Analysis of value engineering application at the design stage of a deep excavation system

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Abstract. This paper introduces a method of value engineering analysis by calculating the value coefficient of the substructure work in an office building project. Value coefficient is obtained by dividing the performance coefficient with cost coefficient, whose result shows that the retaining wall system is the main object to be developed. The retaining wall system used in the initial design is soldier pile consisting of rows of 80 cm diameter bored pile with a one-meter center to center spacing, which in each gap between two adjacent bored piles, a 40 cm diameter bentonite pile was constructed. The construction cost of the substructure generated from the initial design is Rp. 35,554,793,500.00. After implementing VE analysis, the VE team chose spun piles with 60 cm diameter (without bentonite piles) with 70 cm center to center spacing as a substitute for the initial design. The assessment performed by the VE team about the performance of the alternative indicates that there is 20.6% increase of performance compared to initial design and cost savings of 17.75%, resulting in a value coefficient of 1.22, this result is 47% higher than the initial design has, which is 0.83.

1. Introduction
According to SNI 8460:2017, deep excavation comprises excavation of soil or rocks layer which has a depth of 3 meters or more [1]. Deep excavation works have often been found in urban areas for the construction of building basements and infrastructure development such as tunnels and reservoirs. In practice, excavation works contain the risk of failure, which cost much money, even someone's life. One of the examples of deep excavation failure is on April 21, 2004, Singapore, when Nicoll Highway collapsed due to the excavation of Mass Rapid Transit (MRT) construction. The failure had caused the loss of four lives [2]. Therefore, excavation work is one of the works that have to get special attention both in the planning and implementation stages so that the excavation work can be carried out safely. Moreover, the engineer still has to consider the cost and time aspects under the owner's schedule and budget. If the engineer's design fails to meet the owner's budget and schedule, there will be additional time, effort, and cost required to change and adjust the design of the project. In order to get the result which has appropriate performance, cost, and time, Value Engineering (VE) method can be applied in the initial design stage [3]. Value engineering /value methodology is a systematic process that follows the job plan [4]. The number of job plans defined by several organizations for VE analysis might be different from each other [5],[6],[7]. This study aims to develop the Value Engineering analysis method which consists of six job plan activities [4]. Each job plan along with the result of the study will be described in the next section.

2. Methodology
The VE methodology can be applied to any subject or problem. It is a vehicle to carry the project from inception to conclusion [7]. As mention in the previous section, the job plans in this study is conducted in six sequential phases as follows :

2.1. Information phases
The subject of the study was substructure construction of an office tower in Surabaya which consists of 33 levels upper structure and two-level basement. The technical data of the project is shown in Table 1.
Table 1. Project technical data

| Description                   | Site area | Gross floor area | Number of floors (above ground floor) | Number of basement | Seismic force-resisting system                          | Foundation                      | Excavation system       |
|-------------------------------|-----------|------------------|---------------------------------------|--------------------|--------------------------------------------------------|---------------------------------|-------------------------|
| Function                      |           | 2955 m²          | 48000 m²                              | 33                 | Dual system: Special reinforced concrete moment frames + special reinforced concrete shearwalls | Reinforced Concrete Bored piles + Spun piles | Soldier pile with the top-down construction |

In this study, the writer acted as the VE team leader, who has prepared a cost model from the cost estimate prepared by the project team. The model was made to identify major cost items and the proportion of total project cost. The cost model of the project is represented in the form of a table and chart (called Pareto chart) and shown in Table 2 and Figure 1.

