A Comprehensive Value Engineering Approach
for Gas Pipeline Projects Using
Mathematical Models and FAST:
A Case Study of Mazandaran Gas Company

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ABSTRACT
This study explores implementation of value engineering (VE) in gas pipeline projects, focusing on the link among transfer, feed, and distribution lines. For any feed line, there is a City Gate Station (CGS), and for any distribution line, there are some Town Broad Stations (TBS). We assess value in two cases. The first case concerns the location of the TBS’s, allocation of consumption zones to TBS’s, and the routing of distribution lines among the TBS’s and consumption zones. The second case focuses on analyzing activities during the implementation process to identify any extra or malfunctioned activities in order to propose a change of strategy to gain a higher value. For the first case, we apply a combination of a location-allocation mathematical model and the minimum spanning tree (MST) method, and for the second case, we use the Functional Analysis System Technique (FAST). We conduct a case study of a gas company to assess the validity and effectiveness of the value engineering approach.

Keywords: Value engineering, gas pipelines, location-allocation, minimum spanning tree (MST), Functional Analysis System Technique (FAST)

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1. INTRODUCTION

The concept of value has a rich history in academic literature. According to Frondizi [1971], the distinction of the concept of ‘value’ was discovered in the 19th century. The concept of value has since been examined in various disciplines [Rokeach, 1973], notably psychology, philosophy, and economics [Oliver, 1999; Rescher, 1969; and Rokeach, 1973]. Certain notable scholars like Clyde Kluckhohn also dedicated most of their lifetime studying the meaning of the value construct [Kluckhohn, 1959; Rescher, 1969]. Although the concept of value appears to be well studied across disciplines, it is still one of the least understood constructs in the literature [Dawis, 1991; Holdbrook, 1999; and Rokeach, 1973].

The construction and project management literature, however, gives a different picture. Inadequate attention has been given to the direct, empirical, or theoretical study of the value construct in the relevant literature over the years [e.g., Winter et al., 2006]. This observation, however, is on the backdrop of recently increasing interest for value provision in projects, via the use of tools such as value engineering or management [Shen and Chung, 2002; and Younker, 2003].

Value engineering (VE) is a management tool to achieve the essential functions of a product, service, or project with the lowest cost. VE has been practiced for half a century in the construction industry with an aim to produce innovative ideas and solutions for enhanced project value. Surprisingly, little research has been done on how to re-utilize the ideas and solutions generated in previous VE studies for future projects. The construction industry is still practicing VE in the same manner as when it was initiated 50 years ago. Each VE study starts from scratch, and its success relies solely on the VE team members' experience and competence. Experience has shown the VE study to contribute to a cost saving of 5%–10% in a wide range of construction projects. However, there is no significant gain from the VE study in a number of other construction projects. This fact may be one of the reasons that overall public opinion of VE is controversial, as implied by the Engineering News Record website poll, in which about half of the respondents think VE is a valuable constructability tool, whereas around 43% of the respondents consider it a marketing ploy. Value is a well-studied construct in the literature [Holdbrook, 1999; Kluckhohn, 1959; and Rokeach, 1973]. Over the years, scholars have explored, debated and examined (in detail) the components and nature of value [Rokeach, 1973]. This research has provided a useful body of knowledge on the concept, especially in the areas
of philosophy, psychology, economics, and other social sciences [Rokeach, 1973].

The concept of value occupies a central role in gas piping projects in the gas industry. It has directly or indirectly been the focus of many stakeholders in the industry over the years. In recent years, the focus on ‘lower costs’ rather than on ‘value’ in procurement has, for instance, been cited as one of the reasons for the poor delivery of gas [Circ, 2001]. The gas industry has therefore been sensitized to the need for value delivery by recent influential public studies in many places.

