# A Multi-Criteria VA/VE Design Case Study for Fabricating Stainless Steel Equipment 304 and 430

**Maricar M. Navarro**
Industrial Engineering Department
Technological Institute of the Philippines
Cubao Quezon City
mnavarro.ie@tip.edu.ph

**Bryan B. Navarro**
Electrical Engineering Department
Technological Institute of the Philippines
Cubao Quezon City
bryanbnavaro@tip.edu.ph

## Abstract

Value Analysis is the study of the features of an item and their corresponding cost concerning its ability to perform a function or render a service, on the other hand, Value Engineering is a technique for product or process function, this technique will provide significant information to the overall function of the product and process. This also provides information about the reduction or elimination of cost for those functions that do not add value to the process or product. A systematic approach is applied to maintain the required quality and reliability of the product or process. The design of the stainless steel rack was based on manual and automated operation, similarly, the fabrication process will merely depend on the design. The design of the product and process were analyzed based on the six criteria: VA/VE on Material, VA/VE on Product, VA/VE on Process, Material Handling Cost, Waste/Emission, and Life Cycle Cost. The two designs were analyzed based on the Trade-Off Analysis based on the perspective of the designer and customer. The results of the design evaluation for stainless steel overall satisfy VA/VE approach. This study recommends 304 stainless racks which have higher corrosion resistance, good mechanical properties, and the least life cycle cost compared to 430 materials. Total Cost savings will be achieved using 304 stainless steel

## Keywords
Corrosion, Mechanical properties, Life cycle cost, Trade-Off Analysis, Value Analysis, Value Engineering and Genetic Algorithm.

## 1. Introduction
Value Analysis is a system developed for the elimination of unnecessary costs. The concept was first introduced by Lawrence D. Miles back in the late 1940s. The unique part of the value analysis system is the use of “functions” to define products and services. It focused on understanding the function of the component being manufactured and questioned whether the design could be improved or if a different material or concept could achieve the function. At present time, new products must offer high quality and functionality for the customer at a lower price. Competition is always considered a major basis for a re-evaluation of existing design. Inflation, as a result of rising materials and labor costs, requires a thorough investigation into all techniques that can contribute towards a reduction in basic costs without affecting the reliability of performance. Good value has always been a major concern of the customer. As long as there is competition, a comparative reliable lower cost product will always have a greater market value. Profits are still the most important reason to evaluate the design, considering without profit there is no existence of businesses. The technology-based sector needs to acquire relevant technical information to survive in the present competitive situation. According to Lemos and Porto (1998), to improve the innovation process, Information is needed for firms in the technology-based field that needs to survive in the extreme marketplace. The fabrication Industry is one of the technology-based sectors that need relevant information to create a superior design.

The local fabrication of the stainless steel industry comprises a variety of players in the Philippines. The increasing demand for food outlets, restaurants, hospitals, and building construction leads other players to create a distinct competitive advantage. It challenges them for product development projects to sell high customer value at low costs. The competition among the players is strong and customer demands are more personalized. The Industry is facing the pressures and challenges of improving the product, service quality, and reducing delivery times, and reducing the cost of the products which urgently require the industry to upgrade the present management view.

### 1.1 Objectives

This study aims to introduce and apply Value Engineering as a method to design a product and process that will represent the optimum value to the manufacturer and customer in the Stainless steel fabrication Industry. It also aims to evaluate and choose the best material specifications between 304 and 430 stainless steel grades. This study intends to provide a means of total reduction and elimination of cost while maintaining the required quality and reliability of the material, product, and process within a product life cycle. In addition, the Genetic Algorithm was used in the process for the enhancement of facility layout locations and determines optimal material handling cost in the MATLAB platform. This study also aims to determine the emissions of stainless steel that undergo in the production process. Overall, the main objective of this study is to use the Model on Trade of Strategies by Otto and Antonsson (1991) to evaluate the design based on the design criterion of the material, product, process, material handling cost, emissions, life cycle cost, and cost-benefit analysis. Application of Value Analysis to the material, product, and process was performed. VA Cases from different sectors in the literature were presented to investigate the ultimate advantage of Value Engineering.

## 2. Literature Review

Value Engineering is frequently used as a tool to reduce cost and enhance product design in the Construction Industry, among the related literature presenting the Value Engineering approach in the Construction industry is Yan (2012) who presented the current situation of construction management and the important application of value engineering to construction projects in various stages of the life cycle. Moreover, the paper presented by Bing (2009) focused on the application of value engineering using the investment control method of construction projects. Qian and Shoufeng (2008) presented value engineering theory and developed AHP (Analytical Hierarchy Process) method to assess green construction alternatives. As stated by Wang (2006), Value Engineering theory, research, and practice have extensive development in China.

A comprehensive study by Boo Young et al. (2009) proposed an advanced five-phase VE model that consists of a series of steps to better quantify the subjective opinions of VE team members. The study shows that the model proposed improves analysis, assessment, and decision on VE. The new model minimizes subjectivity during the VE process and improves the VE decision-making process by using quantitatively resulting data from the simulation analysis.

Value Engineering has been well-developed and discussed in the construction Industry. Based on Dell'Isola (1998), Omigbodun (2001), Federal Facilities Council (2001), Palmer et al. (1996), and Cheah and Ting (2005), different skilled professionals have different methods in the application of VE to construction projects but usually fall into six phases; information, functional, creative, evaluation, development and implementation phase.

