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VALUE ENGINEERING OF BURIED FLEXIBLE STEEL STRUCTURES[1]

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This paper presents the implementation of the Value Engineering concept in the area of buried flexible steel structures. A short background of Value Engineering is presented to clarify the concept. Furthermore, its specific application is considered based on a holistic approach incorporating all relevant areas such as design, construction, cost, timing, maintenance, value of money in time, decision maker preferences. A short example showing the practical application is presented and discussed in view of the sensitivity of the results.

Key words: Life cycle cost, alternatives, value engineering plan, maintenance, value of money in time, buried flexible steel structures

1. INTRODUCTION

The story dates back to 1947 when General Electric introduced the concept in order to obtain better alternatives at lower costs. The man in charge of the project was Lawrence D. Miles. It was originally called value analysis and, in 1957, renamed to "Value Engineering" (VE) by the Navy's Bureau of Ships and put into a formal VE program [1]. The definition of Value Engineering proposed by the FHWA [2] is as follows: "VE is defined as a systematic process of review and analysis of a project, during the concept and design phases, by a multidiscipline team of persons not involved in the project, that is conducted to provide recommendations for:

1. providing the needed functions safely, reliably, efficiently, and at the lowest overall cost;
2. improving the value and quality of the project; and
3. reducing the time to complete the project."

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As always timing plays an important role in ensuring the efficiency of the process. The earlier on it is initiated the higher potential savings may be achieved. The chart below, copied from the Society of American Value Engineerings (SAVE) (1959) [3], reflects the said rule.

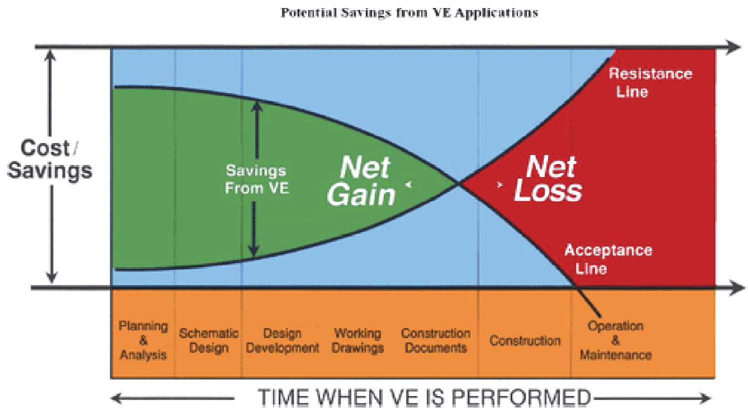


Fig. 1. Cost/savings deriving from VE introduction vs time [4]

The benefits obtained by using the VE approach can be illustrated based on the results achieved by the American FHWA, summarized in Table 1. The systematic approach combined with documenting the outcome of the results can be highly encouraging for any governmental/non-governmental body spending public or private money.

Table 1. Summary of VE savings in FHWA programs, 2010-2014 [2]

Summary Of Past VE Savings Federal-Aid and Federal Lands Highway Programs					
	FY 2014	FY 2013	FY 2012	FY 2011	FY 2010
Number of VE Studies	215	281	352	378	402
Cost to Conduct VE Studies and Program Administration	$8.7 M	$9.8 M	$12.0 M	$12.5 M	$13.6 M
Estimated Construction Cost of Projects Studied	$20.9 B	$23.0 B	$30.3 B	$32.3 B	$34.2 B
Total Number of Proposed Recommendations	1,664	2,381	2,905	2,950	3,049
Total Value of Proposed Recommendations	$3.0 B	$2.91 B	$3.78 B	$2.94 B	$4.35 B
Number of Approved Recommendations	697	1,011	1,191	1,224	1,315
Value of Approved Recommendations	$1.73 B	$1.15 B	$1.15 B	$1.01 B	$1.98 B
Percent of Project Cost Saved	8.32%	5.01%	3.78%	3.12%	5.79%
Return on Investment	200:1	118:1	96:1	80:1	146:1

The considerations presented in this paper do not address another dimension of VE, related to environmental/social impact and resilience. These areas have to be addressed separately in order to understand the full picture of VE.

