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Understanding Different Stakeholders of Sustainable Product and Service Based Systems using Genetic Algorithm for Sustainable Manufacturing

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Abstract

To have a sustainable product or service, product and service systems must equally satisfy all the three stakeholders of sustainability: people, planet and profit generated by the companies. However, if often not the case; this interest of the planet as a stakeholder is often ignored by the other stakeholders. Government tax incentives could act as an enabler to mitigate this difference. In this work, this issue is explored and presented through the development of a strategy to optimize the needs of various stakeholders in selecting the right solution satisfying the needs of users. We develop equations to express the three Ps of sustainability so as to find out appropriate government incentives, as tax that could be left on people and product manufacturing companies to make products and services more sustainable. The multi-objective problem is formulated as an optimization problem and solved using Multi-Objective Genetic Algorithms (MOGA).

Keywords:genetic algorithm, resources, sustainability

1 Introduction

In the recent years, there is a predominant inclination towards service-oriented solution rather than product oriented solution to satisfy the same need of the customers. Converting a product-based system to a service based system requires major changes at various levels of an organization, society, and mind set of the customers. Yet, service oriented approach is often regarded more sustainable than product selling approach for various reasons, such as, encouragement of sharing, dematerialization, reduced use of virgin materials, and creation of repair and reuse network of products. However, service oriented systems are not elixir to the unprecedented and escalating problem of global sustainability issues. Product oriented solution system to satisfy functional requirements of customers still remains as one of the major sales pitch of major product-manufacturing sectors, such as, automobiles, consumer goods, and real estate. However, in highly industrialized countries, almost 70% of all workers are employed in industries commonly thought of as services: communications, transportation, health care, wholesale and retail redistribution, and financial services Mont (2002). This indicates that there often exists, parallel, multiple, or possibly redundant mode of system available, which could increase undue competition among peer product and service providers. For instance for, transportation in any major city, there is often multiple mode available to any user: public transport (such as, bus, tram, and train), personal convenience (such as personal car, minivan, sedan etc.), rental service (such as, rented car), leasing service (such as car lease), sharing service (such as, carpooling) and several other modes. For each of these mode of transportation, for instance, car rental service in any metro, say in New York, there are often more than fifteen companies who are involved in this service (such as, enterprise, hertz, all cars, and avis). This indicates that private services are often initiated based on the common trend “what works best now concept” and not based on what service is best for the city dwellers. This also increases competition among any single mode service producers, often leaving no choice for less competitive service providers to either keep their service at halt (both car and the driver) or to terminate their service. However, instead of starting a business just based only on monetary motivation (by copying what works best for others), service providers should aim to study what service is actually required by most people of the region and invest on the same. This eventually would reduce excessive availability of certain services and products, reduce redundancies among them, and most importantly reduce the use of material and energy requirements.

Often a combination of product and service could be a better approach to address this problem. Product service systems or PSS is an integrated combination of products and services Baines et al. (2007). Baines et al. (2007) states that “A PSS can be thought of as a market proposition that extends the traditional functionality of a product by incorporating additional services. Here the emphasis is on the ‘sale of use’ rather than the ‘sale of product’.” Brandsotteret al. (2003) defined PSS as ‘A PSS consists of tangible products and intangible services, designed and combined so that they are jointly capable of fulfilling specific customer needs. Additionally, PSS tries to reach the goals of sustainable development.’ Mont (2002) while clarifying the concept of PSS says that due to the advent of PSS “more traditional material intensive ways of product utilization

are replaced by the possibility to fulfil consumers' needs through the provision of more dematerialized services (which is PSS here), which are also often associated with changes in the ownership structure." A PSS can also be considered as a special case in servitization, in which asset performance or utilization is given more importance rather than the ownership. It aims to provide value to the customer by adding product and services Baines et al. (2007). There are several successful PSS implementation, for instance, Xerox charging their customers by 'pay-per-copy,' for using copier, Electrolux 'pay-per-wash,' for using washing machines, and Rolls-Royce 'pay-per-hour' for using their engines.

However, even PSS has several issues. Even though the concept of PSS has been around of several years Goedkoop(1999), Manzini et al. (2001), Mont (2008) a uniform implementation is far more difficult than to architect Baines et al. (2007). Mont (2000) states that "Many authors and institutions proposed the concept of product-service systems as a possible answer to sustainability challenges. However, so far, little attention has been given to that concept at a policy level as well as at the operational level." Similarly, Baines et al. (2007) states that "Although many benefits are apparent from the literature and existing cases, some major inhibitors are reported to arise across the design and management of engineering, manufacturing, and supply chain operations."

Another major issue with PSS is the difficulty in selecting product, service, or a combination of these at different levels for a given condition. In this work, we explore this issue by developing methodologies that would optimize the needs of various stakeholders in selecting the right solution to satisfy a given need of users. Next, it sets to develop recommendation on certain solution combination to help policy makers recommend to the government for investment.

