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TRADITIONAL DESIGN & VALUE ENGINEERING: ADVERSARIES OR PARTNERS?

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Abstract

Value engineering (VE) studies are sometimes not performed on transportation infrastructure projects because the design team or owner believes VE is already being done in the traditional design process. Value practitioners don't see it that way. Why? Because VE is a separate and distinct process that is performed using the value methodology. They know that the value methodology does things that traditional design doesn't do, and as a result, often discovers design solutions that the traditional design process does not.

Yet, this answer is generally not very persuasive to the VE skeptic because of a lack of understanding of what the value methodology is. The author's over 45 years of transportation design experience, coupled with his nine years of VE experience have led him to the belief that VE examples are often far more instructional and persuasive in affirming VE's effectiveness. To support this belief, this paper offers five examples of value-improving design solutions that would likely only have been discovered via a design VE study. The paper then comments on some of the things VE does that the traditional design process doesn't do, and concludes with the proposition that the traditional design process and VE are not redundant, nor are they competitive adversaries (as they are sometimes viewed), but rather, are collegial, interdependent partners in achieving an optimum design.

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INTRODUCTION

Have you ever heard this statement?

> "We don't need a value engineering (VE) study. We already do VE in our regular design process." – Project Manager

VE practitioners don't agree. Why?

The typical VE practitioner answer might be: "Because the regular/traditional design process doesn't include a systematic process by a multidisciplinary team to improve the value of a project through the analysis of its functions" (Bolton, et al, 2008, vii)- the value methodology.

As informational and correct as this answer might be, it is generally not very persuasive to the VE skeptic. Rather, the author has found that VE examples are often more instructional and persuasive than VE theory. To support this belief, this paper offers five examples of cost-saving design solutions that would likely only have been discovered via a design VE study.

I-69 Section 4

Example No. 1 is from a value study for I-69 Section 4 owned by the Indiana Department of Transportation (INDOT). I-69 Section 4 consisted of a new 27-mile section of interstate freeway in rural Indiana. The project included three interchanges, 47 bridges, and traversed an extreme ridge/valley rock terrain. Its estimated construction cost was $567 million.

One of the value targets during the workshop was twelve waterway bridges. Some of these bridges crossed both a stream and an adjacent public road or other terrain feature. However, two of them only crossed streams and their length was set by the required waterway opening and allowable backwater. The baseline design concept for the waterway-only bridges was to set bridge waterway openings (and corresponding bridge lengths) for a Q_{100} = 0.14 ft. backwater in accordance with INDOT design standards. This depth of backwater was 0.86 ft. less than the 1.0 ft. legal maximum backwater.

From function analysis, it was determined that a basic function of the waterway structures was "reduce impacts" and a required secondary function was to "limit head/backwater." During the creative phase, the team asked several key VE questions. The first question was, "Is that much secondary function (0.14 ft. backwater) needed to reduce impacts?". The answer was "no" because the upstream land was inaccessible, undevelopable rock outcrops. The second question was, "What is the cost of reducing impacts that much?". After some calculations for a shorter bridge that allowed 1.0 ft. of backwater, the answer was found to be $600K for the two bridges.

The third question was, "Is the cost of reducing impacts that much (0.14 ft. backwater) worth the benefit?". The answer was "no" because the benefit was very low and the cost of providing that benefit was very high. The fourth question was, "Is 'compensate impacts' with a shorter bridge a better value than 'reduce impacts' with a longer bridge?". The answer was "yes" because the cost of a flood easement to "compensate impacts" was insignificant compared to longer bridges that "reduce impacts."

The team therefore developed a VE concept for the I-69 bridge over Indian Creek, which included the following features:

- Shorten waterway bridge by 133 ft. (30% reduction in length)
- Increase backwater by 0.86 ft. to 1.0 ft. legal maximum
- Purchase flood easement for increased backwater impacts
- Total accepted VE cost savings (two bridges): $600,750

The traditional design met INDOT standards, but it was a poor value (low function/cost) within the project ridge/valley terrain. It took a VE study to ask key VE questions, analyze the functions of the waterway structures, eliminate excess functions, and propose a better-value design solution.

US 421 Urban Street Realignment

Example No. 2 is from a value study for the US 421 urban street realignment project (Project 421) in Madison, Indiana, on the north approach to the Milton-Madison Bridge over the Ohio River in southern Indiana. Project 421's scope was to realign 0.32 miles of two-lane US 421 to eliminate three 90-degree, stop-controlled turns through a residential area. Its estimated construction cost was $10.6 million.