Value engineering has received increased attention in the gas piping and project management literature, as one of the useful tools to deal with value issues in project delivery. A number of studies on the topic have focused on value engineering in recent years [Abidin and Pasquire, 2005; Cheah and Ting, 2005; Fong and Shen, 2000; Shen and Chung, 2002; Younker, 2003; and Yu et al., 2005]. Value engineering is an organized application that uses a combination of common sense and technical knowledge to locate and eliminate unnecessary project costs. Applying sound VE principles can effectively reduce costs and thus enhance project value.

Value engineering, first used in the gas industry during the 1960s, has been employed worldwide for more than 50 years. Since its introduction, this technique has been widely applied in gas projects [Palmer et al., 1996; Chen and Chang, 2008; and DeEll’Isola, 1997]. The VE process involves several important elements, including teamwork, functional analysis, creation, cost–worth, and the systematic application of a recognized technique. The incorporation of these elements into a VE job plan distinguishes the VE approach from other cost-cutting exercises. Without these elements, the process is not VE and does not yield the same results [Federal Highway Administration, 2008].

The remainder of this paper is organized as follows. Section 2 describes the problem. Section 3 gives a mathematical model accompanied with an implementation at Mazandaran gas pipelines. Section 4 describes the stages of a FAST analysis. Section 5 discusses a case study to verify the proposed approach, and Section 6 presents our conclusions.

2. DEFINITION OF PROBLEM

A gas pipeline project is implemented in several stages. The stage we concentrate on is the link among transfer, feed, and distribution lines. For any feed line, there is a City Gate Station (CGS), and for any distribution line, there are some Town Broad Stations (TBS’s). We assess value in two cases. The first
case considers the location of the TBS’s, allocation of consumption zones to TBS’s, and the routing of the distribution lines among the TBS’s and consumption zones. The second case focuses on analyzing the activities during the implementation process in order to identify any extra or malfunctioned activities for proposing a change of strategy to gain a higher value. In the first case, we apply a combination of a location-allocation mathematical model and the minimum spanning tree (MST) method. For the second case, we use a Functional Analysis System Technique (FAST). A configuration of the proposed problem is shown in Figure 1. For a FAST analysis, we first determine the locations of the TBS’s and then allocate the consumption zones to an appropriate TBS considering the standard limitations of the gas pipelines. Next, we develop a mathematical model for the location-allocation, and then analyze the gas piping functions using FAST.

Figure 1. Configuration of the Proposed Problem Using FAST
1. PROPOSED MATHEMATICAL MODEL

To obtain a profitable configuration of the TBS’s, we need to identify the geographical coordinates of the candidate locations. For the first phase of the mathematical model, based on the geographical location data, we obtain the optimal TBS locations and determine the appropriate TBS types, considering the amount of gas consumption at zones. The mathematical model for Phase 1 is given below.

Phase 1: Location-Allocation

Sets:

$I$ Set of TBS locations
$T$ Set of TBS types
$Z$ Set of zones

Parameters:

$C$ The cost of piping per distance unit
$S_t$ The establishing cost of TBS of type $t$
$q_z$ Demand of zone $z$
$Q_{it}$ Capacity of TBS of type $t$ at location $i$
$L_i$ Length of TBS at location $i$
$L_z$ Length of zone $z$
$W_i$ Width of TBS at location $i$
$W_z$ Width of zone $z$

Decision Variables:

$X_{i} = \begin{cases} 
1 & \text{if TBS at location } i \text{ is located, } i = 1, \ldots, I. \\
0 & \text{o.w.} 
\end{cases}$

$H_{it} = \begin{cases} 
1 & \text{if TBS at location } i \text{ of type } t \text{ is selected, } i = 1, \ldots, I, t = 1, \ldots, T. \\
0 & \text{o.w.} 
\end{cases}$

$Y_{it} = \begin{cases} 
1 & \text{if zone } z \text{ is connected to TBS of type } t \text{ at location } i, \\
0 & \text{o.w.} 
\end{cases}$
Mathematical Model:

\[
	ext{Min } Z = \sum_{i=1}^{I} \sum_{t=1}^{T} H_{it} \cdot S_i + \sum_{i=1}^{I} \sum_{t=1}^{T} \sum_{z=1}^{Z} Y_{itz} \sqrt{(L_i - L_z)^2 + (W_i - W_z)^2} \cdot C, \tag{1}
\]

s.t.

