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Design Transformation to Reduce Cost in Irrigation Using Value Engineering

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***Abstract*—**Researchers are responding to the environmental challenges of Kuwait in localized, innovative, effective and economic ways. One of the vital and significant examples of the natural challenges is lack or water and desertification. In this research, the project team focuses on redesigning a prototype, using Value Engineering Methodology, which would provide similar functionalities to the well-known technology of Waterboxx kits while reducing the capital and operational costs and simplifying the process of manufacturing and usability by regular farmers. The design employs used tires and recycled plastic sheets as raw materials. Hence, this approach is going to help not just fighting desertification but also helping in getting rid of ever growing huge tire dumpsters in Kuwait, as well as helping in avoiding hazards of tire fires yielding in a safer and friendlier environment. Several alternatives for implementing the prototype have been considered. The best alternative in terms of value has been selected after thorough Function Analysis System Technique (FAST) exercise has been developed. A prototype has been fabricated and tested in a controlled simulated lab environment that is being followed by real environment field testing. Water and soil analysis conducted on the site of the experiment to cross compare between the composition of the soil before and after the experiment to insure that the prototype being tested is actually going to be environment safe. Experimentation shows that the design was equally as effective as, and may exceed, the original design with significant savings in cost. An estimated total cost reduction using the VE approach of 43.84% over the original design. This cost reduction does not consider the intangible costs of environmental issue of waste recycling which many further intensify the total savings of using the alternative VE design. This case study shows that Value Engineering Methodology can be an important tool in innovating new designs for reducing costs.

***Keywords*—**Desertification, functional analysis, scrap tires, value engineering, waste recycling, water irrigation rationing.

I. Introduction

KUWAIT is facing many environmental challenges. Desertification is a defined as assort of land degradation that happens a somewhat dry land area where it becomes progressively barren, characteristically dropping its forms of water, vegetation and wildlife [4], [6]. Few factors can intensify the likelihood of desertification, such as climate change and irresponsible human activities. Desertification is considered one of the significant global ecological and environmental challenges [4]. Fighting desertification [5] requires immense investments and scientific resolutions with good management and maintenance for long periods of time, see Fig. 1.

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(a) (b)

Fig. 1 Fighting desertification: (a) Anti-sand shields in Iraq, south of Baghdad, (b) "Greenbelt" of Nouakchott, Mauritania

Water scarcity is one of the most extreme national problems in the state of Kuwait. Nearly all clean water consumed in Kuwait (near 95%) is obtained from seawater through a high priced and environmentally expensive desalinization procedure [10], [11]. Water consumption is predicted to considerably increase because of rapid population growth which will require the production of larger quantities of desalted water using considerable amounts of plant power. Recently, El Kharraz et al. [12] analyzed the difficulty of water shortage and the position of desalinization. They listed a number of the important environmental effects associated with desalination, along with the dangers that plants intakes pose to sea creatures, expulsion of hot saline water and the release of CO_2. Therefore, sustainability of such use for sea water in desalination may be debatable. There are some different thoughts on agricultural, environmental and hydrological issues that can be found in modern literature. For briefness, interested reader can refer to [14], [20]-[32].

In this study, we present an approach that uses value engineering to come up with an innovative alternate design for plan irrigation to fight desertification and recycle common waste material. The alternative design is show to be cost reducing as well more practical to use in Kuwait environment. This research study tries to successfully achieve the following parallel goals:

- making use of mounting tire dumpsters in country in environmental friendly means.
- Reducing cost by finding an economical alternative design to commercial Waterboxx technology kits.
- Ingathering rain/mist/haze and optimizing water resources.
- Training local farmers to using state of the art techniques in planting shrubs and trees in the country farms.

II. The Main Concept

This research study focuses on having an economical alternative to the famous Groasis Waterboxx kits [20]. This is going to be a crucial a part of this pilot case. It employs used tires and recycled plastic sheets as raw materials to build the design. Hence, the proposed method will not only help rationing irrigation water but also help in disposing of ever developing large tire dumpsters in Kuwait, but will additionally help in avoiding hazards like tire fires in a safe and environmental friendly way.

The Value Methodology (VM) [11]-[13], a systematic and dependent technique, improves products, services, and procedures. VM allows acquiring balance among required features, performance, safety, and scope with the value and other sources essential to accomplish customer requirements by balancing cost for achieving the required tasks. The VM specializes in the optimization of the objective function of: Value = Function/Cost, in which:

- Value is the reliable performance of capabilities to satisfy customer desires at the lowest standard fee.
- Function is the natural or characteristic of a products or services.
- Cost is the overall expenditure essential to supply a service, product, system, or structure.