The baseline design concept included extending US 421 north from 2nd Street to SR 56, signalizing the new channelized intersection at SR 56, and constructing a 360-ft. long bridge over 2nd Street due to the 23-ft. grade differential between 2nd Street and SR 56. **See Fig. 2A**. One value target was the bridge over 2nd Street.

From function analysis, it was determined that the basic function of the bridge was "reduce grade" and that two secondary functions were "eliminate conflicts" and "span [2nd Street] right-of-way." This was somewhat of a surprise to the team because the basic function was originally thought to be "eliminate conflicts" so that US 421 traffic would not have to stop at 2nd Street.

During the creative phase, the team asked several key VE questions. The first question was, "How else can we reduce grade?". The answer was to lengthen the grade by curving the horizontal alignment to the west, which lengthened the distance between 2nd Street and SR 56, and thereby reduced the grade.

The second question was, "How else can we address the conflicts at 2nd street?". It was noted that the 2nd Street cross traffic was very light and would not require a traffic signal at 2nd Street. Stop signs on 2nd Street would adequately "manage conflicts" (rather than "eliminate conflicts") and thereby provide free-flow on US 421 just as a bridge would.

Figure 2A **Baseline Concept**

The third question was, "What is the cost of reducing grade and eliminating conflicts at 2nd Street via a bridge?". After some calculations for a curved-to-the-west alignment that met vertical grade criteria and eliminated the bridge and signalized intersection at SR 56, the answer was found to be over $4 million.

The fourth question was, "Is the cost of a bridge worth the functions provided - "eliminate conflicts" and "span right-of-way?". The answer was "no" because free-flow on US 421 would be provided with two stop signs on 2nd Street, and the incremental value of eliminating the light number of conflicts at 2nd Street (function/cost) vs. managing them with stop signs was very low.

Figure 2B **VE Concept**

The team developed a VE concept for Project 421, which included the following features (**see Fig. 2B**):

- Curve US 421 to the west
- Eliminate signalized intersection at SR 56
- Eliminate grade-separation structure at 2nd St.
- Use at-grade intersection with stop-sign control on 2nd St.
- Total accepted VE cost savings: $4.9 million

During the workshop, numerous alternatives were identified for performing the "eliminate conflicts' and "span right-of-way" functions (to develop a more economical bridge). But the analysis of functions led to a much more economical design solution (project cost cut almost in half) that adequately fulfilled the purpose and need of the project. It took a value study to ask key VE questions, analyze the functions of the 2nd street bridge, eliminate excess functions, and propose a better-value design solution.

This project also illustrated the impact a value study can have even on a smaller project. The 46.2% of construction cost saved on a $10.6 million project freed up nearly $5 million for INDOT to use on other projects.

US 51 Expressway

Example No. 3 is from a value study for the US 51 Expressway project owned by the Illinois Department of Transportation (IDOT). The US 51 Expressway project consisted of 7.04 miles of rural, limited-access, 4-lane expressway in central Illinois. The project included twin mainline structures over the Union Pacific Railroad (UPRR), twin mainline structures over IL Rte. 16 at the US 51/IL Rte. 16 interchange, and traversed very flat agricultural land. Its estimated construction cost was $50 million.

One of the value targets was earth fill. Because of the flat terrain, substantial borrow material would be needed for the approach embankments at the UPRR and IL Rte. 16. The baseline concept for the profile grade at the two mainline structures was to utilize a 2% (desirable) maximum grade.

From function analysis, it was determined that the basic function of the earth fill was to “elevate roadway” and a required secondary function was to “limit deceleration.” During the creative phase, the team asked several key VE questions. The first question was, “Why use desirable 2% maximum grade vs. the allowed 3% maximum?” The ensuing discussion noted that maximum grades are primarily to limit deceleration of trucks on sustained up-grades or limit acceleration on sustained down-grades. The second question was, “How much truck deceleration would occur on a 3% grade vs. 2% grade?”. The team noted that this portion of expressway had low truck volumes and that the maximum profile grade only occurred at the point of reverse vertical curve (PRVC). Thus, the truck deceleration differential would be minimal.