\[
\sum_{t=1}^{T} H_{it} = X_i, \quad i=1, \ldots, I, \tag{2}
\]

\[
\sum_{z=1}^{Z} Y_{itz} \geq H_{it}, \quad i=1, \ldots, I, \quad t=1, \ldots, T, \tag{3}
\]

\[
\sum_{z=1}^{Z} Y_{itz} \geq H_{it} \cdot M, \quad i=1, \ldots, I, \quad t=1, \ldots, T, \tag{4}
\]

\[
\sum_{i=1}^{I} \sum_{t=1}^{T} Y_{itz} = 1, \quad z=1, \ldots, Z, \tag{5}
\]

\[
\sum_{z=1}^{Z} Y_{itz} \cdot q_z \leq Q_{it}, \quad 1, \ldots, I, \quad t=1, \ldots, T, \tag{6}
\]

\[
X_i, Y_{itz}, H_{it} \in \{0,1\}, \quad i=1, \ldots, I, \quad t=1, \ldots, T, \quad z=1, \ldots, Z. \tag{7}
\]

Formula (1) is the objective function minimizing location-allocation cost. Constraints (2) show that each TBS can adopt only one type if it is selected to serve consumers. Constraints (3) and (4) ensure that each TBS covers at least one consumer. Constraints (5) ensure that each consumer receive service from only one TBS. Capacity restrictions are shown by constraints (6). Constraints (7) impose that the variables be binary.

Having obtained the locations and types of the TBS’s from Phase 1, we proceed to Phase 2 of the mathematical model. In Phase 2, the connections among the TBS and the CGS are designed in such a way to have minimum piping length (to minimize gas piping expenditures). Here, we apply a minimum spanning tree model to obtain the proposed objective. The model is as follows.
Phase 2: Minimum Spanning Tree (MST)

Sets:

$I, J$  Sets of nodes

Parameters:

$N$  Number of nodes

$d_{ij}$  The distance between node $i$ and node $j$

Decision Variables:

$u_i = \begin{cases} 1 & \text{if node } i \text{ is a root node, } i = 1, \ldots, I. \\ 0 & \text{o.w.} \end{cases}$

$x_{ij} = \begin{cases} 1 & \text{if there is a directed link from node } i \text{ to node } j, \quad i = 1, \ldots, I, \ j = 1, \ldots, J. \\ 0 & \text{o.w.} \end{cases}$

$f_{ij}$  Amount of flow from node $i$ to node $j$

Mathematical Model:

$$\text{Min } Z = \sum_{j=1}^{J} \sum_{i=1}^{I} x_{ij} d_{ij},$$

s.t.

$$\sum_{i=1}^{I} u_i = 1,$$  \hspace{1cm} (9)

$$\sum_{i=1}^{I} x_{ij} = (1 - u_j), \quad i = 1, \ldots, I,$$  \hspace{1cm} (10)

$$x_{ij} \leq f_{ij}, \quad i = 1, \ldots, I, \ j = 1, \ldots, J,$$  \hspace{1cm} (11)

$$x_{ij} (N - 1) \geq f_{ij}, \quad i = 1, \ldots, I, \ j = 1, \ldots, J,$$  \hspace{1cm} (12)
\[
\sum_{i=1}^{J} f_{ij} - \sum_{i=1}^{I} f_{ji} \geq (u_j, (-M)) + 1, \quad j=1, \ldots, J, \quad (13)
\]
\[
\sum_{i=1}^{J} f_{ij} - \sum_{i=1}^{I} f_{ji} \geq (u_j, M) + 1, \quad j=1, \ldots, J, \quad (14)
\]
\[
u_i, x_{ij} \in \{0,1\}, \quad i=1, \ldots, I, \quad j=1, \ldots, J, \quad (15)
\]
\[
f_{ij} \geq 0, \quad i=1, \ldots, I, \quad j=1, \ldots, J. \quad (16)
\]

