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Multi Objective Optimization Using Genetic Algorithm of a Pneumatic Connector

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Abstract. The concept of sustainability was first introduced by Dr Harlem Brutland in the 1980's promoting the need to preserve today's natural environment for the sake of future generations. Based on this concept, John Elkington proposed an approach to measure sustainability known as Triple Bottom Line (TBL). There are three evaluation criteria's involved in the TBL approach; namely economics, environmental integrity and social equity. In manufacturing industry the manufacturing costs measure the economic sustainability of a company in a long term. Environmental integrity is a measure of the impact of manufacturing activities on the environment. Social equity is complicated to evaluate; but when the focus is at the production floor level, the production operator health can be considered. In this paper, the TBL approach is applied in the manufacturing of a pneumatic nipple hose. The evaluation criteria used are manufacturing costs, environmental impact, ergonomics impact and also energy used for manufacturing. This study involves multi objective optimization by using genetic algorithm of several possible alternatives for material used in the manufacturing of the pneumatic nipple.

1. Introduction

Manufacturing cost to produce a product increased yearly because of increasing material, tool, energy, man power, energy, coolant and lubricant cost due to un-favourable currency exchange rate, inflation rate and government taxes [1]. The costs associated with environmental impact and worker health need to be managed properly because it can be an extra burden. In manufacturing there are a few stakeholders interested in the economic profitability, environmental integrity, energy integrity and social equity. Consumer and end users are those who are interested in the economics aspects because they want to get the best value for money products. The trade associations are interested in the social aspects of the workers such as the quality of life of a worker while the energy and environmental aspects are interested by national environmental agencies, public community and private companies particularly in fulfilling environmental regulations set by the governments. Thus making decision on a product design is difficult since it involves multiple objectives. One approach is to use multi-objective optimization using genetic algorithm. Here, all alternatives are modelled and optimized based on the four objectives by using pneumatic connector as a case study as shown in Figure 1.

2. Triple Bottom Line (TBL) Concept

The Triple bottom line concept was introduced by John Elkington in the 1990's based on the sustainability concept proposed by Dr Harlem Brutland in the 1980's. It encompasses a framework to measure corporate organization performance which went beyond the traditional way of measuring performance where it measures profits, share holder value and return on investment used by company previously. This approach also included environmental and social dimensions assessment. By focusing on financial profitability, social equity, energy integrity and environmental integrity criteria; TBL reporting can be a useful tool to sustain sustainability goals.

The first criterion in TBL is financial profitability which can be measured by using the cost of pollution, cost of products fabrication and other factors in profit calculations. The second criterion is social equity and ergonomics assessment can be used to evaluate social equity [2]. The third criterion is energy integrity which can be measured by using the energy consumed during the product fabrication process [1]. The fourth criterion is environmental integrity where it is a company's commitment towards reduction of environmental impact during product fabrication process. There are no universal indicators that can be used in accessing triple bottom line approach and each problem can be solved by using different indicators which suit the case study [3]. The indicators that can be used to measure financial profitability are personal income, cost of underemployment and total manufacturing cost; while environmental integrity can be accessed by measuring impact to the environment when fabricating products. The suitable assessment methods are air and water quality, energy consume during producing products and disposal of toxic waste [1] and social equity represents the measurement of human happiness in life such as median household income or ergonomics assessment at work such as weight lifting index.

3. Multi-Objective Optimization using Genetic Algorithm

In engineering optimization problems, the objectives are conflicting of each other and it prevents simultaneous optimization of each of the objective [4]. There are 2 approaches to do multi-objective optimization. The first one is to combine the individual objective functions into a single composite function. Here, the determination of a single objective is possible by using the weighted sum method and utility theory but there is a problem when to select a proper solution because it applied decision maker's preferences. The second approach is usually used in real-life case study by determining an entire Pareto optimal solution set or a representative subset. Here, solutions that are non-dominated with respect to each of the criteria are called Pareto optimal solution. When the evaluation is moving from one Pareto to another one, a certain amount of sacrifice in objective(s) is needed to achieve a certain amount of gain in the others. Pareto optimal solutions sometimes referred to a single solution because they can be practical when real-life problem are being considered. Both approaches will give either a single solution or a set of optimized solutions after some trade-offs have been considered. The advantages of using genetic algorithm measurement are that it can handle nonlinear problems and its implicit parallelism where the solution space is explored in multiple directions [5]. Most of the application area of multi-objective optimization using genetic algorithm is in engineering field such as in product design and sustainable product development area [6].

4. Methodology

The pneumatic connector used in this study is shown in Figure 1. This product was selected because the demand for it is high since it has been used in many industries to connect high compressed air hose for multi-purpose usage.

Figure 1. Pneumatic Connector.

