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ENHANCING STORM DRAINAGE SYSTEMS FOR ROAD NETWORKS BY APPLYING VALUE ENGINEERING: CASE STUDY

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ABSTRACT

Storm water is one of the environmental factors that affects the performance of the surface transportation system and road safety. Storm drainage should be used to prevent the roads from flooding. Road drainage involves the removal or control of surface water and subsurface water away from the road surface and the subgrade that supports it. Cost-effective maintenance and enhancement are required to serve infrastructure with minimal costs effectively. It is deemed a thought-provoking task in engineering, particularly in fulfilling the growing demands of society. Despite the remarkable application of value engineering (VE) results to evaluate the modern designs of storm drainage networks. This study presents a typical VE technique for infrastructure projects, particularly for Stormwater Water Drainage Networks (SWDN). A comprehensive VE analysis was conducted to test the case for the proposed SWDN in Cairo, Egypt. The function analysis system technique (FAST) was implemented to study relationships in a logical manner among the components of a project. The study comprised a complex live cycle cost analysis (LCCA) of the study area and a weighted evaluation matrix (WEM), which offers the necessary support to the decision-makers. This paper studied and evaluated ten alternatives to optimize the storm drainage network design, focusing on sustainable materials. Each criterion was carefully considered during the VE analysis. These include constructability, maintenance, and environmental impact. Subsequently, an unbiased criterion was used to select the best drainage design. Inspection chamber cover, Manholes diameter, CHDPE pipes material, catch-basins size and depressed curbs have proven to outperform the other choices. Thus, it saved about 15% of the original design costs (6.0 million Egyptian pound). Therefore, this study inferred that the application of VE analysis has proven to be associated with cost savings. It presents a further enhancement in terms of the sustainability aspect and the overall value. This study's developed value engineering (VE) methodology can guide design engineers and decision-makers working in Storm drainage.

KEYWORDS: Storm Drainage, Road, Road Drainage, Value Engineering, Function Analysis System Technique, Life Cycle Cost Analysis, Weighted Evaluation Matrix, and Value Index.

تحسين أنظمة تصريف مياه الأمطار لشبكة الطرق من خلال تطبيق نظرية الهندسة القيمية

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الملخص

تعتبر مياه الأمطار أحد العوامل البيئية التي تؤثر على أداء نظام النقل البري والسلامة على الطرق. يجب استخدام تصريف العواصف لمنع الطرق من الفيضانات. يتضمن تصريف الطرق إزالة أو التحكم في المياه السطحية والمياه الجوفية بعيدًا عن سطح الطريق والطبقة السفلية التي تدعمه. هناك حاجة إلى صيانة وتعزيز فعالين من حيث التكلفة لخدمة البنية التحتية بأقل التكاليف بشكل فعال. وتعتبر مهمة مثيرة للتفكير في الهندسة، وخاصة في تلبية المتطلبات المتزايدة للمجتمع. على الرغم من التطبيق الرائع لنتائج الهندسة القيمية (VE) لتقييم التصاميم الحديثة لشبكات صرف الأمطار. تقدم هذه الدراسة تقنية VE نموذجية لمشاريع البنية

التحتية، وخاصة لشبكات تصريف مياه الأمطار (SWDN). تم إجراء تحليل VE شامل لاختبار حالة شبكة النفايات الصلبة المقترحة في القاهرة، مصر. تم تطبيق تقنية نظام التحليل الوظيفي (FAST) لدراسة العلاقات بطريقة منطقية بين مكونات المشروع. وتضمنت الدراسة تحليل تكلفة الدورة الحية المعقدة (LCCA) لمنطقة الدراسة ومصفوفة التقييم المرجح (WEM)، والتي تقدم الدعم اللازم لصناع القرار. قامت هذه الورقة بدراسة وتقييم عشرة بدائل لتحسين تصميم شبكة صرف العواصف، مع التركيز على المواد المستدامة. تم النظر بعناية في كل معيار أثناء تحليل VE. وتشمل هذه قابلية البناء والصيانة والأثر البيئي. وبعد ذلك، تم استخدام معيار غير متحيز لاختيار أفضل تصميم للصرف. لقد أثبت غطاء غرفة التفتيش، وقطر غرف التفتيش، ومواد أنابيب CHDPE، وحجم أحواض الصيد، والحواجز المنخفضة أنها تتفوق على الخيارات الأخرى. وبذلك تم توفير حوالي 15% من تكاليف التصميم الأصلي (6.0 مليون جنيه مصري). ولذلك، استنتجت هذه الدراسة أن تطبيق تحليل VE أثبت أنه مرتبط بتوفير التكاليف. إنه يقدم تعزيزًا إضافيًا من حيث جانب الاستدامة والقيمة الإجمالية. يمكن لمنهجية هندسة القيمة (VE) المطورة في هذه الدراسة توجيه مهندسي التصميم وصناع القرار العاملين في مجال تصريف العواصف.

الكلمات المفتاحية : تصريف العواصف، الطرق، صرف الطرق، هندسة القيمة، تقنية نظام تحليل الوظائف، تحليل تكلفة دورة الحياة، مصفوفة التقييم المرجح، ومؤشر القيمة.

1. INTRODUCTION

The study of storm water is of great importance in road planning, as it helps to accurately design roads, and determine how storm water is drained, thus protecting roads from exposure to erosion or landslides when heavy rains fall. The main functions of road drainage are to keep the road's surface and base as dry as feasible so that the durability and stability of the road are maintained and to sustain highway transportation at a low cost, a good drainage system is necessary. Value engineering is systematic teamwork. However, it is impossible without creativity [1, 2]. Creativity is highly needed to solve unusual problems that may minimize the total project cost and improve the project's main function without compromising the project quality [3, 4]. This will be obtained by using the compiled knowledge of each specialist. For example, maintaining an effective drainage system that can guarantee public safety requires the application of value engineering techniques in the design process of a storm drainage system.

