Engineering Trade-Off Strategies Design Evaluation for Fabrication Company in the Philippines

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Abstract

Decision Making has been mathematical science nowadays. It formalizes the thinking of decision maker to make better decision and have transparency in all its aspects. In this paper, the Design on Trade-Off Strategy were introduced to evaluate the design. Design on Trade-off Strategy is a formal method that allows the designers to explicitly make trade-off decisions. The project aims to optimize the operations in one of the fabrication company in the Philippines by designing a production layout that will increase productivity. After series of observations, this paper identified the factors affecting the low productivity in the production. The design of the process and production layout was analyzed based on five design criterions: Economic, Health and Safety, Ergonomics, Environmental and Productivity. The two designs were evaluated using Trade off Strategies in Engineering Design. This paper recommends the first design that can contribute for higher productivity.

Keywords
Economical, production layout, production operations, sustainable, trade-offs

1. Introduction

Design trade-offs is a rewarding method to study decision making. According to Tate and Nordlund (1996), making a design trade-off is an iterative process and unguaranteed to yield a desirable result. The customers and designer's perspective, input requirements, methods, etc. plays a significant role in the process and the outcome of the design. These are somehow can provide insight into how certain decisions are made.

In today's rapid technology driven world, competition is continuously considered as the main basis for 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 cost without affecting reliability of performance. Superior value has always been main concern of the customer. As competition constantly take place, a lower cost creation will always have a better market rate. Profits are still the most essential reason to evaluate the design, without it; there is no existence of businesses. It is imperative for technology based sector to acquire important technical information to survive in the present competitive situation. Lemos and Porto (1998) stated that, information is desirable in the technology based field in order to advance innovation method that wishes to survive in the marketplace. To create a superior design, the fabrication Industry is one of the technologies driven based sector that needs relevant Information.

There is a stiff competition among the various players of stainless steel fabrication industry in the Philippines and customer demands are more distinctive. The ever-increasing demand for food outlets, restaurants, hospitals, building construction lead to other players to create competitive advantage that will defy them for product development projects in selling high customer value for at low costs. The Industry are facing the difficulty and challenges of improving the product, service quality, and reducing delivery times, fabrication cost and reducing the cost of the products which urgently require the industry to upgrade the present management view.

An in depth case study was undertaken; the client was one of the stainless steel fabrication company in the Philippines. The operations officially started in year 1998. The company offers a wide selection of stainless steel equipment to suit every need in kitchen equipment service. The wide range of products include kitchen cooking equipment, food service counters, refrigerated equipment, bakery and preparation, dishwashing and bar equipment as well as industrial and laundry equipment. Each of these is designed to be at par with the latest in the food service technology. Their value proposition is to provide high-quality stainless steel kitchen equipment to its customers by providing time-definite, totally reliable and innovative design food service equipment.

A comprehensive study by Fiksel and Wapman (1994) presented practical suggestions for systematic implementation of Design for Environment (DFE). Their paper explains how manufacturing firms can develop a Design for Environment toolkit, including on-line guidance for product developers and performance assessment capabilities for analysis of design trade-offs. The goal of DFE is to enable design teams to create eco-efficient products without compromising their cost, quality and schedule constraints. According to them, an eco-efficient product is a creation which both minimizes adverse environmental impacts, and maximizes conservation of valuable resources throughout its life-cycle. Factors that have contributed to the growing interest of manufacturing firms in eco-efficiency are market awareness, differentiation, cost savings, eco labeling programs, regulatory pressures, and International standards. The huge change of industry practice that pays attention to environmental responsibility can essentially increase profitability. Minimizing pollution, and designing products and processes that enhance environmental quality will commonly result in increased in productivity, market share and reduced total operating cost.

In product design development, a case study presented by Johnson (2009) proposed a framework for incorporating time, cost, and fidelity trade-offs among design assessment methods in product development. Case study results prove that alternative assessment methods can be used to achieve certain cost, lead time, or certainty goals. A paper by Luyben (2016) presented a design trade-off, particularly in the design of acrylic acid reactor. He explores the effects of the many design trade-offs on capital investment, energy cost, and product selectivity. Namhyung and Kiyoung (2016) explore the use of trade-off in the design of STT-RAM cache. They conducted extensive experiments on various design parameters including scrubbing period, ECC strength, and target failure rate. In the paper on Nassar and Austin (2013), they explore the use of resource description frameworks (RDF) graphs for the representation of graphs of requirements and specification of design component properties. They use trade-off analysis which is based upon a systematic comparison of the feasible system designs measured with respect to cost, performance and reliability.