In software analysis research presented by Jung-Hsing Lee et al. (2015) proposed a model to support the implementation of ERP systems by using Value Engineering and System Dynamics, a Value Engineering-based framework that combines the System Dynamics (SD) method to support the implementation of ERP systems. Another model for Value Engineering proposed by Maisenbacher et al. (2013) introduces the approach of Integrated Value Engineering. The model combines the approaches of value engineering and target costing into an integrated model with a Multiple Domain Matrix (MDM) as a representation of the product in its center

In the manufacturing sector research presented by Zhang et al. (2010) proposed an advanced plan by analyzing the function and cost for the improvement of production operations in an oil field. The results show an increase in initial investment and reduced life cycle cost. In addition, Sison et al. (2018) proposed two designs using VA/VE and the Design of a Facility to optimize the existing processes of a wood manufacturing company. The research demonstrates the application of ProModel Simulation, process VA/VE, and Design Layout in the existing processes, from the simulation, the results generate an increase in production of 80%. Additionally, the study by Palisoc et al.

(2019) intends to improve the remote production setup of a media broadcasting firm while taking into account trade-offs based on relevant constraints such as Material VA/VE, Product VA/VE, Process VA/VE, Ergonomics, Economic, and Productivity. Moreover, other research in the literature aims to optimize production using a relevant Design Trade-Off (Duque et.al (2016); Navarro, M.M, and Navarro, B.B (2016).

A formal method called Design on Trade-off Strategy enables designers to formally decide on trade-offs.
However, in design evaluation, a model of Trade-Off strategies in engineering design allows the designer to make trade-off decisions (Otto and Antonsson, 1991). The model can be used when an engineer desires to give ratings on the design by the weakest feature or by the consideration of the overall performance.

### 2.1 VA/VE Principles

Value Engineering is called VE and is also known as Value Analysis or VA. It is a contemporary management knowledge that combines technology and economics. It intends to improve the thinking process and management skills of the research object value.

As Thew (1967) stated Value Analysis is a group effort required for the selection of the right product to be analyzed. Usually, this group can be a sales engineer, design engineer, production engineer, estimator engineer, purchaser, and value engineer. The sales engineer should ensure that the product is designed based on the customer's requirements. The Design Engineer should ensure that the design of the product conforms to the standard. The Production Engineer's job is to ensure that the product designed shall be economical to manufacture with the available facilities. The Estimator engineer is to set a cost perspective for the design. The Purchaser will play a larger part than in the design since a large part of the cost will be in purchased items. And lastly, the Value Engineer is to manage the whole implementation of the project and ensures that all aspects of the design are reviewed in a relative cost value and priority.
The VA/VE principle is formulated as shown in (1)

$$V = \frac{F}{C} \tag{1}$$

In (1), Value means the ratio between the total function and the total cost of the object. Function means the characteristic that a certain demand can be satisfied. Cost means all expenses to realize all functions of the object. The above principles defined that using VE to evaluate and decide on technological innovation projects has a unique advantage.

## 3. Methods

This study was analyzed using VA/VE approach. The material, product, and process were used to evaluate based on their functions. The function evaluation used in Material, Product, and Process VA/VE was adopted from the Model on Trade-Off Strategies in Engineering Design by Otto and Antonsson (1991) for quantitative scaling. The significance of VA/VE was used to assess and evaluate the Material, Products, and Processes of the company.

In Process VA/VE, the modified method of GA from Maricar and Navarro (2013) was used to determine the optimal material handling cost for the company. Below are the methods applicable to VA/VE processes in the fabrication industry. VA/VE Method for Material, Product, and Process:

***Information Phase***

1. Component Part Identification – Identify the parts and type of the item or process

***Functional Analysis Phase***

2. Functional Analysis – Review such Functions and Specifications
3. Cost Identification – Determine the cost of every part and function of the item

***Creative Phase***

4. Desired Value Expectation – Explore other ways of getting the desired value
5. Cost of Improved Item - Determine the cost of the improved item

***Evaluation Phase***

6. Functions Evaluation – is to calculate further in the field of function quantitatively based on functional system analysis and evaluate the value of its function which has a primary function value and secondary function value.
7. Ranking scale - testing the ability to satisfy a criterion based on the designer's perspective and the customer's perspective

***Development Phase***

8. Execution of selected Ideas- develops the selected Ideas into proposals with documentation. This will allows a decision maker to determine if the alternative should be implemented.

***Implementation Phase***

## 3.1 Material VA/VE

The collected information related to Material Specifications is shown in Table 1. The expression of all functions was accomplished in two words, a "verb" and a "noun". The functions of every component were classified as "P" for the Primary function and "S" as the secondary function The cost of every component in stainless steel material grade was not presented due to the non-availability of information coming from the supplier. The management decided to evaluate and assess the two kinds of stainless steel grade that is 304 and 430. Although stainless steel is black metal, light reflection makes it appear dazzling (Callister 2007). It serves as a general term for metal. Typically, it is described as an iron-chromium alloy containing at least 11% chromium. It frequently incorporates other elements including silicon, manganese, nickel, molybdenum, titanium, and niobium. It is primarily utilized as a corrosion-resistant engineering material in settings with harsh conditions or high temperatures.