Formula (8) is the objective function as minimizing the total distance among nodes (CGS and TBS). Constraints (9) ensure that there is only one root node in the network. Constraints (10) impose that each node will receive only one link from other nodes if it is not the root node. Amount of flow between nodes \(i\) and \(j\) is represented by constraints (11) and (12). Maximum acceptance amount of flow for each link is set to be the number of arcs. Constraints (13) and (14) guarantee that there will be no closed loop in the network. Constraints (15) impose that the variables be binary. Non-negativity of the variables is shown by constraints (16).

1.1. An Implementation

To investigate the validity and applicability of the mathematical model, we consider a numerical example based on gas piping project data in Pol-e-Sefid city in Mazandaran province in Iran. The marketing center has identified 119 gas consumption zones. Therefore, the locations of the TBS and the allocations of the zones to the TBS’s are of importance. The cost of piping per distance unit is set to be 50,000 units. The types of TBS’s and their corresponding capacities and costs are given in Table 1. To facilitate the computations, we apply LINGO 9. The results are shown in Table 2. Note the (X,Y) are coordinates of the locations.

| Table 1
| TBS Types and Their Corresponding Capacities and Costs |
|-----------------|-----------------|-----------------|
| TBS TYPES       | CAPACITY        | COST            |
|                 | (UNIT OF CAPACITY) | (UNIT OF COST)  |
| TBS type 1      | 10,000          | 65,000,000      |
| TBS type 2      | 20,000          | 85,000,000      |
| TBS type 3      | 40,000          | 150,000,000     |
Table 2

<table>
<thead>
<tr>
<th>Location Coordinates and the Corresponding TBS Types</th>
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</thead>
<tbody>
<tr>
<td>TBS 2</td>
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<tr>
<td>-------</td>
</tr>
<tr>
<td>TBS 8</td>
</tr>
<tr>
<td>TBS 8</td>
</tr>
</tbody>
</table>

The graphical configuration of the location-allocation of the TBS’s is shown in Figure 2.

In Phase 2, the connections among the TBS’s and the consumption zones are minimized. The distances between the CGS and the TBS’s are given in Table 3, and the obtained connection between the CGS and the TBS’s is shown graphically in Figure 3. These tasks having been completed, now value is surveyed in the pipeline process. Then, FAST analysis is employed to investigate value in the pipeline process.
Table 3

<table>
<thead>
<tr>
<th></th>
<th>CGS</th>
<th>TBS 2</th>
<th>TBS 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>CGS</td>
<td>0</td>
<td>33.54</td>
<td>56.82</td>
</tr>
<tr>
<td>TBS 2</td>
<td>33.54</td>
<td>0</td>
<td>23.32</td>
</tr>
<tr>
<td>TBS 8</td>
<td>56.82</td>
<td>23.32</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 3. Obtained Connection Between CGS and the TBS’s

2. FAST MODEL BUILDING

Nowadays, the supervision of production systems is becoming increasingly complex, not only because of high values for the number of variables to be considered but also because of the numerous existing interrelations among them. This complexity makes it very difficult to interpret data when the process is highly automated. The challenge in the coming years is to design support systems that give supervisory operators an active role by supplying tools and information.
that allow them to understand the operation of production equipment. Indeed, traditional supervisory systems present many problems that have already been recognized. For instance, operators are sometimes beset with information overload and at other times by information underload which hampers their mental model of the supervised process. Moreover, the supervisory operator has a tendency to wait for the alarm before acting instead of trying to anticipate abnormal states of the system.

It is important to supply the operator with the means to perform his/her own evaluation of the process state. To reach this objective, Functional Analysis (FA) seems to be promising. By allowing operators to understand the operation of production equipment, these techniques permit designers to determine the good information to display through the supervisory interfaces dedicated to every supervisory task (monitoring, diagnosis, action, etc.). In addition, an FA technique could be a good help in designing support systems such as alarm filtering systems. In this study, we perform FAST on seven main factors affecting gas pipeline projects. The fish-bone diagram is shown in Figure 4.

