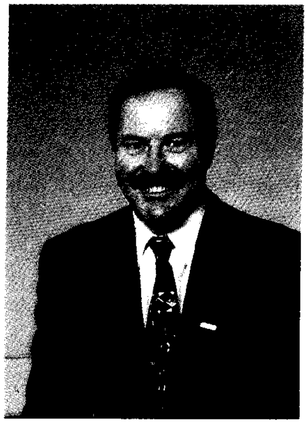
HIGHWAY DESIGN STANDARDS AND VALUE ENGINEERING - A SYNTHESIS



E. J. Kolla, P.Eng.
Delcan Corporation

Ed Kolla is an Associate of Delcan Corporation and is responsible for the planning and design of transportation facilities. He grew up in Saskatchewan and obtained his Bachelor of Science (Civil Engineering) from the University of Saskatchewan. Ed has twenty-three years experience in planning, design and construction of urban and rural roadways, parking facilities, etc., in Western Canada. Prior to 1990, Ed was located in Regina, Saskatchewan where he managed the Saskatchewan Operations and was responsible for planning, design and construction of transportation facilities in Saskatchewan, as well as assisting on projects in Manitoba.

In 1990, Ed moved to Vancouver. He is reponsible for managing the planning and design of transportation facilities. Some of his accomplishments include the planning, design and upgrading of the Lougheed Highway, Highway 99 in Whistler, and planning and functional design of the Trans Canada Highway adjacent to Victoria, including three interchanges. In 1995, he was the geometric design representative as part of the team on a Value Engineering study. He was also the Delcan Project Manager on another project which was reviewed using the Value Engineering process.

ABSTRACT

This paper considers the relationship between the application of Highway Design Standards and Value Engineering. It does so under three basic headings, namely Design Standards, Value Engineering and, finally, the Synthesis of the two.

DESIGN STANDARDS

Design Standards for highway engineering have been around for many years. The Tranportation Assocation of Canada (TAC) has had standards for Geometric Design for over 30 years, and the well-known American Association of State Highway Transportation Officers (AASHTO) standards go back over 60 years. They have been dynamic, have continued to evolve and develop and have served the professional well. This section discusses the intent and purposes of standards, their nature, the application of standards and how they have continued to develop. Standards have had a marked influence on the quality of the product and ultimately the safety of road facilities.

VALUE ENGINEERING

Value Engineering is a relatively new concept, although some would argue that the principles have been applied throughout the history of design engineering without formal recognition.

This section of the paper examines value engineering as a management technique and discusses the purpose and principles of the application of value engineering. Case studies are used to illustrate the success rate for, and the financial justification of, value engineering. The application of design standards during the value engineering process is also examined.

SYNTHESIS

There are a number of issues in examining the relationship between design standards and value engineering that deserve to be addressed. What, if any, is the mutual influence of design standards and value engineering? Do standards influence the value engineering process? Should the evolution of standards be influenced by value engineering? How are standards used to test the conclusions or recommendations of value engineering and how should they be applied?

These issues and others are examined and some preliminary conclusions are drawn.

DESIGN STANDARDS

The Technical Introduction of the 1986 metric edition of the "Manual of Geometric Design Standards for Canadian Roads" (TAC)(1) states "*...The manual provides a set of standards that has application throughout Canada. Road authorities across the country have cooperated in the preparation of these standards, which reflect current practice, and embrace sound engineering principles and the latest technology in road engineering.*

Safety, economics and environmental considerations are fundamental to road design and are taken into account throughout the manual. A high level of safety is achieved by accommodating the natural behaviour of drivers and vehicles and by anticipating and meeting driver expectation. Standards have been developed to promote these qualities in design."

The American Association of State Highway and Transportation Offices (AASHTO) states in the foreword of the 1990 "Policy on Geometric Design of Highways and Streets"(2)..... "*the guidance applied by this text, A Policy on Geometric Design of Highways and Streets, is based on established practices and is supplemented by recent research. This text is also intended to form a comprehensive reference manual for assistance in administrative, planning and educational efforts pertaining to design formulation.*" The third paragraph states "*....The intent of this policy is to provide guidance to the designer by referencing a recommended range of values for critical dimensions. Sufficient flexibility is permitted to encourage independent design tailored to particular situations.*"

The authors and publishers of these documents clearly identify that this information should be used as a guideline by designers and approving jurisdictions to develop the most cost-effective and safe solutions for road users. To do this, there must be a better understanding of what designers are trying to accomplish.