2. SHORT DESCRIPTION OF VE PROCESSES

General description of VE process flow can be illustrated as follows:

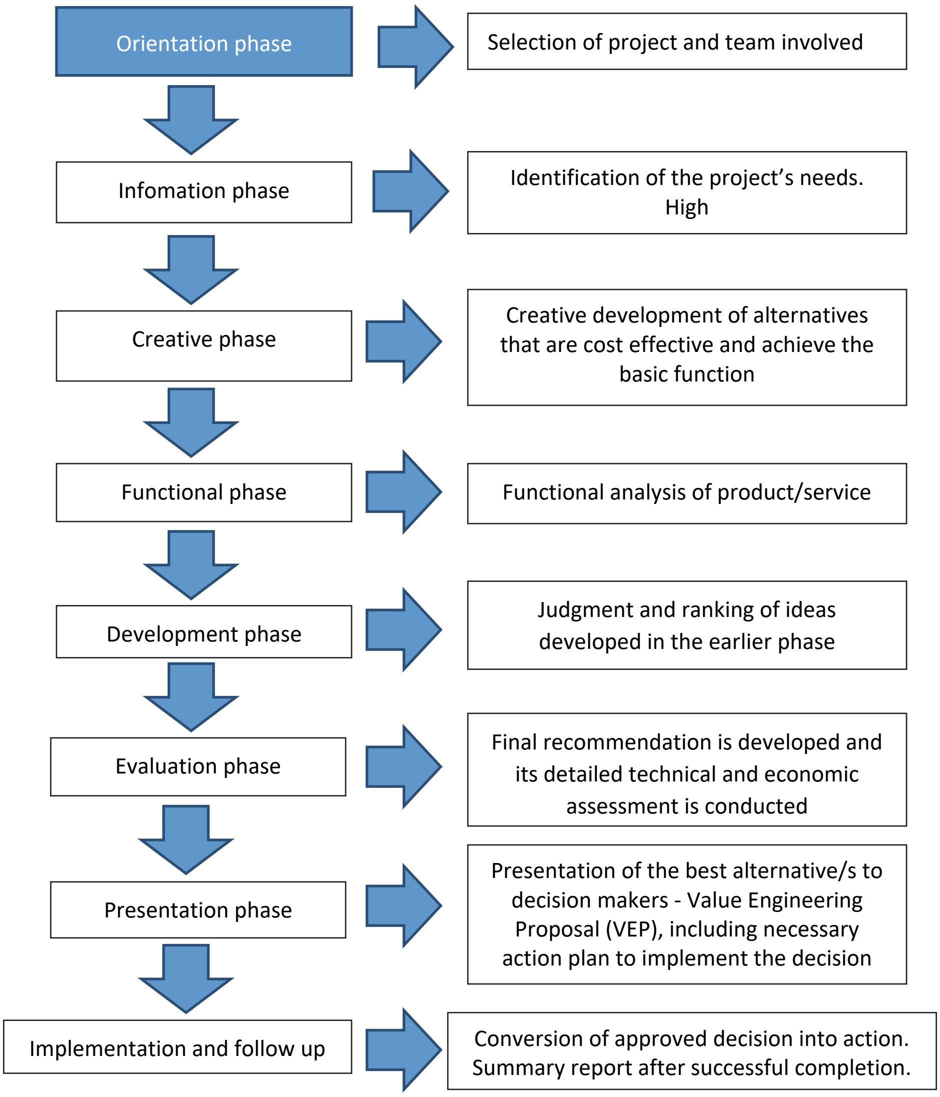


Fig.2 Process flow of VE implementation

In a nutshell, the process is a systematic review and analysis of a project during its various stages by a person/team not involved in the original idea. The process aims at ensuring the needed functions safely, reliably and efficiently at the lowest overall cost, while improving project value and quality and reducing the completion time [2], [5].

This approach can lead not only to alternative solutions that are beneficial to the project but also can attract bids from contractors who initially were discouraged by the project's technical specifications. In the USA, FHWA encourages all DOTs to participate in the VE program and applies share benefits concept with contractors. Polish VE practice mainly follows clause 13.3 of the FIDIC conditions [6], although the Polish Board of Roads is now preparing for introducing certain modifications in this regard.