The systematic and structural approach comes from the VM activity plan. It is a general activity plan that consists of the following seven levels:

1. Information Phase: Gather information to understand the task.
2. Function Analysis Phase: Analyze the project to apprehend and clarify the specified functions and features.
3. Creative Phase: Generate thoughts on all the viable approaches and alternatives to perform the required capabilities.
4. Evaluation Phase: Synthesize thoughts and ideas to select viable ideas for development into design alternative.
5. Development Phase: Select and put together the "exceptional" opportunity(s) for enhancing the design and cost.
6. Presentation Phase: Present the cost advice to the challenge stakeholders and customer.
7. Implementation Phase: employing the recommendation of the value team and follow up.

The VM procedure produces the best results when applied with the aid of a multi-disciplinary team and know-how relative to the sort of mission to be studied. A Certified Value Specialist leads the VM team to make certain proper engagement with value management and practices. Value Specialist needs to be licensed from the SAVE International® [7] to steer such team. VM is embraced via a global spectrum of agencies and industries: constructing designers and contractors; automobile producers; chemical processors; pharmaceutical corporations; and so forth. Benefits realized by means of those organizations, the use of VM does not only yield in value improvement, but also can be used as a well-recognized cost reduction medium. Hence, VM will help in achieving savings in time, cost, and making good contributions to improve competitive functions.

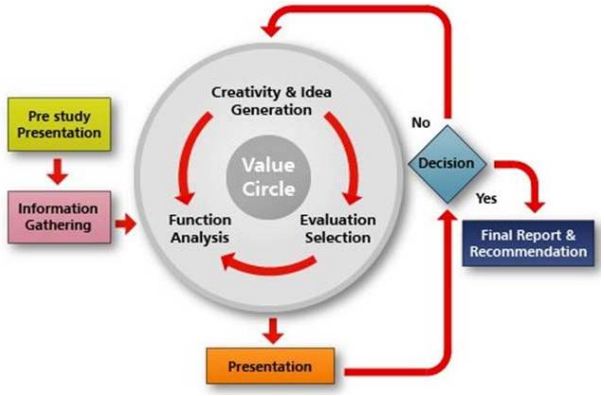

Fig. 2 The seven phases in value engineering methodology

In this research, we use VM to come up with an alternative design that is economical and cost reducing for a stand-alone irrigation system of plants to fight desertification. Readers interested in more information about VE may additionally refer to [7], [16], [17]. In summary, Value Engineering can be defined formally as

> "an organized team effort aimed at analyzing Functions and Quality of projects (goods, services and processes) in order to generate practical cost-effective alternatives that meet customer requirements".

It is not a cost reduction tool, since cost reduction does not ensure improving quality. Merle L. Braden and John D. Sankey, Office of Value Engineering, U.S. Army Corps of Engineers stated that

> "Value Engineering has great potential in hazardous, toxic, and radiological waste remediation. Environmental work is usually of high-cost. It offers greater opportunities for VE savings".

Providers of environmental services must deliver quality to retain certification of compliance while containing costs to ensure viability [8], [9].

The VE process can focus on eliminating waste, enhancing staff creativity and effectiveness, and lowering the costs of investigation, analysis, construction, operations and future maintenance – while maximizing the effectiveness of environmental solutions to meet the needs of the public needs. While countries pass increasingly stricter environmental laws, industrial and governmental organizations face increasing pressures. They must deliver safe and effective solutions that are **cost-effective** as well:

- Quick, creative, effective solutions
- Optimized environmental impact
- Maximized resources
- Optimized construction expenditures
- Lower life-cycle costs
- Alternative technology discoveries

This study used the seven phases in value engineering methodology to assess the environmental solution alternatives to judge their value indices that incorporate both quality and cost issue in the solutions.

III. Functional Analysis

FAST: In this phase of VM job plan, the VE team identifies the basic feature of the design and its components. The foremost reason and objective of every component is recognized and listed. Mapping deficiencies in quality of the original design is recognized in this phase and prepare the team to create ideas to mitigate deficiency issues, enhance quality and improve the appearance of the design. A FAST diagram is designed at this phase to narrate all basic and secondary features and functions of the components of the original design. This phase differentiates VE engineering process from comparable methodologies.