In the fabrication Industry, 430 is a common grade used in fabricating stainless steel kitchen equipment. It is ferritic chrome steel with better heat and corrosion resistance, a magnetic type of stainless steel, and no composition of Nickel content. See Table 1. It has less corrosion resistance compared to 304 stainless steel grade. However, the latter is the most commonly widely used in austenitic grades. Stainless steel grade 304 has a higher corrosion resistance compared to 430. It offers good corrosion resistance in many chemicals and Industrial atmospheres. It belongs to the Austenitic grade type which is non-magnetic. The most common austenitic alloys are Iron-Chromium Nickel steels and are widely known as the 300 series. Austenitic grades, which have a chromium and nickel content of about 18% and 8% respectively, are frequently used in the manufacture of heat exchangers, chemical processing machinery, food, dairy, and beverage processing equipment, and gentler chemicals. Stainless steel kitchen appliances can also use it. The material VA/VE process evaluates the stainless steel based on two criteria; corrosion or heat resistance, and mechanical properties Table 2 shows the functions and chemical content of each component.

Chromium promotes oxidation and corrosion resistance. The chromium reacts with oxygen to create a thick layer of chromium oxide that adheres to the surface of the steel and is invisible and passive. This film is self-healing if mechanically or chemically damaged. Carbon is used to strengthen and harden carbon and alloy steels, although ductility suffers as a result. As a result, carbon makes maintaining an edge's sharpness easier and longer. While maintaining ductility and toughness, nickel adds strength and hardness. High degrees of ductility and the capacity to change shape without breaking provide increased resistance to corrosion and scaling at hot temperatures. Manganese increases weldability hardens carbon and alloy steel and reduces the propensity for cracking during hot working activities. Ductility is enhanced by silicon. It strengthens low alloy steels.

The Thermo Scientific Niton XRF Analyzers were used to identify positive materials in seconds to ensure the safety of process manufacturing. Niton XL3t Series perfect for weld analysis and comprehensive component inspection between 304 and 430 stainless steel grade was performed. Figure 1 shows the Carbon-Iron graph. It shows the composition of Iron and carbon content. Austenitic stainless steel grade 304 with 0.08% Carbon content annealed at 1000 degrees temperature in the Austenite part of the graph.  However Stainless steel 430 with 0.12% of carbon content annealed at 600 degrees temperature in the Ferrite part of the graph. It shows that the annealing process in the Austenite grade was enhanced compared to the Ferritic grade. Table 1 shows the mechanical properties of 430 and 304. Using Brinell Hardness analysis, tensile strength, and percent elongation shows the advantage of 304 compared to 430. But for yield strength, 430 shows an advantage. Increasing the carbon content of the material makes 430 stainless steel grade develops a much larger yield strength.

Strain is defined as a change in length over the initial length. The change in length is due to tensile stress. Based on the stress-strain curve shown in Figure 2 stainless steel 304 grade shows an advantage on tensile stress compared to 430. grade material.

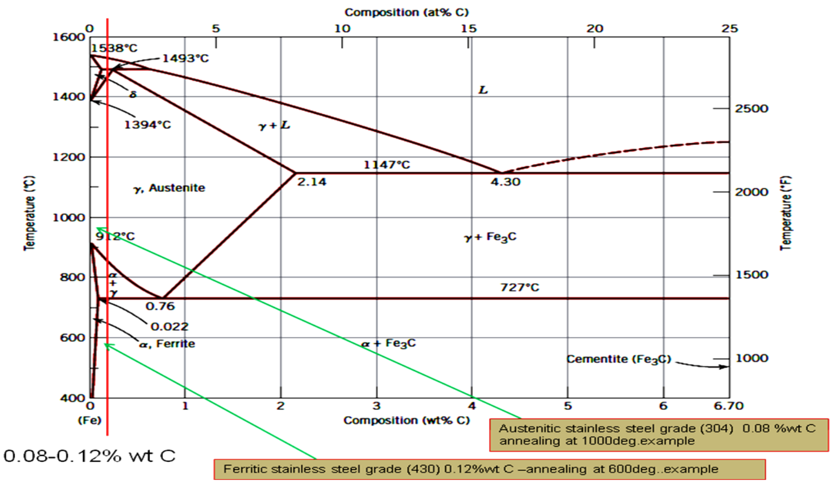


Figure 1. Iron-Carbon Phase Diagram

Table 1. 1st Criteria: Corrosion or Heat Resistance

| Typical Analysis | Stainless Steel Grade 430 Ferritic | P | S | 304 Austhenitic | P | S | Verb | Noun |
|---|---|---|---|---|---|---|---|---|
| Chromium | 14 - 18 % | * | | 18 - 20% | * | | Prevent | Corrosion |
| | | * | | | * | | Repair | stainless steel surface |
| Carbon | 0.12% Max. | * | | 0.08% Max. | * | | Strengthen | Stainless Steel |
| | | * | | | * | | Harden | Stainless Steel |
| | | | * | | * | | Sharpen | Edge |
| Nickel | | | | 8 - 11% | * | | Strengthen | Stainless Steel |
| | | | | | * | | Harden | Stainless Steel |
| | | | | | * | | Increase corrosion resistance | Stainless Steel |
| | | | | | * | | Improve ductility | Stainless Steel |
| Manganese | 1% Max. | * | | 2 % Max | * | | Decrease crack | Stainless Steel |
| | | * | | | * | | Harden | Carbon |
| | | * | | | * | | Harden | Alloy Steels |
| | | | * | | | * | Promote Weldability | Stainless steel |
| Silicon | 1%n Max | * | | 1% Max | * | | Improve ductility | Stainless Steel |
| | | | * | | | * | Strenghten | Low Alloy Steel |

