Green Product Design for Mobile Phones

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Abstract—Nowadays, manufacturers are facing great challenges with regard to the production of green products due to the emerging issue of hazardous substance management (HSM). In particular, environmental legislation pressures have yielded to increased risk, manufacturing complexity and green components demands. The green principles were expanded to many departments within organization, including supply chain. Green supply chain management (GSCM) was emerging in the last few years. This idea covers every stage in manufacturing from the first to the last stage of life cycle. From product lifecycle concept, the cycle starts at the design of a product. QFD is a customer-driven product development tool, considered as a structured management approach for efficiently translating customer needs into design requirements and parts deployment, as well as manufacturing plans and controls in order to achieve higher customer satisfaction. This paper develops an Eco-QFD to provide a framework for designing Eco-mobile phone by integrating the life cycle analysis LCA into QFD throughout the entire product development process.

Keywords—Eco-design, Eco-QFD, EEE, Environmental New Product Development, Mobile Phone.

I. INTRODUCTION

WITH the increase in environmental concerns during the past decade, a consensus is growing that environmental pollution issues accompanying industrial development should be addressed together with supply chain management, thereby contributing to green supply chain management (GSCM). Nowadays, manufacturers are facing great challenges with regard to the production of green products due to the emerging issue of hazardous substance management (HSM). In particular, environmental legislation pressures have yielded to increased risk, manufacturing complexity and green components demands ever since the Restriction of Hazardous Substance (RoHS) directive was passed by the European Union (EU). This directive prohibited the use of certain substances in electrical and electronic equipment (EEE) starting from 1 July 2006. As a result, assembly manufacturers have worked on the components containing hazardous substance in order to control the use of certain hazardous substances in EEE. Because of these obligations that have a

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direct impact on purchasing organizations, environment-related supplier initiatives have become essential to firm's strategies.

One definition of green supply chain management (GSCM) is from Srivastava [1]. His study collected and classified previous literatures relating to green supply chain management. He defined GSCM as integrating environment thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers, and end-of-life management of the product after its useful life. According to this definition, GSCM is related to a wide-range of production from product design to recycle or destroy, or from cradle to grave. This principle is similar to lifecycle of product. Product lifecycle is an idea that products pass through a cycle of life, similar to human, birth, maturity, death.

From product lifecycle concept, the cycle starts at the designing of product. According to Srivastava [1], literatures related to green design emphasize both environmentally conscious design and life cycle assessment/analysis. In designing a product, the designing team can change the raw materials or substances used during the manufacturing to be less toxic, more environmental friendly. Some terminologies are related to design for green such as design for environment or Eco-Design. This paper proposes an Eco-QFD methodology for Eco-Design process of a mobile phone, by defining firstly QFD in NPD and then Eco-QFD procedures.

II. NEW PRODUCT DESIGN IN EEE WITH RESPECT TO ENVIRONMENT: ECO-DESIGN

The EuP (energy-using products) directive is the first directive requiring the incorporation of life-cycle-based environmental considerations into the product development process. Several aims of EuP directive have been stated: to ensure the free movement of energy-using products within the EU, to improve the overall environmental performance of these products and thereby protect the environment, to contribute to the security of energy supply and enhance the competitiveness of the EU economy and to preserve the interests of both industry and consumers. The EuP directive requires manufacturers to integrate eco-design considerations into the product design stage and establish eco-profiles for products via a lifecycle approach.