An understanding of driver behaviour and the environment in which they operate is required to apply the correct design standard to a facility. There are five major elements which interact in a complex manner in the driving environment...

- driver behaviour (perception, reaction time, etc.)
- vehicle (height, width, weights, length, etc.)
- roadway (design speed , superelevation, lanes and shoulder widths, maximum grades, side slopes, horizontal and vertical geometry)
- traffic control devices
- environment

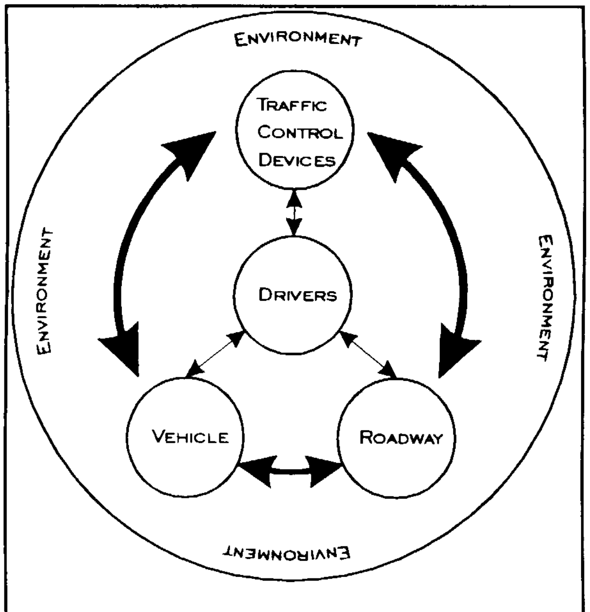


Figure 1
MAJOR ELEMENTS IN DRIVING ENVIRONMENT

as shown in ***Figure 1***. These five major elements of the driving environment are considered as input variables in the science and engineering of geometric standards. Geometric standards (guidelines and design rules) follow from mathematics and technical experience. Proper application of these design standards and design rules will result in a highway alignment that meets all the constraints and limiting factors of the major elements of the driving environment.

Highway design standards have been developed through the application of physics and engineering mechanics. These standards are developed by taking into consideration the relationship between the driver, vehicle, and roadway, and incorporate the necessary traffic control devices within the applicable environment in which the design is being carried out.

Elements that are taken into consideration in the establishment of design standards are:

- design speed selection
    - reflects the character of the terrain and type of roadway

- travelled lane widths
  - consistent for the corridor
  - accommodate the design vehicle
  - accommodate the roadway geometrics

- horizontal alignment
  - accommodate required sight distances e.g., stopping, passing and decision
  - use of appropriate horizontal curves
  - application of superelevation to fit the climatic conditions, terrain, urban or rural setting and speed
  - provide the required degree of safety and comfort

- vertical alignment
  - accommodate required sight distances e.g., stopping, passing and decision
  - establish the maximum gradient to suit the road environment and vehicle type
  - use of vertical curves

- cross-section elements
  - be consistent along a corridor to provide driver safety and convenience
  - take into account: vehicle type and traffic volume; topography traversed by the route; local climatic conditions e.g., rain, ice, drifting snow; inner and outer shoulder widths; side slope and back slope configuration; medians, boulevards and walkway configuration

- intersections
  - accommodate the safe joining of two or more roadways
  - design considerations include traffic volumes, design vehicle, intersection type, sight distance, channelization

- interchanges
  - accommodate the safe joining or crossing of two or more roadways
  - design considerations in the selection and design of interchange types should include corridor/driver continuity, corridor classification, adjacent land use, roadway network design speeds, traffic volumes, composition of traffic, environmental considerations, topography, property issues, relationship of other features of the affected roadway system

- design controls effecting both horizontal and vertical geometry
  - these controls would include safety, external environmental issues such as drainage and snow drift, intersections, access control and adjacent land use

Road authorities throughout North America and in countries around the world have utilized the work done by TAC and AASHTO and have either adopted, or acknowledged, work done by these agencies to develop their own internal design manuals that are either used as standards or guidelines for the design of safe, efficient and effective transportation facilities. These manuals are then used to provide some procedural policy and guidelines for setting the priorities, definition of scope and for carrying out the design of new or rehabilitation projects.