FAST is utilized in defining, analyzing and employing the know-how logic of functions of a design, how the functions relate to each other, and which functions require interest if the cost of a project is to be improved. In Value Management, the functions are determined by asking the question, "What does it do?" All designs, processes and strategies contain many functions. The team first determines the design functions. During this method, it will become apparent that these functions have one basic function of significance in the design. Due to this reality, the group subsequent evaluations and categorizes the functions. The techniques for defining and classifying features are as follows:

A product or service may have, rarely, more than one primary characteristic that considered as basic functions, however care need to be exercised to ensure that the two (more) different basic functions do not belong to separate components. As a rule, most designs have simplest one fundamental feature as basic function. The Function Evaluation ought to be completed through the steps indexed underneath:

1. Start growing a listing of functions by means of asking the question, "What does it do?" Each feature should be expressed in two words - an "active verb" and a "measurable noun".
2. After figuring out which functions are part of the component, distinguish the Basic Function(s). The remaining functions are considered as Secondary Functions. Identify those secondary functions as required, aesthetic or unwanted.
3. Ask "Why?" for the basic function as the fundamental feature is being achieved. The solution could be the Higher Order Function. This higher order function is out of the scope of the study, but is crucial to the team understanding of the domain of the study.
4. Specification gives meanings to functions by and their identification. Specifications can be either: Specific, for design constraints and requirements; or can be General, in which limits are obligatory yielding from design concepts. Where possible, it is encouraged to express what are the exact quantities required.

Following the Value Engineering seven phases technique, the functions of original design of the Waterboxx (as shown in Fig. 3) have been then translated into a FAST diagram, as shown in Fig. 4. This was done via asking "How-WHY? Logic" and figuring out the primary feature is being finished. The solutions to those questions constructed the Higher Order to Lower Order of Functions abstraction stage.

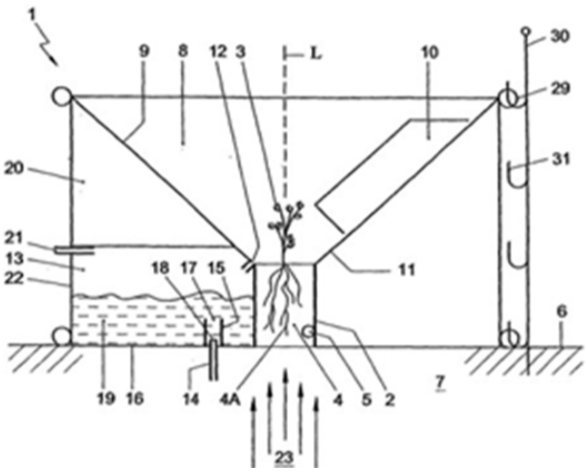

Fig. 3 The original design of the WaterBoxx that the function analysis started with

The FAST diagram helped the VE team in know-how the functional design of the WaterBoxx and developing with new thoughts on improving the design using extra environmental friendly components as proven within the dashed box of Fig. 7

IV. The Alternative Design

In the alternative design generation stage, the value engineering team members typically ask the following questions: What are the various alternative ways of meeting requirements? What else will perform the desired functions and features?

Evaluation/development - Design alternatives are evaluated to determine how sound they meet the vital functions and how this will reflect on the overall cost. Several methods are used to do evaluation such as:

- Pre-evaluation: where all impossible to implement and impractical ideas will be eliminated.
- ABCD Ranking: Where ideas are categorized into one of four categories as shown in Fig. 8a. Only those ideas which reside in square one and square two and few of those ideas that reside in square three will be considered (i.e., A, B, and C).
- Weighted Evaluation Matrix: In such evaluation technique, group evaluates thoughts or set of thoughts towards each other's considering numerous criteria. It is important to notice that due to the multi-objective nature of quality axioms of a product or service that need to be improved, in which we can find two or more performance criteria that can be conflicting with each other. Hence, the VE team needs to determine the criteria's weights through comparing them against each other using the weighted evaluation matrix, which is considered an easy technique for this task.