In the past, several environmental impact analyses and evaluation tools have been developed for Eco-Design products. For example, health hazard scoring (HHS) is an evaluation method for health hazard assessment. Kuo [2]

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presented a disassembly planning method for the end-of-life products during the initial design stage. Sage [3] offered sustainable process indices based on an operational definition of sustainability, which relies not only on environmental risk, but also includes economic and technical feasibility as well as political compromise. Horvath et al. [4] developed an approach to track toxic releases and associated risks over time based on the data of the Toxic Release Inventory (TRI) and relevant toxic indices. Costic et al. [5] estimated the environmental performance of conventional lead-based solders and their substitutes using life cycle analysis (LCA). The life cycle of a product refers to the sequence of interrelated steps of a product from the acquisition of raw materials for manufacturing to the disposal of the used product, i.e. its end-of-life. At the end-of-life, the product can be either disposed off, or still in use to extend its life cycle (see Fig. 1). Design for Environment (DfE) –for some authors "eco-design"- is perhaps the most recent discipline in the DfX family [6], where X stands for a design under consideration such as Manufacturability, Testability, Installability, Compliance, Reliability, Disassembly etc [7]. In general, DfE is a design process in which a product's environmentally preferable attributes – including recyclability, disassembly, maintainability, refurbishability, and reusability – are treated as design objectives rather than as constraints. DfE gives guidelines for the design engineer to examine environmental soundness of a product over its entire life cycle by introducing modifications early in the product design process [8].
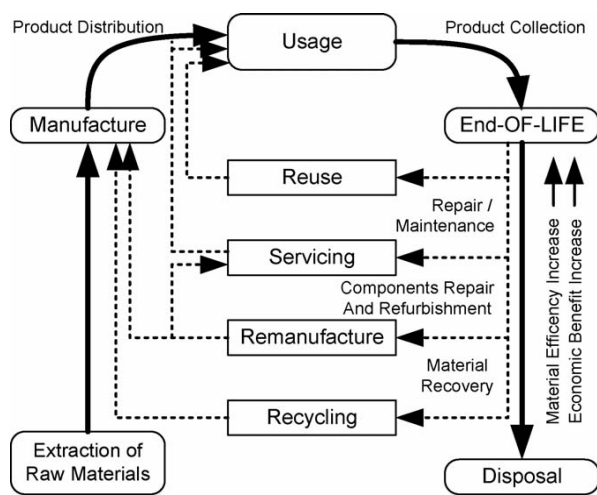

Fig. 1 Product life cycle

To create environmental new product, it is clear enough that regulations, such as European Union's RoHS (Restriction of Hazardous Substances), WEEE (Wastes from Electric and Electronic Equipment), ELV (End-of-Life Vehicle (ELV) Directive), etc., put pressure on firms and tend to make them responsible for the End of Life (EoL) of their products. For instance, WEEE regulation encourages designers to develop products with recycling in mind. Japan is slightly in advance compared to the EU and the USA, having already started to aggressively pursue the removal of lead from the manufacturing process of electronic component. These regulations insist on the fact that the products have to be designed in order to lower their environmental load, notably through the increase of recycling rate. Thus, the designers' task and environmental new product development approach becomes central [6]. Zuidwijk and Krikke studied also on the impact of regulations [9]. They addressed two possible strategic responses to the WEEE-directive by industry: Product eco-design (PDM and DfX) versus new recovery process technologies. The overall conclusion is that the first beats the latter but has a delayed effect. This means that the EU policy to make Original Equipment Manufacturers primarily responsible for recovery, as implemented by the WEEE-directive, is appropriate. But the directive aims both to promote the reuse and recycling by imposing collection and recovery quota, and to reduce e-waste by enhancing the eco-design of products. The current directive definitely stimulates collection and recovery but more incentives are needed to reward product eco-design. Hence according to them, in its current form the WEEE-directive is more of a waste avoidance act.

However, these Eco-design products are not favorable in the market place as expected even though they sound more environmental friendly and economical. This situation may be due to that they are focused solely on environmental impact analysis without paying much attention to customer needs and cost considerations. In other words, the key issue for a successful Eco-Design product is not only to meet environmental objectives such as resource and energy conservation and environmental burden reduction but also to take into account cost effectiveness, market demand, and multi-functionality requirements. The main environmental concerns in the EEE sector stem from soil and water contamination, resource depletion, energy use and waste. At the production stage, obtaining raw metal for EEE production consumes a large amount of energy, especially the process of extracting resources, which can also lead to degradation of the surrounding environment. When raw metal is shipped to a plant, it goes through a complex, high-energy-consuming process as it is converted into a finished product.