VALUE ENGINEERING

The definition of value engineering (VE) by the Society of American Value Engineers (SAVE) is "*The systematic application of recognized techniques which identify the function of a product or service, establish a value for that function, and provide the necessary functional reliability at the lowest overall cost. In all instances, the required function should be achieved at the lowest possible life-cycle cost consistent with requirements and/or performance, maintainability, safety and aesthetics.*"

Value engineering should provide a process of assuring that maximum value is delivered for the capital invested, where:

$$\text{“} \mathit{value} = \frac{\mathit{function}}{\mathit{cost}} \text{”}$$

The American Association of Cost Engineers International (AACEI) provides the following definition of value engineering in its publication "....Skills and Knowledge of Cost Engineering".

"*Value Engineering is a multi-discipline, systematic and proactive function that is targeted at the design itself. The objective is to use value engineering to develop a facility or item design that will yield the least life-cycle cost or provide the greatest value while also meeting all functional, safety, quality, operability, maintainability, durability and other criteria established for it.*"

The principle approach in value engineering is to analyse functionality focusing on elimination or modification of any component of a facility that adds cost without contributing to functionality and safety. In considering

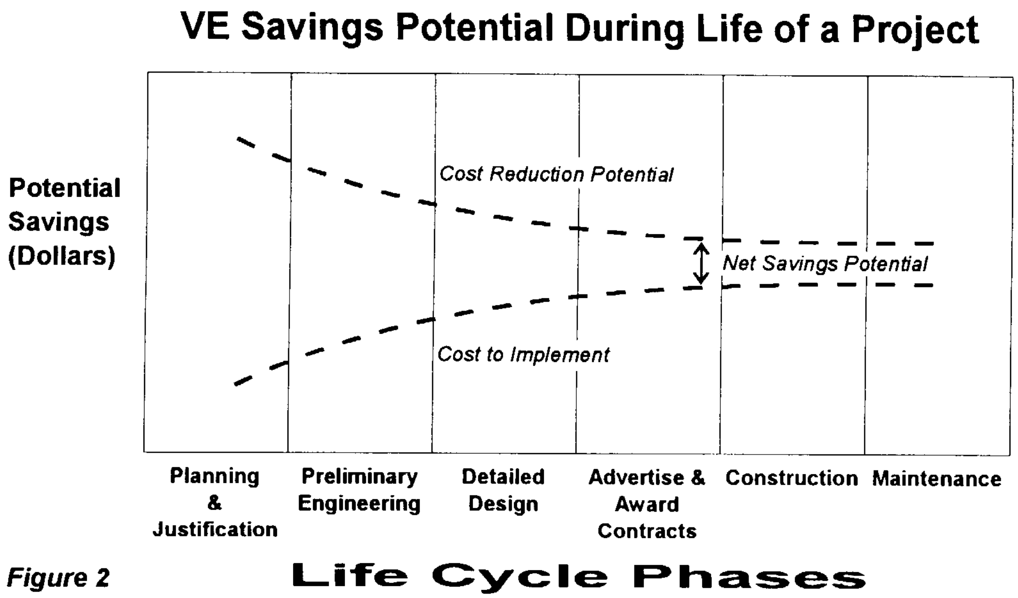

VE Savings Potential During Life of a Project

Figure 2

the cost, however, the life-cycle cost of the facility (e.g., overall safety of a transportation facility) is the operable parameter.

In order to achieve the required answers when applying value engineering, a number of questions need to be asked about a facility and possibly the design standards adopted at the start of the process:

- what it is?
- what it does?
- what must it do?
- what does it cost?
- what is it worth?
- what else might do the job?
- what does the alternative cost?
- what will satisfy all the facility needs?
- what is needed to put the change into effect?

In order to most effectively respond to the above, value engineering is best carried out or emphasized at the earliest stages of the project development. ***Figure 2*** graphically illustrates the cost/benefit over time for value engineering.

Two alternate approaches can be used to achieve effective value engineering.

- *Option 1:*
  This option is to create an environment wherein the design team is allowed the opportunity to "brainstorm" and pursue alternatives. This requires a mindset that recognizes and accepts that some additional design time and cost is necessary to reduce the overall project life-cycle costs. This concept will not be effective if the mindset is to achieve the design based on the least level of effort (least cost design) while expecting the designer to produce the lowest overall project cost. This approach does not encourage ingenuity or initiatives, it simply causes the designers to use safe and true means which may or may not achieve the least overall cost.

- *Option 2:*
  This option is to bring in an independent design review team to assess the work of the original design team. This process can work well, provided each member of the team truly appreciates the concept of value engineering. Understandably, the first design team feels a natural need to defend their original design. The second design team has an inherent tendency to prove they can do better than the first team. If proper teamwork prevails (with the ultimate objective to produce the most cost-effective and safe design) then this option can work very effectively.

