Case Study Through the Application of VE – Tunnel Construction

Author: José L. Ortiz Reyes
Advisor: Cristhian Villalta Calderón, PhD.
Civil Engineering Department

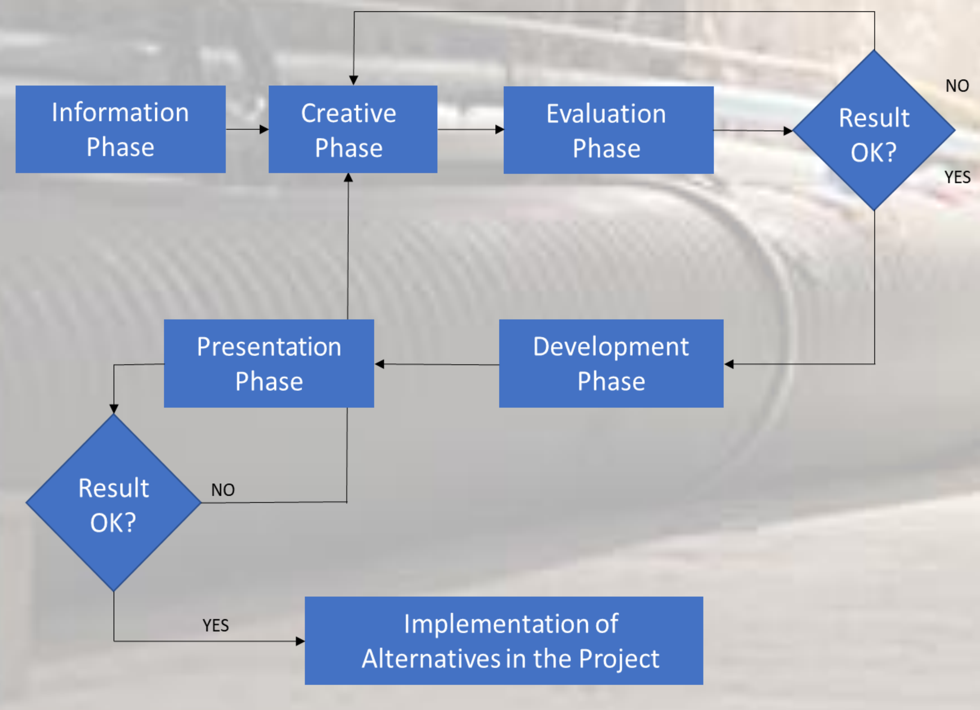
Abstract

Value engineering is an effective approach used by many industries that aims to analyze a product or project to optimize it while reducing costs. VE does not just focus on cost reduction; its purpose is functional cost-effectiveness. This project presents the five phases of the VE process: information, creative, evaluation, development, and report applied to a construction project. A case study was performed on a 5-mile stormwater drainage tunnel where the original design includes two different cross-sections to be excavated using a tunnel boring machine. The alternative was proposed by the contractor, and it resulted in a solution that provides the following advantages: improved schedule, cost savings, add functionality, and simplifies operation and maintenance in the long run. This alternative result in a cost-saving of $1.4 million. VE analysis developed by the builder, or the contractor adds significant value or advantages to the project due to its expertise in construction methods.

Background and Objectives

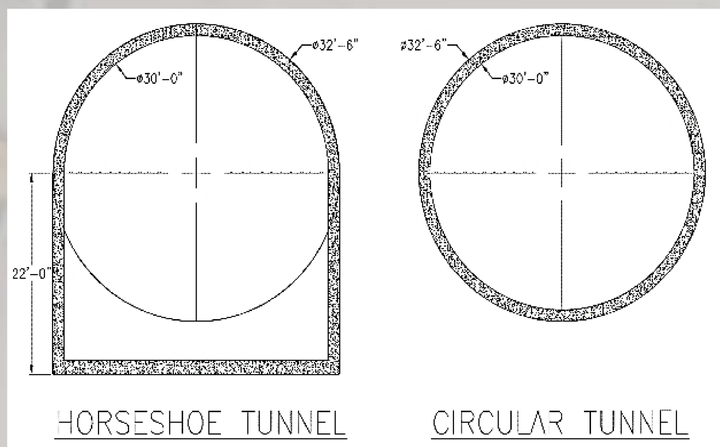
Construction companies are always looking for ways to reduce costs without compromising quality and functionality, which also translates to improving the schedule [1]. This last statement is referred to as Value Engineering (VE), which originated in the 1940s. Value engineering is defined as “a systematic application of recognized techniques by multi-disciplined team(s) that identifies the function of a service or product, establishes a worth for that function; generates alternatives through the use of creative thinking; and provides the needed functions, reliably, at the lowest overall cost” [2]. It is important to recognize that there is a difference between cost reduction and value engineering. As mentioned before, the construction industry has been improving since the beginning of times, especially in the last century with all the new technologies, therefore reducing the cost of construction was easily done. In contrast, VE does not just focus on cost reduction; its purpose is functional cost-effectiveness. It is not looking for a way to make the construction easier or deliver a cheaper product. It must bring a better value while at the same time bringing financial benefit.