The drainage network system can be divided into two parts: a) The major Storm Water Drainage System, which is made up of water conduits and reservoirs that hold and channel water from a catchment area (basin region), and b) Small stormwater drainage system, which collects and drains water from rainfall catchment regions using drainage and drainage complementing drainage systems. Understanding the Stormwater Drainage System (SDS) is critical since it has become a deterministic system, particularly under current environmental change. The system removes the excess water from heavy precipitation, which can interrupt day-to-day activities [5]. There are two types of road drainage systems which are surface and sub-surface drains, the road drainage system can be divided into two parts: a) surface road drainage, which is collected and disposed of the surface water. The nearest stream, valley, or other source of water is used as the final disposal location after the water is first collected in the longitudinal drains, often in the side drains. Surface water from the roadside drains may require disposal through cross drainage structures like culverts and small bridges and b) drainage below the surface, which is changes in the groundwater table, seepage flow, rainwater percolation, capillary water movement, and even water vapour can affect the moisture content of sub-grade. The variance of moisture in sub-grade soil is intended to be kept to a minimum during subsurface drainage of roadways. However, the typical drainage system just drains gravitational water.

The VE process comprises six phases: information, function analysis, creativity, evaluation, development, and presentation [6]. It involves value and function analyses to determine the cost-efficiency of the suggested alternatives and their feasibility. It could be accomplished by trying to reach the determined function of the endeavour with the lowest cost. Therefore, promoting the function and decreasing the cost is essential since it can enhance value. Likewise, sustainability characteristics and (VE) in the project stages (Design and Construction) are required. For instance, the sustainability aspects relevant to the storm drainage network are water quality, waste reduction, energy efficiency, renewable and recyclable materials, disposal, durability, and comfort [6]. Value engineering aims to provide a practical design and construction strategy that lowers costs, raises quality, and solves potential problems. Value Engineering has become an integral component of current construction projects that aim to enhance value [7]. Conversely, the VE studies' results, including executed VE methods and established theories and options, are seldom published, undermining information sharing in transportation projects [8].

In recent times, (VE) has become more recognized and vital in construction and engineering applications. The VE is found to be a well-organized process that catches the potential opportunities that could be an improvement to the product value and eliminate any extra costs. Moreover, those pre-structured planning processes have proven that there are a quality improvement and an added value for the projects to accomplish continuous social growth. Moreover, VE is considered a decision–making tool that facilitates the selection among many alternatives after checking various aspects such as sustainability, profitability, and cost-efficiency. Around 800 accepted VE transportation-related proposals for federal infrastructure projects are estimated to be submitted in 2020. These recommendations have led to a cost savings of about 10% ($3.1 billion) for the $32 billion worth of projects considered [8], as presented in **Table 1**.

Table 1. Money-saving for the past five years from VE implementation.

Year	2020	2019	2018	2017	2016
Number of Value Engineering Studies	334	246	175	160	198
Cost to Conduct VE Studies and Program Administration	$11 M	$12,50 M	$7,30 M	$6,60 M	$7,70 M
Estimated Construction Cost of Projects Studied	$23,25 B	$32,0 B	$22,70 B	$20,80 B	$16,70 B
Percent of Project Cost Saving	8%	10%	5%	5%	5.20%
Total Saving Achieved	$2.0 B	$3,10 B	$1,20 B	$1,10 B	$910 M
Return on Investment	172:01:00	247:01:00	157:01:00	159:01:00	113:01:00

In this review, the term "project" is used to refer to a building project, which is a project involving the construction industry (development). Some of the project's qualities have been described based on the above definition and limitations. These qualities are: 1) There is a time constraint on the project, 2) The outcomes should not be replicated, 3) Atypical phases of actions, 4) intensity of activity, 5) A wide variety of activities, which necessitates a diverse energy classification, 6) allocation of land for a specific project and 7) Explicit project specifications.

The phase of a construction project can be divided into three (3) phases: 1) design phase (planning), 2. auction phase (procurement phase). Project implementation phase (construction phase). However, each project's phase can further be divided into minor activities. **Fig. 1** illustrates the flow chart developed by SAVE International. As shown in **Fig. 2**, the cost of VE is high during the planning phase and decreases during project execution [9]. It implies that there will be a higher cost of change to apply the required developments [9]. This paper presents a study on enhancing storm drainage system for road networks by applying value engineering.

