Buletinul Ştiinţific al Universităţii "Politehnica" din Timişoara

Seria HIDROTEHNICA

TRANSACTIONS on HYDROTECHNICS

Tom 55(69), Fascicola 2, 2010

Description of the Dynamic Comparison of Costs for Technical Alternatives of a Hydraulic Engineering Project

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Abstract – This paper describes the German methodology of selecting, at the feasibility study stage, the optimum technical alternative from an economic point of view for hydraulic engineering projects.

Key words: alternative, cost, analysis, conversion.

1. INTRODUCTION

Romania must comply with the EU requirements regarding environmental protection, water and wastewater. Thus, in the near future, a lot of projects will be elaborated for the water and wastewater infrastructure of populate centres. These projects will be funded either from EU funds or from own funds. It is very important to select the optimum technical solution for each project from the point of view of costs. For a lot of years now, Germany has been successfully using, at the feasibility study stage **the dynamic cost comparison method** of the various alternatives of a project (which solves the problem from a technical point of view), the result being the selection of the best alternative. This method has been standardised by the German Water, Wastewater and Waste Association (DWA) within a work group made up by the best specialists in the field.

This paper shortly describes the methodology used when utilising this dynamic comparison method, as it is comprised in the German standard.

2. GENERAL ASPECTS

Cost comparison is used to select the best solution from an economic point of view from a set of relevant alternatives proposed to serve the same purpose. It helps put into practice the principle of economy according to which a specific objective must be reached by using the financial resources as good as possible. However, there are constraints which lead to the use of other analysis instruments (extended cost comparison, cost-benefit analysis, etc.), for instance social impact, which cannot be expressed in monetary units. Under these circumstances, the method must be seen as an interim stage in the full evaluation process.

Generally, investment analysis from the point of view of costs can be done statically or dynamically. Taking into account the big life duration of hydraulic engineering assets, any static approach will lead to significant errors of interpretation and that is why the dynamic approach is used, with the accumulation or deduction of costs appearing throughout the life of a dynamic process.

After identification and description of alternatives, as well as after confirmation of the applicability of the method, selecting the optimum variant implies the following steps:

a) **Establishing costs** for each alternative;

b) **Cost levelling** – mathematical processing of costs in order to allow for the determination of the present value and of the yearly cost for each alternative;

c) **Comparison of present values** of costs, **respectively of the yearly costs** of the alternatives;

d) **The sensitivity analysis** – determination of critical values;

e) **Evaluation of results and proposing the optimum alternative**.

3. ESTABLISHING OF COSTS

The costs taken into account within the dynamic comparison scheme are:

- Investment costs – for example: costs incurred with land, with the preliminary stages of the project (topographical measurements, expertise, etc.), execution costs;
- Reinvestment costs – for those assets or components with a shorter economic life than that of the whole system;
- Operation costs – personnel costs, materials used for maintenance, energy, etc.

4. COST LEVELLING

Usually, the costs of a project are distributed throughout its entire period, from the preliminary stage of investigation, during the execution stage and up to the end of the economic life of the assets. Lining those costs throughout a given period of time, series of costs are obtained. Thus, each project can be characterised by its own series of costs, according to figure 1. As a rule, the entire life cycle must be taken

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into consideration when analysing. In order to eliminate errors of calculus when comparing the alternatives, costs need to be converted to a common **reference date**. The value of a nominal cost adjusted to the reference date represents its **present value** or **the present value of the costs of a project**, if reference is made to the project. The value with which a cost is updated in time will **accumulate** for the costs incurred before the reference date and will be **deducted** for those incurred after this date.

- series of uniform costs – uniform yearly costs;
- Series of progressively increasing costs – yearly costs which increase with a certain percentage every year.