2 Objective and Methodology

In this work, we discuss the following question and we aim to find optimum solutions for this scenario.

How to select a product, service, or a combination of them for a given need (function) while considering the interest of all the stakeholders together (customer, manufacturer, society and the environment)?To address this research question, we need to understand the stakeholders and their objectives.

2.1 Understanding Stakeholders

There are generally two stakeholders for any product or service, viz. the buyer (the users) and the seller (the product manufacturer). However, for a sustainable product or service, there is another stakeholder, the environment. Additionally, government policies act as an enabler of any system to become sustainable. We believe that, the interest of these stakeholders could be expressed in terms of the three pillars of sustainability, the Triple bottom line (TBL) approach or 3Ps, plant (environment or reduced environment impact), profit (economical or profitable), and people (social or socially valuable) Hubbard (2009). According to Elkington (2002), "TBL agenda focuses corporations not just on the economic value that they add, but also on the environmental and social value that they add or destroy."

Since, products or services are developed to satisfy the need of the people in the society, we take this as the first stakeholder. People would purchase a product or avail a service to satisfy a need, also expressed as a function. When we consider an individual, there are often several factors that could affect ones decision to select a particular product, service, or a combination of them to satisfy a need. However, the major factors are affordability (economical) and availability. Since, society consists of different kinds of people, belonging to different economical segments with different purchasing powers; the numbers of factors that could affect this decision are large. Thus, there is no one best fit all selection decision for the variety of products and services that the people of the society can select to satisfy a function, such as, transportation. However, from the government policy development point of view, it would be nice to support that solution which would satisfy the need of maximum number of people in the society. Thus, government policy makers generally support socially valuable solutions.

We take the second stakeholder as the seller or the manufacturer of a product or the service provider. For any service provider, the most important factor that affects the decision to select manufacturing a particular product or provide a particular service is profit. Recently, several manufactures are aggressively moving towards creation of sustainable product and services. However, to sustain in this tough competitive environment, with open market, exposure to global competitions, companies consistently focus on supporting only those products and services that have more number of buyers (or users), ensuring continuous profits. This however, means that for a given set of possible solutions (product, service, and combination of them) for a function (need), a company would opt for only that solution which is most valuable socially, as described in the previous paragraph.

The third stakeholder is the environment. This stakeholder is a passive stakeholder with no part in the decision making process for selecting the appropriate solution for a given function. However, with the recent issues with the global climate change, reduction in available material, and escalating prices of energies especially crude oil, satisfying this stakeholder, that is developing sustainable products and services are no more an option but an ardent need of the society as well as the product manufacturer. From the discussions in the previous paragraphs, it is clear that both the society and the manufacturers would opt for the most socially valuable solution. It would be nice for this stakeholder (environment), if the selected solution have least environmental impact and uses less material and energy. To ensure this, optimization is required to select such as solution that would satisfy all three stakeholders (people, company, and the environment), equally, to the maximum extent possible. Here, government policy

could act as an enabler, as policies are often viewed as technology enabler (or very rarely impeder) for the successful implementation of any solution in a society.

In this work, we discuss how to select the appropriate sustainable solution (product, service, or a combination of them) to satisfy a need (function) while satisfying the three stakeholders (planet, profit, and people). Additionally, we are interested in exploring the introduction of possible incentives through policy development for ensuring proper implementation of the solution in the society.

2.2 Development of System Equations

The system described above depends upon the three important functions, profit, environmental effect and social interest. Here, let us consider a case study of a car manufacturing company. The company purchases raw material for manufacturing of cars, and thus, affects the nature directly and hence environment getsaffected. As the company starts manufacturing, then also it is going to effect the environment by the emission of gasesto the environment. It clearly shows that the car manufacturing company is affecting the environment in number of ways. Now, government have to apply some green tax on the company, so that the effect on the environment by company is compensated. Due to these taxes company might have to restrict the number of cars to be manufactured.

In addition to the above, the people/users those will use the car would also affect the environment by consuming natural resources (fuel) and emitting dangerous gases to the environment. Thus, government needs to levee some additional amount of taxes on the people for the purchase of cars as a compensation for the environmental affect. These taxes already exist in different names such as sales tax and Value added tax on the company and people. Table 1, below shows the trend how the interest of people varies for use of new cars according to the rise or fall in fuel price and taxes. Upward arrows shows the increase in price or interest, while the downward arrows shows the decrease in values of these parameters.