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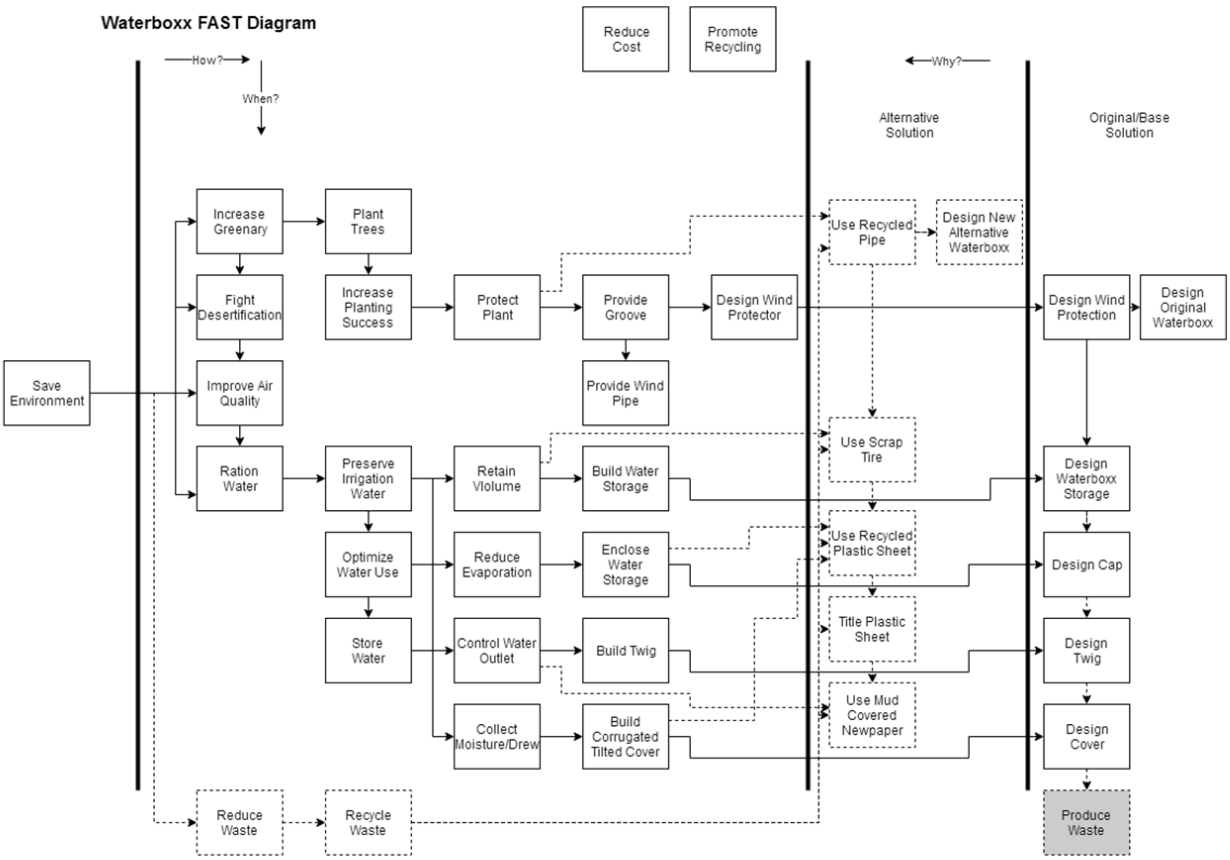


Fig. 4 The constructed FAST Diagram of the Waterboxx Designs

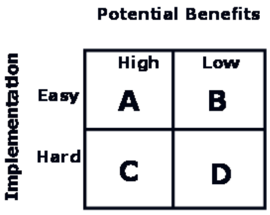


Fig. 5 ABCD ranking method

A. Focus Points

In Value Management, the functions are recognized by asking the following, "*What does it do?*" All designs, procedures and strategies involve many functions. The team first determines the capabilities and functions that can optimize the cost of the project. During this procedure, it becomes obvious that these capabilities and functions have different ranks and importance in the design. Due to this fact, the team needs to review and categorize the capabilities and functions that their alteration makes big effects on the design [16]. There are many two techniques that usually in use in VE Process:

B. First Technique: The Pareto Law

Pareto's Law states that the 80/20 rule = Only 20% of the items makes up 80% of the cost. This rule is used for defining and classifying functions to recognize which components of a product or a service have most effect on the total cost of the product. Using the Pareto Law, Table I states the cost estimated for planting 1000 trees for three years using the regular Waterboxx, see also Fig. 6. The costs are in Kuwaiti Dinars (1.0 US$ ~ 0.303 KD).

TABLE I
COST OF ITEMS IN WATERBOXX FOR THREE YEAR LIFE SPAN

Item	Cost (KD)
Trees	450
Fertilizer	900
Water	1095
Labor	3240
Kit	8000

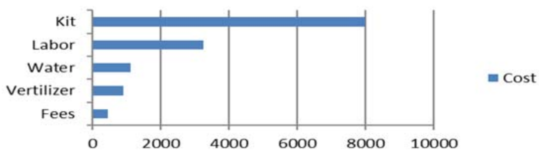


Fig. 6 *Pareto's Law* of the cost Waterboxx

C. Second Technique: The Deficiency in Quality Profile

This technique for defining and classifying functions can start by analyzing the quality criteria of the original design and the proposed alternative. Table II and Fig. 7 demonstrate the quality profile of both designs. Quality deficiencies in the profile identify potential design flows that need attention in the alternative design.