3. LIFE CYCLE COST

For every product/project, its life cycle can be defined. These phases/cycles are:

- planning/designing,
- production/ construction,
- service,
- maintenance/repair,
- replacement/demolition.

During these stages an obvious degradation of a product (bridge, road, etc.) will occur. Both expenses and technical conditions are related to each other and they are spread over in time. The picture below illustrates their nature.

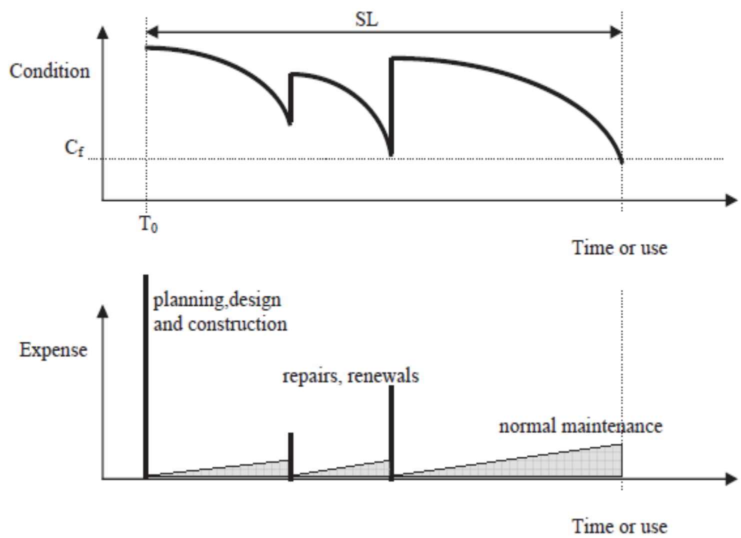


Fig. 3. Change of condition and expenses of any product during its service life (SL)

This leads to the following conclusion related to cost analysis: in order to have a complete cost analysis result one should look at life-cycle cost. Lifecycle Cost Analysis (LCCA) is the desired approach from the job owner prospective as it covers all expenses borne throughout the whole life cycle as well as takes into account cash flows in time. To illustrate the full picture of the LCCA one can use the following simplified formula (1) [8], [9]:

$$PV = A + PVAs + PAr + PVrs \tag{1}$$

where, *PV* – present value of total cost
A – initial investment cost (including design and construction)
PVAs – present value of future repairs
PVAr – present value of future maintenance costs
PVArs – present value of future replacement/ reconstruction costs

An LCCA approach commonly applied by FHWA in bridge engineering is presented in Figure 4 [7].