Table 1: Trend of people interest using new car on basis of car price, fuel price and taxes

New car price + Tax	Fuel price + Tax	No. of people buying new car	Duration of usage
↑	↑	↓	↓
↑	↓	↓	↑
↓	↑	↑	↓
↓	↓	↑	↑

It is needed to maintain some relationship between the profit of company on the sale of cars, impact on the environment by the company due to intake of raw material and release harmful gases in the environment, and interest of people of the purchase of cars as due to increased taxes on cars may lose the people interest for purchase of new car. To study these relationship here we are driving to three functions for profit, environmental impact and social impact. Study of these functions is important to find out the optimal results for different parameters, number of cars, sale price, taxes etc.

2.2.1 Profit

Profit is a financial benefit that is realized when the amount of revenue gained from any business activity exceeds the expenses, costs and taxes needed to sustain that activity. In our case study, we are considering the case of a car manufacturing company. Profit of a car manufacturing company dependent on sale price, fixed cost, variable cost and taxes. Fixed cost depends upon the initial investment – machinery, building etc. to start company, variable cost depends upon the cost of raw material, salaries/wages to workers etc., and taxes are applied by the government to the company, so as to penalize it for deterioration of the environment.

Profit = Sale Price – (Fixed Cost + Variable Cost) – Company Taxes

Profit = (Sale Price/unit – Total cost/unit – Company Tax/unit) × no. of units.

2.2.2 Environment Impact

Environmental impact is considered due to following factors: CO_2 emissions, new material intake, and waste produced. Government apply tax based on these factors to control the environmental impact while converting them to CO_2 equivalent. CO_2 equivalent is the concentration of CO_2 that would cause the same level of radiative forcing as a given type and concentration of greenhouse gas. Thus, tax is considered in terms of carbon tax by converting all the factors affecting environment into CO_2 equivalent.

Environmental Impact = (CO_2 equivalent (kg)/day × no. of days × cost of CO_2 equivalent/kg - Company Tax/unit) × no. of units.

2.2.3 Social Impact

Social Impact shows the interest of society/people for use of the product. Social interest depends upon how many people are using the product, how long they use the product, and frequency of using the product each day, taxes on use of product. Table 1 shows that if fuel price is less than more number of people are interested and vice-versa. From the factors affecting the social impact, we comes arrives to the following relationship.

Social Impact = Social interest × no. of units + People Tax/unit × no. of units

Social Impact = (Duration of use × Frequency of use/day × Total no. of days × Cost of use/hour/unit + People Tax/unit) × no. of units

Social Impact = (Total cost of use/unit + People Tax/unit) × no. of units

2.2.4 Problem Formulation

Three functions are developed for the complete set of problem and it is desired that company always wants to make its profit maximum, governments need to control environmental impact by applying the taxes, which should be minimum and finally social impact should by maximum so as to sell more number of cars.

The problem developed here is having multiple numbers of functions and these functions have four variables Sale Price (x_1), Number of Units (x_2), Company Tax (x_3) and People Tax (x_4) and the others like Cost of CO_2 equivalent, fuel cost etc. may be assumed as parameters. According to these four variables three functions are defined:

Max. F1 (Profit), Min. F2 (Environment) and Max. F3 (Social Impact)

Subject to:

$0.3 \times$ Sale Price $\leq$ Company Tax $\leq 0.8 \times$ Sale Price

$0.1 \times$ Sale Price $\leq$ People Tax $\leq 0.3 \times$ Sale Price

$900{,}000 \leq$ Sale Price $\leq 1{,}200{,}000$

$0 \leq$ No of Units $\leq 10{,}000$

Where,

Total Cost = 400,000/- Rupees (cost of one car to company),

CO_2 Equivalent = 10,000 per tons of CO_2 released and Total Cost of Use = 'Fuel Cost' × 'Daily Use of a Car' × 'Total Days'.

Assuming,

Cost of CO_2 Equivalent =50/- Rs/ ton;

Fuel Cost = 50/- Rs/litre;

Daily Use of a Car = 200 Kilometres per day;

Total Days (Car Life Time) = 5475 Assuming 15 years of car use

3 Solution Methodology

The problem formulated above is Multi-objective problem and for the solution of such problem we are using the Multi-Objective Genetic Algorithm (MOGA) Deb (2001) and Deb (2002). The solution comes in form of Pareto-optimal solutions, the solutions which are non-dominant of all other solutions and also non-dominant to each other. To obtain the corresponding Pareto-set, Non-Dominated Sorting Genetic Algorithm-II (NSGA-II) algorithm Deb (2002) is used. The following subsections describe the implementation of MOGA.

The problem formulated is solved for Pareto front using NSGA-II. In this method Deb (2001), first all the variables are represented by random numbers within the lower and upper limit and then according to their corresponding decimal value function values are computed. On the basis of function value fitness value is found. The according to these fitness values populations are arranged in order of fronts according to their non-dominance. Now the populations from the best fronts are taken for next generation and if the front is having more population as compared to required then crowding distance method is used to select the best population. Then crossover and mutation operators are applied on the selected population. The above mentioned procedure is repeated for a number of iteration until the variation of fitness between last two iteration is within the required tolerance. At that iteration the population obtained results in form of Pareto front.

