Hybrid Case-Based Reasoning Approach to Value Engineering in Road Rehabilitation and Traffic Improvement Projects

Tariq Shehab, Ph.D.
American University of Ras Alkhaimah, Department of Civil and Infrastructure Engineering, UAE

Mohamad Mahani
California State University, Long Beach, Department of Civil Engineering and Construction Engineering Management, USA.

Abstract
Many roads in the United States have approached the end of their design and/or service lives. In a recent report published by the American Society of Civil Engineers (ASCE), 42% of highways in the United States are congested and cost the economy about $100 billion in wasted time and extra fuel consumption. Due to the poor condition of the national highway network, it has been given a grade “D” by the ASCE in its 2013 Infrastructure Report Card. To improve the nation’s roads and highways, $1.7 trillion needs to be invested during the next ten years. With limited resources, many state highway administrations use value engineering (VE) to deliver the same, or higher, quality projects at a reduced cost. Implementing VE programs is time consuming, costly and requires a great deal of experience. These limitations might impede the popularity and/or participation of junior engineers in VE processes. This paper presents a cased-based reasoning approach to reduce the time and cost associated with VE processes. It provides a screening tool that points to high-potential improvement areas and suggests alternative options. Furthermore, it provides a useful tool to junior engineers through which they can learn from more experienced colleagues. The presented tool uses 30 Caltrans’ projects and 76 VE solutions to perform the required task.

INTRODUCTION
Value engineering (VE) is used to maintain or improve quality at less cost. It was first introduced by the US Department of Defense (DOD) in the 1940s and transferred to the 2 construction industry by the 1970s [1]. Since its introduction to the construction industry, it has gained more popularity, replaced conventional cost- reduction programs, and proved its effectiveness and profitability by yielding very high returns on investments. It was documented that its return on investment could be up to $121 for every dollar spent, which could save the highway and transportation administration departments about $1 billion per year [2].

VE workshops consist of six phases: 1) information, 2) function analysis, 3) creativity, 4) evaluation, 5) development, and 6) presentation [3]. In the first phase, the team defines the current project condition and sets the VE study goals. In the second phase, the team defines the project functions using the two-words approach (i.e. verb and noun) to determine which one is to be improved and/or eliminated to meet the goals set in the first phase. In the third phase, the team performs brainstorming sessions to identify other ways to perform the functions defined in phase two. In the fourth phase, the team selects the best way(s) to satisfy the project function(s). In the fifth and sixth phases, they implement the agreed-upon improvement strategies and prepare a report, respectively.

Although VE workshops follow well-structured steps, their implementation is very challenging and time-consuming [4 and 5]. This is attributed to many reasons, among which are the need for well-trained and experienced team members, specifically in the creative and evaluation phases, and the need for an effective leadership to achieve a specific set of VE goals [3 and 5] al. 2005). Furthermore, it was documented that the duration of VE workshops depends on the size and complexity of projects, which can take up to 15 days [3]. Other challenging factors that may limit the implementation of VE programs include the need for continuous building on gained experience and the lack of a spirit of teamwork [6].

In an effort to overcome the challenges associated with VE workshops, many research efforts have been made to develop tools to facilitate their successful completion. Assaf et al. (2000) presented a computerized system for the application of VE methodology in residential construction industries [7]. It used an algorithm, developed in a FOXPRO environment, to perform tasks, but no intelligent approaches were proposed. The purpose of the system was to walk the users, including students, through the VE workshop processes in a structured manner.
Shen and Chung (2002) and Shen et al. (2004) presented a framework of group decision support systems (GDSS), which is a branch of the information technology field, to facilitate decision making in the evaluation phase of VE workshops. The researchers used the proposed framework to build a prototype that demonstrates the effectiveness of GDSS in group discussions, communications and deliberations throughout the various VE workshop phases. Sanchez et al. (2005) presented a decision support system to evaluate multiple alternatives proposed in the VE workshops. The proposed system used a fuzzy set–based approach to perform its task. It has the capabilities to process quantitative and qualitative decision-making attributes. Fan et al. (2007 and 2008) pushed the GDSS framework proposed by Shen and Chung (2002), and Shen et al. (2004) pushed it a step further [3, 8, 9, 11]. This was achieved by proposing a generic computer system that assists in generating alternatives during all phases of VE workshops. It used a traditional database to perform its task, did not include artificial intelligence components, and was applicable to residential and commercial projects only. It should be noted that the researchers presented multiple challenges usually encountered in performing VE workshops, such as lack of information, knowledge, and participation, and demonstrated how their developed computer system could assist in overcoming these obstacles.