Table 2. 2nd Criteria – Mechanical Properties

| **Typical Analysis** | **430** | **304** | **Details** |
|---|---|---|---|
| Brinell Hardness | 15 | 17 | The higher the index, the harder the material. |
| Tensile - KSI | 75 | 85 | The higher the manganese content, the higher the tensile strength. |
| Yield - KSI | 45 | 34 | The higher the carbon content, the higher the yield strength. |
| Elongation in 2"-% | 30 | 60 | 304 are more ductile, so easy to elongate. |
| Reduction in Area-% | 65 | 70 | 304 has a higher reduction in area since it has a higher elongation which leads to decrease its cross sectioned area. |
| Welding Characteristic | * | | Fair-Brittle weld, slight response to annealing. |
| Welding Characteristic | | * | Very good - tough weld. |

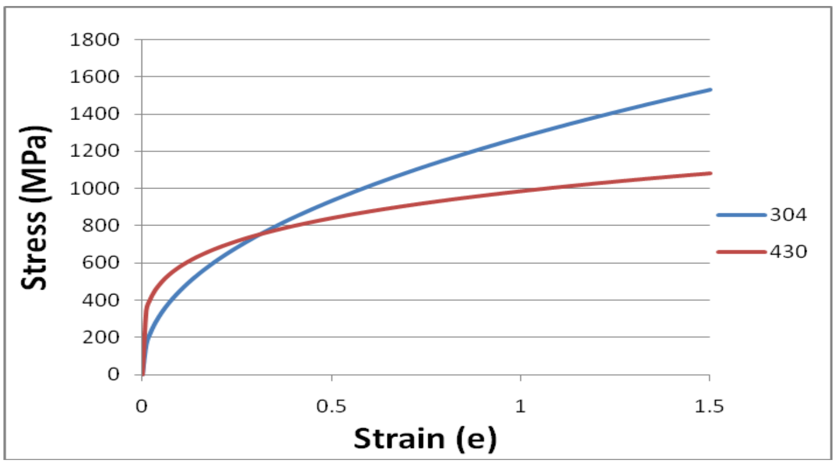


Figure 2: Stress-Strain Diagram of Stainless Steel 304 and 430

### 3.2 Product VA/VE

The slotted utility rack is the main product of this case. Two kinds of the slotted rack were fabricated. The slotted tubular rack is manually fabricated and made of 430 materials and the slotted angular rack is turreted and made with 304 material

Table 3 and 4 shows the function of every part of the slotted rack. The expression of all functions was accomplished in two words, a "verb" and a "noun". The functions of every component were classified as "P" for the Primary function and "S" as the secondary Function

Table 3. 430 Slotted Rack Tubular Legs

| **(430) SLOTTED RACK TUBULAR LEGS 810mml x 508mmw x 1154mmh** | | | | | | **Functions** | |
|---|---|---|---|---|---|---|---|
| **Component** | **Unit** | **Qty** | **P** | **S** | **Unit cost** | **Verb** | **Noun** |
| **SS SHEETS 430H.L** | | **0.76** | | | **3982.80** | | |
| sheet 1.2 (772 x 390) | sht | 0.10 | * | | 911.47 | support | utility rack |
| sheet 1.2 (470x 390) | sht | 0.06 | * | | 554.91 | support | utility rack |
| sheet 1.0 (520X1220) | sht | 0.21 | * | | 896.26 | support | utility rack |
| sheet 1.0 (450x 1220) | sht | 0.18 | * | | 775.61 | support | utility rack |
| sheet1.0 (490x 1220) | sht | 0.20 | * | | 844.55 | support | utility rack |
| **Legs** | | | | | **1700.00** | | |
| tubular legs 202 1.2 thck | ft | 20.0 | * | | 1300.00 | sustain | sheets |
| adjustable bullet footing | pcs | 4.00 | * | | 400.00 | carry | Bullet footing |
| **ASSEMBLY CONSUMABLES** | | | | | **4.55** | | |
| filler rod 1.6 | pc | 1.00 | * | | 1.00 | joint | Ss sheets |
| Argon | tank | 0.20 | * | | 0.20 | Weld | ss.sheets |
| Tungsten | pc | 0.10 | | * | 0.95 | absorb | force |
| | | | * | | | reduce | recoil |
| cutting wheel | pc | 3.00 | * | | 3.00 | cut | Stainless |
| | | | | * | | smooth | ss. steel edge |
| grinding stone | pc | 0.25 | * | | 0.25 | cut | ss. steel |
| **FINISHING CONSUMABLES** | | | | | **193.75** | | |
| Sanding Disc | pc | 5.00 | * | | 65.00 | finish | Ss sheets |
| Waterproof #120 | pc | 6.00 | | * | 42.00 | smooth | Ss sheets |
| Waterproof #400 | pc | 4.00 | * | | 28.00 | smooth | Ss sheets |
| Scotch Brite | pc | 0.50 | * | | 6.25 | clean | Ss steel |
| Buffing Stone | pc | 0.25 | * | | 37.50 | smooth | Ss edge |
| Buffing Cloth | pc | 1.00 | * | | 15.00 | Clean | Buffing stone |
| **TOTAL MATERIAL COST** | | | | | **5,881.95** | | |