TABLE II
QUALITY PROFILE OF ORIGINAL AND PROPOSED DESIGNS

NO.	CRITERIA	WATERBOXX	USED TIRES
1	Ease of Assembly	5	10
2	Robustness	4	10
3	Durability	6	10
4	Availability	5	10
5	Scalability	6	9
6	Reuse	6	9
7	Solving Current	2	10
8	Learning Curve	5	9

D. Creative Idea List

The following are some of the creative ideas generated throughout the VE creativity/improvement phase. They are ranked according the ABCD ranking technique, see Table III.

Notice that during VE method, if the team is encouraged to use and target the simple ideas of type A. If there had been no sufficient count of ideas of type A, then ideas of classification B have to be taken into consideration. In our case, there was enough class A ideas to be developed.

E. Alternative Design

Alternative design methodologies were considered to take the best known design framework for our project. The team decided to go for the rapid prototyping technique. Rapid prototyping is a set of procedures used to rapidly construct a scale prototype of an actual design part or assembly using computer three-dimensional CAD design [1], [2]. Building a part or an assembly is usually done using simple manufacturing systems, 3D printing or "additive layer manufacturing" technology [3], [4]. Early attempts for rapid prototyping ware presented in the late 1980s and were used to create replicas and prototype parts. Nowadays, rapid prototyping is used for many applications and is used in manufacturing of production of high quality parts, in rather small numbers, without the typical cost overheads [18], [19]. The original Waterboxx design and the proposed new alternative design using recycled tires are shown in Fig. 8. Detailed design specifications could not be disclosed in this paper due to patent office restrictions.

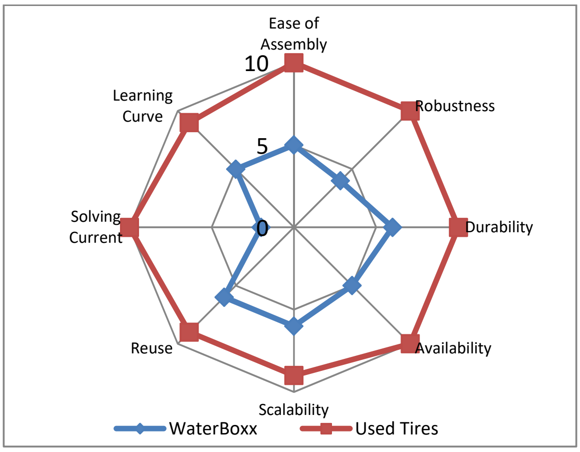
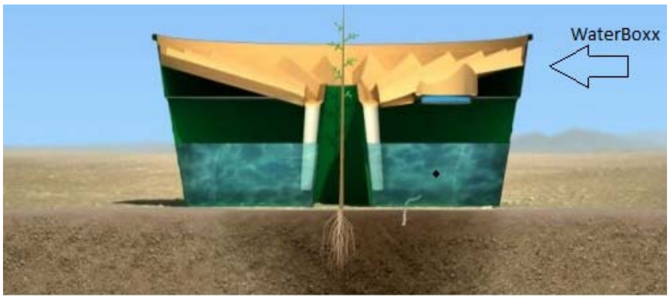


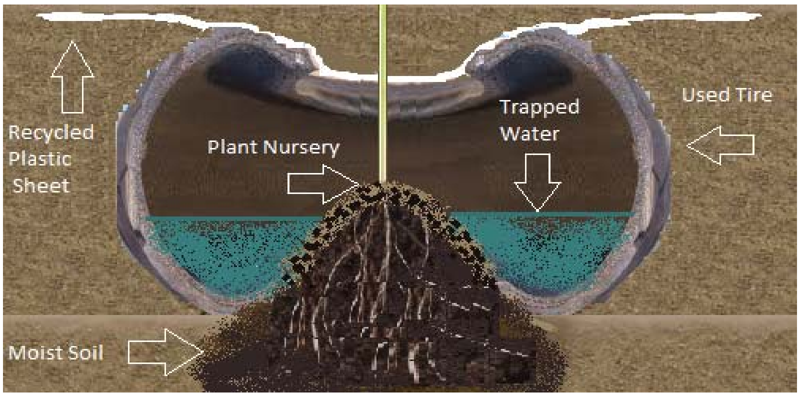
Fig. 7 Quality profiles of original design (in red) and proposed alternative design (in blue)