The main objective of this project is to apply the value engineering job plan to a 5-mile tunnel construction project by evaluating an alternative without compromising the functionality of the deliverable while reducing cost and improving the schedule.

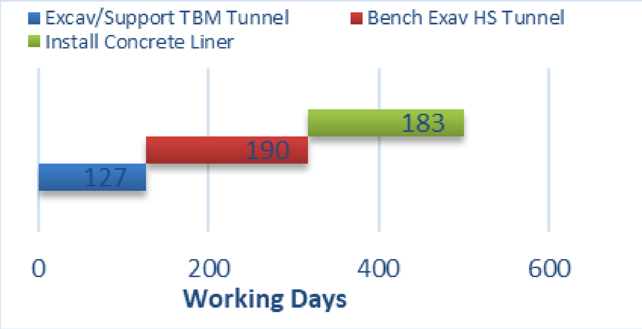


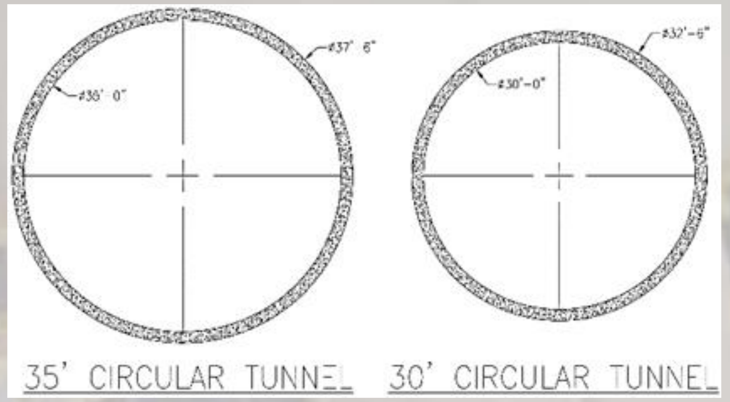
Case Study

Tunnel construction is becoming the preferred method of underground utility construction on heavily urbanized zones due to the lack of space. Utilities like water, wastewater, and storm sewer are often required to be replaced with a larger size system due to the city’s growth. VE starts with the information phase. Technical data, standards, and drawings were collected during this phase. The project was divided into four key elements: intake structures, shaft structures, lateral tunnels, and the primary tunnel. After compiling all the available information, the creative phase took place. In this phase, each key element was evaluated based on functionality and cost. The key element that provides more value engineering opportunities is the primary tunnel. This element is the most expensive and is also on the critical path of the overall project schedule. The proposed stormwater drainage tunnel was designed with two different cross-sections, a circular cross-section to handle 15,000 ft3/sec (reach #2) and a horseshoe shape cross-section to handle 20,000 ft/sec (reach #1).Thus, it is typical to have various tunnel diameters or cross-sections in a tunnel construction project; tunnel contractors will require to utilize different size Tunnel Boring Machines (TBM) to complete each reach or tunnel runs for a specific cross-section. Due to easements, the access to this cross-section change is offset from the tunnel centerline alignment. For this reason, the original design proposes a 30’x 35’ horseshoe cross-section for reach #1 and a 30’circular cross-section for reach #2. The horseshoe cross-section will allow the use of the same 30ft diameter TBM and then complete the horseshoe bottom using a roadheader. To overcome this problem, the proposed alternative consists of providing a similar circular cross-section area that can effectively replace the horseshoe to eliminate the extra cost and time of the bench excavation activity.

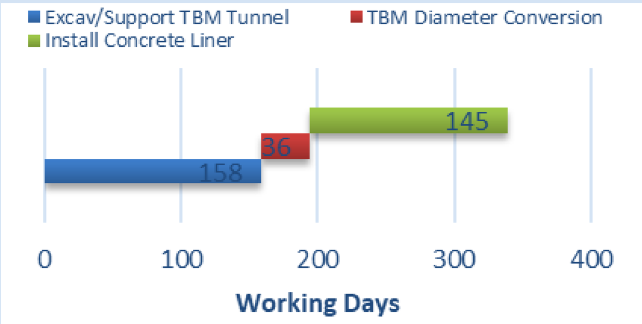


	Original Design		Aletrnative Design	
	Reach #1	Reach #2	Reach #1	Reach #2
Shape	Horseshoe	Circular	Circular	Circular
Excavated Dimensions (ft-in)	38'-9" X 32'-6"	32'-6" Ø	37'-6" Ø	32'-6" Ø
Finish Dimensions (ft-in)	35' X 30'	30' Ø	35' Ø	30' Ø
Concete Liner Thickness (in)	15	15	15	15