Table 4. 304 Slotted Rack Angular Legs

| **Design 1 (304) SLOTTED RACK ANGULAR LEGS (NEW DESIGN) 810mml x 508mmw x 1154mmh** | | | | | | **Functions** | |
|---|---|---|---|---|---|---|---|
| **Component** | **Unit** | **QTY** | **P** | **S** | **Unit cost** | **Verb** | **Noun** |
| **SS SHEETS 304** | | **1.79** | | | **8644.14** | | |
| sheet 1.0 (4X8) | sht | 1.00 | * | | 4700.00 | support | utility rack |
| sheet1.5mm (575X2438) | sht | 0.47 | * | | 2358.10 | support | utility rack |
| sheet 1.5mm (575X895) | sht | 0.17 | * | | 865.53 | support | utility rack |
| sheet 15mm (1530x280) | sht | 0.14 | * | | 720.51 | support | utility rack |
| **ASSEMBLY CONSUMABLES** | | | | | **253.95** | | |
| filler rod 1.6 | pc | 1.00 | * | | 13.00 | joint | Ss sheets |
| Argon | tank | 0.10 | * | | 240.00 | Weld | ss.sheets |
| Tungsten | pc | 0.10 | | * | 0.95 | | |
| **FINISHING CONSUMABLES** | | | | | **39.50** | | |
| Sanding Disc | pc | 1.00 | * | | 13.00 | finish | Ss sheets |
| Waterproof #20 | pc | 2.00 | | * | 14.00 | smooth | Ss sheets |
| Scotch Brite | pc | 0.50 | * | | 12.50 | clean | Ss steel |
| **TOTAL MATERIAL COST** | | | | | **9,016.59** | | |

## 3.3 Process VA/VE

Time study is one of the tools used to determine the standard time of fabricating a slotted utility rack. The identification of every process in fabricating two kinds of slotted utility racks is performed. Tables 5 and 6 are the summary of the total hours of the slotted rack fabricated in two different designs. The expression of all functions was accomplished in two words, a “verb” and a “noun”. The rounded standard time was tabulated in hours and minutes per job category (Table 5 and 6).

Table 5. 430 TMS Summary Process

| Job Category | Functions Verb | Functions Noun | Rounded Standard Time(HR) | Rounded Standard Time(Min) |
|---|---|---|---|---|
| Ridings | Draw | Equipment | 2.50 | 150 |
| Preparation | Preparing | Equipment | 2.00 | 120 |
| Preparation | Cut | Sheets | 0.75 | 45 |
| Preparation | Belt | Cutted (2B)Stainless Sheet | 1.00 | 60 |
| Preparation | Notch | Stainless steel | 0.50 | 30 |
| Preparation | Bend | stainless sheet | 1.25 | 75 |
| Assembly | Assemble | Product Materials | 10.00 | 600 |
| Finishing | Finish | Equipment | | |
| **Total Hr** | | | **20** | **1,185** |

Table 6. 304 TMS Summary Process

| Job Category | Functions Verb | Functions Noun | Rounded Standard Time(HR) | Rounded StandardTime(Min) |
|---|---|---|---|---|
| Ridings | Riding | Equipment | 2.7 | 162 |
| Preparation | Preparing | Equipment | 1 | 60 |
| Preparation | Cut | Sheets | 0.25 | 15 |
| Preparation | Belt | Cutted (2B)Stainless Sheet | 3 | 180 |
| Preparation | Punch | Turret Machine | 1.75 | 105 |
| Preparation | Notch | Stainless steel | 0.25 | 15 |
| Preparation | Bend | stainless sheet | 1.25 | 75 |
| Assembly | Assemble | Product Material | 1.75 | 105 |
| Finishing | Finish | Equipment | 1.75 | 105 |
| **Total Hr** | | | **8.75** | **525** |

## 3.4 Optimal Material Handling Cost

To reduce overall material handling costs, Misola and Navarro's (2013) suggested method was used in the VA/VE process. Tompkins and White (1996) state that the majority of the entire operational cost is made up of total material handling expenses. A proper facility architecture can cut material handling costs by 10% to 30%. Manufacturing costs range from 10% to 80%. Material handling costs range from 20% to 50% of total operating costs. Therefore, a small reduction in material handling costs can help to reduce overall operating costs. Value engineering uses genetic algorithms since its application through layout is already optimal. The simulation was performed using Matlab Software.

### 3.4.1 Problem Formulation

The total material handling cost of the system is the objective function TC for the facility planning issue. The reduction of overall material handling expenses is the study's goal. The latter is a measurement of how well the facilities are organized. The formula for calculating TC is as follows:

Where $F_{ij}$ is the quantity of material flow between equipment $i$ and $j$, $C_{ij}$ is the unit material handling cost between equipment $i$ and $j$, locations, $D_{ij}$ is the rectilinear distance between those centroids, and TC is the system's overall material handling cost.

$$\min TC = \sum_{i=1}^{n} \sum_{j=1}^{n} F_{ij} C_{ij} D_{ij} \tag{2}$$

In Tables 7, 8, 9, 10, 11, and 12, the distance matrix, material flow matrix, and unit material handling cost of the 430 and 304 processes were displayed (Figure 7- Figure 12).