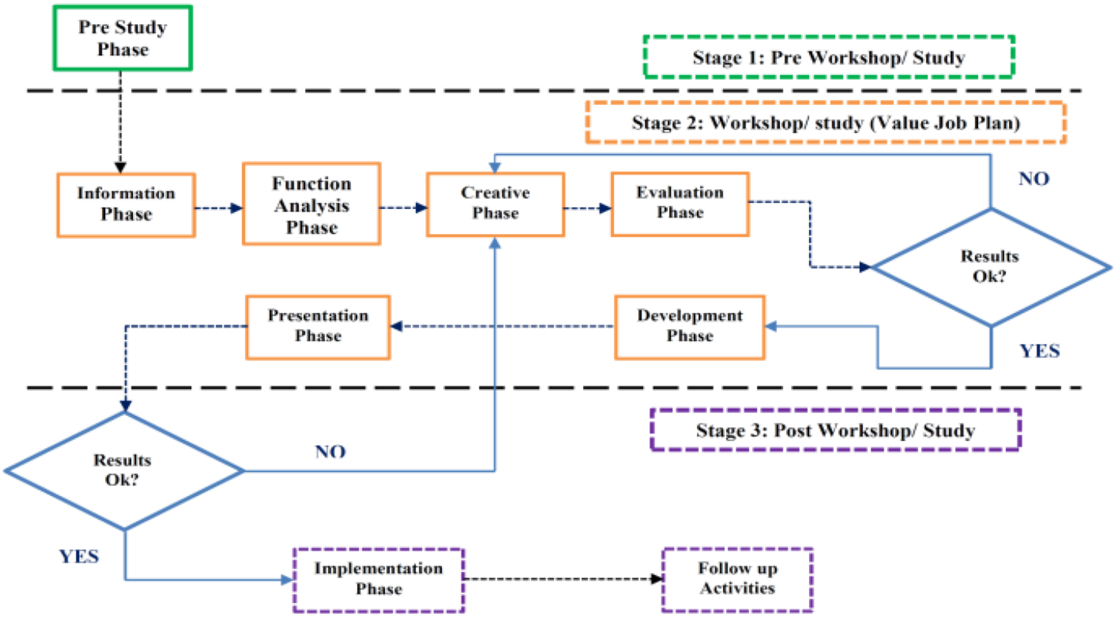


Fig.1. Major VE process activities for this study [8].

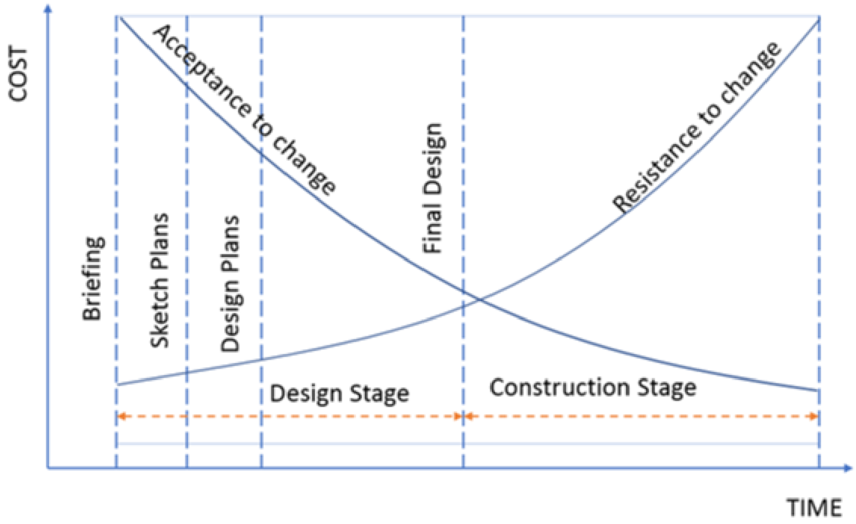


Fig. 2. Value Engineering phases in the project concerning expected cost savings [8].

2. Methodology

To apply the VE methodology, a consecutive procedure should be followed to manage the available resources efficiently [10, 11]. Sticking to the formal method named job plan is shown in **Fig. 3**, the job plans shed light on certain strategies to assess the output (service or product). The well-experienced VE teamwork carried out many workshops to brainstorm the potential parameters that affect the design of the storm drainage network generating various scenarios with different alternatives those are later filtered to choose the most suitable alternative. The use of an official procedure referred to as a job plan is illustrated in **Fig. 3**. The job plan highlights specific strategies to assess a product or service to perform the tasks required by goods or services [12, 13].

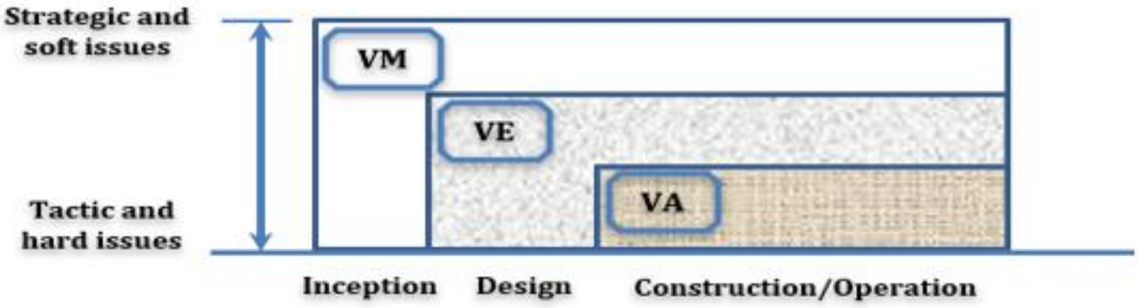


Fig. 3. Value Study Process Flow Diagram [12, 13].

The VE team shall include a diverse group of engineers as per the following: 1) hydrology expert (hydrologist), 2) storm drainage modelling expert, 3) road design expert, and 4) Consultants from various disciplines. Value Analysis (VA) is defined as a technique for enhancing the product's value by increasing the relationship between work-cost through functional analysis [14, 15]. The VE is similar to VA except that it emphasizing application during product design or development [16, 17]. Finally, value Management (VM) is also similar to VA, however emphasizes the application as a management method. The VE technique was applied to the proposed storm drainage network in Egypt.

The location lies in the western part of the 5th settlement area at the eastern of Cairo. The study area is estimated to be 0.30 km^2, ring road at the west, a Teseen street at the north, an existing storm drainage line surrounding the study area. A road of 60 meters' width to the south, and a residential area to the north as shown in **Fig. 4**). In this study, the VE analysis is restricted to road grading, storm drainage network, and surface drainage [18, 19].

Coordination between civil and hydrological was done at the start of the design stage to get the best site grading possible. However, the site's profile and grades were tweaked as necessary. A mix of surface drainage and storm drainage network was explored to find the most cost-effective design configuration for the storm drainage system. The project's environmental effects and socioeconomic constraints are unavoidable. Concerns include not just allowing pollutants to flow directly into the outfall; when clogged in metropolitan areas, they can also contribute to runoff contamination and floods [20, 21]. It involves lowering pipe diameter, modifying manhole material, reducing construction time, boosting durability, optimizing the planned network's durability, and minimizing maintenance frequency.