Trade-off analysis is also used in the urban irrigation scheme considering energy and water consumption (Yang and Wang, 2015) and in the analysis of infrastructure management (Laumet and Bruun, 2016).

This paper presents a study of design trade-offs in the fabrication industry. This paper aims to design a process that will stand for the optimum value to the stainless steel fabrication industry. The main objective of this study is to use the Model on Trade-off Strategies by Otto and Antonsson (1991) and to evaluate the design based on the Economic, Health and Safety, Ergonomics, Environmental and Productivity constraint. Design Trade Offs cases from different sectors in the literature were also presented to validate the used of trade-offs in design.

2. Project Analysis

The operations formally started on October 1998. The observed productivity rates were 50%. The source of low productivity is due to the overall manual procedures of fabricating stainless equipment and backtracking process of requesting materials, accessories from preparation, assembly and finishing department to warehouse division. The main objective of this project is to design two production layouts and determine the best layout that will improve productivity rate of the processes by evaluating the designs with considerations of the applicable constraints such as Economic, Health and Safety, Ergonomics, Environmental and Productivity. The service utility rack was the main product observed using Time and Motion Study. Time and motion study was conducted as basis for work measurement for the existing process. It is a tool used to determine the standard time of a particular product. The identification of every process is performed and the data were gathered through observations in all processes. Each area was composed of preparation, assembly, and finishing and technical process. Initial observations were gathered, and using the formula from Freivalds and Niebel (2009), this paper determined the ideal number of observations needed for the study.

The proposed method by Misola and Navarro (2013) using genetic algorithm approach was applied in the process to lower down total material handling cost. The advantage of using GA in the process was the application through layout will be optimize. According to Tompkins and White (1996), total material handling costs constitutes the major part of total operating cost. Material handling cost range to 20%-50% of the total operating cost, total manufacturing cost range to 10%-80% and a good facility layout can reduce 10%-30% of material handling cost. Hence little enhancement in material handling cost can contribute to lower down total operating cost.

3. Applicable Constraints, Standards, and Trade-Offs

Multiple constraints were used in this study to determine the most capable design for implementation. The constraints discussed in this study were economic, health and safety, ergonomics, environmental and productivity. The constraints were defined and the values for each constraint will be an input to evaluate the trade-offs. Different constraints consists of different level of significances, applicable standards were also applied. The design with the highest total weighted score based from the calculation of the ranking scale will be chosen.

3.1. Economic

This study was composed of total cost consist of operations cost like labor, total material handling, energy cost and project implementation cost. Another criterion for economic constraint is life cycle cost of proposed lighting material. According to Davis et al. (2005), Life Cycle Cost analysis is a means of quantifying the choice of materials for a product or construction, with the aim of selection of the most economical alternative. In this case, Equation 1 and Table 2 show the comparative model and breakdown of life cycle cost analysis between LED T8 and Fluorescent T5 lighting material. The analysis shows that there was a cost savings of Php 23,469 for Fluorescent T5 materials within 14.37 years. Distance flow and material flow matrix was used for the computation of total material handling cost. The last criteria for Economic constraint were project benefits. Project Benefits were computed based on the additional production output and energy savings that can be achieve on the two design alternatives. Based on the computed data, annual benefits for design 1 (LED T8) is Php 2,770,426 and Php 2,906,899 for design 2 (Fluorescent T5) as Table 1 shown.

Cost analysis of each design was analyzed in order to meet this criterion. A rate of 5 (highest) in terms of its importance was given. This constraint will help the proponents decide whether the design should be pursued from a financial perspective.