The third question was, “What is the cost of borrow to limit (reduce) truck deceleration?”. After developing a 3%-maximum profile grade line and calculations of fill quantities, the answer was about $1.2 million. The fourth question was, “Is the cost of borrow worth reducing that much deceleration?”. The answer was “no” because the deceleration differential was insignificant compared to the cost of borrow to achieve that performance differential, and was therefore a poor value (function/cost).

The team therefore developed a VE concept for the profiles at the UPRR and IL Rte. 16, which included the following features:

- Utilize 3% maximum grade vs. 2% at the UPRR and IL Rte. 16
- Low truck ADT, short length of maximum grade, reduce required borrow
- Total accepted VE cost savings: $1.2 million

The traditional design met IDOT standards, and responded to FHWA preference for utilizing desirable design criteria where feasible, but using the desirable maximum grade did not consider the context of the project (flat terrain) and the very limited length of the maximum-grade application. Therefore, it was a poor value (function/cost low). It took a VE study to analyze the functions of the earth fill, discover the hidden cost of the 2% grade, eliminate the excess function, and propose a better-value design solution.

IL 104 Bridge Over Illinois River

Example No. 4 is from a value study for the IL 104 Bridge over the Illinois River project owned by the Illinois Department of Transportation (IDOT). The IL 104 Bridge over the Illinois River project consisted of the replacement of the existing truss bridge at Meredosia, Illinois, with a 2740-ft. long, 10-span bridge with tied-arch navigation span. The project included an earth-fill west approach and an MSE-wall-retained east approach within the city limits of Meredosia. Its estimated construction cost was $45 million.

Two of the value targets were the bridge substructure and the earth borrow on the west approach. The baseline concept included use of a 4% maximum grade on both sides of the river and a west approach span that provided a standard local-road minimum clearance over the west-bank levee of 13 ft.- 5 in.

From function analysis, it was determined that a basic function of the substructure and earth fill was to "elevate roadway" and a required secondary function was "limit speed-change" (both deceleration and acceleration). During the creative phase, the team asked several key VE questions. The first question was in regard to the 4% maximum grade. During the information phase, it was learned that the existing bridge used a 6% maximum grade and that the maximum grade for this classification of roadway was 6%. However, since the new bridge was on a new alignment one block north of the existing alignment and that there was a school nearby, a 4% grade had been specified for safety reasons. So, the question was asked, "Is 4% maximum grade needed on the west side of the river?". The answer was, "no" only on the east side."

The second question was, "Does the bridge need to clear the levee?" This question was asked because the existing bridge did not clear the levee. It terminated at the levee. The third question was, "If it must clear the levee, by how much?'. Since the existing bridge did not clear the levee, the team initially proposed a VE concept that terminated the bridge at the levee. However, a later clarification from IDOT indicated that it must provide for a maintenance pickup truck.

The fourth question was, "What is the cost of substructure and borrow to limit (reduce) speed-change on the west side of the river and clear the levee by the baseline distance of 13 ft.-5 in.?". After developing a 5% maximum grade profile on the west side of the river and calculations for reduced substructure and borrow, the answer was found to be over $700K. The fifth question was, "Is the cost of limiting speed-change on the west side of the river and clearing the levee by the baseline distance worth the cost?". The answer was "no" because increasing deceleration inbound and increasing acceleration outbound on the west side of the river due to the steeper grade is actually better performance operationally. In addition, the lower clearance for a pickup truck met the operational need.

The team therefore developed a VE concept for the profile grade of the bridge, which included the following features:

- Use 5% maximum grade on the west side of the river; 4% east side
- Reduce the levee clearance to 8 ft.- 5 in.
- Reduce west-approach borrow & substructure height
- Total accepted VE cost savings: $764,000

The traditional design met IDOT standards. But in the case of the 4% grade, a bridge with a symmetrical grade line was designed without considering the separate operational requirements of each side of the river and their associated costs. In addition, the operational requirements of the levee did not require a standard local street clearance. In both cases, excess function was built into the design. It took a VE study to ask key VE questions, analyze the functions of the substructure, earth fill, and maximum profile grade to discover and eliminate these excess functions and their costs.

Morgan Street Bridge Replacement

Example No. 5 is from a value study for the Morgan Street Bridge replacement project. In addition to 3,400 ft. of urban street reconstruction, the project included replacing the existing concrete, spandrel-arch bridge over the Rock River and dual Illinois Railroad tracks with a three-span, tied-arch bridge in Rockford, Illinois. The estimated construction cost was $21.8 million.