In financial profitability criteria, the total manufacturing cost approach is adopted because it represents the cost needed to produce pneumatic connector. The total manufacturing cost calculation was adopted from [7] with some modifications as shown in Equation (1).

Total cost=Material cost+ Tool cost+ Coolant cost+ Lubricant cost+ Energy cost+ Labor cost (1)

Material Cost = Standard size price (RM/gram) x Required raw material weight (gram) (2)

Tool cost = tool cost per unit (RM) / number of product produced (n) (3)

This method has been adopted because the determination of tool life based on experimentally is totally different compared to reality. Researchers used new cutting tool in the experiment to get the results but in reality, the cutting tool being used until it wear which can produced many products using one cutting tool [8]. Hence Equation (3) is proposed to measure tool cost in this study.

Energy cost = Energy used (kWh) x electrical tariff (RM/kWh) (4)

Labor cost = Monthly Salary (RM) / average monthly output (5)

In this paper, machining time did not being considered in the labor cost since the worker perform multi tasking work such as control the machine, record the waste product amount and do product quality checking. For coolant and lubricant cost, equation (6) – (8) were used.

Coolant Cost = Coolant or lubricant volume x Coolant or lubricant cost rate (6)

Coolant volume = (tank capacity + makeup volume) / (month used x actual output) (7)

Makeup volume = (tank capacity x coolant loss rate) / (1 – coolant loss rate) (8)

The environmental integrity assessment in a production line consists of cutting tool impact, chip recycling impact, disposal of coolant and lubrication impact; and energy impact (Narita et al., 2012). This study only considered chip re-cycling impact and energy impact because the number of product being produce when using the same cutting tool is high compared to the weight of a cutting tool, coolant and lubricant used; hence it can be neglected [8]. The chip recycling impact is assessment adopt [9] method which considers the amount of carbon weight released into the air by the scrap material produced from the fabrication process such as shown in equation (9).

$$Ch_e = (raw\ material\ weight(kg) - \ finish\ product\ weight(kg)) \times LCI(M) \quad (9)$$

Where Che is chip re-cycling impact; LCI (M) is metal chip recycling emission intensity. The energy impact for CNC turning process is given by Equation (10) - (13) adopted from [10]:

$$P_{c\_turn} = \left(\frac{V_c \times a_p \times f_n \times K_c}{60000}\right) \quad (10)$$

$$P_{c\_drill} = \left(\frac{V_c \times a_p \times f_n \times K_c}{240000}\right) \quad (11)$$

$$P_{c\_boring} = \left(\frac{V_c \times a_p \times f_n \times K_c}{60000}\right) \times \left(1 - \frac{a_p}{D_c}\right) \quad (12)$$

$$\sum P_{c\_total} = \sum P_{c\_turn} + \sum P_{c\_drill} + \sum P_{c\_boring} \quad (13)$$

Where P_{c_turn} is power required to perform turning; P_{c_drill} is power required to perform drilling; P_{c_boring} is power required to perform boring; V_c is cutting speed (m/min); a_p is depth of cut (mm); f_n is federate (mm/min); K_c is Specific cutting force (N/mm^2) for Aluminum 6061 is 400 and 550 for Brass C3604 and Dc is drill diameter. In this paper the workers life quality is adopted for ergonomic assessment because it reflects the immediate impact on labor of the machining production floor [1]. The assessment is based on the revised Lifting Equation with some modification as proposed by [11] specific for South East Asia male, where the evaluation method is based on Equation (14) and (15).

$$LI = \frac{Load\ Weight}{Recommended\ Weight\ Limit} = \frac{L}{RWL} \quad (14)$$

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \quad (15)$$

Where LC is load constant = 23kg; HM is Horizontal Multiplier; VM is Vertical Multiplier; DM is Distance Multiplier; AM is Asymmetric Multiplier; FM is Frequency Multiplier, and CM is Coupling Multiplier which can be referred in tables provided by the developer. In this study, Multi-objective optimization using genetic algorithm (GA) is used to optimize the results by using Matlab Software such as proposed by [4]. In GA, a solution vector x϶X is called a chromosome. Chromosome are made from discrete units called genes, while each genes controls one or more features of the chromosome. In this paper, the genes are represented by 14 variables used in the study such as shown in Figure 2. Normally a chromosome correspond to a unique solution x in the solution space. This requires a mapping mechanism (encoding) between the solution space and the chromosome.

0110	1010	1001	1111
Gene/Variable1	Gene/Variable2	Gene/Variable3	Gene/variable4

Population	Chromosome1/ Solution A1/B1	01101010
	Chromosome2/ Solution A2/B2	10101001
	Chromosome3/ Solution A3/B3	10011111
	Chromosome4/ Solution A4/B4	11110110

Figure 2. The example of case study to understand the gene, chromosome and population in GA.