Fig. 4. Study area location.

3 Results and Discussion

The results of this study, comprising the VE phases and the associated activities, as shown in **Fig. 1**, are presented below.

3.1 VE phases and the associated activities

3.1.1 Information Phase

The relevant information was gathered from current study area reports, studies, and design requirements to identify the basic project configurations and obtain their vital components. Regarding alignment and geometry, the selected study area is roughly 5.0 km of storm drainage lines comprising 110 maintenance holes. Regarding budgeting and cost estimation, the total cost of a storm drainage network is 6.0 million Egyptian pound. It comprises site clearing, mobilization, construction layout, connection to the existing network, final clean-up, and construction of the proposed storm drainage system. The price breakdown (expressed as a percentage) for the study area items up to the construction completion is presented in **Fig. 5.**

Road grading accounted for 41% of the capital cost breakdown for the proposed storm drainage network. It is followed by gravity storm drainage pipes which accounted for (61%), storm drainage manholes (26%), gravity storm drainage lead pipes (3%), storm drainage inlet (8%) and inspection chamber (2%). These results are comparable to Lee and Selvakumar [22]. The cost breakdown is further illustrated in **Table 2**. Adopting a storm drainage system to accommodate increased rainfall caused by climate change [23]. The collected data was sorted and classified for the subsequent VE phases. The VE team has managed to identify high-cost areas of the study area.

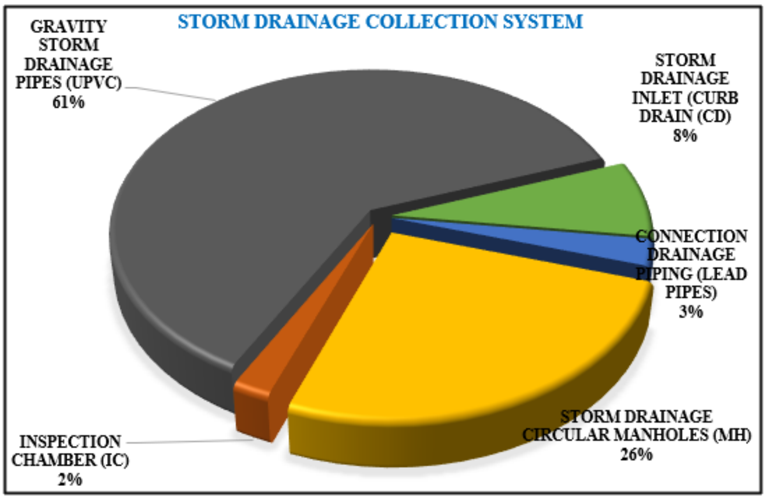


Fig. 5. Proposed storm drainage network cost breakdown (6.07-million-pound total cost).

Table 2. Cost breakdown for the proposed storm drainage network.

Item	Initial Cost, (LE)	Percentage, %
Storm Drainage Inlet (Curb Drain (CD)	461760	7.60
Connection Drainage Piping (Lead Pipes)	159,480	2.63
Storm Drainage Circular Manholes (MH)	1,584,746	26.10
Inspection Chamber (IC)	128,505	2.12
Gravity Storm Drainage Pipes (UPVC)	3,737,560	61.55
Total Budget	6,072,051	100.00

3.1.2 Function Phase

The (VE) function phase allows for a clear and objective knowledge of the project requirements [24-26]. This is the logical phase in which the project's criteria and objectives are defined and achieved. The VE team can use functional analysis to convey multidisciplinary project functions. Team members usually define and describe the functions in a two-word description that includes an "active" verb and a "measurable" noun, ensuring that the objectives are highlighted. The project's functions were connected and organized using the function analysis system approach (FAST) in **Table 3**. It better reflects the relevance and purpose of those functions [27]. The FAST diagram prepared by the team for this study area is seen in **Fig. 6**.

Table 3. Component description.

Component Description	VERB	NOUN	KIND
Storm Drainage Inlet (Curb Drain (CD)	Prevent	Clogging	All time Function
	Minimize	Maintenance	All time Function
	Collect	Water	Secondary Function
Connection Drainage Piping (Lead Pipes)	Convey	Water	Basic Function
Storm Drainage Circular Manholes (MH)	Enhance	Safety	Project Objective
	Direct	Flow	Secondary Function
	Contain	Water	Secondary Function
Inspection Chamber (IC)	Prevent	Clogging	All time Function
	Minimize	Maintenance	All time Function
	Collect	Water	Secondary Function
Gravity Storm Drainage Pipes (UPVC)	Convey	Water	Basic Function