Lee et al. (2009) developed a case-based reasoning approach for residential construction [9]. Although the proposed system assisted VE residential designers and construction practitioners to facilitate the creativity phase, the input to the case-retrieval process was very limited. This input included the item description (e.g., door) and its 88 location (e.g., living room) only. Furthermore, it allowed for the acceptance of alternatives with higher operation and/or maintenance costs, which may not be in agreement with VE principles. Luo et al. (2010) developed a case-based reasoning system to support the functional phase of VE workshops. It assists the VE team in formulating the functional requirements by identifying, formulating, and classifying functions. It also calculates the weights of all functions and establishes the relationships between them. Zarandi et al. (2011) developed a generic fuzzy case-based reasoning system to be used in residential, commercial, and heavy civil VE projects[13]. The system assists VE teams in the creative phase by suggesting solutions that match stated functions. Although the system demonstrated fair results, the authors suggested the development of more domain-specific systems (e.g., heavy civil projects) to improve its performance. Marzouk (2011) presented the ELECTRE III mathematical decision support system to evaluate and rank VE proposed solutions. The researcher worked out a numerical example to demonstrate its use in VE workshops and suggested its improvement through further programming and/or automation research efforts. Ranjbaran and Moselhi (2014) developed a 4D-based VE system [4]. The system assists VE teams to better evaluate alternatives by providing a visual tool. It uses the analytical hierarchy process and BIM technology to perform its task. The authors pointed out the lack of sufficient research and/or development of automated systems that address VE workshops.

Based on the presented literature review, all case-based reasoning systems developed for VE workshops have either addressed phases other than the creative phase and/or projects other than heavy civil (e.g., highways). Furthermore, Zarandi et al. (2011) called for VE domain-specific tools, and Ranjbaran and Moselhi called for more automated VE systems [13].

This paper assists in overcoming the limitations of current research efforts in VE by responding to the need for the development of automated VE domain-specific tools. It presents a hybrid automated case-based reasoning system for heavy civil projects and addresses two specific types of highway projects: 1) rehabilitation and 2) traffic improvements. It provides an easy tool to generate ideas in the creative phase of VE workshops. This paper also helps senior engineers avoid reinventing the wheel, and it helps junior engineers learn from more experienced colleagues. It uses 30 Caltrans’ projects and 76 VE solutions to perform the required tasks.

SYSTEM DEVELOPMENT
Case-based reasoning is an artificial intelligence field that enables the use of a database of problem solutions to address new problem-solving situations [14]. It has been used to address many engineering issues, including VE [9,12,13,14]. The following sections explain the development of the proposed VE system.

Data Collection
To develop the proposed system, 30 Caltrans’ projects were selected that were built during the past 10 years, and their costs ranged from $16,000,000 to $95,000,000. They were associated with 30 VE reports that included 76 VE final proposals. In an effort to be project specific, the 30 projects were grouped into two categories: 1) highway rehabilitations and 2) Traffic improvements

Selection of CBR Software Tool
Commercial case-based reasoning (CBR) software tools are generic shells to be customized in generatin domain-specific applications. To select the shell to be used in the proposed VE application, a comparison of popular shareware VE shells was
performed. In this comparison, the following attributes were considered:

- Number of database fields: As most shareware and trial versions of popular software packages come with many limitations, it was important to select a shell that supports a large number of database fields because the more fields the CBR tool supports, the better a project could be described.
- Type of supported data: It was required to select a CBR shell that supports alphanumeric database inputs.
- Programming knowledge: Some CBR shells require programming knowledge. Although this feature provides high development flexibility, its negative side is that it requires high programming knowledge and experience, which some users may not have.
- Similarity measures: To solve a new CBR problem, the identification of cases that contain the most useful knowledge is required. It is a big advantage that a CBR software tool allows customizing similarity measures.
- User-friendly interface: If a software tool has this feature, it is easier to work with.
- Supports complex CBR applications: When there is a complicated relationship between inputs and outputs (i.e., output is not a simple function of input), the database should be configured in detail by the user to obtain proper results. Not all CBR software tools provide such an opportunity.

Based on the above selection criteria, the research team chose to use myCBR. It can be downloaded free for educational and research purposes. Although other case-based reasoning shells seemed to be feasible, they were excluded due to their need for high programming skills.

BUILDING THE DATABASE
To build the proposed CBR system, 30 VE reports were collected from the California Department of Transportation (Caltrans). These reports were reviewed in detail and classified into two categories based on their main purpose: 1) highway rehabilitations (17 projects) and 2) traffic improvements (13 projects). To adequately describe the projects in each category, 18 aspects of information were extracted from their VE reports and are described below.

