334 \, Q^{0.637} = 310561.697 | Q= 2160 | Q= 250-4000 |
|                    | 2123 \, Q^{0.540} = 134138.986 |                |                   |
|                    | 3090 \, Q^{0.349} = 45048.759 |                |                   |

For second stage of WWTP the investment costs functions (equation (4), equation (5), equation (6), and equation (7)) are:

\[ IC = 2630 \, A^{0.678} \]
\[ IC = 6338 \, A^{0.325} \]
\[ IC = 10304 \, V^{0.477} \]
\[ IC = 8590 \, OC^{0.433} \]

where: \( A \) = area of settler, \([m^2]\), and \( V \) = volume of aeration tank, \([m^3]\), \( OC \) = oxygen capacity of aeration system, \([kgO_2/h]\).

The values for these investment costs functions are presented in table 2:

| Name of equipments | Cost function IC [Eu] | Parameter, A[m^2], V[m^3], OC[kgO_2/h] | Range of parameter |
|--------------------|------------------------|-----------------------------------------|-------------------|
| Sedimentation      | 2630 \, A^{0.678} = 1212801.827 | A= 8491, [m^2] | 175-1250 |
Oxidation system
Aeration system

For third stage of WWTP the investment costs functions (equation (8), equation (9), equation (10)) are:

\[ IC = 5038 Q^{0.304} \]  \hspace{1cm} \text{(8)}
\[ IC = 5559 V^{0.473} \]  \hspace{1cm} \text{(9)}
\[ IC = 3350 Q^{0.363} \]  \hspace{1cm} \text{(10)}

where: \( Q \) = flow rate of sludge recirculation, [m³/h];

\[ IC = 6592 Q^{0.498} \]  \hspace{1cm} \text{(11)}
\[ IC = 2031045 \text{ [Euro]} \]
\[ IC = 3873 Q^{0.772} \]  \hspace{1cm} \text{(12)}
\[ IC = 14989033 \text{ [Euro]} \]
\[ IC = 16482 Q^{0.383} \]  \hspace{1cm} \text{(13)}
\[ IC = 1250695 \text{ [Euro]} \]
\[ IC = 2438 Q^{0.351} \]  \hspace{1cm} \text{(14)}
\[ IC = 158364 \text{ [Euro]} \]

where: \( Q \) = flow rate of effluent, [m³/h].

The values for these investment costs functions are presented in table 3.

Table 3. Investment costs functions for third stage of Constanta North’ WWTP.

| Name of equipments | Cost function IC [Eu] | Parameter, \( Q \) [m³/h], \( V \) [m³] | Range of parameter |
|--------------------|-----------------------|------------------------------------------|-------------------|
| Recirculation of mud sedimentation tank and thickening agent | \( 5038 Q^{0.304} \) = 17491.065 \( 5559 V^{0.473} \) = 119850.805 | \( Q \) = 660, [m³/h]; \( V \) = 10.093, [m³]; | \( Q \) = 35-2340; \( V \) = 8-30 |
| Effluent unit | \( 13350 Q^{0.363} \) = 37041.797 | \( Q \) = 750, [m³/h] | 125-2130 |

Another investment costs functions are the costs for construction equation (11), infrastructures equation (12), electricity equation (13) and instrumentations equation (14). The formulas for these functions are [1, 6]:

\[ IC = 6592 Q^{0.498} \]  \hspace{1cm} \text{(11)}
\[ IC = 2031045 \text{ [Euro]} \]
\[ IC = 3873 Q^{0.772} \]  \hspace{1cm} \text{(12)}
\[ IC = 14989033 \text{ [Euro]} \]
\[ IC = 16482 Q^{0.383} \]  \hspace{1cm} \text{(13)}
\[ IC = 1250695 \text{ [Euro]} \]
\[ IC = 2438 Q^{0.351} \]  \hspace{1cm} \text{(14)}
\[ IC = 158364 \text{ [Euro]} \]

where: \( Q \) = rate of flow, [m³/h].

The total investments costs are \( TIC = 18429137 \text{ [Eu]} \).