4 Interpretation of Results

The solution obtained by use of NSGA-II in form of Pareto Front is depicted in the Fig. 1. The Pareto front giving a number of solution, all are best with respect to the optimal value of three functions formulated according to our problem of maximizing the company profit and people interest for purchase of product, while minimizing the impact on environment.

The simulation of program is run for a number of times and each time we obtain the similar results, as shown in the Table 2, show one result in each row from the Pareto front obtained every time. These results are shown in form of four variables viz: Sale Price, Number of Units, Company Tax and People Tax. These results are interpreted as, if for particular value of sale price selected, the given number of unit should be manufacture and also the corresponding amount of Taxes should be applied by the government so as to optimize the formulated three function for profit, environmental impact and social interest.

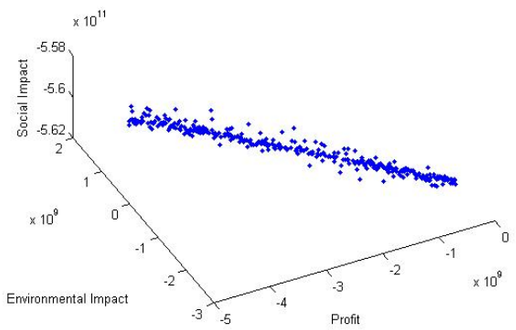

Figure 1: Pareto front

Table 2: Simulation results for a section of Pareto front

Run	Sale Price (x1) (Rupees)	Number of Units (x2) (Units)	Company Tax (x3) (Rupees)	People Tax (x4) (Rupees)
1	1137145/-	9960	371671.5/-	176722.8/-
2	1155707/-	9995	753416.4/-	150409.3/-
3	1170804/-	9976	719967.2/-	160594.9/-
4	1189748/-	9976	395494.6/-	156953.3/-
5	1162678/-	9995	686071.6/-	143372.3/-
6	1151124/-	9948	616378.3/-	118521.2/-
7	1184926/-	9924	595195.2/-	174234.6/-
8	1185823/-	9921	557701.4/-	141882.4/-
9	1172028/-	9999	736714.0/-	164801.6/-
10	1175439/-	9946	418218.6/-	128812.8/-

4.1 Results and Analysis

Our main aim of this study is to provide optimal solution to the problem with three stakeholders – manufacturer, users and environment. For this reason, we consider the case study of a car manufacturing company. This car manufacturing company always wants to maximize its profit, while user wants the maximum comfort, and both of them are going to affect the environment. Therefore, the government should

apply some amount of taxes on both of these stakeholders as a penalty to affect the environment and possible use the collected to mitigate environmental impact by implementing green initiatives, such as, tree plantation, recycling waste materials.

In our case study, three objective functions are developed for maximization of profit of company, minimization of environmental affect, and maximization of peoples' interest to purchase the car. This multi-objective problem is solved using NSGA-II. From the results of simulation above it is interpreted that for the any fixed value of parameters like total cost, CO_2 equivalent, cost of CO_2 equivalent, fuel cost etc.mentioned as above, Pareto front having the non-dominant solutions from other solutions and also from each other will be formed for the three objective functions.And the data points on which the function values comes on Pareto front are the optimal point. The program is simulated for ten times to check the convergence in program and each time similar results are obtained, out of those population of results one result is noted here in Table 2.

From Table 2, let us consider the case of simulation result of 5th run. For the fixed parameters as mentioned above, the results obtained for sale price is 1162678/- rupees, number of unit of cars to be manufactured is 9995 units, company tax 686071/- rupees, and people tax 143372.3/- rupees. It is expected from this result that the car manufacturing company should manufacture 9995 unit of car and selling price of each car should be 1162678/- rupees and government should apply 686071/- rupees as tax to company and 143372.3/- rupees as tax to people for affecting the environment. In this way, all of three stakeholders are optimally satisfied.

5 Conclusion

Product service systems or PSS is an integrated combination of products and services. One of the major issues with PSS is the difficulty in selecting product, service, or a combination of these at different levels for a given condition. In this work, we explore this issue by developing methodologies that would optimize the needs of various stakeholders in selecting the right solution to satisfy a given need of users. "How to select a product, service, or a combination of them for a given need (function) while considering the interest of all the stakeholders together (customer, manufacturer, society and the environment)?" is the question we answer here. We express profit, environmental impact and social impact and formulate them in equations. Next we use Genetic Algorithm to find the appropriate number for tax one people and company that government should levee on them to balance the interest of all the three stakeholders. We use NSGA-II algorithm in MOGA to generate balanced conditions for different cases. The results shows that by modifying applicable taxes government could control the harmful effects on the environment while having the people and companies satisfied.

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