TABLE III
CREATIVE IDEAS GENERATED FOR THE PROPOSED DESIGNS, THEIR IMPACT AND ABCD CATEGORIZATION

#	Idea Description	Implementation Easy/Hard	Impact High/Low	Category
1	Use recycled pipes to protect plant	Easy	High	A
2	Use scrap tire to retain volume for water storage	Easy	High	A
3	Use recycled plastic sheet to contain the kit	Easy	High	A
4	Use recycled plastic sheet to help condense dew/vapor and collect rain drops	Easy	High	A
5	Use gravitational force to allow water in	Easy	High	A
6	Use recycled newspaper sheets to transport moisture and control capillary	Easy	High	A
7	Use recycled materials	Easy	High	A
8	Reuse the tires for next planting	Easy	High	A
9	Make molded plastic cover to help collect moisture and rain	Hard	High	B
10	Make molded plastic plant cover to help protect against wind	Hard	High	B
11	Make deep holes to access deep land moisture	Hard	Low	D
12	Make large wind sheets to collect moisture from early down fog	Hard	Low	D
13	Add Nano particles to regulate irrigation	Hard	High	B
14	Use solar power to condense air moisture	Hard	High	B
15	Use cotton stuffing to collect moisture	Easy	Low	C
16	Use plastic valves to regulate water movement	Hard	High	B
17	Use water gel to retain moisture	Easy	Low	C
18	Use metal body to store water	Hard	Low	D
19	Use shredded rubber tires to mix with soil to produce tiny water tanks	Easy	Low	C
20	Use type of plants that can quickly access water table	Easy	High	A
21	Use draught resistant plants	Easy	High	A
22	Use evergreen plants	Easy	High	A
23	Use plants that natural to desert habitat	Easy	High	A
24	Reduce effect of wind through wind screens	Easy	High	A
25	Reduce sun heat through partial shading	Easy	High	A
26	Use recycled Waterboxx	Hard	High	B



(a)



(b)

Fig. 8 Waterboxx kit: (a) Original design, (b) Proposed alternative design

Alternative designs were tested for potential implementation in the lab prior to full fledge field test at this controlled environment first. The most promising designs will be tested at the field sites.

F. Alternative Design Cost

Table IV states the cost estimated for planting 1000 trees for three years using the regular Waterboxx and the alternative design. The costs are in Kuwaiti Dinars (1.0 US$ ~ 0.303 KD).

Total savings in the cost (cost reeducation) using the alternative design is 43.84%. This cost reduction does not consider the intangible cost of the environmental issue of recycling the tires, newspapers and plastics used in the alternative design.

TABLE IV
WATERBOXX & ALTERNATIVE DESIGN ITEMS' COST FOR A THREE YEAR LIFE SPAN

Item	Waterboxx Cost (KD)	Alt. Design Cost (KD)
Trees	450	450
Fertilizer	900	900
Water	1095	1095
Labor	3240	3240
Kit	8000	2000
Total Cost	13685	7685

G. Patent Application

The design concept of the project was submitted for patent registration in USA under Patent file number: **Docket No. 23588.79,** "Utility Application for Planter System Using Waste Materials", 2016. Details of the design will be released in due time after the patent file application is completed and the patent registration is finalized. Please note that the information shown below is only allowable information for public disclosure due to the patent registration procedure requirement.

H. Abstract of the Disclosure

The planter system using waste materials repurpose waste materials to construct a self-irrigating planter that promotes plant growth in a protective environment. The planter system includes a water reservoir constructed from scrap tire defining a hollow interior serving as water storage, the reservoir being buried in soil. A condensation funnel having a sloped condensation skirt extends into the center opening of the scrap tire to direct condensate into the water reservoir. A root ball cover made from scrap newspaper covers the root system of a plant, and the plant is buried in the center opening of the scrap tire. A soil protection cover is placed atop the root ball cover to protect the soil of the root ball, and a support tube extends therefrom to protect the stem of the plant from environmental conditions. A valve regulates delivery of water to the reservoir. Most components are made from scrap plastic.

V. SITE EXPERIMENT PERPETRATION

This venture proposes to construct a case to make use of a team expertise in VM to embody a possible alternative design to reuse scrap tires to combat desertification and help in water rationing for irrigation that help in applications of wind breaking using native plants and greeneries. The progressive idea is to utilize the used tires from the tire dumpsters as a cost-effective opportunity to well-known technology of Waterboxx kits. Waterboxx kits had been proved to help lowering the quantity of irrigation used to help plant bushes in deserts. The Project will focus on the subsequent three guidelines:

1. Getting rid of ever developing big tire dumpsters in Kuwait in a secure and environmental friendly way.
2. Harvesting rain water and managing the maximum valuable water assets.
3. Capacity building in planting shrubs and bushes in Kuwait deserts using state-of-the-art techniques.

The alternative design will be evaluated on a range of test locations for its proper evaluation. To do this, the team proposed to test using candidate locations of four farms of around 5000 square meters, as shown in Table V.