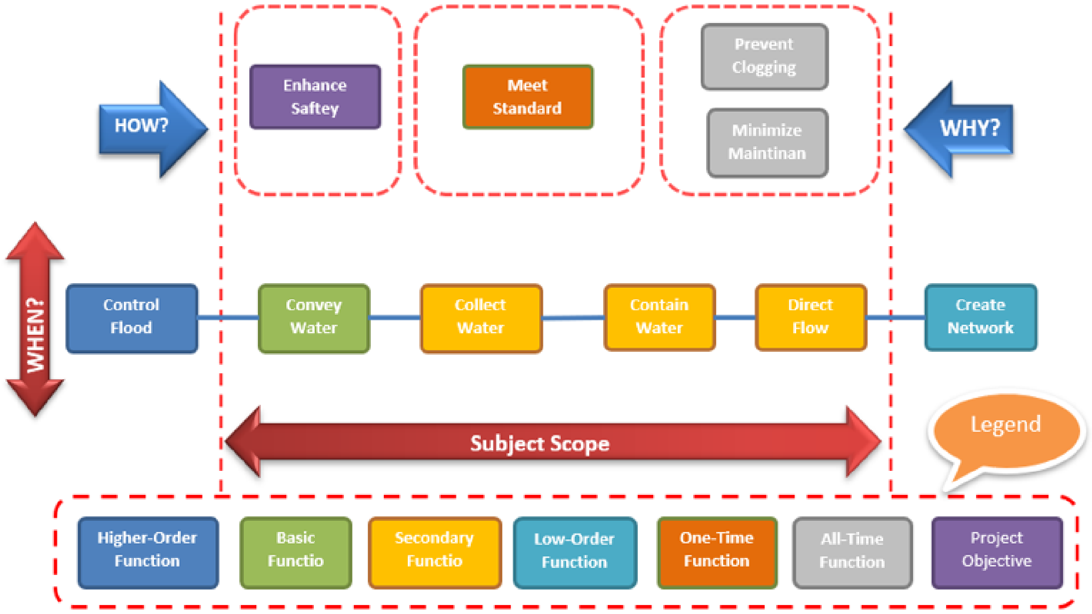


Fig. 6. Storm drainage system Function analysis system technique (FAST) diagram [27].

As presented in **Fig. 6**, high-order function in this study area: control flood, while sustaining the environment [28, 29]. The all-time function of the study area, as defined by the VE team, is to prevent clogging and minimize maintenance [30]. Therefore, further advances can be obtained by employing integrated methods, runoff source control, pollution, improved resilience of receiving waters, and adaptive management of stormwater; specifically, new strategies and technologies are required for stormwater management, and tools for operations and analysis of drainage systems [31]. As a part of function analysis is to distribute the cost for each function and create function resources matrix as shown in **Table 4** the function resources matrix will help the value engineering team to know the high value area by creating pareto analysis as shown in **Table 5**. The high values in the proposed storm drainage network as per the pareto analysis are convey water with 64.70% from the total cost, direct flow with 18.77%, collect water with 5.22% and contain water with 4.05% which will be considered in the creativity phase.

Table 4. Function Resources Matrix.

Project Elemets	Cost	Function (Verb + Noun)						
		Prevent Clogging	Minimize Maintenance	Collect Water	Enhance safety	Direct flow	Convey Water	Contain Water
Storm Drainage Inlet (Curb Drain (CD)	461,760	92,352	138,528	230,880				
Connection Drainage Piping (Lead Pipes)	159,480						159,480	
Storm Drainage Circular Manholes (MH)	1,535,957				161,475	1,130,322		244,160
Inspection Chamber (IC)	128,505	19,276	25,701	83,528				
Gravity Storm Drainage Pipes (UPVC)	3,737,560						3,737,560	
Total Cost	6,023,262	111,628	164,229	314,408	161,475	1,130,322	3,897,040	244,160
Function Percentage (%)	100%	1.85%	2.73%	5.22%	2.68%	18.77%	64.70%	4.05%

Table 5. Function Pareto Analysis.

Function Pareto Analysis			
Functions	**Cost**	**Percentage %**	**Cum. Percentage %**
Prevent Clogging	111,628	1.85%	1.85%
Minimize Maintenance	164,229	2.73%	4.58%
Collect Water	314,408	5.22%	9.80%
Enhance safety	161,475	2.68%	12.48%
Direct flow	1,130,322	18.77%	31.25%
Convey Water	3,897,040	64.70%	95.95%
Contain Water	244,160	4.05%	100.00%
Total Cost	6,023,262	100.00%	

3.1.3 Creativity Phase

During the creative phase, new ideas and alternatives are produced through unrestrained brainstorming [32]. This enables "out-of-the-box" or unconventional solutions to be generated, regardless of their merits. Therefore, only the storm drainage network components that were part of the study's scope were studied [33, 34]. A preliminary screening was undertaken to establish the components shown in **Fig. 6** and **Table 5** to determine their utility in the study area. The experts presented twenty-seven ideas, and ten suggestions were accepted due to the voting. As stated in **Table 6**, these ideas are discussed based on their benefits and drawbacks.

Table 6. Component description of proposed ideas and their description.

Idea No.	**Function**	**Proposed Ideas description**
1	Convey Water	Create bond at lower point of the Site and use fountains.
2		Use GRP pipes instead of UPVC.
3		Using Manual Excavation instead of having Excavator for the pipes.
4		Use Shallow System by minimizing the cover above the pipe.
5		Decrease the benching around the pipe.
6		Use CHDPE pipes instead of UPVC.
7		Use Y connection to connect catch basins to pipes network.
8		Use surrounded channel and levelling up site to use surface drainage system.
9		Reduce Pipe Diameter considering the quantity of Water.
10		Reduce the pipes cover to be 1.0 m.
11		Reduce the Excavation width for laying the pipes by reducing pipe size.
12		Reduce the water to be conveyed by using the water in irrigation and landscaping.
13		Optimize the pipe diameter.
14		Minimize the route length.
15	Collect Water	Use the roadside slope.
16		Periodical operation and maintenance for catch basin.
17		Use depressed Curb to minimize the number of CB.
18		Change (IC) cover of GRP or GRC.
19		Use Precast CB instead of Cast In-Site.
20		Change catch basins dimension to 50 x 50.
21	Direct Flow	Use straight paths as possible and avoid turns.
22		Use Precast Manholes instead of Cast In-Site.
23		Reduce no. of Manholes. By increasing the pipes length.
24		Create Storm ditch for site protection.
25	Contain Water	Change manholes internal diameter to 1.0 m instead of 1.20 for depths less than 2.50m
26		Use GRP Manhole Material.