![Fish-Bone Diagram of Seven Main Factors in Gas Projects](image)

FAST analysis was worked out in five stages: (1) administration of the questionnaire; (2) interpretation of data; (3) integration and coordination of team leaders; (4) ability of team leaders to control job plan and schedule; and (5) completeness and clarity of recommendations.
4.1. Administration of Questionnaire

Based on the work of Palmer et al. [1996], Fong and Shen [2000], Fong [2004] and Spaulding et al. [2005], a sectioned questionnaire was administered that included a mixture of closed-ended, open-ended, scaled, and matrix questions. The range of issues included within the survey instrument was drawn from the literature [see Palmer et al., 1996; Fong, 1998; Kelly et al., 2004; Ellis et al., 2005; Spaulding et al., 2005; and Male et al., 2007]. Respondents were asked to grade the importance of each factor in relation to VE performance assessment using a five-point Likert scale, in which 5 represents “extremely important” and 1 represents “least important.”

The questionnaire contained four sections:

- **Section A – Demographic Information** (age and experience of respondents, membership in value management associations, position within their organization, characteristics of that organization)
- **Section B – Respondents’ Awareness of VE**
- **Section C – Use of VE Within Respondents’ Organization** (use of VE, the focus of VE activities, perceived usefulness of VE, and whether VE activities are predominantly handled internally within the organization or externally)
- **Section D – Nature and Extent of VE Use** (reasons for the adoption of VE, extent of VE use on projects, factors influencing the use of VE, the relative importance of client value system factors such as capital costs and running costs, benefits perceived to be derived from using VE, VE methods used on projects, international VE benchmarks or standards used, and metrics for measuring VE effectiveness on construction projects)

4.2. Interpretation: The Important Factors

Based on the consensus of the survey respondents, some factors with an average score exceeding a specified value are identified as important criteria for VE performance. The number of recommendations should be clarified in terms of size and dimension in order to assess the factors on an equal basis. Attendance stability of VE team members is important because the frequent change of VE team members impedes the continuity of value methodology implementation and synergy generation. Experienced team leaders will form a solid multi-disciplined team based on their VE experience and knowledge and their professional
problem-solving abilities. Experienced team leaders schedule workshops in a timely and effective manner to minimize resource expenditures.

4.3. Integration and Coordination Ability of Team Leaders

The beauty of VE is in the way it enables simultaneous sharing of member expertise. A VE team leader must coordinate and integrate both inside and outside the gas project site. Externally, the team leader must probe and realize the project directions as well as the goals of the consumer. The team leader must integrate the requirements of the functional departments of the consumer and coordinate the VE team to include corresponding integrated solutions in proposals, because innovative proposals cannot create value without customer acceptance. Internally, it is essential for team leaders to coordinate the teams technically and to control the team dynamism during a limited VE. Attention should also be paid to exercising functional analysis and functional analysis system technique (FAST) diagrams fluently, because FAST is a powerful core technique for integration and coordination in VEs.

4.4. Team Leaders’ Ability To Control Job Plan and Schedule

The job plan and schedule are also vital for VE success. Before a VE, in the pre-workshop stage, the team leader should understand the features of the environment, company culture and level of participation of team members, in addition to the variables and attributes of the workshop object.

4.5. Completeness and Clarity of Recommendations

The project owner requires a corresponding multidiscipline review and approval of every recommendation, both technically and financially. The information requirements are reduced with information completeness and clarity. Completeness of recommendations expedites approval. The level of completeness and recommendation clarity is achieved during the development phase. Descriptions, discrepancies, advantages, disadvantages, life cycle costs, cost estimation and the technical packages of the original design and the recommendations should be fully elaborated. The VE recommendations should be distinguished by alternatives to meet the rapid pace of the VE.

