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Design for a Sustainability of a Commercial Product: A Case Study of a Dynamic Loudspeaker

Sensitivity-based analysis carried out on the production of dynamic loudspeakers for client (A) and (B) showed that client (A) has reliability efficiency 0f 20.4% with 90% of Tp, 30%-Ep, 50%-Ecp, while client (B) has 30%-Tp, 90%-Ep and 50%-Ecp respectively. Sustainability of client (B) is higher than (A) with 0.06. It has 99% and 20.1% system and efficiency reliabilities. Client (B) has the flexibility of indoor and outdoor which Client (A) lacks. The overall simulation analysis shows that client (B) product is better than (A).

Keywords: *Loudspeaker, Client, Efficiency, Analysis, System, Reliability, Performance*

1. Introduction

Loudspeakers and the variety of enclosure box in which they may be mounted have been studied intensively, in order to achieve high quality standards in terms of product performance. These loudspeakers are complex electromechanical systems, with behaviour governed by an interaction of acoustics, electricity and mechanics (Basilio *et al*, 2009).

In sustaining a loudspeaker, a better policy and strategy were ensured in prolonging the efficiency and usage of this product. A product can be relevant today and be obsolete or irrelevant in the nearest future. According to Telsang (2006) "the main objective of every organization is to satisfy the implied needs of the customer". Thus, there are needs for an effective decision making and dynamic product restructuring, in order to sustain the relationship existing between the manufacturer and the end-user of the product. Philip Sutton (2004), argue that sustainability is the balancing or integration of environmental, social, and economic issues. The World commission on Environment and Development (WCED) 1987 defined sustainability as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Oyedepo and Olayinka, 2012).

The object of this study is to critically evaluate and compare relevant factors of sustainability, which are technical, environmental and economical, for two selected models of dynamic loud speakers and deduce the market needs and performance.

2. Sustainability of Dynamic Loudspeaker

Tore and Uday (2003) suggest that one of the approaches in the sustainability of product such as loudspeakers gives rise to implementation of RAMS in product design and development, this is related to integration of reliability, maintainability and risk analysis tools and methods to enhance performance efficiency, to reduce product life cycle cost (LCC) and delivery time, and to increase customer satisfaction and product attractiveness. The framework of the product manufacturer must define these stages involved in the life cycle of the product. Young (2000) identifies the stages of project life cycles as follows:

1. Product conception
2. Product definition
3. Product planning
4. Product launch and execution
5. Product closure
6. Post-product evaluation

The demand of the consumers must be the basic for redesigning of the loudspeakers as they are the customers with kin interest in the technicality of the speakers, the economical and environment friendliness of the loudspeaker product. This performance map can be bridge by closing the reliability gap that exists in the existing product and the desired once.

Nave (2006) describes the mechanism of loudspeaker as an electromechanical process in which the amplified audio signal moves the speaker cone in order to produce sound corresponding to the original sound wave or audio signal. Nave (2006) explains that the audio signal of a dynamic loudspeaker produces an electrical signal with the same harmonic and frequency of the audio signal and a sound image that reflects the relative intensity of the audio signal and sound as it changes. It amplifier magnifies the electrical signal in order to power the coils of a loudspeaker, and it transferred the electrical signal to the voice coils of the loudspeaker. This creates a vibration in the voice coil with a vibrating sequence corresponding to the variations of the original sound signal. The purpose of this voice coil is to power the cone of the loudspeaker which drives the air surrounding it, and this in turn produces audio sound outwardly of the original audio signal. Most loudspeakers are enclosed in such a way that it generates pleasant sound.

The diaphragm in a dynamic loudspeaker is connected to a voice coil positioned in the air space of a magnet system with the aid of a flexible suspension. Immediately the current flows through the voice coil in the presence of a magnetic field, both the diaphragm and coil are accelerated as a result of theLorentz force. Both an inhomogeneous magnetic field and the excursion-dependent stiffness of the suspension account for a nonlinear behaviour of the transducer. (Dietrich et. *al*, 2001).

The nature of the voice coil and the kind of enclosure of the loudspeaker actually reflects the quality of sound from these speakers, thus there is need to reengineer and redesign the loudspeaker component and compartment in order to boost its sustainability (Nave, 2006).