ROADWAY REHABILITATION CATEGORY
1. Total length of project: The total length of project is directly related to the cost of the project. In VE, the road may be broken into segments to promote the bidding process.
2. Requirement for cold planing/grinding/milling of pavement: Cold planing, grinding, and milling are pavement preservation techniques. They remove some depth of the pavement surface layer to eventually improve the ride quality.
3. Overlaying of rubberized hot mix asphalt (RHMA): It is typically done when there is minor to modest damage to the existing pavement layer. When constructing an overlay, the old surface is typically milled, planed, or ground off.
4. Overlaying rubberized asphalt concrete (RAC): Same as number 3, but RAC is used.
5. Selectively removing and replacing pavement slabs: Severely damaged slabs are selected throughout the project length and then removed and replaced.
6. Removing and replacing lane(s) with Portland cement concrete (PCC): This is done when the whole lane is severely damaged.
7. Removing and replacing lane(s) with Rapid Strength Concrete (RSC): Same as number 6, but RSC is used.
8. Removing and replacing lane(s) with rubberized asphalt concrete (RAC): Same as number 6, but RAC is used.
9. Grooving pavement: Grooving is a surface restoration procedure that involves the use of saw blades. It improves drainage and traction characteristics.
10. Improving drainage: This is done when the existing road drainage system needs improvements.
11. Median barrier upgrade: Median barriers are longitudinal barriers used to separate opposite directions of traffic.
12. Side barrier upgrade: Side barriers are used to protect traffic from roadside hazards such as slopes and lakes.
13. Upgrading traffic lighting and signs: Traffic lighting and signs are upgraded to comply with updated regulations and/or code requirements.
14. Replacing/installing new traffic metering loops: Traffic metering loops detect vehicles passing or arriving at a certain point. When a vehicle passes over the loop, it sends a pulse to the traffic signal controller signifying the passage or presence of a vehicle. This information could be used in many applications, such as determining average daily traffic (ADT) counts.
15. Proximity to residential and/or business zones: If the project is close to residential and/or business zones,
then it will have visual, noise, dust, and construction traffic impacts on nearby businesses and residents.

16. Depth of groundwater: If the groundwater table is high, it could interfere with construction and could be a cause of pavement failures over time.

17. Time limitations: When the traffic volumes are high, construction is planned only on weekends.

18. Availability of high-occupancy vehicle (HOV) lanes within project limits: HOV lanes are used by vehicles with two or more occupants during certain times of the day and days of the week. Buses, motorcycles, and clean-air vehicles can also use this lane during these times. During all hours outside of the set hours, the lanes could be made available for all vehicles, regardless of the number of passengers. If there are HOV lanes within the project limits, they could be used as mixed-flow lanes during construction to improve traffic operation.

IMPROVING TRAFFIC OPERATION CATEGORY

1. Total length of project: The total length of the project is directly related to the cost of the project. In VE, the road may be broken into segments to promote the bidding process.

2. Requirement of auxiliary lane additions: Auxiliary lanes are lanes other than the main driving lanes of a roadway, such as turn lanes and merge lanes.

3. Requirement for mixed-flow lane addition: Mixed-flow lanes are the main driving lanes where vehicles with any number of occupants can drive anytime.

4. Requirements for high-occupancy vehicle (HOV) lane addition: HOV lanes are defined above.

5. Requirements for truck lane additions: A truck lane is intended for trucks, and they must use this lane if it is available so they do not slow down traffic.

6. Requirements for ramp and/or connector widening: A ramp is a road for driving onto or off a large main road. A connector is a road that connects two large main roads.

7. Requirements for ramp and/or connector realigning: Realigning is done to modify the curve radius and traffic operations.

8. Existence of a bridge: If there is an existing bridge on the project way, it makes the road widening more difficult, and accordingly, it is important to take this into consideration.

9. Requirement for bridge widening: Sometimes bridge widening is not done in a roadway widening project due to the difficulties or high costs. In such cases, eliminating shoulders and bridge re-striping are done to allow more lanes.

10. Existence of sound-wall construction: Sound-walls are noise control walls designed to protect against noise pollution. If the roadway is close to residential/business areas, sound-walls are constructed to mitigate the roadway noise.

11. Proximity to residential and/or business zones: Same as explained above.

12. Depth of groundwater table: Same as explained above.

13. Construction time limitations: Same as explained above.

14. Proximity of HOV lanes in project limits: HOV lanes are defined above.

15. Requirement for retaining wall construction: Retaining walls are constructed on roadways to hold back earth, loose rock, etc.

16. Requirement of median reconstruction: The median is the portion of a divided highway separating traffic in opposite directions.