It appears that to develop a risk assessment framework to systematically manage the green components' suppliers is an urgent need for manufacturers. This framework has to minimize the negative environmental impact over the life cycle of EEE by promoting clean technology and green design and also the generation of e-waste. Eco-design of electrical and electronic equipment in life cycle management approaches include on improving the recyclability of EEE, maximizing resource recovery from end-of-life EEE management, strategies for extending the life of e-equipment, promoting clean technologies, approaches to promote and encourage eco-design, selecting criteria for eco-design, setting targets for the environmental performance of products and eco-design to address occupational health and safety issues.

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III. QFD AND ECO-QFD : AN APPLICATION FOR MOBILE PHONE

Quality function deployment (QFD) is ''an overall concept that provides a means of translating customer requirements into the appropriate technical requirements for each stage of product development and production (i.e., marketing strategies, planning, product design and engineering, prototype evaluation, production process development, production, sales)'' [10].

The applications of QFD have been expanded to a wide variety of areas, such as design planning, engineering, management, teamwork, timing, costing, to name a few. Moreover, Cristopher et al. [11] developed the Green QFD (GQFD) method to integrate life cycle analysis and QFD to evaluate products using environmental considerations. Furthermore, Zhang et al. [12] presented the GQFD II that integrates life cycle assessment, life cycle costing and QFD into an efficient tool that deploys customer, environmental, and cost requirements throughout the entire product development process. QFDE is carried out in four phases. Phases I and II allow the user to identify environmentally significant components (component parts and devices) of the product. Phases III and IV allow the user to choose the most environmentally friendly design from alternative design proposals.

The major advantages of the QFDE or Eco-QFD framework are summarized as follows. The Eco-QFD is a useful tool to integrate not only the environmental concerns but also quality, cost, and customer needs to improve the product design process. It is essentially important to satisfy customer needs from a wide variety of considerations if the Eco-product is to be successful in the market place. Finally, various technical attributes and environmental concerns can be prioritized such that the product development team can concentrate their limited resources on critical issues to develop customer-oriented environmentally friendly products. [13].

A. Voice of customer (VOC) and engineering metrics (EM) on environmental aspects

When designers improve their products environmentally, they will listen to the voice of green consumers. In recent years, many companies have been extending their responsibility to consider the upstream environmental impacts of manufacturing and the downstream impacts of consumer use and disposal of products. OECD work on extended producer responsibility (EPR) began in 1994, and the trend is towards the extension of EPR to new product groups [14]. Here, EPR is a policy approach under which producers accept significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products. Based on the EPR policy approach as mentioned above, not only consumers (users) but also recyclers, the government and the environment are considered to be customers in this study. The environmental VOC and EM are highly inspired by Masui et al. in 2003 [15]. Designers can use them effectively by

ignoring some of them or dividing one into multiple items in more details depending on the type of the product. Furthermore, designers who are not familiar with environmental science can understand the environmental VOC and EM. It should be noted that these VOC and EM can be employed by incorporating them with VOC and EM for an ordinary design with no modification to the framework of traditional QFD.

B. QFDE for the Mobile Phone

As described in detail in Waste in the Wireless World [16], mobile phones (and other electronic devices) are an especially problematic component of the waste stream because they contain a large number of hazardous substances, which can pollute the air when burned in incinerators and leach into soil and drinking water when buried in landfills. Many of these toxic substances — including antimony, arsenic, beryllium, cadmium, copper, lead, nickel, and zinc — belong to a class of chemicals known as persistent toxins, which linger in the environment for long periods without breaking down. Some of them — including the metals lead and cadmium — also tend to accumulate in the tissues of plants and animals, building up in the food chain to dangerous levels even when released in very small quantities. These persistent, bioaccumulative toxins, or PBTS, have been associated with cancer and a range of reproductive, neurological, and developmental disorders. They pose a particular threat to children, whose developing systems are especially vulnerable to toxic assault. Most of the persistent toxins and PBTs contained in cell phones are in the printed wiring board and liquid-crystal display. Table 1 shows the deployment of VOC to engineering metrics (EM) for the design of a mobile phone. The VOCs are explained below.