Table 2. Cost model

| No | Cost item       | Cost               | Percent of total | Cumulative percentage |
|----|-----------------|--------------------|------------------|-----------------------|
| 1  | Raft Foundation | Rp10,288,500,000.00| 28.94%            | 28.94%                |
| 2  | Soldier Pile    | Rp9,618,535,000.00  | 27.05%           | 55.99%                |
| 3  | Spun Pile       | Rp7,424,375,000.00  | 20.88%           | 76.87%                |
| 4  | Excavation      | Rp4,466,880,000.00  | 12.56%           | 89.43%                |
| 5  | Concrete wall   | Rp2,024,575,000.00  | 5.69%            | 95.13%                |
| 6  | Bored Pile      | Rp1,022,436,000.00  | 2.88%            | 98.00%                |
| 7  | Capping Beam    | Rp438,612,500.00    | 1.23%            | 99.24%                |
| 8  | Lean Concrete   | Rp169,300,000.00    | 0.48%            | 99.71%                |
| 9  | Crusher         | Rp101,580,000.00    | 0.29%            | 100%                  |
|    | TOTAL           | Rp35,554,793,500.00 | 100.00%         | -                     |

2.2. Function analysis phase
Among the many techniques used to solve problems, only the VE approach calls for function analysis followed by the application of creative thinking techniques [6]. The purpose of this phase is to understand the project from a functional perspective; what must the project do, rather than how the project is currently conceived [4]. Functions are defined in verb-noun statements to reduce the needs of the project to their most elemental level. The example of function defined for the soldier pile and raft foundation is shown in Table 3.
After all the function had been defined, the VE team can construct the Function Analysis System Technique (FAST) diagram. The FAST diagram is best accomplished as a team effort [7]. The interplay of different viewpoints causes deeper thinking about the subject and, therefore, more thorough investigation. The FAST diagram of the project is shown in Figure 2.

Table 3. Verb-noun statement of soldier pile and raft foundation

| Component       | Verb   | Noun   | Component       | Verb   | Noun   |
|-----------------|--------|--------|-----------------|--------|--------|
| **Soldier Pile**| Retain | Material | **Raft Foundation** | Transfer | Load   |
|                 | Prevent | Damage   |                 | Prevent | Leakage|
|                 | Save   | Cost     |                 | Minimize | Deformation |
|                 | Bear   | Load     |                 |         |        |

Figure 1. Cost model (Pareto chart)
VE team also need to define performance attribute which posses a range of acceptable levels of performance. Those attribute will be used then in the development phase. Performance attribute along with their relative importance used in this study can be found in Figure 3.

2.3. Creative phase
During the creative phase, the VE group did the brainstorming session to generate ideas on how to perform the various function. The ideas generated from the VE group is shown in Figure 5.

**Figure 3** Relative importance of performance attribute

| Performance attribute | Relative importance |
|-----------------------|---------------------|
| Project safety        | 39.6%               |
| Project schedule      | 32.0%               |
| Construction impact   | 14.4%               |
| Maintainability       | 7.5%                |
| Aesthetic             | 6.5%                |

**Figure 4** Creative idea list

- **Baseline concept**: Borepile D = 800 mm ctc 1000 mm; with bentonite pile + concrete wall t=400mm
- **Idea number 1**: Bored piles D = 800 mm ctc 1000 mm; without bentonite pile; + concrete wall t=250mm
- **Idea number 2**: Borepile D = 600 mm ctc 700 mm without bentonite pile + concrete wall t=250mm
- **Idea number 3**: Diaphragm wall with 600 mm thickness
- **Idea number 4**: Corrugated Prestressed Concrete Sheet Pile + concrete wall t = 250mm
- **Idea number 5**: Spun pile D = 600mm; 100 mm thickness; ctc 700 mm without bentonite pile + concrete wall t =250mm
2.4. Evaluation phase
In this stage, VE group compared each idea with its baseline concept to determine whether the performance of the was better than, equal to, or worse than the baseline concept. The rank of the performance is described below:

- 5 = Major value improvement
- 4 = Moderate value improvement
- 3 = Possible value improvement
- 2 = Moderate value degradation
- 1 = Major value degradation

Each idea from the creative phase was then evaluated until reaching a consensus on the overall ranking of the idea. Ideas rated 4 and 5 were developed further. Figure 5 showed the result VE team consensus from the evaluation phase.