Table 7. 430 Distance Matrix

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 3 | 6.5 | 9.5 | 13 | 19.5 | 5 | 7.5 | 8 | 0.5 | 11 | 2 | 16 |
| 2 | 3 | 0 | 3.5 | 6.5 | 9.5 | 16.5 | 2 | 4.5 | 4.5 | 4 | 7.5 | 4.5 | 13 |
| 3 | 6.5 | 3.5 | 0 | 3 | 5.5 | 12.5 | 5.5 | 8 | 8.5 | 7 | 11.5 | 8 | 15 |
| 4 | 9.5 | 6.5 | 3 | 0 | 3 | 10 | 4 | 4.5 | 4 | 10 | 7 | 11 | 12 |
| 5 | 12.5 | 9.5 | 5.5 | 3 | 0 | 7 | 7 | 9.5 | 4.5 | 13 | 3.5 | 20.5 | 8.5 |
| 6 | 19.5 | 17 | 12.5 | 10 | 7 | 0 | 9.5 | 12 | 7 | 13 | 4 | 13.5 | 8.5 |
| 7 | 5 | 2 | 5.5 | 4 | 7 | 9.5 | 0 | 2.5 | 3 | 5.5 | 5.5 | 6 | 11 |
| 8 | 7.5 | 4.5 | 8 | 4.5 | 9.5 | 12 | 2.5 | 0 | 4.5 | 4 | 8 | 6.5 | 13 |
| 9 | 8 | 4.5 | 8.5 | 4 | 4.5 | 7 | 3 | 4.5 | 0 | 8.5 | 3 | 9.5 | 8 |
| 10 | 0.5 | 4 | 7 | 10 | 13 | 13 | 5.5 | 4 | 8.5 | 0 | 12.5 | 0.5 | 17 |
| 11 | 11 | 7.5 | 11.5 | 7 | 3.5 | 4 | 5.5 | 8 | 3 | 13 | 0 | 12 | 5 |
| 12 | 2 | 2 | 8 | 11 | 21 | 13.5 | 6 | 6.5 | 9.5 | 0.5 | 12 | 0 | 17 |
| 13 | 16 | 13 | 15 | 12 | 8.5 | 8.5 | 11 | 13 | 8 | 17 | 5 | 17 | 0 |

Table 8. 430 Material Flow Matrix

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 9. 430 Unit Material Handling Cost Matrix

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 60 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 10 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 10. 304 Distance Flow Matrix

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 6.5 | 10.5 | 9.5 | 12.5 | 15.5 | 7 | 3.5 | 9.5 | 12.5 | 18 |
| 2 | 6.5 | 0 | 4 | 3 | 6 | 14 | 5.5 | 7 | 8 | 11 | 15.5 |
| 3 | 10.5 | 4 | 0 | 4 | 7 | 15 | 8.5 | 10 | 8.5 | 11.5 | 17 |
| 4 | 9.5 | 3 | 4 | 0 | 3 | 11 | 4.5 | 6 | 5 | 7 | 13 |
| 5 | 12.5 | 6 | 7 | 3 | 0 | 8.5 | 7 | 8.5 | 4 | 4.5 | 10.5 |
| 6 | 15.5 | 14 | 15 | 11 | 8.5 | 0 | 11 | 12.5 | 8 | 4.5 | 9 |
| 7 | 7 | 5.5 | 8.5 | 4.5 | 7 | 11 | 0 | 1.5 | 4.5 | 7.5 | 13 |
| 8 | 3.5 | 7 | 10 | 6 | 8.5 | 12.5 | 1.5 | 0 | 4.5 | 7.5 | 13.5 |
| 9 | 9.5 | 8 | 8.5 | 5 | 4 | 8 | 4.5 | 4.5 | 0 | 4 | 9.5 |
| 10 | 12.5 | 11 | 11.5 | 7 | 4.5 | 4.5 | 7.5 | 7.5 | 4 | 0 | 6 |
| 11 | 18 | 15.5 | 17 | 13 | 10.5 | 9 | 13 | 13.5 | 9.5 | 6 | 0 |

Table 11. Unit Cost

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 12. 304 Unit Material Handling Cost Matrix

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 26 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 53 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The optimal material handling cost for 430 is 21,450 and for 304 17,287.50 with a scale of 25 meters per unit distance. The entire simulation was encoded in MATLAB Platform.

## 3.5 Emissions/Waste

Positive products are the cost of good products however; negative products are the cost of all emissions that undergo the production process. In this case, there are 3 areas of processes to fabricate stainless steel racks; the preparation, assembly, and finishing area. This method aims to identify waste or emission of stainless steel per area. The results of the Emission are shown in Table 13.

Table 13: 430 and 304 Emissions per area

| **Production Area** | **430 Tubular Rack** | **304 Angular Rack** |
|---|---|---|
| Preparation | 13.851 | 0.45 |
| Assembly | 0.283 | 0.09 |
| Finishing | 0.125 | 0.18 |
| Total Kg | 14.258 | 0.72 |

### 3.6 Life Cycle Costs

Davis et al. (2005), Life Cycle Cost analysis is a means of quantifying the choice of materials for a product or construction, to select the most economic alternative. Where *Fc* is the First Cost, the summation of total material cost and labor cost with a percentage of margin, TMC is the total maintenance cost, the product of the number of times the maintenance of the product and maintenance cost over inflation rate multiplied by the series worth of payment equation, RC is the replacement cost, and i is equivalent to 6.2444% based on average inflation rate in 20 years.