Conversion factors

1) Conversion of an individual cost into its present value at the reference date

- *Conversion of an individual cost incurred before the reference date*

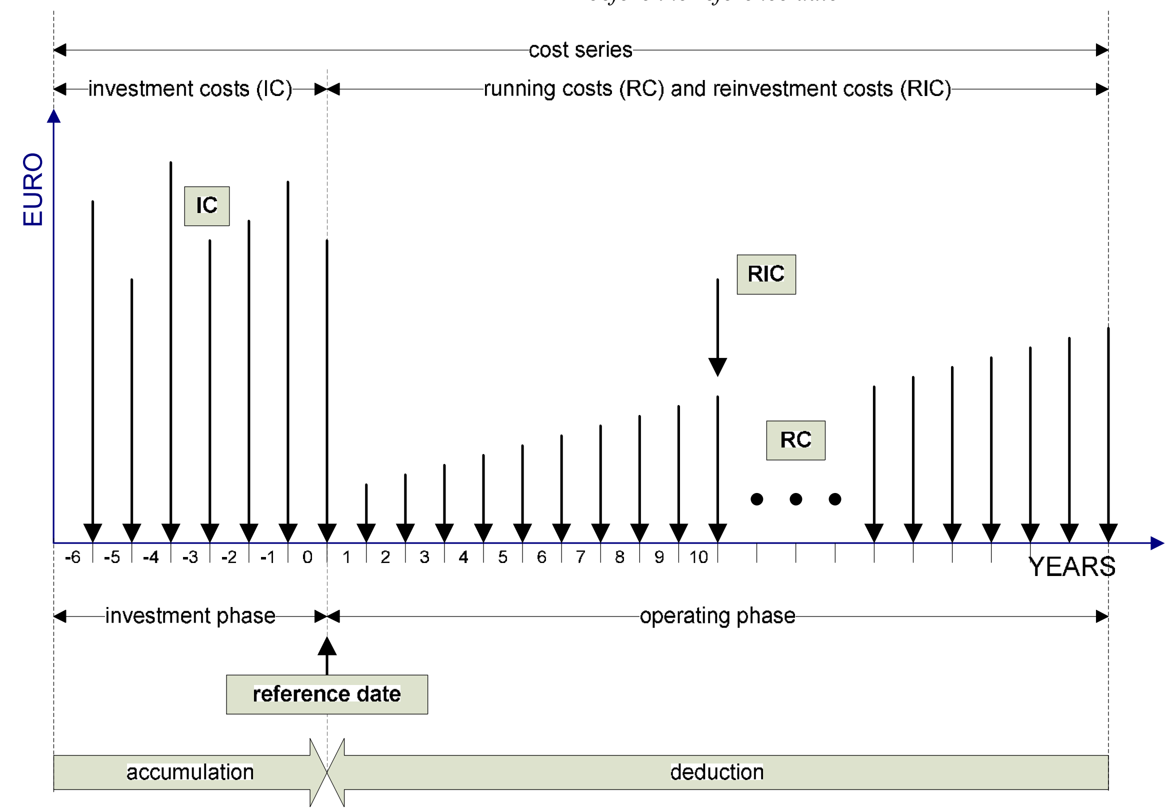

Fig. 1 Distribution of costs along the life of a project

Temporary conversion of nominal costs is done by using **mathematical conversion factors**. These factors use two very important parameters:

- **price adjustment rate (i)** – following an economical study, Germany has approved a standard adjustment rate of 3% p.a. (per annum) for long term comparisons and for the sensitivity analysis, a variation between 2% and 5%;
- **Analysis period** – when calculating, the economic life of the designed assets must be taken into consideration. As a rule, the economic life of an asset ends when the operation costs exceed the benefits. As it is very difficult to anticipate this moment in time, life estimation is based on real data obtained in time for similar assets. In Germany a guide containing the medium life of hydraulic components is used.