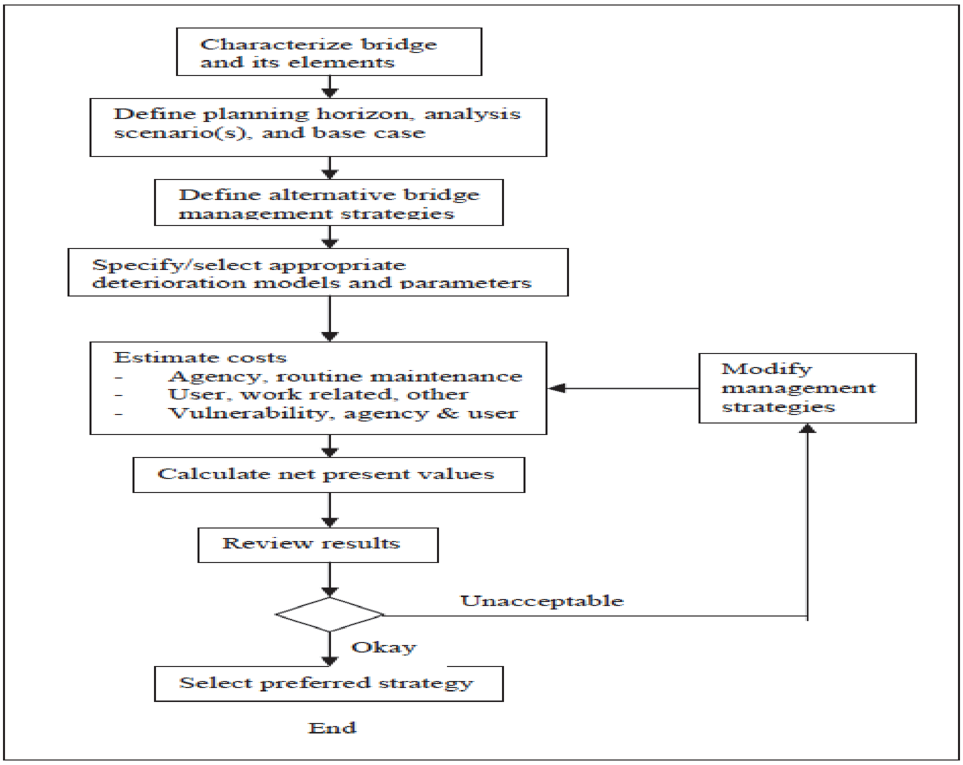
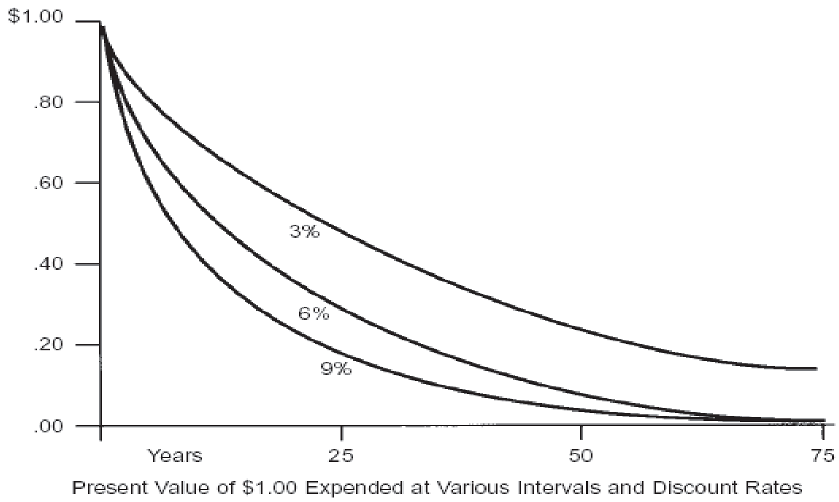


Fig. 4. LLCA in bridge engineering after NCHRP [7]

Besides technical aspects including design, construction, maintenance and repair, formula (1) also incorporates financial items.

As commonly known in economics the later money is expended, the better. This simple rule is illustrated in Figure 5 below, showing the present value of one US dollar spent at various time intervals assuming various discount rates. This picture is simplified as it is not adjusted for inflation. However, the higher the discount rate and the later the spending the less present value (PV) of USD spent.

Present Value of $1.00 Expended at Various Intervals and Discount Rates			
	Discount Rate		
Year	3%	6%	9%
0	1.00	1.00	1.00
25	.48	.23	.12
50	.23	.05	.01
75	.11	.01	.01



Picture 5. Present value (PV) of future spend of 1 US dollar at various discount rates

The formula relating future spending to net present value (PV) for the elements of formula (1) can be shown as:

$$PVAs = As/(1+dr)^n \quad (2)$$

$$PVAr = Ar * ((1+dr)^n-1) /(dr(1+dr)^n) \quad (3)$$

$$PVArs = Ars/ (1+dr)^n \quad (4)$$

where

$$d_r = (1+d)/(1+I) - 1 \quad (5)$$

I – inflation rate
d – discount rate

dr– real discount rate
n – number of years after completion of construction works when repair/replacement occurs
As – cost of the planned repair
Ar – recurring annual maintenance cost
Ars – replacement cost
PV – present value