3.1.4 Evaluation Phase

The ideas developed during the innovation phase are systematically assessed, vetted, prioritized, and selected for their cost-reduction and value-adding potential. The initial phase's discussions were expanded to include a variety of related storm drainage system characteristics, including manhole materials, pipe materials, site grading, and other constructability issues. These problems are comparable to other studies concerning stormwater drainage systems. Consequently, the importance of system selection and constructability examination was emphasized as follows: (a) GO - NO GO — discard concepts that do not pique your attention, (b) champion – someone who believes in the concept, (c) GFI (Go for It) - discuss the benefits and draw a vote. - The GFI is the team's average. - Mix and match concepts; add new ones. - When voting, keep track of all assumptions, and (d) quantify performance attributes through a trade-off study. – using pair-wise comparison, etc., choose the best choices. - expert choice software could be used. - when voting, keep track of all assumptions and (e) customer acceptance - Establish consumer acceptability criteria and quantify them. - compare and contrast surviving ideas to the norm and danger. - create scenarios for your idea [35]. The proposed design ideas from the creativity phase are critically evaluated in this step. The method entails rejecting low-potential, unrealistic, and impractical alternatives by comparing them to the original concept. To eliminate repetition, similar design ideas are integrated [36]. In this step, the team offered and pre-screened ten possibilities based on the considerations above and needs as shown in **Table 7**. In this stage the selected idea with high ranking will pass to the development stage, the Using depressed curb will minimize the CB and storm drainage network with average rank 8, the changing the proposed pipes to be CHDPE instead of UPVC with average rank 8, changing the Inception chamber cover to GRP or GRC with average rank 8, changing the catch basins dimension to be 50 x 50 cm with average rank 8 and changing manholes diameter for the depths less than 2.50m to be 1.0m diameter with average rank 8.

Table 7. Proposed storm drainage system alternatives in this study.

No.	Idea Description	Environmental Impact (EI)	Constructability (CON)	Schedule (SC)	OPEX	CAPEX	Meet Function	Improve Quality & add Value	Owner Acceptance	Average	Rank	GO - N0 GO
1	Use GRP pipes instead of UPVC	6	5	5	7	7	7	4	4	6	M	NO GO
2	Use depressed Curb to minimize the number of CB.	8	8	6	8	8	8	8	7	8	H	GO
3	Use CHDPE pipes instead of UPVC	7	3	7	8	7	7	3	7	8	H	GO
4	Change (IC) cover to GRP or GRC.	7	8	8	8	9	9	8	7	8	H	GO
5	Use Precast CB instead of Cast In-Site.	8	8	8	7	4	8	8	5	7	M	NO GO
6	Change catch basins dimension to 50 x 50.	8	7	8	8	7	8	7	8	8	H	GO
7	Use Precast Manholes instead of Cast In-Site.	7	8	7	7	4	9	8	5	7	M	NO GO
8	Change manholes internal diameter to 1.0 m instead of 1.20 for depths less than 2.50m	7	8	7	7	8	7	8	8	8	H	GO
9	Decrease the benching around the pipe	6	5	6	5	8	5	8	7	6	M	NO GO
10	Use Y connection to connect catch basins to pipes network.	5	7	6	4	8	6	8	7	6	M	NO GO

3.1.5 Development Phase

Results revealed that cost analysis of many projects could be adapted/enhanced to identify suitable measures for cost estimation services. Thus, the LCCA is combined with the weighted evaluation matrix to determine the highest-ranking development alternative(s). **Table 5** summarises the structural configurations of the developed possibilities for review and development. **Table 3** shows the cost breakdown for the recommended alternatives.

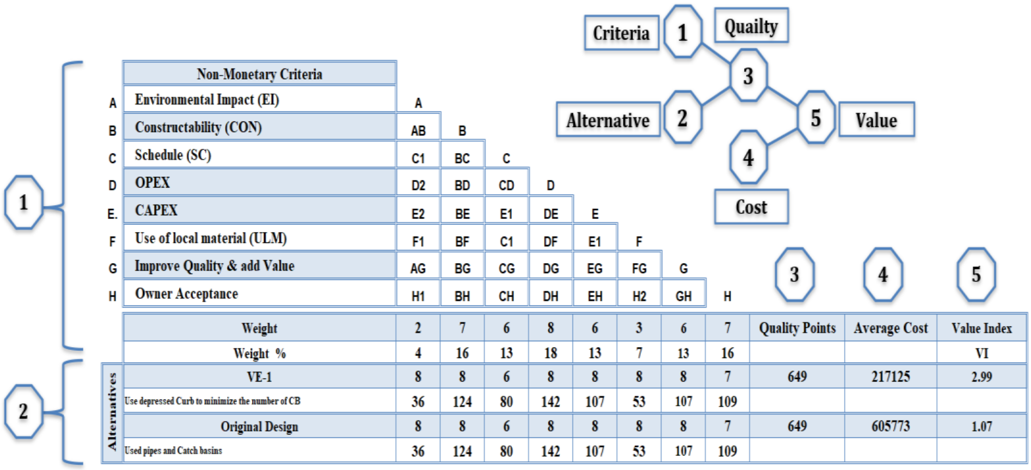
3.2 Weighted Evaluation Matrix (WEM)

The final stage of this phase is to choose the best option for achieving the study's goals and developing them further. It can reduce resources and financial expenditure (cost) and maximise the benefits (performance). The value index is defined as the quality (performance) ratio to cost [37-39]. It can quantitatively quantify this.

$$VI = \frac{Performance}{Cost} \times 100 \qquad \textbf{(2)}$$

The procedure was systematically carried out using the analysis matrix illustrated in **Fig. 7**. It is noteworthy to understand that the weights and criteria in the method were set through detailed explanations within the team to improve objectivity. Both weights and criteria rely on the project's specifics, priorities and perspective. The criteria set for implementation consider non-monetary components, as well as the environmental impact, are Schedule (SC), Constructability (CON), Environmental Impact (EI), Capital Expense (CAPEX), Operational Expense (OPEX), Use of Local Material (ULM) and Owner Acceptance (OA). Therefore, the best substitute is the one that takes the highest VI. In this procedure, the value of created substitute is compared to the Proposed Design (PD) value. The studied alternatives comprising the non-monetary criteria are outlined in Fig. 7. Each substitute is ranked against all other substitutes using a five-point Linkert scale from 5 (excellent), 4 (good), 3 (fair), 2 (poor), and 1 (very poor). The Linkert scale is widely used in criteria concerning construction projects [46, 47].