Table 1.Economic Cost for Design 1 and Design 2

Economic (Annual)	Level of Importance	Design 1	Design 2
Total Cost (Annual)	5	7,899,708.00	7,928,547.20
Life Cycle Cost (proposed lighting material)	5	208,661.87	185,192.11
Project Benefits (Annual)	5	2,770,426	2,906,899

$$LCC_{LED(T8)} = LCC_{Flourescent(T5)}$$

$$FC*n + \frac{EC + FC*RT*n}{i}\left[1-(1+i)^{-Lifespan(LED(T8))}\right] = FC*n + \frac{EC + FC*RT*n}{i}\left[1-(1+i)^{-Lifespan(Fluorescent(T5))}\right] \quad (1)$$

Table 2.Life Cycle Cost for Design 1 and Design 2

Life Cycle Cost	Design 1	Design 2
First Cost (Php)	350	230
Burning Hours	30000	24000
Number of Units (n)	100	50
Average Usage per Day (Hours)	8	8
Lifespan (Years)	14.37	11.49
Replacement Times (RT) for 14.37	0.00	0.20
Wattage (Watts)	8	14
Wattage (kW)	0.008	0.014
Average Pesos per kWh	11	11
Energy Cost per Year (Php)	18374.4	16077.6
Inflation Rate (Assumed)	0.06	0.06
Life Cycle Cost (LCC) in 14.37 years	208,661.87	185,192.11

Where;
LCC = Life Cycle Cost
EC= Energy Cost per year
FC = First Cost Equivalent to Selling Price
RT = Replacement Time
i = inflation rate equivalent to 6% based on average rate in 15 years
Lifespan= (Burning Hours/Average Usage per Day/ (21.75*12 Days per Year)

3.2. Health and Safety

The principle of this paper was the assurance of the products, people and the processes are zero from harm or injury. This constraint was measured through the use of severity rate formula from Chen and Andersen (2014). An indirect method was used to determine the severity rate of the proposed design. A survey of severity rate was acquired based on perspective of the employees on the two designs. Initially, the historical data of work related injuries/illnesses from the current design was shared to respondents to give basis for the two designs. A rate of 5 (highest) in terms of its importance was given. Table 4 shows that design 1 has low severity rate compare to design 2.

Table 3.Severity Class and Severity Exponential Function

Rank(n)	Severity classes of work-related injuries/illnesses.	The exponential severity function.	
		$n-(\Sigma n)/N$	$e\hat{}n-(\Sigma\, n)/N$
1	Less than a week absent from work	-3	0.049787
2	Less than a month absent from work	-2	0.135335
3	Less than 3 months absent from work	-1	0.367879
4	Less than 6 months absent from work	0	1
5	Less than a year absent from work	1	2.718282
6	Occupational disability (the person will not be able to work in the previous job again)	2	7.389056
7	Fatalities	3	20.08554

$$\text{Severity} = \sum_{n=1}^{N} e^{n} - \left(\frac{\sum n}{N}\right) * \left(I_n\right) * \left(\frac{200{,}000}{HX}\right) \quad (2)$$

Where:
$e\hat{}n-(\Sigma\, n)/N$ = Exponential rank of the incident/injury
I_n = number of injuries of the severity class n
H = Hours required to finish a product
X = number of product produced

Table 4.Health and Safety Constraint

Health and Safety	Level of Importance	Design 1	Design 2
Severity	5	18.51	29.19

3.3. Ergonomics (Lighting Material)

This paper considered the luminance factor of the existing lighting material of the company. Lighting is an important factor that affects the workers' performance during operation. The luminance was computed for each design of the proposed lighting material. A rate of 5 (highest) in terms of its importance was given since it significantly influences the performance of the workers. The luminance was computed based on the luminous flux of each proposed lighting material for designs 1 and 2. Table 5 shows the computed amount of luminous flux for both designs.

Table 5.Ergonomics Constraint

Ergonomics Constraint	Level of Importance	Design 1(LED T8)	Design 2(Fluorescent T5)
Illuminance (in Lux)	5	358.10	298.41

Table 6.Light Luminance for Design 1 and Design 2

Ergonomics	Design 1	Design2
Technical Data	LED T8	Fluorescent T5
Wattage (W)	8	14
Luminous Flux (lm)	720	1200
Lifespan	30000	24000
Number of Units	100	50
Intensity (candle)	5729.56	4774.64
Height	4	4
Illuminance (lux)	358.10	298.41

Luminous Intensity formula:

$$I = \frac{F}{4\pi} \quad (3)$$

Where:
l=luminous intensity (in candle or candlepower)
F=Luminous Flux

Illuminance formula:

$$E = \frac{I}{d^2} \quad (4)$$

Where:
E=Illuminance ($in \frac{lumen}{m^2} orLux$)
I=luminous intensity (in candle or candlepower)
d=distance of light location above the ground (in meters)