17. Requirement of re-striping: Sometimes, side and middle shoulders are wide enough for roadways to be re-striped to provide more lanes.

18. Requirement of ramp closures: ramps are defined above.

USER INTERFACE

In an effort to simplify and facilitate the VE process, a user interface was developed. It solicits the user’s requirements to retrieve VE solutions for road rehabilitation or traffic improvement projects (Figure 1). Once the user makes his/her selection, 18 questions are asked about the project in hand. These 18 questions are those presented above for road rehabilitation and traffic improvement projects, respectively. The answers to these questions are either “yes” or “no,” except the length of the road (Figure 2). Upon feeding all the information for the project and activating the retrieval process, myCBR calculates the similarity percentages between this project and all other projects available in the database. Projects with high similarity percentages should be considered. It should be noted that if no similar projects are available in the database, unsatisfactory similarity percentages and/or unsatisfactory VE suggestion results are revealed, myCBR allows adding new projects and/or project attributes to update the database, if needed (Figure 3).
Figure 1: Selection screen

Figure 2: Input screen

Figure 3: Updating mode
CASE EXAMPLE

To demonstrate the use of the developed case-based reasoning system in VE workshops, the road rehabilitation mode was considered. Out of this group, project 7 was randomly selected. Figures 4 and 5 depict the input of project 7 and similar projects into the database that was revealed through the retrieval process (i.e., projects 1, 2, 5, and 15), respectively. As shown in Figure 5, project 1 was found to be very close to project 7 and demonstrates the highest similarity (i.e., 83%). Upon comparison of the attributes of projects 7 and 1, it was noticed that all project attributes are the same except their lengths. The lengths of project 7 and 1 are 12 and 6.6 miles, respectively.

Table 1 compares the VE suggestions for both projects. As shown in this table, five VE suggestions were reported for project 7, among which two are the same as in project 1. VE suggestions 2 and 3 in project 7 are the same as VE suggestions 1 and 2 in project 1. These suggestions are to increase construction hours and the use of HOV lanes. This outcome demonstrates that about 40% of the time and cost associated with project 7’s creative phase could have been saved if the proposed case-based reasoning system had been used.

Upon further analysis of other VE suggestions for project 7, it was noticed that although projects 7 and 1 had high water table issues, no VE suggestions regarding the groundwater table were mentioned for project 1. Lack of access to other project 1 documents, such as designs and soil reports, prohibited a reasonable explanation of this deviation between both VE studies.

Table 1: VE Suggestion Comparison for Projects 7 and 1

<table>
<thead>
<tr>
<th>VE Suggestion</th>
<th>Project 7</th>
<th>Project 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Increase construction hours</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2. Use HOV lanes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3. Increase construction hours</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>4. Use HOV lanes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5. Add night work</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Figure 4: Project 7 input attributes

Figure 5: Project similarity outcomes
Table 1: VE outcomes

<table>
<thead>
<tr>
<th>Project # 7</th>
<th>Project # 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>VE Suggestion #1: Increase public outreach and communication to reduce traffic volumes, and improve detour signage in the field for alternate routes</td>
<td>Adjust the traffic management plan to allow for full-shift construction (6 hours) versus approximately 3 to 4 hours of nighttime construction windows</td>
</tr>
<tr>
<td>VE Suggestion #2: Increase the hours available for construction from 7 hours to 9 hours</td>
<td>Use the HOV lanes for mixed-flow traffic to increase the construction work window</td>
</tr>
<tr>
<td>VE Suggestion #3: Redirect truck traffic to adjacent facilities during construction and limit allowable hours for trucks in order to reduce volumes during construction</td>
<td>N/A</td>
</tr>
<tr>
<td>VE Suggestion #4: Investigate the groundwater/subbase condition on the mainline to pinpoint the failure mechanism on the existing slabs</td>
<td>N/A</td>
</tr>
<tr>
<td>VE Suggestion #5: Perform site investigations for surveying and soil boring ASAP to aid the design effort</td>
<td>N/A</td>
</tr>
</tbody>
</table>

CONCLUSION
A case-based reasoning approach was presented to reduce time and costs associated with VE processes. The proposed system addresses the creative stage of VE studies, which assists in filling the gap in the current research work. It saves about 40% of the time, effort, and cost associated with the creative phase of VE workshops. It provides an easy tool that points to high potential improvement areas and suggests alternative VE options. Furthermore, it provides a useful tool to junior engineers through which they learn from more experienced colleagues. The presented tool uses 30 Caltrans’ projects and 76 VE solutions to perform the required tasks. Although the system demonstrated reasonable results, its performance could be further improved by increasing the size of its database.

REFERENCES