For the purpose of applying the mathematical formulae of temporary adjustment, costs can be classified in:

- individual costs – single time costs throughout the period taken into account;

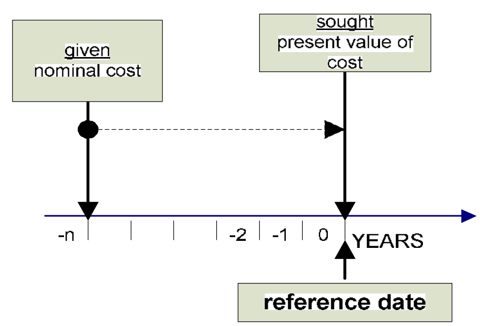

Fig.2 Conversion of an individual cost incurred before the reference date

A cost incurred during year $-n$ before the reference date is converted into the present value by multiplying its nominal value with the accumulation factor for individual costs (AFIC). If i represents the adjustment rate and n represents the number of years between the date when the cost was incurred and the reference date, then:

$$\text{AFIC}(i, n) = (1 + i)^n \quad (1)$$

- *Conversion of an individual cost incurred before the reference date*

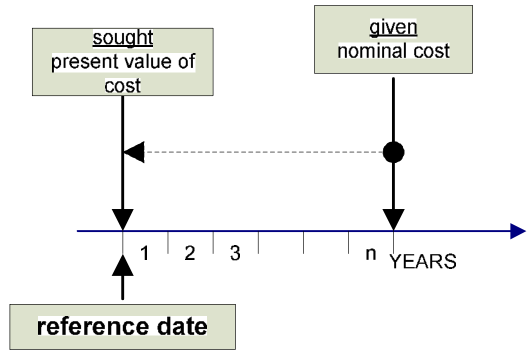

Fig.3 Conversion of an individual cost incurred after the reference date

A cost incurred during year *n* after the reference date is converted into a present value by multiplying its nominal value with the deduction factor for individual costs (DFIC). If *i* represents the adjustment rate and *n* represents the number of years between the reference date and the date when the cost was incurred, then:

$$\text{DFIC}(i, n) = \frac{1}{(1+i)^n} \tag{2}$$

2) Conversion of an individual cost into a series of uniform costs

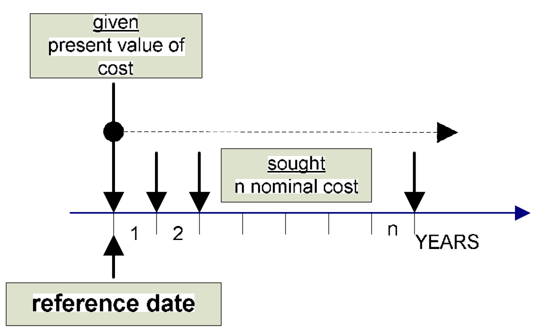

Fig.4 Conversion of an individual cost into a series of uniform costs

For the transformation of an individual cost into a series of yearly uniform costs for duration of *n* years, the nominal value of the individual cost is multiplied with the annuity factor (AF):

$$\text{AF}(i, n) = \frac{i \,x\, (1+i)^n}{(1+i)^n - i} \tag{3}$$

It is used when the project has, aside from individual costs, yearly uniform costs. By adding the results of the multiplication to these, the yearly project cost is obtained.

3) Conversion of a series of uniform costs into its present value at the reference date

- *Conversion into a present value of a series of uniform costs incurred before the reference date*

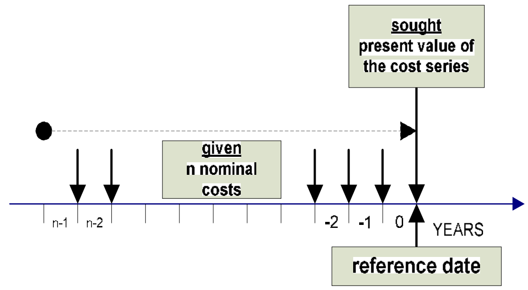

Fig.5 Conversion into a present value of a series of uniform costs incurred before the reference date

The present value of a series of uniform costs incurred during a period of *n* years, starting with year *0* up to year *-(n-1)*, is obtained by multiplying the yearly nominal cost with the accumulation factor for series of uniform costs (ACSUC):

$$\text{ACSUC}(i, n) = \frac{(1+i)^n - 1}{i} \tag{4}$$

- *Conversion into a resent value of a series of uniform costs incurred after the reference date*