Reach #1 Cost Comparison (in Millions)		
Cost	Horseshoe Cross-Section	Circular Cross-Section
Equipment	$3.7	$3.5
Materials	$47.7	$48.6
Labor	$7.5	$5.1
Design	$0.0	$0.3
Total	$58.9	$57.5
Total Savings	$1.4	



In the third phase of VE, the design alternative is evaluated. To evaluate the feasibility of this alternative, the first step was to determine the equivalent circular cross-section area that can provide the same capacity as the horseshoe shape. Calculations showed that the equivalent would be a 35ft diameter. Once determined that the alternative proposed for reach #1 excavation is feasible, the development and recommendation phase begin. In this phase, an in-depth analysis of the life cycle cost estimations and drawings were prepared. Original design costs were broken down for the primary tunnel of reach #1, which is the alternative in evaluation. The Cost Comparison table shows the original design and the alternative. The breakdown is considering the typical cost aspects of construction, which are equipment, material, labor, and design. The cost of this special equipment represents a saving on the equipment cost of the alternative design.

The original design requires a total of 500 working days (WD) to complete reach #1; 38% of this time frame belongs to the bench excavation. The developed schedule for the alternative design shows clear schedule improvement. Although the TBM excavation will consume more time than the original design, the alternative design will require 339 WD to complete reach #1. This represents an effective reduction in the schedule of 161 WD. The schedule reduction represents savings in the labor of $2.4M. However, the alternative design’s total savings are reduced due to the higher cost of material and the design cost. The potential cost-saving that this alternative can provide is estimated at $1.4M. The primary tunnel is in the critical path of the overall project schedule; the schedule reduction offered by the alternative design can be used as contingency days in the schedule for any unforeseen issue that the project may encounter that caused delays. Also, this improvement can potentially offer savings in overhead costs.

The functional improvement of this job plan is focused on the operation and maintenance of the tunnel. This tunnel is equipped with a dewatering station; this station will drain the entire tunnel as needed to allow maintenance and inspection. Stormwater systems carry debris and sediments. Looking at the tunnel profile, inverted siphon conveyance tunnel, we can expect that due to its geometry, it will collect and accumulate all the debris and sediments of its drainage basin in reach #1. Evaluating both cross-sections, the original design, and the alternative design, it is expected that the horseshoe shape will allow for more sediment accumulation due to its geometry. Circular cross-sections are expected to self-clean because it does not contain corners where sediment will likely accumulate. The circular shape will provide a reduction in operation and maintenance costs to the owner. After the development phase is completed, the final phase of reporting takes place. Since the alternative presented is on the critical path, implementing this alternative is time sensitive. The designer of the alternative and TBM manufacturer needs to work simultaneously to expedite details, requirements, and recommendations. These details include the excavation diameter 37’-7”, the concrete liner thickness 15”.

Conclusions and Future Work

The value engineering methodology is an effective way to improve a project. VE can be applied to infrastructure and construction projects. These projects are very costly and have exceptionally long design processes. When studied in detail, there are always alternative solutions to consider that add functionality. However, in this industry, there is resistance towards VE. This industry has different entities involved, one is the builder, and the other is the designer. Engineers spend years designing and developing plans and specifications without really understanding construction methods. A VE analysis developed by the builder or the contractor adds significant value or advantages to the project due to its expertise in construction methods. In this case study, the solution or alternative was proposed by the contractor, and it resulted in an alternative that provides the following advantages: improved schedule, cost savings, add functionality and simplifies operation and maintenance in the long run. This alternative result in a cost-saving of $1.4 million. The diameter conversion of a TBM inside the tunnel has never been done before; this can represent a disadvantage of the alternative; unforeseen issues can arise that can potentially impact the schedule and cost. For this reason, it is important to evaluate the total savings after the process is completed before sharing savings. It is expected that in a lump sum price contract, the owner will want to have some of the savings.

Tunnel design and construction are becoming more popular nowadays because cities are fully developed and there is a lack of space for new utility construction, and it is suggested that Value Engineering analyses and practices are conducted, especially in large-scale projects since every project will provide different VE opportunity.

References

[1] N. L. Rane, "Application of Value Engineering Techniques in Building Construction Projects," *International Journal of Engineering Sciences and Research Technology*, pp. 857-863, 2016.

[2] P. Mahajan, M. Chamarthi, V. Bangar and P. S. Patel, "A Case Study Analysis Through The Implementation Of Value Engineering," *International Research Journal of Engineering and Technology (IRJET)*, pp. 2472-2477, 2019.