The alternative VE-3 can offer a good quality solution since it was ranked high (7 points) in numerous criteria ('EI', 'CON', 'OPEX', 'SC', 'CAPEX', and 'OA'). However, alternative 'VE-3' with low rankings (5 points) is anticipated to provide low quality. It is worth noting that the quality scores an alternative can obtain in any set of criteria are determined by the product of criteria importance (weight%) multiplied by the score for the alternatives. In this paper, Author chose a normalized VI as a measure for comparative value to allow a direct contrast with PD.



	Non-Monetary Criteria								
A	Environmental Impact (EI)	A							
B	Constructability (CON)	AB	B						
C	Schedule (SC)	C1	BC	C					
D	OPEX	D2	BD	CD	D				
E.	CAPEX	E2	BE	E1	DE	E			
F	Use of local material (ULM)	F1	BF	C1	DF	E1	F		
G	Improve Quality & add Value	AG	BG	CG	DG	EG	FG	G	
H	Owner Acceptance	H1	BH	CH	DH	EH	H2	GH	H

	Weight	2	7	6	8	6	3	6	7	Quality Points	Average Cost	Value Index
	Weight %	4	16	13	18	13	7	13	16			VI
Alternatives	VE-1	8	8	6	8	8	8	8	7	649	217125	2.99
	Use depressed Curb to minimize the number of CB	36	124	80	142	107	53	107	109			
	Original Design	8	8	6	8	8	8	8	7	649	605773	1.07
	Used pipes and Catch basins	36	124	80	142	107	53	107	109			

Fig. 7. Criteria used in weighted Evaluation Matrix (WEM).

Using the normalized relative value $VI\ in\ WEM$, the accomplishing alternatives can simply be identified. Alternative 'VE-2' and 'VE-4' are perceptively the best design solution, followed by 'VE-3', 'VE-1’ and 'VE-5' by an insignificant merging. It can be inferred that the real alternatives offer a considerably greater value over the base design as mentioned in the **Table 8** for the Weighted Evaluation Matrix (WEM) for the studied alternative.

Table 8. Weighted Evaluation Matrix (WEM) for the studied alternatives.

	A	B	C	D	E	F	G	H
A		1	1	2	2	1	1	1
B	1		1	1	1	1	1	1
C	0	1		1	1	0	1	1
D	0	1	1		1	1	1	0
E	0	1	0	1		0	1	1
F	0	1	1	1	1		1	2
G	1	1	1	1	0	0		1
H	0	1	1	1	0	0	0	
Total	2	7	6	8	6	3	6	7

	Non-Monetary Criteria								
A	Environmental Impact (EI)	A							
B	Constructability (CON)	AB	B						
C	Schedule (SC)	C1	BC	C					
D	OPEX	D2	BD	CD	D				
E	CAPEX	E2	BE	E1	DE	E			
F	Use of local material (ULM)	F1	BF	C1	DF	E1	F		
G	Improve Quality & add Value	AG	BG	CG	DG	EG	FG	G	
H	Owner Acceptance	H1	BH	CH	DH	EH	H2	GH	H

	Criteria Relation Weight	2	7	6	8	6	3	6	7	Quality Points	Average Cost	Value Index VI
	Weight %	**4**	**16**	**13**	**18**	**13**	**7**	**13**	**16**			
Alternatives	**VE-1 Evaluation Weight**	**8**	**8**	**6**	**8**	**8**	**8**	**8**	**7**			
	VP: Use depressed Curb to minimize the number of CB	**36**	**124**	**80**	**142**	**107**	**53**	**107**	**109**	**758**	**5783151**	**13.10**
	OD: Used pipes and Catch basins	**36**	**124**	**80**	**142**	**107**	**53**	**107**	**109**	**758**	**6072051**	**12.48**
Alternatives	**VE-2 Evaluation Weight**	**7**	**3**	**7**	**8**	**7**	**7**	**3**	**7**			
	VP: Use CHDPE pipes instead of UPVC	**31**	**47**	**93**	**142**	**93**	**47**	**40**	**109**	**602**	**3418950**	**17.61**
	OD: Used UPVC Pipes.	**31**	**47**	**93**	**142**	**93**	**47**	**40**	**109**	**602**	**3737560**	**16.11**
Alternatives	**VE-3 Evaluation Weight**	**7**	**8**	**8**	**8**	**9**	**9**	**8**	**7**			
	VP: Change (IC) cover of GRP or GRC.	**31**	**124**	**107**	**142**	**120**	**60**	**107**	**109**	**800**	**58980**	**13.56**
	OD: Cast iron frame and heavy-duty cover	**31**	**124**	**107**	**142**	**120**	**60**	**107**	**109**	**800**	**128505**	**6.23**
Alternatives	**VE-4 Evaluation Weight**	**8**	**7**	**8**	**8**	**7**	**8**	**7**	**8**			
	VP: Change catch basins dimension to 50 x 50	**36**	**109**	**107**	**142**	**93**	**53**	**93**	**124**	**758**	**432000**	**17.54**
	OD: Catch basins dimension 60 x 40	**36**	**109**	**107**	**142**	**93**	**53**	**93**	**124**	**758**	**461760**	**16.41**
Alternatives	**VE-5 Evaluation Weight**	**7**	**8**	**7**	**7**	**4**	**9**	**8**	**5**			
	VP: Change manholes internal diameter to 1.0 m instead of 1.20 for depths less than 2.50m	**31**	**124**	**93**	**124**	**53**	**60**	**107**	**78**	**671**	**1371518**	**4.89**
	OD: Manholes with internal diameter 1.20m.	**31**	**124**	**93**	**124**	**53**	**60**	**107**	**78**	**671**	**1584746**	**4.23**