2.2. Waste Water Treatment plant fixed and variable operating costs

We can use different cost functions to estimate fixed and variable operating costs (table 4, table 5).
Table 4. Fixed operating costs [2, 7].

| Cost                          | Parameter, PE | Cost function                              | Symbols, units                          | Values/year [Euro] |
|-------------------------------|---------------|--------------------------------------------|-----------------------------------------|--------------------|
| Normal operation and maintenance | Population Equivalent, PE | \[L = U_c \times PE \] \[1, 2\] | \[L\] = labour, [man-hour/y] \[U_c\] = unit cost, [man-hour/y/PE] | 231 111 111 |
| Small equipments of second stage (N= 3) | Population Equivalent, PE | \[C = N \times U_c \times PE \] \[1, 2\] | \[C\] = cost, [Euro/y] \[N\] = number of equipments’s stage | 693 333 333 |
| Human costs                   | Population Equivalent, PE | \[C = U_c \times PE \] \[1, 2\] | \[C\] = cost, [Euro/y] \[U_c\] = unit cost, [man-hour/y/PE] | 231 111 111 |

TOTAL fixed cost is ~1 155 556 480 [Euro].

Table 5. Variable operating costs [2, 8].

| Cost                          | Parameter                  | Cost functions                              | Symbols and Units                        | Values/year |
|-------------------------------|----------------------------|--------------------------------------------|-----------------------------------------|-------------|
| Pumping power                 | Flow rate Q [m³/h]         | \[P = Q \times \gamma \times H / \eta\] \[1, 2, 6, 8\] | \[P\] = power, [kW] \[\gamma\] = specific weight of the liquid, [N/m³] \[H\] = dynamic head, [m] \[\eta\] = pump efficiency, [%] | 4 610 758 [Euro] |
| Chemicals Consumption         | \[C_n\] [kg]              | \[U_c \times C_n\] \[1, 2, 6\]             | \[U_c\] = unit cost, [Euro/kg chemicals] | 1 664 000 |
| Effluent taxes                | COD (chemical oxygen demand), BOD5(biological oxygen demand), N(nitrogen), P (phosphorus), TSS (Total solids sediments) | \[L = U_c \times (k_{org} \times N_{org} + k_{nut} \times N_{nut})\] \[1, 2, 6\] | \[U_c\] = unit cost, [Euro/kg] \[N_{org}\] = f (Q, BOD, TSS, COD) \[N_{nut}\] = f (Q, N, P) | 73955555 |

TOTAL variable cost is ~ 80 230 314 [Euro].

2.3. Waste Water Treatment plant total costs
The total cost of a sewage plants is the sum of all cost, that means the value is TC= 5 577 642 876 [Euro/y]. All of the annual operating costs for each process are converted to the value of today's correspondence and added to the cost of investment for each process, which leads to getting net worth [2].

2.4. The implementation of cost functions in a software tools
For optimization the design of WWTP we can consider, firstly, to assess the ability of the smallest design to treat the maximum loading rates and, secondly, to compare the cost of the two alternatives
for average and maximum loading rates [3]. We can study the implementation of cost functions in a software tool. We can simulate with a modular, multi-purpose computer program a model of our plant, with graphical icons, select the process models, and assign parameters values. There are many sophisticated simulator, with on-screen sliders, switches, and controls tools that help us to operating our plant in a virtual time (figure 1).

![Software tools example](image)

**Figure 1.** An example of software tools from a multi-purpose program [9].

With help of software tools and development of operation stages, we can perform automatic sensitivity analysis, which allows to clearly define the relationship between effluent quality and operational settings. Additionally, we can perform a multi-dimensional parameter search to find the best model inputs to achieve a desired outcome. On simulation, in technical literature [5] the results of this impact is analyzing on NPV (net present value) for different design of WWTPs, where the increase in the investment cost being compensated by a decrease of the operating cost. The sludge treatment and disposal represents the main operating cost, followed by the power consumption.

### 3. Conclusions

We can study the impact of the influent characteristics on the costs [1, 3, 5] by economic analysis. It is more economical to build a larger plant, especially if maximum loading rates are reached. The variable operating costs together fixed operating costs are very important values, too investment costs. If we want to optimize the design and operation of a plant, the definition of a standardized cost criterion is required to compare different treatment scenarios. The actual target of operational management is to directly implement the presented cost functions in a software tool, in which the design of a plant and the simulation of its behavior are evaluated simultaneously.

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