4. VALUE ENGINEERING OF BURIED FLEXIBLE STRUCTURES

Buried flexible structures very often come as a “second choice”, or an alternative bid. It simply follows from the fact that other products, especially concrete, have been widely and traditionally applied as the first option in many projects. In the vast majority of cases an alternative solution with the use of a buried flexible steel structure appears at a construction phase where it is challenging to obtain approval for construction technology change. Nevertheless, in many cases it is quite possible and appropriate handling of VE procedures is necessary to ensure successful change implementation. One needs to be observant though of what kind of contract used in the project - is it build, is it design and build or is it design/build and maintain? In most cases the analysis performed by a contractor who has design/ build or build options is to minimize costs at the design/ design construction stage. However if a contractor is also responsible for maintaining the road/ structure over a period of time after its construction, his perspective is more like the ultimate owner perspective. Then maintenance, repairs, replacement and cost of money in time matters. From the job owner perspective one of the fundamental issues is to ensure the required service life-time for any type of bridge/culvert. This leads to technical consequences in terms of required maintenance, repairs and replacement costs spread over time. In many countries the design life time for bridges / including corrugated bridges is 100 years. It can be mistaken a bit as for traditional bridges various life time periods are addressed differently for different bridge components like deck, supports etc. Example 1 below demonstrates a possible alternative VE process for selecting a buried corrugated steel structure vs concrete underpass.

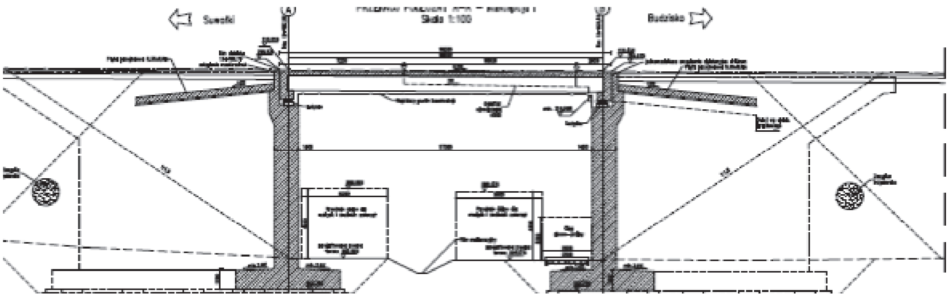
Example 1

The first example does not take into account the possible change of foundations and addresses only the main structural part of the bridge with shallow foundation (strip). It assumes repairs and maintenance as for any concrete bridge / corrugated bridge.

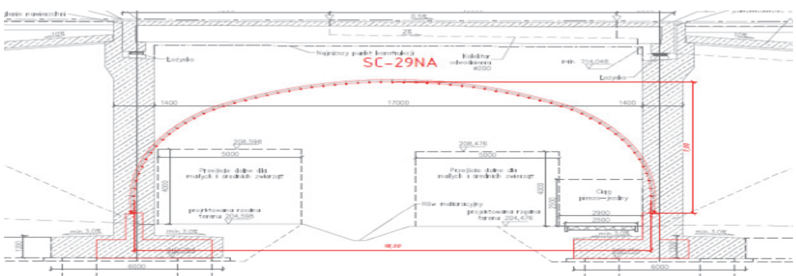
Fig. 6. Two bridges having the same function – a) concrete,
b) buried corrugated steel bridge

Parameters of the analyzed structures:

a) span: 17.0 m; cross direction length: 29 m



b) span: 18 m, cross direction length (bottom length): 56 m, (no head walls)



	LCCA MODEL				
	FILL IN GREEN				
1/	function		Underpass		
2/	load class		A	Polish standard	
3/	design life		100	years	
4/	environment		medium aggressive		
5/	span		17	18	m
6/	bottom length		29	56	m
7/	cover		0	3	m
8/	thickness of the wall		Alt 1	Alt 2	Alt 3
	[mm]		n/a	7/ 5,5	0
9/	Alternatives		Alt 1	Alt 2	Alt 3
			Concrete	Corrugated steel	
10/	material life time (years)		100	100	0
10/	total investment costs [pln]		Alt 1	Alt 2	Alt 3
			2421000	2250000	0
11/	REPAIRS COST	YEAR OF SERVICE	Alt 1	Alt 2	Alt 3
	[pln]	10	137152	0	0
		20	345509	0	
		30	137152	100000	0
		40	345509	0	
		50	137152		
		60	345509	100000	
		70	137152		
		80	345509		
		90	137152	100000	
		100			
			2067794,08	300000	
12/	AVERAGE ANNUAL MAINTENACE COST		Alt 1	Alt 2	Alt 3
	Ar [pln]		1340	650	0
13/	REPLACEMENT COST				
		YEAR	Alt 1	Alt 2	Alt 3
		100	3300000	2500000	0