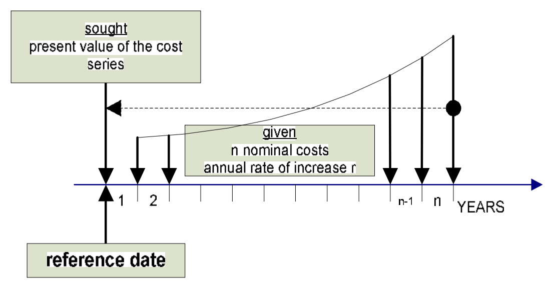

Fig.6 Conversion into a resent value of a series of uniform costs incurred after the reference date

The present value of a series of uniform costs incurred on a period of *n* years, starting with *1* up to year *n*, is obtained by multiplying the yearly nominal cost with the deduction factor for series of uniform costs (DFSUC):

$$\text{DFSUC}(i, n) = \frac{(1+i)^n - 1}{i \,x\, (1+i)^n} \tag{5}$$

4) Conversion of a series of progressively increasing costs into its present value at the reference date

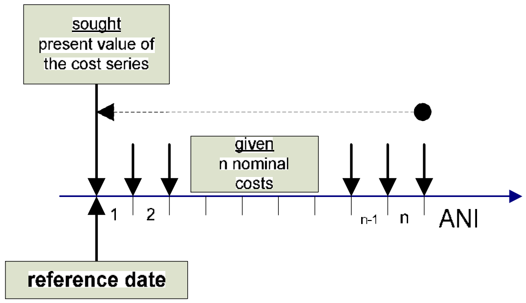

Fig.7 Conversion of a series of progressively increasing costs into its present value at the reference date

If r represents the yearly increase rate of the nominal value for a series of costs, its present value is obtained by multiplying the yearly nominal cost with the deduction factor for series of progressively increasing costs (DFSPIC):

$$(6)\ DFSPIC\,(r, i, n) = (1 + r)\ x\ \frac{(1 + i)^n - (1 + r)^n}{(1 + i)^n\ x\,(1 - r)}$$

5. COST COMPARATION

For the purpose of comparison, the costs of a project can be expresses in two ways:

- as **present value** of the project costs at the **reference date** – meaning the sum of nominal project costs distributed throughout the entire duration converted at their value at the reference date;
- as a **yearly cost** of the project – meaning the transformation of all the costs into a value equal to the average of the yearly costs along the duration taken into consideration (without the investment phase).

For the analysis the entire life cycle is taken into consideration for each alternative. If this is different, the lowest common multiple of the analysed durations is taken into consideration. In case this multiple greatly exceeds realistic planning for water infrastructure measures, for the comparison we use the time variation of the present value of the costs of the alternatives. Because it leads to errors of calculus, it is recommended to avoid taking into consideration the residual value.

6. SENSITIVITY ANALYSIS

This analysis is used to determine the effect of the variation of the initial constant factors taken into consideration (adjustment rate, price of energy, etc.) on the final result.

The critical value of an initial constant factor is obtained when, by changing its value, the present value or the yearly cost of the previously determined alternative as being the cheapest exceed the similar values of an alternative determined as being more expensive. The critical value represents the maximum or minimum value of an alternative from the point of view of profitability.

7. EVALUATION OF RESULTS AND PROPOSING THE OPTIMUM ALTERNATIVE

The last step in the dynamic comparison process of costs is the analysis of the calculus and the result will be the optimum alternative form the point of view of costs. Occasionally, in order to make a just decision, the evaluation of the aspects or implications (side objectives, limit conditions, etc.) that cannot be expressed in monetary units must not be neglected because, after their analysis, the result might change. But these aspects will have to be based on a relevant justification.

8. EXAMPLES

A. Execution of a sewerage system which receives and transports wastewater from a populated center to the existing wastewater treatment plant dimensioned for this volume.

There are two alternatives:

Alternative 1: Gravitational system

The length of the main sewerage network is of 11.6 km, and the house connections have a total length of 2.6 km.

Alternative 2: Under pressure sewerage system

The length of the main sewerage network is of 11.4 km. 6 stations for compressed air are necessary as well as 40 precast manholes provided with pumps for each house. The service connections have a total length of 900 m gravitational system and 1.6 km under pressure, laid at a depth of 1.50 m.