The operation of GA starts with a collection of chromosome called population. The population in GA is randomly initialized. As the search for optimization evolves, the population includes fitter and fitter solutions until it eventually converges or dominated by a single solution. GA use crossover and mutation to generate new solutions. By iteratively applying the crossover operator, the good chromosome are expected to appear more frequently in the population which leads to producing a good solution [4].There are 5 steps involved where it starts with a randomly initial population, P_0. Set *t=0*. The A1, A2, A3, A4, and B1, B2, B3, B4 are two different initial populations based on material type. Then, if the stopping criterion is satisfied, return toP_t. Next, evaluate the fitness population by assigning a rank $r(x,t)$to each solution x ϵ $P_t$using the ranking scheme$r_2(x,t) = 1 + nq(x,t)$; assigning a fitness values to each solution based on the solution's rank as: $f(x,t) = N\sum_{k=1}^{r(x,t)=1} n_k - 0.5 \times \left(n_{r(x,t)} - 1\right)$ where n_k is the number of solutions with rank k. Then,calculate the niche count nc(x, t) of each solution x ϵ $P_t$using $nc(x,t) = N\sum_{y \in P, r(x,t)} max\left\{\frac{\sigma_{share} - dz(x,y)}{\sigma_{share}}, 0\right\}$. Next, calculate the shared fitness value of each solution x ϵ P_t by using *f'(x, t) =f(x, t)/nc(x, t)* and then, normalized the fitness values by using the shared fitness values. To select parents for mating pool a stochastic selection is used based on *f''*. Crossover and mutation on the mating pool is applied until the offspring population Qt of size N is filled; Set $P_{t+1} = Q_t$. In step 5; Set *t=t+1*. Lastly, Step 2 will start back the step until exits.

5. Results and Discussions

Two types of materials involved in this study are Aluminum 6061 steel and Brass C3604. Both materials were chosen because they are commonly used to produce pneumatic nipple hose connector. The design of experiment used in this study is full factorial with three cutting parameters; hence the number of experiment needed is 2^3=8 experiments. The machining process involved are rough turning, fine turning, center drill, drilling three different size of drill bit and thread cutting using OKUMA LB15-II CNC lathe machine. The energy consumed being measured by power harmonic analyzer during the machining process. Machining parameters used in this study follows [12] as shown in Table 1.

Table 1. Machining parameters used in the case study

SET	Description
1	Cutting Speed: 42m/min; Feedrate: 0.1mm/rev; Depth of Cut: 0.50, 0.25mm;
2	Cutting Speed: 42m/min; Feedrate: 0.2 mm/rev; Depth of Cut: 0.50, 0.25mm
3	Cutting Speed: 83m/min; Feedrate: 0.1mm/rev; Depth of Cut: 0.5, 0.25mm
4	Cutting Speed: 83m/min; Feedrate: 0.2 mm/rev; Depth of Cut: 0.50, 0.25mm

Drilling process used center drill, diameter 10.0 mm, 13.0 and 14.5 mm drill tools with feed rate of 0.1 mm/rev and cutting speed of 30 m/min for both materials. Lastly for threading process, the cutting depth is 0.25mm and the cutting speed is 30 m/min. Both materials were sent to the laboratory to confirm the material grades. Figure 3 shows the comparison chart summary for theoretical and experimental results for all four criteria where A stands for Aluminum and B stands for Brass.