$$LCC = FC + TMC + RC \tag{3}$$

$$TMC = \frac{NT * MC}{i}\left[1-(1+i)^{-n)}\right] \tag{4}$$

Table 14: Life Cycle Cost

| Life Cycle Cost Components | Stainless Steel Grade | |
|---|---|---|
| | **430** | **304** |
| First Cost | 11,763.90 | 18,033.18 |
| Frequency of Maintenance (NT =No of Times for Maintenance /year) | 3 Months (4 times a year) | 6 Months (twice a year) |
| Lifespan | 10 | 20 |
| Maintenance Cost (MC) | 200.00 | 200.00 |
| Maintenance Cost per Year(MCY) | 800.00 | 400.00 |
| Total Maintenance Cost (TMC) | 8,996.62 | 4,498.31 |
| Replacement Cost (RC) | 11,763.90 | |
| Life Cycle Cost (LCC) in 20 years | 32,524.42 | 22,531.49 |
| Cost Savings | **9,992.93** | |

Table 14 shows the comparative breakdown of Life cycle cost analysis between 430 materials and 304 materials. The analysis show cost savings of 9,992.93 pesos for 304 materials within 20 years life span.

### 3.7 Design Ranking

The ranking used in this paper used a principle from the Model on Trade-Off Strategies in Engineering Design by Otto and Antonsson (1991) for quantitative scaling. The importance of each criterion (on a scale of 0 to 5, with 5 being the highest importance) was assigned, and each design methodology's ability to satisfy the criterion (on a scale of 0 to 5, as 5 is the highest ability to satisfy the criterion) was also tabulated. On the other hand, the designer and customer set the governing rank for each criterion involved which was based on the initial research and analysis made for the design. The computation of ranking ability to satisfy the criteria of the design proposal is as follows

$$\%Difference = \frac{HigherValue - LowerValue}{LowerValue} \tag{5}$$

$$SubRank = GovRank - (\%Difference * 10) \tag{6}$$

The designer's preference determines the governing rank. The importance of each criterion was valued according to the designer's subjective assessment. The variable that reflects its percentage% separation from the ruling rank along the ranking scale is the subordinate rank Equation 6. The subordinate ranks of the other designs with higher values will be computed under Equation 6 from the governing rank along the ranking scale, while the governing tradeoff in terms of which the design yielded the lowest value will be subjectively ranked the same as the criterion's level of importance, for which criteria belongs when testing the ability to satisfy a criterion. When evaluating a criterion's ability to be satisfied, the trade-off that determined which design produced the lowest value will be subjectively ranked at the same level of importance as the criterion to which it belongs, while the subordinate ranks of the other designs with higher values will be calculated under Equation 6.

## 4. Results and Discussion

Using the model of trade-off analysis per VA/VE process will give the designers ability to rank the design for every method such as Material, Product, Process, Material Handling, Emissions, and Life Cycle Cost.

Table 15. Trade Off-Designer's Perspective

| Decision Criteria | Criterion's Importance (on a scale of 0 to 5) | 430 material | 304 material |
|---|---|---|---|
| 1. Material VA/VE | 5 | 1.6 | 5 |
| 2. Product VA/VE | 5 | 5 | 0.33 |
| 3. Process VA/VE | 5 | 3.34 | 5 |
| 4. Material Handling Cost | 5 | 2.59 | 5 |
| 5. Emission | 5 | -5 | 5 |
| 6. Life Cycle Cost | 5 | 0.56 | 5 |
| Average Rank | 5 | 1.44 | 4.22 |

Table 16. Trade Off-Customers Perspective

| Decision Criteria | Criterion's Importance (on a scale of 0 to 5) | 430 material | 304 material |
|---|---|---|---|
| 1. Corrosion or Heat Resistance | 5 | 1.6 | 5 |
| 2. First Cost | 5 | 0.33 | 5 |
| 3. Life Cycle Cost | 5 | 0.56 | 5 |
| Average Rank | 5 | 0.83 | 5 |

Based on Trade-Off from Customer's Perspective, (Table 16) In terms of Corrosion or Heat resistance, the 304 material resulted to received a a rank of 5 compare to 430 who has a rank of 1.6, both with the First Cost ( Selling Price), and Life Cycle Cost, all the afformentioned decision criterion resulted to a rank of 5 in fabricating stainless steel equipment using 304 material. The results show that fabricating 304 materials will have a higher score compared to 430 materials based on the computed average rank on trade-off analysis of designers' and customers' perspectives (Tables 15 and 16).

## 5. Conclusion and Recommendation

This paper developed a case methodology that will represent the optimum value to the manufacturer and customer using VA/VE approach. The method used is to analyze and interpret the results based on design ranking.

The solutions show that high scores from designing a 304 material will give benefits to the manufacturer and customer based on Value Analysis on material, product, process, material handling cost emissions, and its product life cycle cost. Value Engineering is not only advantageous but also necessary because Improvements in the project's functioning frequently result in significant initial and life-cycle cost savings. The assurance that all plausible alternatives have been investigated comes from taking a "second look" at the design created by the designers. A thorough review is done to ensure that no costs or scope statements have been overlooked or understated and best value will be obtained. Future works of this case study may expand the method into a multiconstraint and multi-objective optimization problem

## References

A. J. Dell'Isola , Value engineering in the construction industry. Washington, DC: Smith Hinchman & Grylls.1998.

Bing, Xu , Application research on the investment control of construction project with value engineering at design stage. School of Economics and Management North China University of Technology Beijing, China.2009.