3.4. Environmental

This paper analyzed and compared the importance of environmental constraint with the consideration of carbon being emitted by the available equipment and the proposed lighting material for each design. In addition to the carbon emitted by the lighting material, the machines available in the current design were two bending machine, one turret, notching, cutting, drilling, belting, and twenty tig-welding machine. The yearly energy consumption of the design was computed and multiplied by 0.0007 metric tons per kilowatt-hour carbon footprint. This conversion was gathered from the webpage http://www.epa.gov/cleanenergy/energy-resources/calculator. This constraint was given a rate of 3. The paper considered that carbon emission was radically affecting the environment and should be taken into consideration for the enhancement of each design proposal. The carbon foot print of the existing design was 243.25 metric tons per year. In this case, Table 7 shows the lowest carbon footprint was Design 2 which is 242.91 metric tons per year. Shown in Tables 8 and 9 are the annual carbon footprint of available machines and the two proposed lighting materials.

Table 7.Environmental Constraint

Environmental Constraint	Level of Importance	Design 1 with (LED T8)	Design 2 with (Fluorescent T5)
Total carbon emissions per year	3	243.06	242.91

$$\text{Annual Carbon footprint of each machine} = (\text{kWh}) * (0.0007\,\text{metric tons of} / \text{kWh}) * (\text{number of units}) * (12) \quad (5)$$

Table 8.Carbon Emission of Available Machine

Machine Technical Data	Bending Machine (Manual)	Bending Machine (Programmable)	Turret Machine	Notching Machine	Cutting Machine	Tig-Welding Machine	Drilling Machine	Belting Machine
kW	19.55	20.4	9	4.25	2	5.015	5	5
Usage per Day (hours)	8	8	8	8	8	8	8	8
Number of Units	1	1	1	1	1	20	1	1
Metric Tons of CO2 per kWh	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
CO2 Emission per Month	2.38119	2.48472	1.0962	0.51765	0.2436	12.21654	0.609	0.609
CO2 Emission per Year	28.57428	29.81664	13.1544	6.2118	2.9232	146.5985	7.308	7.308
Total CO2 Emission per Month	20.1579							
Total CO2 Emission per Year	241.8948							

Table 9.Carbon Emission of Lighting Material

Technical Data	LED T8	Fluorescent T5
Wattage (W)	8	14
Usage per Day (hours)	8	8
Number of Units	100	50
Metric Tons of CO2 per kWh	0.0007	0.0007
CO2 Emission per Month	0.09744	0.08526
CO2 Emission per Year	1.16928	1.02312

3.5. Productivity

This paper examines the increase in labor productivity (%) from the current design, the first design, and the second design alternatives It was given a rate of 5 (highest) in terms of its importance in relation to the economic constraint, it influence the profitability of the company, and it evaluates the efficiency of the workers to its production layout conducted to the first month of operation, and was projected based on the proposed design alternatives. The percentage increase in labor productivity was computed between the difference of the proposed design alternatives and existing design. Labor productivity was measured based on the annual production output over the amount of equipment produced per year. Table 10 shows that the design 1 has an increase of 6.11% labor productivity, while design 2 yielded 6.77% increase of labor productivity.

Table 10.Productivity Constraint

Process	Design 1 Labor Productivity increment	Design 2 Labor Productivity increment
Total	6.11%	6.77%

3.6. Standards

The two design proposals conform to the following codes and standards: The purpose of the standards is to protect every working man against the dangers of injury, sickness or death though safe and healthful working conditions.

1. OSHA RULE 1060 Premises of Establishments
2. OSHA RULE 1070 Occupational Health and Environmental Control
3. OSHA RULE 1080 : Personal Protective Equipment
4. OSHA RULE 1090: Hazardous Materials
5. OSHA RULE 1100: Gas and Electric Welding & Cutting Operation
6. OSHA RULE 1150 :Material Handling Storage
7. OSHA RULE 1210 :Electrical Safety
8. OSHA RULE 1940 : Fire Protection and Control
9. OSHA3125 : Ergonomics – The Study of Work
10. OSHA3088 : Planning for Workplace Emergencies and Evacuations

4. Trade-Offs

The constraint evaluations are summarized and ranked according to the level of importance using a formula from the Model on Trade-Off Strategies in Engineering Design by Otto and Antonsson (1991) for the quantitative scaling of constraints. The importance of each criterion (on a scale of 0 to 5, as 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 being the highest ability to satisfy the criterion) was also tabulated. On the other hand, this study set the governing rank for each criterion involved and 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:

$$\%\text{Diff} = \frac{\text{Highest - Lowest Value}}{\text{Lowest Value}} \quad (6)$$

$$\text{Sub. Rank} = \text{Governing Rank} - (\% \textit{Difference} \ {*}10) \quad (7)$$