Both alternatives provide the same service and the same capacities. There are no social costs or other aspects that can influence the selection. Thus, dynamic comparison is a proper instrument for choosing the optimum alternative from an economic point of view.

Establishing costs

Tab.1 Costs Alternative 1 and Alternative 2

Alternative 1	Costs	
Investment costs IC1		
Main network		
2,855m ND 250 x 300 EUR/m	EUR	856,500
3,070m ND 250 x 325 EUR/m	EUR	997,750
3,721m ND 300 x 310 EUR/m	EUR	1,153,500
1,943m ND 300 x 350 EUR/m	EUR	680,050
Sewerage connections		
2,600m DN 150 x 150 EUR/m	EUR	390,000
Investment costs IC1total	**EUR**	**4,077,800**
Operation costs OC1		
Maintenance costs		
11,589m x 1.75 EUR/(m x a)	EUR/a	20,300
2,600m x 1.00 EUR/(m x a)	EUR/a	2,600
Operation costs OC1total	**EUR/a**	**22,900**

Alternative 2	Costs	
Investment costs IC2 Sewerage network under pressure 1.50 m deep		
2,200m ND 125 x 175 EUR/m	EUR	385,000
2,550m ND 150 x 200 EUR/m	EUR	510,000
5,315m ND 200 x 230 EUR/m	EUR	1,222,450
1,350m DN 250 x 275 EUR/m Compressed air stations powered by electricity	EUR	371,250
6 pieces x 53,000 EUR/pcs,	EUR	318,000
Service connections		
900m DN 150 x 145 EUR/m	EUR	130,500
1,600m DN 125 x 130 EUR/m	EUR	208,000
Precast manholes		
40 pieces x 7,300 EUR/pcs,	EUR	292,000
Investment costs IC2 total	**EUR**	**3,437,200**
Operation costs OC2 Material and maintenance personnel costs	EUR/a	11,800
Energy costs	EUR/a	3,100
Operation costs OC2 total	**EUR/a**	**14,900**

Cost levelling

An adjustment rate i = 3% p.a. is taken into consideration. Also, the average life duration for the gravitational and under pressure networks is considered to be 50 years, and for the compressed air stations and the manholes equipped with pumps, 25 years.

For the calculus of the present value of the costs of the alternatives at the date of reference 0, the operation costs will be converted into the present value by using DFSUC (3; 50). Taking into consideration the lowest common multiple of the life durations for the two alternatives (50 years), there result investment costs after 25 years for Alternative 2. They will be converted into their present value at the reference date 0 by using DFIC (3; 25).

For the calculus of the yearly cost of the alternatives, the investment costs will be converted by using the AF (3; n) and the result will be added to the operation costs.

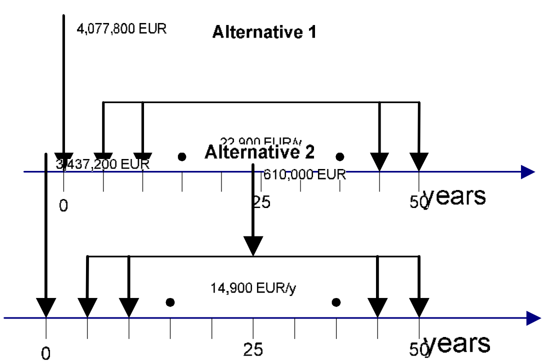

Fig.8 Series of costs for alternatives 1 and 2

Tab.2 Calculus of present value for Alternative 1 and Alternative 2

Alternative /type of cost	**Conversion factor**	**Present value EUR**
Alternative 1		
Investment costs IC1		4,077,800
Operation costs OC1 22,900 EUR/a x	DFSUC (3;50) 25.73	589,200
Present value (PV1) Alternative 1		**4,667,000**
Alternative 2		
Investment costs IC2 (initial)		3,437,200
Re-investment costs RIC2 - compressed air stations after 25 years 318,000 EUR x	DFIC (3;25) 0.4776	151,900
- manholes equipped with pumps after 25 292,000 EUR x	DFIC (3;25) 0.4776	139,500
Operation costs OC2 14,900 EUR/a x	FDSU (3;50) 25.73	383,400
Present value (PV2) Alternative 2		**4,112,000**