Value engineering is not restricted to the early stages of a project. It does, however, offer the greatest opportunity to maximize potential savings with the minimum impact on project engineering costs and scheduling if it is implemented as early as possible in the project.

The value engineering process must:

- be responsive to the needs of the project at all stages
- directly use and involve input from designers, reviewers, and the road authority
- produce results without incurring inordinate additional costs
- not add another layer of process or procedures
- be consistent with good design, construction, safety, and operational practices of the proposed facility
- motivate designers and value engineering reviewers to discover new and more effective designs or to significantly improve current practices

Value engineering is closely linked to quality and continuous improvement of life-cycle costing and safety of the facility, which ultimately aims to increase the overall project (program) value.

The benefits of utilizing a value engineering process in an appropriate way throughout the design process are:

- all feasible solutions can be addressed
- encourages creativity, input from designers and the approving authority
- obtains buy-ins by all parties to agreed solutions
- builds confidence within designer and owner teams
- adds value and quality: delivering the optimum value and the highest quality service to the end users

Value engineering is ultimately aimed at adding value to a project. This can be done in many ways, including the reduction of costs of one or more of the following:

- design and engineering (cost to re-design)
- capital costs (construction, equipment, etc.)
- life-cycle cost replacement, maintenance, operations, safety of the transportation facility, etc.
- risk (reduce the risk to the owner throughout all phases of the project including commissioning and operation)
- improve the highway system without compromising the safety and operational efficiency of the facility

SYNTHESIS

The application of value engineering has been proven as a valuable process and has produced effective results. The evidence of this can be seen by the establishment of such organizations as the Society of American Value Engineers (SAVE) and the American Association of Cost Engineering International (AASEE).

Transportation authorities in Canada have also adopted these principles. Agencies including the Toronto Transit Commission, have used value engineering on a number of projects and have developed a value engineering manual for their rapid transit expansion program. The Vancouver Island Highway Project Management Team and the BC Ministry of Transportation and Highways conducted formal value engineering assignments in 1995 and 1996.

The Vancouver Island Highway Project Management Team in conjunction with the BC Ministry of Transportation and Highways, initiated nine value engineering studies on the Vancouver Island Highway Project in 1995. A further study was done in 1996 on another section of the Vancouver Island Highway Project. The Ministry of Transportation and Highways also conducted value engineering studies on the Trans Canada Highway HOV Project -Vancouver to Cape Horn, the Okanagan Lake Bridge, and Monte Creek Interchange.

Value engineering is not new to the engineering process. Designers have always attempted to apply the value engineering principles to the design of a particular facility. The application of a formal value engineering process can have merit because the designer may, without appreciating it, carry forward through the design process assumptions and criteria that were appropriate and correct at the time they were established. These assumptions or criteria, however, may not be applicable as the design progresses. Unfortunately, the designer or the design team is so close to the project that they may fail to recognize that some of these initial assumptions or criteria have changed and therefore should be modified. A fresh look by an independent review team suited to the particular project requirements, could identify any inconsistencies or need for modifications.

The process used in the value engineering assessment of the Vancouver Island Highway Project(3) was to assemble value engineering teams that would carry out a formal review of a particular project. The mandate of these teams was to follow the traditional five step value engineering plan as follows:

- *Investigation Phase*
  To acquire knowledge of the design to be studied and to assess its major functions, costs, and relative worth.
- *Speculation Phase*

To "brainstorm" the basic functions of high cost items and to develop a number of alternatives to each.

- *Evaluation Phase*
  To analyse the results of the Speculation Phase and, through review of the various alternatives, select the best ideas for further expansion.

- *Development Phase*
  To collect additional data and thoroughly analyse those alternatives selected during the evaluation phase, including preparation of cost estimates.

- *Presentation Phase*
  To put the recommended alternatives before decision-makers to support justification.

The value engineering studies carried out in British Columbia produced 228 value engineering recommendations, 18 of which had some specific reference relating to TAC/AASHTO design standards. ***Table 1*** identifies the breakdown of recommendations for the different studies. ***Table 2*** describes the types of standards that were assessed. Within this grouping, the recommendation varied from alternate interchange types (which were identified in a number of cases and may actually encompass more than one standard or may not encompass any improvements or changes to design standards or the use of a different type of interchange), to cross-section type where the recommendation looked at changing lane widths from 3.7 m to 3.6 m, or varying the width of inside and outside shoulders and side slope grades.