VOC.1. Cheap/quality: ratio of cost per quality.

VOC.2. Lightness

VOC.3. Additional services and accessories: such as SMS for text messaging, email, packet switching for access to the Internet, gaming, Bluetooth, infrared, camera with video recorder and MMS for sending and receiving photos and video, MP3 player, radio and GPS.

VOC.4. Operates safely: related to radiation, degree of battery heating, etc.

VOC.5. Operates easily: includes use of the main menu related to the software and ergonomic features.

VOC.6. Repairable/Updatable

VOC.7. Reliable: service support, warranty period

VOC.8. Aesthetic appearance: color, shape, screen type, swivel, folder or classical type, etc.

VOC.9. Durable: expectance of robustness and long lifetime.

VOC.10. Safe emission: related to radiation emission degree

VOC.11. Less material usage

VOC.12. Renewable/reusable

VOC.13. Energy efficient: related to battery types, alternative energy sources (solar cells, wind power, etc.)

VOC.14. Resource efficient: use of fewer resources.

VOC.15. Harmless to the living environment: absence of

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toxic materials and radiation.

*VOC.16. Safe disposa*l: safely incineration or landfilling.

VOC.17. More recyclable material usage: such as non-toxic metals.

VOC.18. Easy to disassemble.

The weights of the VOCs are determined over a 1-5 scale.

On the other hand, EM items are chosen separately for EEE producers and from environmental point of view. The EMs are explained below.

EM.1. Development Time: the total time required for all stages from designing to final stocking.

EM.2. Tooling Cost: cost of production of a mobile phone.

EM.3. Energy Cost: cost of energy used during the production of a mobile phone.

EM.4. Physical lifetime: the physical lifetime of the mobile phone.

EM.5. Weight: the weight of the mobile phone, depends on especially the amount of plastic and ceramic.

EM.6. Volume: the volume of the mobile phone.

EM.7. Number of parts: the number of parts in the mobile phone.

EM.8. Number of types of materials: the number of types of materials in the mobile phone.

EM.9. Hardness: the hardness of the parts in the mobile phone.

EM.10. Software: the software used for the main menu.

EM.11. Multimedia support: camera, mp3 player, etc.

EM.12. Communication channels: Bluetooth, Wi-Fi, GPS

EM.13. Antenna

EM.14. Keyboard

EM.15. Microphone and speaker

EM.16. Display: such as LCD, color screen, touchscreen, etc.

EM.17. Printed Circuit Board

EM.18. BFR usage: the amount of Brominated Flame Retardants used in the mobile phone.

EM.19. Energy resource: different types of batteries (such as Ni-Cd, Li-ion, Ni metal hydride, lead acid), solar cell, wind power.

EM.20. Rate of recyclable material: the rate of recyclable materials in the mobile phone.

EM.21. Rate of standard components: the rate of standard components which are used to increase reusability.