NOMINAL DISCOUNT RATE	d=	5%	5%
AVERAGE ANNUAL INFALTION	I=	2%	2%
REAL DISCOUNT RATE	dr=	2,94%	2,94%

Net Present Value	Alt.1	Alt.2
NPV=	**3262832**	**2475450**
INVESTEMENT	**Alt.1**	**Alt.2**
A=	**2421000**	**2250000**
SELECTION	0	Alt.2

Example 2

The second example (Example 2) demonstrates the choice between reinforced concrete pipe (RCP) and corrugated steel pipe (CSP) that has two different corrosion protection systems (Zn 600- 600g/m2 and polymer coating Zn 600 + 300 um of trenchcoat (TC)). All pipes have the same internal diameter of 1500 mm.

Fig. 6. Three pipes used to build a culvert– a) CSP galvanized b/ CSP in TC c) RCP (reinforced concrete pipes)

	LCCA MODEL				
	FILL IN GREEN				
1/	function		culvert		
2/	load class		A	Polish standard	
3/	design life		100	years	
4/	environment		medium aggressive		
5/	span		1500	mm	
6/	bottom length		20	m	
7/	cover		1,2	m	
8/	thickness of the wall		**Alt 1**	**Alt 2**	**Alt 3**
	[mm]		2	2	70
9/	Alternatives		**Alt 1**	**Alt 2**	**Alt 3**
			HC Zn600	HCTC	concrete pipes
10/	material life time (years)		25	100	100
10/	total investment costs		**Alt 1**	**Alt 2**	**Alt 3**
			80000	95000	120000
11/	REPAIRS COST	YEAR OF SERVICE	**Alt 1**	**Alt 2**	**Alt 3**
	[pln]	25	30000	0	0
		40	20000	20000	
		50	20000	0	20000
		75	20000	20000	
12/	AVERAGE ANNUAL MAINTENACE COST		**Alt 1**	**Alt 2**	**Alt 3**
	Ar [pln]		500	300	200
13/	REPLACEMENT COST				
		YEAR	**Alt 1**	**Alt 2**	**Alt 3**
		100	80000	140000	165000

NOMINAL DISCOUNT RATE	d=	5%	5%	5%
AVERAGE ANNUAL INFALTION	I=	2%	2%	2%
REAL DISCOUNT RATE	dr=	2,94%	2,94%	2,94%

Net Present Value	**Alt.1**	**Alt.2**	**Alt.3**
NPV=	**124453**	**120898**	**140210**
INVESTEMENT	**Alt.1**	**Alt.2**	**Alt.3**
A=	**80000**	**95000**	**120000**
SELECTION	0	Alt.2	0

Sensitivity of the results shows that by assuming the same amount of spend in the future and by changing only the financial parameters (real discount rate) Alternative 1 becomes priority when the real discount rate is equal to 3.86%. If we play with investment cost then at investment cost of Alternative 3 equal to PLN 100500 Alternative 3 is the most attractive. When using alternative replacement costs for galvanized CSP at level of PLN 60000, Alternative 1 becomes the priority. The sensitivity analysis opens up options for optimal design of buried flexible structures reflecting all life-cycle aspects.

5. SUMMARY

Value engineering (VE) reaches out to another dimension of engineering practice outside the daily routine. It shows engineers options and opens up room for improvements and optimization of designs/ contracting works. It saves money. This tool gives unbiased judgment for both contracting parties as it uses common denominators that could be identified by the Contractor and Job Owner. Buried flexible structures having various technological advantages will broadly enjoy the use of VE as an additional tool for finding optimal solutions and creating a win-win situation between Job Owners and Contractors. Understanding the technological implications is of crucial importance in using VE. Users must be aware of product life time constraints, maintenance/ repairs needs as well as structural and functional constraints. Thus, VE is a link connecting the world of technology with the world of economy.

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