3.2.1 Presentation Phase

The proposed storm drainage network combines surface drainage with storm drainage network and road safety from flooding, which was connected to the existing storm drainage line in the surrounding roads. This is anticipated to improve the region's present and prospective drainage conditions. It will also provide regional economic development in the site area and overall improvement to local communities, particularly in the existing residential areas surrounding the site. To aid decision-making, there is a need to closely examine cost reduction for an individual alternative. It cannot be carried out in isolation from value considerations. As indicated in **Fig. 8**, the VE-3-unit cost exceeded the cost of the original design which will be discarded. The proposed alternatives VE-1, VE-2, VE-4 and VE-5 were all less expensive than the original design cost.

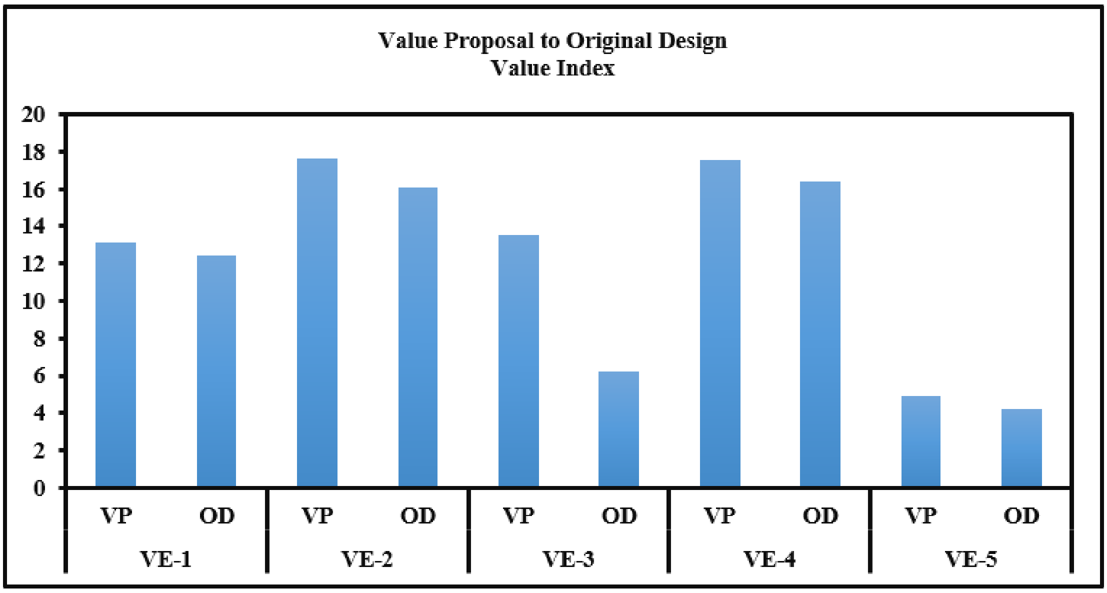


Fig. 8. The Storm drainage network comparative value of alternative and savings where VP is the Value Proposal and OD is the Original Design Value Index.

All solutions suit the project's purpose and necessity while lowering the overall investment and life cycle cost. The VE suggestions are aimed at reducing environmental consequences even further than the initial concept. This study revealed that all alternatives are feasible choices with many advantages. The VE-5, for example, was shown to outperform all other options, as shown in Fig. 8. However, depending on the owner's financial availability and choices, VE-2 and VE-4 offer an excellent mix of superior value and initial cost. The alternative VE-5 has several benefits over the base design (original design), including cheaper initial construction costs, lower maintenance and operation costs, a much lower drainage network life cycle cost (LCC), and decreased environmental and ecological impact. In addition, this option can save construction time and lower the cost (out of the scope of the study).

In this study, the VE increases the quality of life, minimizes construction's environmental effects, decreases the risk of floods, and boosts preservation. If taken into consideration, these advantages would increase the difficulty of implementing the alternatives offered in this study. The usage of LWC in the alternatives VE-1, VE-2, VE-3, VE-4, and VE-5 gives various network features and solutions that may be considered sustainable. Using GRP manholes in LWC provides a distinct environmental advantage. The LWC has been shown to be a long-term solution that does not compromise performance.

Conclusion and Recommendation

The current study presents a value engineering decision-making methodology for enhancing storm drainage system design in Egypt. The following summarises the study's findings on the proposed approach, barriers to VE implementation in storm drainage network design, and recommendations:

i. It is vital to note that the sustainability factor employed in this study may be broken down into different aspects of sustainability during the project's lifetime (e.g., improved resilience, reduced energy use, and emissions).

ii. Hydrology and Drainage Engineers are mostly unaware of the significance of the environment, sustainability features, and conservation of natural resources.

iii. Decision-making Culture - The expense and effort of conducting VE are compensated by the gain in value, which should motivate stakeholders to use VE for storm drainage design. When evaluating alternatives, decision-makers must discern between value and cost.

iv. For Drainage System Implementation, the VE method is rarely used to its full potential This is fuelled by the belief that the work and time required for VE are unreasonable, especially for minor projects.

Therefore, this study concluded that enhancing storm drainage systems for road networks by applying value engineering will have environmental benefits and lead to effective cost savings. Current results can be used to redesign the costs of projects which could increase the potential savings through a value enhancement solution being offered.

Future work could involve developing case studies to document VE's impact on project outcomes and exploring advanced modeling tools to better visualize cost-function relationships. This approach can support more efficient and sustainable stormwater management in future projects.

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