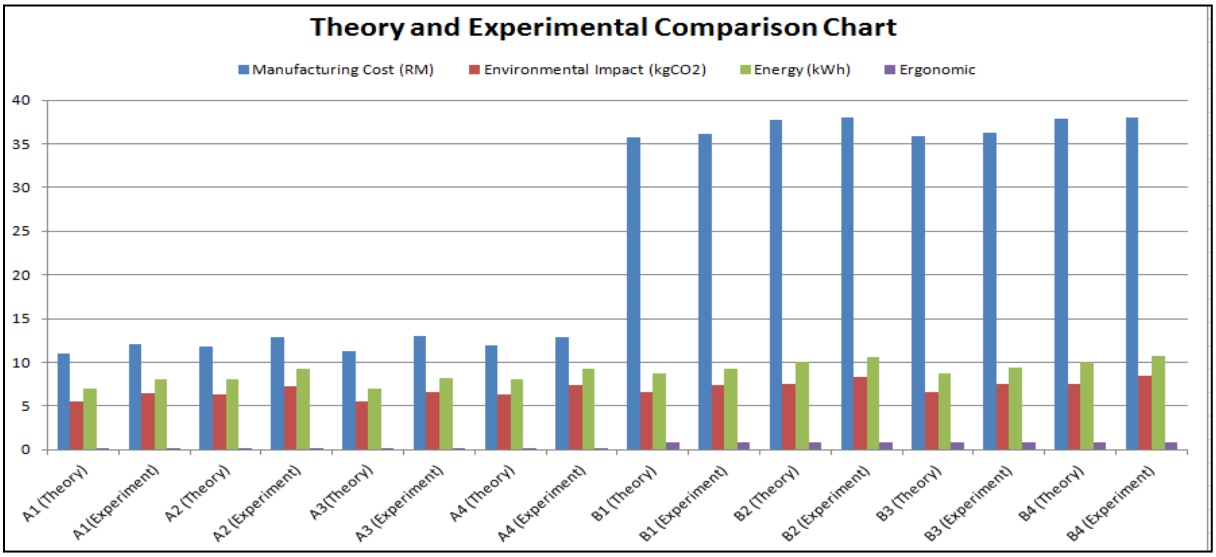

Figure 3. Comparison chart summary for theoretical and experimental results for all criteria

Manufacturing cost, environmental impact and energy increases when the cutting parameters such as cutting parameter for turning process increases such shown in figure 3. Manufacturing cost to produce brass pneumatic nipple hose is higher compared to Aluminum because of brass is more expensive. Increasing cutting speed and feed rate increases the energy consumption during the machining process. For the ergonomics criterion, the results are the same since for all solutions the location of raw material pallet is the same. When comparing both theoretical and experimental data, it shows that experimental result recorded a higher value compared to theoretical results. The difference is less than 10% for Brass material and less than 20% for the Aluminum material for energy criteria and in the acceptable range such as stated by [13]. Few factors that contribute to this results such as the chips stuck at the cutting tool during machining process, wire and spare part components being replace supplied by different manufacturers have been identified in this study. Lastly, the machining process is assumed to run smoothly but in reality it need to be stopped for trouble shooting such as chip stuck at the cutting tool during machining process. In calculating environmental impact and energy impact criteria, the raw material weight and finish product weight used is assume the same value theoretically but in reality they are different. Since the energy consume during the machining is different, the energy impact to the environment is also different because they are inter-related to each other. The same thing goes for the manufacturing cost. That is why it is higher compared to the theoretical results. There are two mathematical functions used in this study; one for Aluminum and the other one for Brass. Pareto front plot function is used in this study since it plots the first objective function against the second objective function. There are 14 variables involved in this study which can be manipulated to get the optimum results based on situation that contribute to the 4 criterion results. The 14 variables are seven types of tool life, feed rate, cutting speed, coolant and lubricant loss rate; average monthly output, raw material length and finished product weight. The initial population used in this study is 200 and the stopping rule used is the default setting. Optimization result shows that for each different case, the optimization result is different; such as shown in Table 2.

Table 2. Optimization results for each criteria.

Material	Manufacturing Cost	Environmental Impact	Energy Impact	Ergonomics
Aluminum	Raw material Length: 54.58mm Cutting Speed:63.08 mm/min Feedrate:0.1975 mm/rev	Raw material Length: 54.50 mm Cutting Speed: 42.06m/min Feedrate: 0.1001mm/rev	Raw material Length: 54.50mm Cutting Speed: 42.47 m/min Feedrate: 0.1000mm/rev	Raw material Length: 54.50mm Cutting Speed: 42.00 m/min Feedrate: 0.1000 mm/rev
Brass	Raw material Length: 54.70 mm Cutting Speed: 83.78m/min Feedrate: 0.1044 mm/rev	Raw material Length: 54.50mm Cutting Speed: 42 m/min Feedrate: 0.1000 mm/rev	Raw material Length: 54.50mm Cutting Speed: 42 m/min Feedrate: 0.1000 mm/rev	Raw material Length: 54.50mm Cutting Speed: 42.00 m/min Feedrate: 0.1000 mm/rev

Based on the results in Table 2, the results are different for each criteria. For manufacturing cost criteria different cutting speed, federate and raw material length recorded for both aluminum 6061 and Brass C3604. For environmental impact criteria, cutting speed and federate is different while raw material length is the same for both material. For energy criteria the results for both materials are almost the same for both material while for ergonomics criteria the optimization results is the same for both materials. From the optimization that has been done, optimization evaluation for manufacturing cost criteria is the most comprehensive evaluation because 11 out of 14 parameters were varied.

6. Conclusions

As a conclusion, triple bottom line concept can be implemented at the product design stage and the machining parameters can be optimized when evaluating its impact on the environment, energy, economics and social dimension. Multi-objective optimization by using genetic algorithm method can be used to optimize the machining parameters and material for the product based on the four dimensions optimization evaluation.

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