TABLE I THE DEPLOYMENT OF VOCs TO EMs

	VOC	Rw	w	Mobile Phone EMs																	Environmental EMs									
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Market demand	1	7,25	5	3	9	9	1	1		3	3		9	9	9	1	1	1	1	3		3	3	3					3	
	2	5,80	4					9	3	3	1	1			1	1	1		1		3	1	1						
	3	5,80	4		1				3	3			9	9	9		1													
	4	5,80	4																		9				9	1				1
	5	5,80	4	1				3	3				9				3	1	3											
	6	5,80	4	1	1		9		1	1	1	1											9						
	7	5,80	4	1			9			3		1											3						
	8	4,35	3						3							1	3		9										
	9	4,35	3				9				9																		
	10	4,35	3															1		3	3		9	9	1	1		9
Environmental and governmental demands	11	2,90	2				9		1		9											3	1		1	1	1	1	
	12	5,80	4		1					3												3	9						
	13	7,25	5		9																	1		1					
	14	5,80	4		3			1	1	3	9											9	9					9	
	15	7,25	5																3	9		3		3	9	9	9		9
	16	4,35	3																3		9		3	9	9	9		9
Recycler demand	17	5,80	4			1		3			3								1		9		9	9	9	9	9	
	18	5,80	4	1	1				3														9						
	w-importance			44,928	88,406	153,623	150,725	126,087	79,710	131,884	128,986	56,522	169,565	117,391	117,391	17,391	40,580	13,043	82,609	50,725	143,478	156,522	218,841	250,725	131,884	204,348	163,768	163,768	139,130	201,449
	Rw			0,013	0,026	0,046	0,045	0,038	0,024	0,039	0,039	0,017	0,051	0,035	0,035	0,005	0,012	0,004	0,025	0,015	0,043	0,047	0,065	0,075	0,039	0,061	0,049	0,049	0,042	0,060

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EM.22. Radiation and electromagnetic wave: the volumes of the radiation, electromagnetic wave given out during the use of the mobile phone.

EM.23. Mass of air pollutant: the mass of emission of air pollution substances along with all the life-cycle stages.

EM.24. Mass of water pollutant: the mass of emission of water pollution substances along with all the life-cycle stages.

EM.25. Mass of soil pollutant: the mass of emission of soil pollution substances along with all the life-cycle stages.

EM.26. Mass of valuable materials: the mass of valuable materials used in mobile phone, such as gold, silver, copper, platinum, indium, palladium, etc.

EM.27. Toxicity of materials: toxicity of the materials, such as lead, cadmium.

At crossing-points between VOC items and EM items are shown numbers indicating the magnitude of both factors called "relational strength" determined by the experts in consensus over a 1-3-9 scale. The total of the sum multiplied by "customer weights" and "relational strength" is the "raw score (weight-importance)" for each EM item. Furthermore, "relative weight (Rw)" for each item is obtained by the raw score/sum of the raw score.

According to the weight-importance results of the deployment of VOCs to EMs, the rate of standard components *(EM.21)* is the most relatively important engineering metric among the others. The rate of recyclable materials *(EM.20)* and mass of air pollutant *(EM.23)* follow as second and third relatively important EM. In respect of all weight-importance scores, it can be clearly stated that environmental EMs are more dominant than mobile phone's EMs.

So, it is inferred from these results that the producers should primarily increase the rate of standard components and the rate of recyclable materials in order to augment the reusability and recyclability. Thus higher resource efficiency for mobile phones is attained. This design modification allows conserving the environment by decreasing the number of waste components of mobile phones that are going to be landfilled or incinerated.

The mobile phone producers should also consider decreasing the mass of air pollutant during the design step. This design change will be critical especially for the incineration phase of the waste mobile phone, and will avoid the emission of toxic pollutants to the air.

IV. Conclusion

In this paper, a QFDE for mobile phones by incorporating environmental aspects into original QFD is developed. The voice of customers is considered not only as the voice of final consumers but also as the voice of government, recyclers and the environment itself. The demands of market and recyclers, and the laws of governments which emphasize the conservation of the environment are taken into account. The environmental and mobile phone's engineering metrics are precised to satisfy related voice of customers.

The deployment of VOCs to EMs gave us the relative weight-importance of EMs. It is observed that the environmental EMs are more important than the mobile phone's EMs and the rate of standard components has the highest effect on satisfaction for all types of customers. Therefore, for the designing step, it will be given priority to this metric. This design modification will assure the reusability and prevent the depletion of resources.

For the future works, the study will include the next three phases of QFDE for mobile phones.

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