Based on this, Client A's concern is on optimum performance and minimum emphasis on life cycle cost and environmental impart, with a 90% technical performance, 30% environmental performance and 50% economic performance. Client B is highly environmental conscious in line with regulations irrespective of the cost of implementing a well functional loudspeaker, with a 90% environmental performance, 50% economic performance and 30% technical performance.

3. Reliability of Dynamic Loudspeaker

The loudspeaker comprises a bass speaker, woofers large to efficiently impedance match to the air, tweeters with high frequency sound signal, framework and enclosure box. In order for a more reliable performance in terms of audio output, the aperture is made on the enclosure to assist in echoing the sound from the loudspeaker in form of sub-woofer. The complete life cycle of the loud speaker is taken to consideration, from manufacturing stage of it sub-components, to the components assembling, the distribution of the speakers and its exact life spam in the hands of the customers. This defines the performance of the loudspeaker and its durability, which can be computed by software.Software is design which focused on final with emphases on the parameter relationships of the speakers. The purpose of the software is to avoid the computation of equations governing loudspeaker systems and to highlight the features the designed loudspeaker before production as reviewed by (Basilio *et al*, 2009).

4. Supportability and Sustainability Index of Dynamic Loudspeaker

A thorough sequence of step-by-step processes involved in the product redesign is study so as to define what goes into the system and what comes out of the system

> *''Due to design problems and poor product support, manufacturer equipment and systems are not able to meet these requirements. However with proper consideration of reliability, availability, maintainability and supportability(RAMS) in the design, manufacturing, and assembly phase of the dynamic loudspeaker, the number of failure could be reduced and their consequences minimized''*.(Saraswat and Yada2008)

In the quest for system sustainability, most products fails to sustain in meeting the manufacturer goals if its design is no longer compatible with the objective, vision, culture and structure of the manufacturing firm in the face of present development. So a product must be of positive socio-economic significance to both the manufacturer and the customers with little or no effects on the human environment.

The product can then be redesign by introducing present constrains or necessity the existing once fails to handled, and reengineered in such a way that the system of the product can be well supported, and this will not affect the life cycle of the product. At this phase, the manufacturer tends to put in all available resources in re-building a new product with high level of system supportability and acceptability.

> *"A parametric loudspeaker has a potential of fascinating usage because it has a sharp directivity compared to a conventional loudspeaker, and is then feasible to transmit speech or audio signals to a specific area that cannot be detected by people in adjacent locations. Especially, such kind of loudspeakers enables us to create quietsound environments outside the area and to retain private listening space"*(Sakaiand Kamakura, 2008).

5. Life cycle assessment of the loudspeaker

Sustainability and Life Cycle Management (LCM) of product is focused on information management of system, effective reengineering and product redesigning and system analysis associating with product customer's response. This creates a road map of the product from the manufacturer down to the customers with a corresponding constraint and feedback at each stage of the road map or pathway (Lecturer's note, 2013). At a glance, one can tell the level of product sustainability, when to enhance or modify the product and the development of new product.

6. Technological Obsolescence

The life cycle of the dynamic loudspeaker system is considered as a device ranging from manufacture, distribution and functional life span up to recycling and disposal operation. The environmental performance of the dynamic loudspeakers is calculated by conducting an LCA study according to International Standards Organization (ISO) 14O40 series, (Guinee, 2002, pp.311-313) and Johnannes (1998). Duan *et.al* (2008) explains that PC can be related to dynamic loudspeakers as follows: The functional unit of dynamic loudspeakers is the tweeter, woofer, sub-woofer, voice coil, cone and enclosure made up of wood. It is assumed that the speakers use 8.2hours per day active and 4.6hours in standby. The speakers are expected to technically work at least 90% for the duration of 5years to complete its life cycle before handing over for treatment .Once they are no longer in use, they can be recycled by recoiling the voice coil and replacing the cone with a new once. Those whose enclosure box were destroyed, are either rebuild, amended or reconstructed in other to serve its exact purpose.

7. Material utilization principle/Life cycle Costing and Economic Analysis

The voice of customer was the most important factor in designing these Loudspeakers in other to satisfy their needs. In view of this, quality function deployment (QFD) has to be employed in other to developed ''technical specifications that can be used by designer and production"Telsang (2006,p.547). Loudspeaker is usually enclosed in a box or single compartment, and the resulting sound output was not meeting the desired taste of its customers. In restructuring this compartment, one must first define the type of vibration emanating from the voice coil and its sound. So the question is "what is the strength of the electric signal powering the voice coil?" It is discovered that the level of vibration of a lighter voice cone is different from that of a heavier voice cone when subjected to the same electrical signal. Thus, in redesigning of a loudspeaker, a light voice coil is used which can vibrate freely inside the magnetic field of a strong permanent magnet.