TABLE V
SET OF CANDIDATE LOCATIONS FOR TESTING PROPOSED METHODOLOGY

Locations	# of Farms	Area of each Farm
Location # 1	4	5000 Square yard
Location # 2	4	5000 Square yard
Location # 3	4	5000 Square yard
Location # 4	4	5000 Square yard

The research team met with Kuwait Public Authority of Agriculture & Fishery (PAAF) representatives and mentioned feasible collaboration venues on execution of the assignment. PAAF turned into supportive to the venture and counseled few possible take a look at sites for the experimentation to take region. The team studied the possible sites and determined the places for the check websites and took samples of soil and water for use in proposed sites.

The research team is testing the test in two ways. One way is though close monitoring in an environmentally controlled testing lab. The second is by field deployment of the kits in the real life environment, see Fig. 9 (a). The two tests were conducted in parallel. A testing container box is being designed (see Fig. 9 (b)), for use as a controlled test environment inside one of the labs at Kuwait University. The box represents a test site having its actual soil taken from the test site. A test site is shown in Figs. 9 (c) and (d). Water also taken from the test site well will be used as the irrigation water.

To measure the quality of the methodology of the newly proposed alternative design for Groasis Waterboxx technique using scrap tires (Tire-Waterboxx) would be considered, we will consider multiple test locations. In each test location, number Tire-Waterboxxes would be tested. This will be translated into a contingency matrix of 2×2, as presented in Table VI. In this contingency matrix there are four values; TN, FP, FN, and TP, where T, F, N, and P denote to true, false, negative, and positive, respectively. These values have the following explanations:

- TN: is the count of nurseries correctly grown to not trees,
- FP: represents the count of nurseries incorrectly grown to trees,
- FN: represents the count of nurseries incorrectly grown to not trees,
- TP: refers to the count of nurseries correctly grown to trees.

To assess the performance of the new design of Tire-Waterboxx technique, we use the typical *precision* and *recall* evaluation criteria that were proposed by Olson and Delen [18]. *Precision* and *recall* evaluation criteria are defined as:

$$precision = \frac{TP}{TP + FP} \text{ and } recall = \frac{TP}{TP + FN}.$$

Both *precision* and *recall* are combined in a single value that measures the quality of the classification. We call this value the *Fmeasure* [15]. *Fmeasure* can be formally defined as the harmonic mean of *precision* and *recall* and it is computed using:

$$Fmeasure = \frac{2 \times precision \times recall}{precision + recall}.$$

TABLE VI
CONTINGENCY MATRIX

		Actual Plants planted	
		0	1
Nurseries developed to trees	0	TN	FN
	1	FP	TP

The proposed design evaluation method that uses the above contingency matrix will allow testing techniques on variety of farms for its proper adaptability. It is expected, after extensive experimentations, that the proposed technique would yield very high quality results.

The conditions of Kuwait test sites will be simulated in the lab, and document everything happening under the soil. It will be done by taking a side view and computer workstation video recording the plant lifecycle using the proposed methodology of the test next to the Waterboxx equipment as well as the alternative designs. A simulation software packages for the water/soil behavior are being considered.

VI. CONCLUDING REMARKS

The accomplishment results of using of cost effective alternative design based VE methodology paved the ground for more aggressive strategy that will be in place to develop a comprehensive national scheme to apply this new technique to optimize the water resources and fight desertification while helping the environment and tire recycling. The planter system using waste materials repurpose waste materials to construct a self-irrigating planter that promotes plant growth in a protective environment. The planter system includes a water reservoir constructed from scrap tire defining a hollow interior serving as water storage, the reservoir being buried in soil. Most components are made from scrap tires, newspaper and plastic [33].

Experimentation showed that the new proposed alternative design was similar, or superior, in effectiveness as the commercial design with much less cost. It is estimated that the total cost reduction using the VE redesign shows an overall saving of 43.84%. This is not considering any intangible savings for the environmental issues of waste recycling, which may significantly intensify the total cast reduction of using such an alternative design. This study presented a case that proves that Value Engineering Methodology can be a vital means in innovating new designs that reduce costs.