Tab.3 Calculus of yearly cost for Alternative 1 and Alternative 2

Alternative /tip cost	**Conversion factor**	**Yearly cost EUR/a**
Alternative 1		
Operation costs OC 1		22,900
Investment costs IC 1 4,077,800 EUR x	AF (3;50) 0.03887	158,500
Yearly cost (YC1) Alternative 1		**181,400**
Alternative 2		
Operation costs OC 2		14,900
Investment costs IC 2 - gravitational and under pressure sewerage system 2,827,200 EUR x	AF (3;50) 0.03887	109,900
- manholes equipped with pumps 292,000 EUR x	AF (3;25) 0.05743	16,800
compressed air stations 318,000 EUR x	AF (3;25) 0.05743	18,300
Yearly Cost (YC2) Alternative 2		**159,900**

Cost comparison

The difference between the present values and yearly costs of the alternatives should be made. Thus, the difference between PV1 and PV2, i.e 555,000 EUR shows that from the point of view of the saved capital, Alternative 1 is better than Alternative 2. It's the same from the point of view of the yearly cost: a difference of 21,573 EUR/a between YC1 and YC2.

Sensitivity analysis

The sensitivity analysis is used to verify if Alternative 2 remains favourite in the case of the

Variation of the adjustment rate from 2% to 5% and in the case of the increase of the price paid for energy by 2% yearly according to Tables 4 and 5.

Tab.4 Calculus of yearly cost for Alternative 1 and Alternative 2 for an adjustment rate of 3% per year and an increase in the price of energy of 2% per year

Alternative /Cost	**Yearly Cost EUR/a**
Alternative 1	
Yearly cost AC1	**181,400**
Alternative 2	
Yearly cost derived from investment costs (109,900 + 18,300 + 16,800)	145,000
Operation cost without energy cost	11,800
Energy cost increasing with 2%/year 3,100 x DFSPIC (2;3;50) x FA (3;50) 3,100 x 39.375 x 0.03887	4,700
Yearly cost YC2	**161,500**
Comparison yearly costs	
Economy for A2: YC1-YC2	19,900

Tab.5 Calculus of yearly cost for Alternative 1 and Alternative 2 for an adjustment rate of 2% per year, respectively 5% per year

Alternative/ Cost	**i = 2 % p.a.**		**i = 5 % p.a.**	
	Conversion factor	AC EUR/a	Conversion factor	AC EUR/a
Alternative 1				
Investment costs IC *1*				
4,077,800 x AF (i;50)	0.03182	129,800	0.05478	223,400
Operation costs OC *1*		22,900		22,900
Yearly Cost YC 1		**152,700**		**246,300**
Alternative 2				
Investment costs IC *2*				
Gravitational and under pressure sewerage system				
2,827,200 x AF (i;50)	0.03182	90,000	0.05478	154,800
Compressed air stations powered by electricity				
318,000 x AF (i;25)	0.05122	16,300	0.07095	22,600
Manholes equipped with pumps				
292,000 xAF (i;25)	0.05122	15,000	0.07095	20,700
Operation costs OC *2*		14,900		14,900
Yearly Cost YC2		**136,200**		**213,000**
Comparison Yearly Cost				
Economy for A2: YC1-YC2		16,500		33,300

After calculations it can be observed that Alternative 2 remains favourite in both situations.

<u>Evaluation of results and proposing the optimum variant</u>

From the comparison of the two alternatives, there clearly results that Alternative 2 is optimum from the economic point of view and thus it will be chosen.

9. CONCLUSIONS

Thanks to its efficiency, this methods id the subject of a project initiated by the DWA which aims to implement this selection method of the optimum alternative at the feasibility study phase in the countries which benefit from European funds, among which Romania.

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