The governing rank is the subjective choice of this study. Assigning the value for each criterion's importance was also based on the subjective judgment. The subordinate rank (equation 7) is a variable that corresponds to its percentage (%) distance from the governing rank along the ranking scale. In testing the ability to satisfy a criterion, the governing trade-off in terms of which design yielded the lowest value (depending on the criteria) will be subjectively ranked the same as the criterion's level of importance, for which criteria it belongs, while the subordinate rank of the other design with higher values (depending on the criteria) will be computed in accordance to equations 6 and 7.

Table 11.Results and Discussion

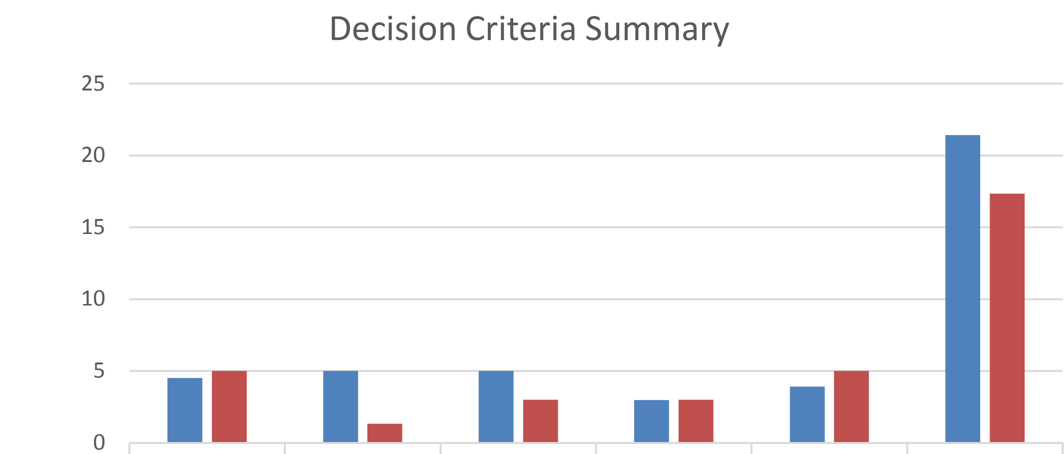
Constraints	Level of Importance	Design 1	Design 2
Economic (in Php)	5	4.51	5
Health and Safety (severity)	5	5	1.34
Ergonomics (Illuminance in lux)	5	5	3
Environmental (CO2 Emissions)	3	2.99	3
Productivity	5	3.92	5
Over-all rank	23	21.42	17.34

Table 11 shows the trade-offs (decision criteria), that have been develop in order to compare the first design to the second design. The design with the highest score using the equation of Otto and Antonsson (1991) will be considered as the best design as it is measured using the applicable constraints. The first design yielded 21.42 while the second design yielded 17.34 score.

5. Conclusions and Recommendation

Figure 1 shown is the summary of all the computed rankings of the applicable constraints. The final decision is based on the computed ranking. Graphical comparison of the over-all rank of both designs is shown in the figure above. Based on the analysis of the trade-offs and the over-all ranking of the two designs based on the applicable constraints which are Economic, Health and Safety, Ergonomics, Environmental and Productivity, this paper choose the first alternative design or Design 1. The chosen design yielded a rank of 4.51 in the Economic constraint, 5 in the Health and Safety constraint, and 5 in the Ergonomic constraint, 2.99 in the Environmental constraint and 3.92 in the Productivity constraint.

Based on observations and results of the study, this paper recommends the following; Application of the first design layout alternative in the production with consideration of applicable constraints and standards, Installation of LEDT8 for production area lighting, perform training and seminar for the production safety aligned with the OSHA Standards and monitoring of the operations for continuous improvement.



	Economic (in Php)	Health and Safety (Severity)	Ergonomics (Illuminance in Lux)	Environmental (CO2 Emissions)	Productivity	Over-all rank
Design 1	4.51	5	5	2.99	3.92	21.42
Design 2	5	1.34	3	3	5	17.34

Figure 1. Decision Criteria Summary

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