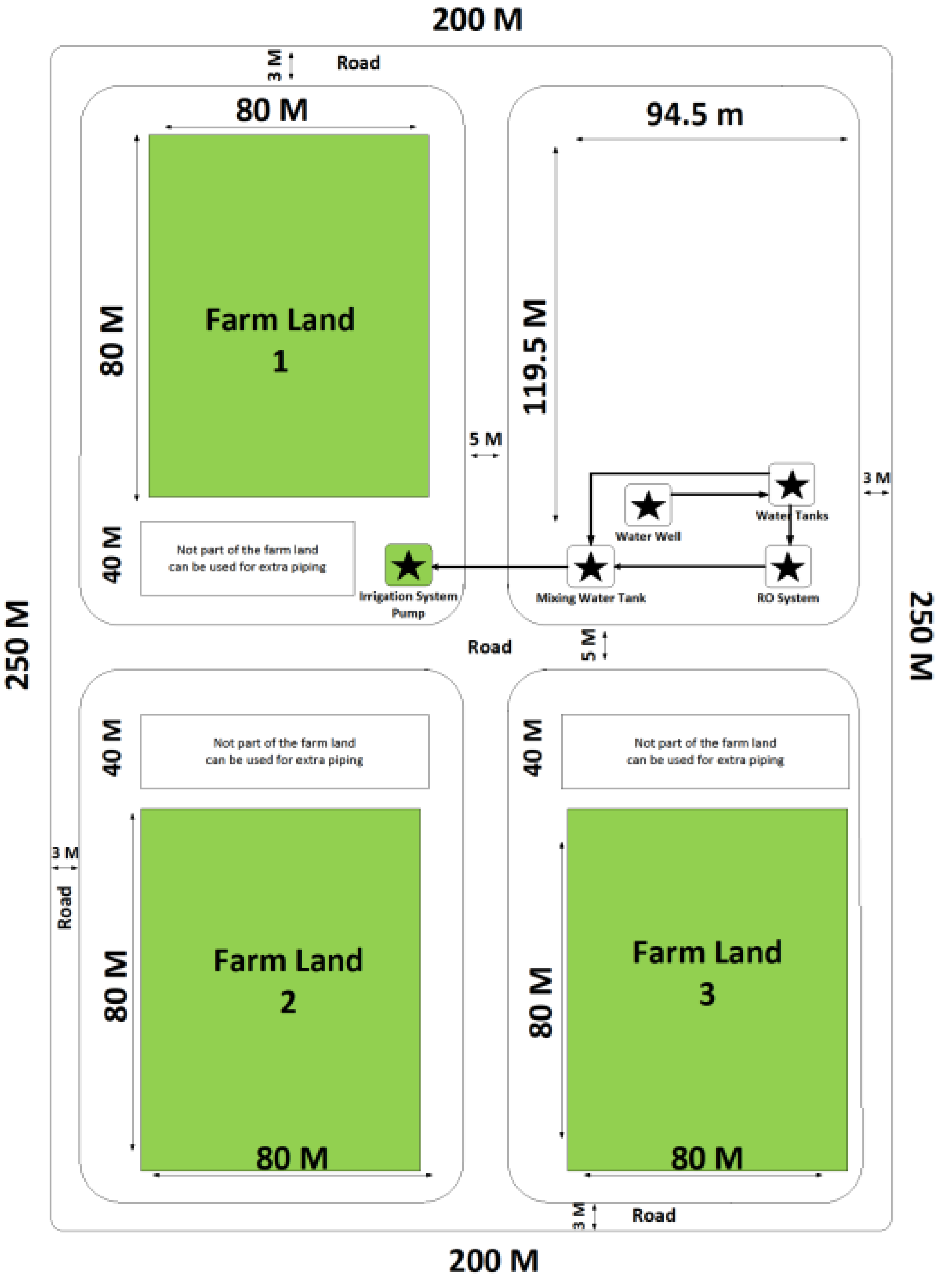


Fig. 9 (a) A proposed structure of a test site

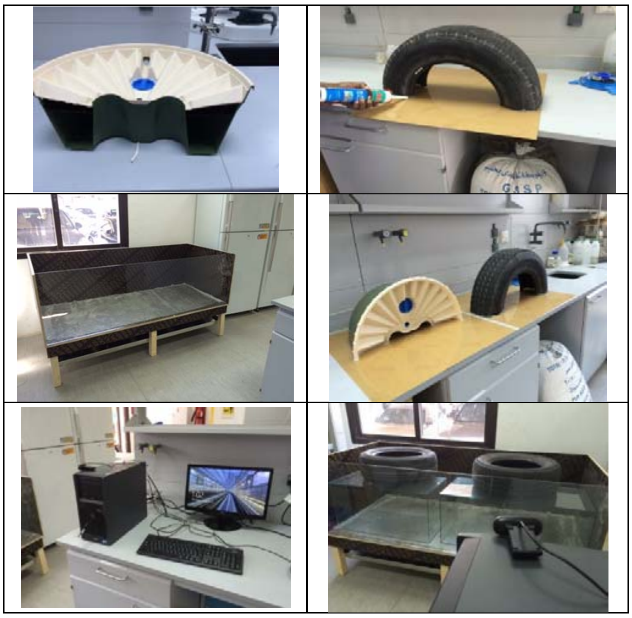


Fig. 9 (b) Various pictures of the box being manufactured and designed for use as a controlled test environment

Fig. 9 (c) Various pictures of the land being prepared and ready for use as a field test environment

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