Two of the value targets were the bridge main span and the RR flagger. The baseline concept for the bridge consisted of a 300-ft. main span with vertical deck hangars, and 116-ft. approach spans. The main-span piers were in the river, and as such, required temporary cofferdams to construct them. **See Fig. 5A**. During the site visit, the team noted the high velocity of the river and was advised of the scour-prone riverbed. The baseline concept included a RR flagger full time for the duration of the project along with mandatory railroad insurance.

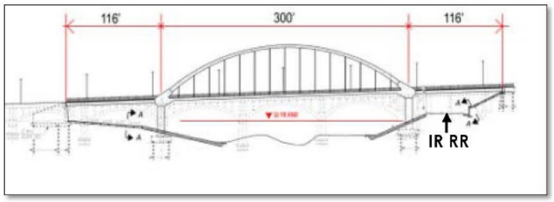

Figure 5A **Baseline Concept**

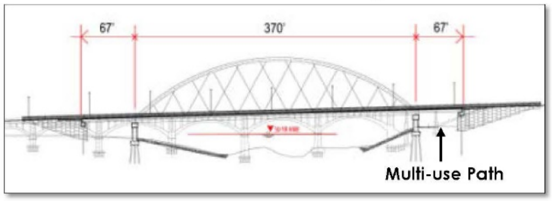

Figure 5B **VE Concept**

The accepted VE concept for the bridge included the following features (s**ee Fig. 5B**):

- Relocate IR RR permanently to the CCP RR
- 370-ft. main span vs. 300-ft. baseline main span, main-span piers out of the river
- East pier on former RR right-of-way, x-pattern (“network”) deck hangers
- Multi-use path under the bridge on former RR right-of-way
- Accepted VE cost savings: $815,000

How did this happen? It began with a simple VE question that was never asked by the design team, “How can the RR flagger and its cost ($240,000) be eliminated?” The answer was, “*Temporarily* relocate the IR Railroad traffic to the CCP Railroad on the west side of the river.” This idea was classified as a *design suggestion* because it was not possible to obtain an official answer from two railroads during the workshop. However, post workshop follow-up by the city found that both railroads accepted the idea, but wanted the IR relocation to be *permanent* so that an at-grade “diamond” crossing of the two railroads south of the project could be eliminated along with significant railroad operation & maintenance costs and liability exposure.

This unexpected agreement had a significant impact on the bridge design concept. The VE team had recommended that a single-span bridge concept that spanned the IR right-of-way and the Rock River be investigated by the design team. But when the city learned that the IR Railroad would be relocated to the CCP Railroad permanently, the city authorized the design team to “optimize” the bridge spans. This resulted in the optimized span arrangement of the VE concept above, which was now able to utilize the former IR right-of-way for one of its piers, and move both piers out of the river. The VE bridge concept resulted in VE cost savings of $815,000, which included the cost savings of RR flagger elimination.

In addition to the project benefits, the VE concept yielded four significant off-site benefits that accrued to the city and the railroads (**see Fig. 5C**).

1. Eliminated four at-grade street/rail intersections south of the project
2. Allowed the city conversion of abandoned RR right-of-way to a future multi-use path
3. Eliminated 0.9 miles of track and rail structure maintenance by the IR Railroad
4. Eliminated the O&M costs and safety concerns of the “diamond” track crossing for both railroads

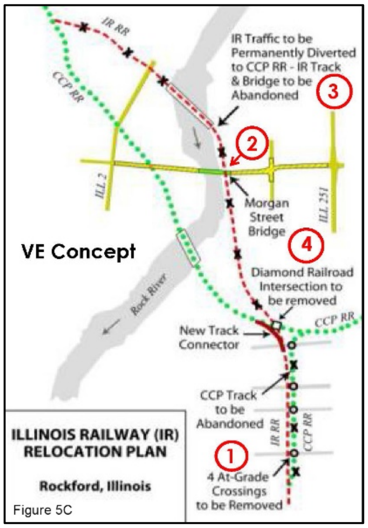

Figure 5C

The author believes that the design solution that emerged from this VE study and all the “bonus” off-site benefits would never have occurred through the traditional design process. The baseline design to VE design began with a simple question that was never asked during regular design: “How can we eliminate the flagger?”