The recommendations from the nine value engineering studies completed in 1995 on the Vancouver Island Highway Project were reviewed by the owner and the original designers, and 37 of the recommendations were approved in 1995 for implementation on the respective projects.

In 1994 and 1995, the BC Ministry of Transportation and Highways carried out a review(4) of their design guidelines that specifically related to rehabilitation of existing highways and roads. Although the work was not carried out in a formal value engineering environment, it was recognized that with funding limitations, standards may need to be modified on projects to reflect these budget limitations and yet provide safe and operationally efficient improvements.

In 1996, the BC Ministry of Transportation and Highways undertook a review(5) of the current design standards and practices with the intent of finding ways to cut costs without decreasing safety. The review committee has identified:

- Changes in standards including:
  - clear zone standards
  - guard rail approach flare widths
  - guard rail opposing flares
  - crest vertical curves.

- Change in standards with clarification of design procedures relating to:
  - asphalt thickness
  - base and subbase thickness
  - slope of subgrade
  - unsuitable waste excavation material

- Clarification of process:
  - side road bridges

- Clarification of Ministry Operation Policy relating to:
  - type 1 and 3 sign poles
  - pole loading on rehabilitation projects.

TABLE 1
VALUE ENGINEERING RECOMMENDATION

STUDY	RELATED TO TAC/AASHTO DESIGN STANDARDS	TOTAL
Okanagan Lake Bridge(6)	2	12
Millstream Connector(7)	2	8
Craig's Crossing(8)	1	7
Colwood Overpass(9)	0	16
14th Avenue to Meredith Road(10)	2	48
Mud Bay to Tsable River(11)	1	9
Seven Standard Underpasses(12)	1	21
Transfer Beach to Jones Road(13)	2	38
Tsable River Upstream Bridge(14)	0	14
Moster Road to Superior Road(15)	3	27
Kilmalu Road to Miller Road(16)	3	21
TCH - HOV Project(17)	1	7
	18	228

TABLE 2
DESIGN CRITERIA QUESTIONED

RECOMMENDATION	POTENTIAL VALUE IN $,000
Improve geometric design of Interchange	not specifically identified
Alternate interchange design	$1,000
Cross-section type	330
Alternate alignment (4-lane)	1,500
Parapet height	not specifically identified
Reduce design speed	not specifically identified
Alternate design storm event and requirements	20
Road classification - lane widths	128
Eliminate truck climbing lane	140
Intersection alignment	360
Intersection improvements	-335
Shoulder width/enforcement bays	4,400

CONCLUSIONS

The assessment of value engineering exercises carried out in British Columbia demonstrate that there is a synergy between highway design standards and value engineering. In order for this synergy to function effectively, the designer has to be given the freedom to use the design standards (guidelines) and apply them in the most appropriate way to suit the facility being designed.

The British Columbia Value Engineering process indicated that a small percentage of the recommendations involved a reassessment of design standards. The value engineering process can be used as a triggering mechanism to review certain standards, however, it should not be considered, and has not been used as, an approach to reducing costs by reducing standards.

The formal value engineering review provides an opportunity by an independent team to assess if additional value can be brought to a project, not by reducing standards but by ensuring that standards (guidelines) are being applied correctly. Or, in an extreme case, the value engineering team may recommend that a particular standard be assessed to ensure that it is still applicable to current project requirements and conditions. This can also apply to standards that may have been developed by local jurisdictions to supplement the AASHTO and TAC standards. The process may bring into question local standards that are being applied. These standards may have been developed to correct a particular local problem or need and may not be applicable for all conditions.

TAC and AASHTO are presently reviewing the wording associated with the description of the tools and applications used by designers. For example, the Urban Supplement produced by TAC is referred to as "guidelines", not "standards". The change in wording implies that the designer can potentially bring more value to a project, since what is in the manual should be used as a guideline to develop the most cost-effective and yet safe design. The word "standard" could be interpreted to mean that what is in the manual has to be applied or else you have not met the minimal requirements.

The use of the word "standards" can have a far-reaching impact and cost, since litigators can use, as a defence, the fact that the something has not met a standard which therefore implies that it is not acceptable. However, if it is referred to as a "guideline", engineering interpretation is required during both the design and implementation stages.

Designers strive to produce the most cost-effective and safe design. The Value Engineering process demonstrates that more design effort spent to eliminate life-cycle costs and to provide the safest and most efficient facility during the design process can ultimately bring the most value to a project. It can also be concluded that additional engineering early on in the design process can net greater savings in the performance of the ultimate facility, therefore, netting true value to the owner.