Using the above considerations helps to justify and reduce the cost of piping operations. As stated before, a cost parameter exists between any two TBS’s, zone, consumer, or node. A conceptual cost between any two nodes is shown in Figure 5.
The aim of using FAST is to identify the unsuitables or malfunctions for modification or elimination to achieve a lower cost. To analyze the functions, we apply the following value evaluator:

\[
\text{Value} = \frac{\text{Function} + \text{Quality}}{\text{Cost}} = \frac{F + Q}{C}. \tag{17}
\]

Therefore, a value for each activity is obtained and using that the economization of gas piping activities is worked out.

5. CASE STUDY AT MAZANDARAN GAS COMPANY

Table 4 presents the questionnaire used in our case study at Mazandaran Gas Company, showing the seven main factors and the 22 corresponding sub-factors. The survey was administered to a group of experts at Mazandaran. Their responses are shown in Table 5. In this table, the notion of weighted score is used to identify the effective factors for value analysis. Considering the five options (very effective, effective, fairly effective, less effective, and ineffective) as weights \(W_i\) for \(i=1,\ldots,5\) and the number of experts choosing an option for each sub-factor (question) as \(X_{ij}\), for \(i=1,\ldots,5\), \(j=1,\ldots,22\), the weighted scores are then computed as follows and recorded in the corresponding row of Table 5.

\[
\text{weighted score} = S_j = \sum_{i=1}^{5} W_i \times X_{ij}, \quad \forall j. \tag{18}
\]
## Table 4
Questionnaire Administered in Mazandaran Case Study
Showing Main Factors and Sub-Factors

<table>
<thead>
<tr>
<th>MAIN FACTORS</th>
<th>SUB-FACTORS</th>
<th>OPTIONS</th>
</tr>
</thead>
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<td></td>
<td></td>
<td>5 4 3 2 1</td>
</tr>
<tr>
<td>1. Human resources</td>
<td>1.1. Skill</td>
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</tr>
<tr>
<td></td>
<td>1.2. Number of workers</td>
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<tr>
<td>2. Materials</td>
<td>2.1. Material substitution</td>
<td>5 4 3 2 1</td>
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<td></td>
<td>2.2. Material provision</td>
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<td></td>
<td>2.3. Material consistent with environment</td>
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<td>2.4. Method of providing material</td>
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<tr>
<td>3. Licensing</td>
<td>3.1. Appropriate time for licensing</td>
<td>5 4 3 2 1</td>
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<td>3.2. Other organizations' cooperation</td>
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<td>5.3. Candidate locations</td>
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<td>7. Tools and equipment</td>
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Table 5  
Results and Weighted Scores for Mazandaran Questionnaire

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Since the maximum possible score is 80 (16*5=80), we considered items corresponding to scores higher than 60 to be important sub-factors for our analysis. The histograms of all the sub-factors are given in Figure 6. Note that the sub-factors (questions) marked by a star (*) are the ones with scores higher than 60.
Figure 6. Histograms of Questionnaire Results
Then, we prioritized the selected sub-factors for analysis in a brainstorming process to propose improvement strategies being considered as change policy. The change policies were obtained after comprehensive discussions. Using the data on change policies, strategy values were computed using (17).

6. CONCLUSIONS

The incorporation of VE and target costing in a gas pipeline project is an important element affecting the cost. VE and target costing are complementary processes, where one relates to cost reduction and the other corresponds to a target for guaranteeing the long-term profitability of a company.

We assessed value in two steps. The first step corresponded to determining the locations of the TBS, allocations of the CGS to the TBS, and the routings of the distribution lines among the TBS and the consumption zones. The second step analyzed the activities in the implementation process to identify the unsuited or malfunctioned activities and proposed change policies to gain higher values (lower costs). In the first step, we made use of a location-allocation model and minimum spanning tree (MST). In the second step, we used the Functional Analysis System Technique (FAST). A case study of Mazandaran Gas Company in Iran was conducted to assess the validity and effectiveness of the proposed value engineering approach.
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