![Figure 5 Evaluation phase consensus result](image)

2.5. Development phase
In this study, of the 5 ideas that were generated during the creative phase, 3 of those ideas (shown in Table 4) were evaluated high enough to be analyzed, compared, and developed further.

| Recommendation  | Description                                                                 |
|-----------------|-----------------------------------------------------------------------------|
| Baseline concept| Bored piles D = 800 mm ctc 1000 mm; without bentonite pile + concrete wall with 400mm thickness |
| Alternative 1   | *Borepile, D = 80 cm, ctc 100 cm, tanpa bentonite pile + concrete wall t=250mm* |
| Alternative 2   | Diaphragm wall with 600 mm thickness                                          |
| Alternative 3   | Spun pile D = 600mm; 100 mm thickness; ctc 700 mm without bentonite pile + concrete wall t=250mm |

The objective of this phase is to get the value coefficient from each alternative. Value coefficient was calculated by determining performance and cost coefficient. Value coefficient can be calculated by the following equation [8]:
According to the equation above, to get the value coefficient, the VE team have to determine the performance and the cost from each alternative. To determine the performance, the VE team need to do a performance assessment. As the team developed recommendations, the performance of each was compared to baseline for potential value improvement. While for the cost, the VE team can determine the cost from each alternative with relatively simple cost estimation. The results of performance assessment and cost estimation are shown in Figure 6 and Figure 7.

\[
\text{Value coefficient} = \frac{\text{Performance coefficient}}{\text{Cost coefficient}}
\]

(1)

Figure 6 Performance assessment result of each alternative

![Figure 6 Performance assessment result of each alternative](image)

Figure 7 Cost estimation of each alternative

![Figure 7 Cost estimation of each alternative](image)

Figure 6 indicates that the alternative number 2 (Diaphragm wall) has the best performance among all the alternatives, while Figure 7 indicates that alternative number 3 (spun piles) is the most economical option. In this scenario, the determination of value coefficient plays a significant role to help the VE team making the decision to chose the best alternatives. The summary of value coefficient calculation is shown in Table 5 Value coefficient summary.
Table 5 Value coefficient summary

| Alternative | Performance | Performance coefficient | Cost (Billion rupiah) | Cost coefficient | Value coefficient |
|-------------|-------------|-------------------------|-----------------------|------------------|-------------------|
| Baseline concept | 5.00 | 0.22 | 35.55 | 0.26 | 0.83 |
| 1 | 5.35 | 0.23 | 33.52 | 0.25 | 0.94 |
| 2 | 6.45 | 0.28 | 36.28 | 0.27 | 1.05 |
| 3 | 6.03 | 0.26 | 29.24 | 0.22 | 1.22 |
| Total | 22.83 | 1.00 | 134.59 | 1.00 | |

The alternative that has the highest value coefficient will be recommended to be used as a replacement of the baseline concept. According to Table 5, alternative 3 has the largest value coefficient of 1.22, hence, the VE team recommended alternative 3 as a replacement of the baseline concept.

2.6. Presentation phase
Communication is essential to the success of a VA effort [9]. Therefore, the VE team has to present each of the alternatives to the user/owner so they could understand the intent of each alternative. The outline of the presentation phase is to anticipate roadblocks to be overcome and to prepare a written proposal which consists of summarize the study, expected advantages/disadvantages, the recommendation of specific action, and implementation plan [5].

3. Conclusion
By applying Value Engineering analysis in this project study, the project stakeholder can understand which factors are the most dominant in determining the performance of the excavation system, which is: 1) project safety, 2) project schedule, 3) construction impact, 4) maintainability and 5) environment impact. The result of the study also indicated that there will be an increase in value when applying a new alternative as the replacement of the initial design. By using spun piles instead of the cast in placed bored pile for soldier pile structure, the new alternative has value coefficient 47% greater than the initial design.

4. References
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