WHY DOES VE DISCOVER DESIGN SOLUTIONS TRADITIONAL DESIGN DOES NOT?

As this paper has illustrated, VE often discovers value-improving design solutions that the traditional design process often does not. Why is this? The primary reason, as stated in the introduction, is that VE utilizes “a systematic process by a multidisciplinary team to improve the value of a project through the analysis of its functions.” That is, VE uses the *value methodology*. The value methodology offers a highly efficient, effective, and proven job plan, which is executed in a six-phase (information, function analysis, creative, evaluation, development, presentation). Based upon the author’s experience in both traditional design and VE, this paper proposes that the value methodology does certain things systematically that are not done systematically in the traditional design process. And though it is beyond the scope of this paper to describe all of them, a key difference in each phase of the VE job plan is summarized below.

Information Phase

The information phase of the workshop provides the team with a thorough understanding of the project purpose and need, how the baseline design fulfills the project purpose and need, and the cost of each major project component/function that contributes to fulfilling the project purpose and need. This information exchange offers the opportunity for the team to discover underlying, design assumptions that may be contributing to high-cost, low-worth components/functions.

Function Analysis Phase

The “analysis of functions” is unique to the value methodology and helps focus the team on alternative solutions that provide project functions at a lower life-cycle cost. During the function analysis phase, the team *asks a lot of questions* not asked in the traditional design process such as:

- What is the standard/past-practice design’s function?
- Is that function needed to meet purpose and need (or design objectives)?
- Is *all* that function needed to meet purpose and need (or design objectives)?
- Is there another less costly was to accomplish that function?
- Is there a less costly construction method than that required by the baseline design?

But why are these questions usually not asked during traditional design?

One reason is that traditional design often utilizes standard/past-practice designs and standards-driven designs. Standard/past-practice designs are proven solutions, so it’s considered a waste of time to identify and analyze their functions. Another reason is that surplus function(s) within traditional design solutions can sometimes provide a safety factor or contingency that give the design team a higher design comfort level, even though the project is costing more than purpose and need, or design criteria require. A third reason is that there is often little to no incentive for the design team to improve the value (function/cost) of standard/past-practice designs from the traditional design process. “Why reinvent the wheel?” philosophy can subtlely stifle inquiry and innovation. And finally, design consultants are sometimes dis-incentivized to pursue alternative designs by client pressure to lower design fees, firm pressure to minimize design liability or reduce effort to stay in budget, and by concern with displeasing clients that sometimes results from questioning the client’s scope/standard designs.

In contrast, one of the VE team's *primary jobs* is to ask these questions. As the example VE studies in this paper have demonstrated, the team's function-based questions and answers are one of the most important reasons value-improving design solutions are discovered in VE studies.

Creative Phase

The creative phase of the workshop invites alternative ideas from the team. But they are not evaluated until the succeeding evaluation phase. This separation of idea generation and idea evaluation is effective in preventing sometimes lengthy and unproductive debates of ideas as they are generated (Law, 2017,1). In addition, the evaluation phase's mechanisms for evaluating ideas using numerical scoring or voting provide an efficient and relatively objective, team-based rating of ideas against project performance criteria. Design decisions in traditional design are often made either based on cost alone, or intuitively based on experience, without a performance-based decision-making process.

Development Phase

The development phase turns creative ideas into clear descriptions, sketches, and preliminary costs. This allows a relatively quick check of the idea's impact on value by calculating the *value index* of the idea (idea performance rating divided by the revised cost of the project) and comparing it to the value index of the baseline project (baseline performance rating divided by the baseline cost). This comparison provides a rational ranking of creative ideas and a rational comparison of creative ideas to the baseline project. Traditional design usually compares only the cost of design alternatives without a rational, integrated way to compare *both* cost and performance.

Presentation Phase & Report

The VE study presentation and post-workshop report to senior, owner officials provide clear descriptions of VE proposals along with cost impacts. They are sometimes eye-opening to the design team and senior, owner officials because they often present innovative solutions not previously known to the organization, and/or disclose unneeded or excess function(s) and costs that were "hidden" within the standards/past-practice, baseline design. The evidence-based supporting function descriptions, performance ratings, sketches, costs, and value indices included in the report provide a sound basis for deciding upon acceptance or rejection of VE proposals by the design team and senior, owner officials (Law, 2017, 4-5).