Boo Young, C., Syadaruddin, S., Hyung Seok, J. and Young Hoon, K. , Applying process simulation technique to value engineering model: a case study of hospital building project. IEEE Transactions on Engineering Managment, 56 (3).2009.

Cheah, C. Y. J., and Ting, S. K., Appraisal of value engineering in construction in Southeast Asia. Int. J. Project Manage., 23 (2), 151–158.2005.

Davis, M., Coony, R., Gould, S., and Daly, A. , Guidelines for life cycle cost analysis. Standford University Land and Buildings, Oct. 2005.

Duque, S.B.,Navarro, M.M.,Verrey, J.C.,and Zantua,S.M, Design Optimization of Warehouse Operations for Logistics Company in the Philippines, *Proceedings of the Asia Pacifici Industrial Engineering and Management Systems Conference*, Taiwan. 2005. , https://apiems2016.conf.tw/site/userdata/1087/papers/0147.pdf.

Federal Facilities Council , Sustainable federal facilities: a guide to integrating value engineering, life-cycle costing, and sustainable development. Nat. Res. Council, Washington, DC, Federal Council Tech. Rep., 142.2001.

Jung-Hsing Lee, L., Leu, J. D., and Huang, Y. W. , Implementation of enterprise resource planning sing the value engineering and system dynamics methods. 2015.

K. N. Otto and E. K. Antonsson , Model on trade-off strategies in engineering design. 1991.

Kalpakjian and Schmid , , Manufacturing Processes for Engineering Materials. 4th Edition, 2003.

Lemos, A. D. and Porto, A. C. , Technological forecasting techniques and competitive intelligence: tools for improving the innovation process. Industrial Management and Data Systems, 98 (7), 330-337, 1998.

Maisenbacher, S., Behncke, F. G. H., and Lindemann, U. , Model for integrated value engineering, 2013.

Misola, M. G. and Navarro, B. B, Optimal facility layout problem solution using genetic algorithm. International Journal of Mechanical, Industrial Science and Engineering, World Academy of Science, Engineering and Technology (WASET), 7 (8), 622-627. 2013.

Navarro, M.M, and Navarro B.B., Engineering Trade-Off Strategies Design Evaluation for Fabrication Company in the Philippines, Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management Detroit, Michigan, USA, September 23-25, 2016, http://ieomsociety.org/ieomdetroit/pdfs/167.pdf

N. Wang , Introduction to Value Engineering Economic, Science Press.

Omigbodun, A., Value engineering and optimal building projects. J. Archit. Eng., **7** (2), 40–43, 2001.

Palmer, A., Kelly, J., and Male, S. , Holistic appraisal of value engineering in construction in United States. J. Constr. Eng. Manage., **122** (4), 324–328, 1996.

Qian, S. and Shoufeng, C, Evaluation of green construction alternatives based on value engineering. 2008.

Sison, J.P.,Jalac,P.I., Dinglasan J.M.,Navarro,M.,Palisoc, A., and Torres, M.J., Process Value Analysis for Wood-Based Furniture Company in the Philippines using VA/VE Approach, *Proceedings of the International Conference on Industrial Engineering and Operations Management,* Bandung, Indonesia, March 6-8, 2018. http://ieomsociety.org/ieom2018/papers/602.pdf

Palisoc, A.A, Semifrania,G.O, Kurata, Y.B and Navarro M.M., Design Optimization of Equipment Controls Setup and Workstation Tables for the Remote Production Taping of a Media Broadcasting Company, *Proceedings of the International Conference on Industrial Engineering and Operations Management Bangkok*, Thailand, March 5-7, 2019, http://ieomsociety.org/ieom2018/papers/602.pdf

Thew, P. F, Value engineering in the electronic industry. Joint I.E.R.E.-I.E.E. Conference at Nottingham in July 1967.

W. D. Callister, Jr. , Materials science and engineering "an introduction". 7th Edition., 2007.

Yan, L. , Value engineering application in construction project management. School of Economics and Management China University of Petroleum Qingdao, Shandong, China. 2012.

Zhang, T., Cao, H., and Diao, Y, Study on application of value engineering in improvement of production operation in oil field. 2010.

## Biographies

**Maricar M. Navarro** is a Professional Industrial Engineer (PIE) awarded by the Philippine Institute of Industrial Engineers (PIIE) and an ASEAN Engineer (AE) awarded by the ASEAN Federation of Engineering Organizations. She is an Assistant Professor IV in the Department of Industrial Engineering and a Lecturer in the Graduate School Program at the Technological Institute of the Philippines-Quezon City. Engr. Navarro has done research projects that deal on the optimization of production, warehouse operations, and service operations. Her research interests include manufacturing, simulation, optimization, facility layout, and design, She is an active member and Professional Industrial Engineer of the Philippine Institute of Industrial Engineers (PIIE) organization in the Philippines.

**Bryan B. Navarro** is an Assistant Professor in the Department of Electrical Engineering at the Technological Institute of the Philippines and is currently a Staff Engineer at Manila Electric Company (MERALCO). He earned B.S. in Electrical Engineering from the Technological Institute of the Philippines, Quezon City, Master of Science in

Electrical Engineering major in Power Systems from the University of the Philippines, Diliman, Quezon City. He has published journal and conference papers. He is an active member of the Institute of Integrated Electrical Engineers of the Philippines (IIEE).