Multi-disciplinary Team

In addition to the six-phase job plan, the value methodology's "multi-disciplinary team" brings together experienced subject matter experts (SMEs) with independent, "fresh eyes" from the applicable disciplines of the project, who then inject a huge, collective dose of expertise and experience into the workshop. Operating under the guidance of a VE-trained facilitator, the SMEs are able to define functions and ask the applicable VE questions described above, rate the performance of ideas with experienced engineering judgment, offer alternative creative ideas that synergize the team's collective experience, and develop value-improving alternative VE proposals.

A traditional design team may be multidisciplinary, but all the team members are rarely together for all the steps in the traditional design process. The traditional design team seeks cost-effective solutions, but rarely, if ever, identifies and analyzes the functions of the project in developing the preferred alternative design solution.

TRADITIONAL DESIGN/VE RELATIONSHIP

The author believes that the traditional design process and the VE process both have important, but separate, interdependent roles. Traditional design develops a baseline design that meets the purpose and need of the project along with a detailed cost estimate. VE analyzes the functions of the baseline design and offers alternative design concepts that provide equivalent performance at a lower life-cycle cost, improved performance at the same life-cycle cost, or improved performance at a lower life-cycle cost.

VE proposals very often propose eliminating unneeded or excess function(s)/costs. For example, in VE Example No. 1, the waterway bridges needed to "limit backwater," but they did not need to limit backwater as much as the baseline design. In VE Example No. 2, the vertical profile of the overpasses needed to "limit deceleration," but not as much as the baseline design. In VE Example No. 5, the secondary function "accommodate RR operations" was eliminated by railroad relocation along with two of the bridge's basic functions, "span railroad" (horizontally) and "clear railroad" (vertically).

To some degree, a traditional/standard design is like an off-the-rack suit. It fits the average person. No alterations or alteration costs are needed. It looks and fits great right off the rack. However, the off-the-rack suit doesn't fit persons smaller or larger than average. Without alterations, the suit exhibits poor value: it is too tight on a larger-than-average person; it is too baggy on a smaller-than-average person.

Similarly, the traditional/standard design fits the average project. No alterations to standard designs or alteration costs are required. But it doesn't fit non-average project conditions. Without alterations, the project can exhibit poor value: non-required functions, excess functions, more costly functions; and, excess cost to meet the purpose and need of the project. VE makes the necessary "alterations" (alternative VE concepts) to precisely fit (provide best value to) the "wearer" (the project purpose & need). **See Fig. 6**.

Figure 6

[1]Excess Function

CONCLUSION

The author believes that the most efficient and effective way to achieve the optimum design on a transportation project, is for the design team to develop a baseline design using the traditional design process, and then, for an independent VE team to conduct a VE study at key design stages (Bolton, et el, 2008,13): concept design (25-35% complete), detailed design (prior to 65-75% complete), and on some projects, at 95% complete for optimizing constructability. **See Fig. 7**. If only one VE study is to be performed, it is best performed at the concept design stage. This approach to design makes sure mandatory standards and criteria are met, the relevant standard/past-practice solutions are applied for efficiency and their proven performance, but performance-enhancing, cost-reducing, and/or value-improving alterations to the baseline design are made via VE to produce a best-value, optimum design solution.

Thus, from the author's perspective, traditional design and VE are complementary and non-redundant. Each performs a necessary and beneficial aspect of the design process. So, rather than being competitive *adversaries*, as these processes are sometimes viewed, they work in harmony with each other as collegial, interdependent *partners* (as shown in **Fig. 7)**, to achieve the optimum design for the ultimate benefit of the infrastructure owners, users, and user-fee payers.

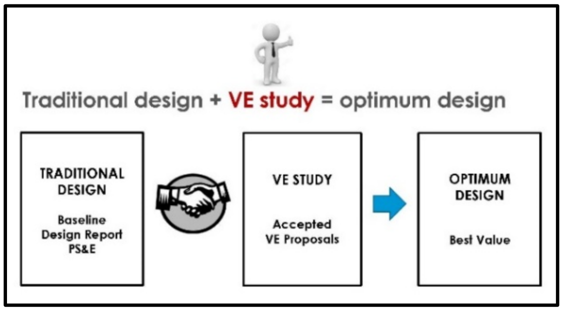

Figure 7

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