Table 1. Material Utility Analysis for a Dynamic Loudspeaker

Component	Material utilization m	Cost of production /component y	Relative Production Cost X=y\Σy	Partial utilization value mX
MA	0.185 1.5\8.1	**£0.95**	0.446	0.083
MB	0.247 2.0\8.1	**£0.58**	0.272	0.067
MC	0.173 1.4\8.1	**£0.18**	0.085	0.015
MD	0.222 1.8\8.1	**£0.20**	0.094	0.021
ME	0.173 1.4/8.1	**£0.22**	0.103	0.018
TOTAL		**£2.13**	1	0.204

Weight of loudspeaker compartment- 8.1 kg

7.1. Material description

MA- Pioneer TS-G1321i 13cm dual cone speaker system 200 Watts, 1.5kg

MB-Loudspeaker enclosure box, 2.0kg
MC- Tweeter speaker, 1.4kg
MD- Woofer, 1.8kg
ME- Sub-woofer, 1.4kg
Material Utility (m) = `$W_{component}$\ $W_{material\ used}$ (Lecturer's note, 2013)

The efficiency of the producing Loudspeaker with the above component is 20.4%, which needs improvement in boosting its usability.

7.2. Technical Description of Producing Loudspeaker for Client A

7.2.1. Product A

Technically is made up of a heavier voice coil and cone, with a moderate sound output and intensity. It is composed of multiple loudspeakers, since a single loudspeaker cannot deliver optimally balanced sound desired by the customer over the audio sound spectrum. Typically, these loudspeakers are enclosed with a crossover network to produce a nearly uniform frequency. This is done in order to minimize the impact of this resonant frequency among the speakers.

The compartment speakers comprises of a tweeters (with high frequency sound signal),a bass speaker to balance the audio sound, a woofer and sub-woofer.

Thus, in producing loudspeaker with 90% technical performance, 30% environmental performance and 50% economic performance, emphases must be on improving the quality of the sub-woofer speaker, by replacing the existing one with a more powerful and reliable one (with about a moderate cost and same component weight).

Table 2. Material Utility Analysis for Client A loudspeaker with an improved Sub-woofer

Component Number	Material utili-zation (m)	Cost of production /component (y)	Relative Production Cost (X=y\Σy)	Partial utiliza-tion value (mX)
MA	0.185 1.5\8.1	**£0.95**	0.361	0.067
MB	0.247 2.0\8.1	**£0.58**	0.221	0.055
MC	0.173 1.4\8.1	**£0.18**	0.068	0.012
MD	0.222 1.8\8.1	**£0.20**	0.076	0.017
ME	0.173 1.4/8.1	**£0.72**	0.274	0.474
TOTAL		**£2.63**	**1**	**0.625**

The efficiency of Client A producing a Loudspeaker with an improved Sub-woofer having same weight and a cost of **£0.72** (because it is the main component that can increase the technicality performance of the loud speaker), will increase from 20.4% to 62.5% performance, thus boosting its usability and market value.

7.2.1.1 System Reliability

The loudspeaker is design for a life span of 5 years, of which the loudspeaker compartment is at use at 14 hours a day (both usage and standby) and switch off at 10 hours a day.

For 5 years, the total operating hours of the loudspeaker = 14x365x5= 25,550 hours

In assumption, 1 system fails in every 5,000 hours, an average of 5 loudspeakers is likely to fail throughout the life cycle of the system.

Failure rate of the loudspeaker for Client A:

λ= number of failure\total operating hours

= 5\ 25,550 = 0.0001957

MTBF = 1\ λ

= 1\ 0.0001957 = 5109.86 hours

The Reliability of the loudspeaker at 5 years of 25,550 operating hours,

$R(t) = e^{-\lambda t} = e^{-t/m}$

$= e^{-0.0001957 \times 25550}$

= 0.0067 (Telsang , 2006 pp.488-494)

The probability of the loudspeaker surviving for 25,550 operating hours is 0.67%.

7.2.2. Maintainabilityof Dynamic Loudspeaker System

The loudspeaker system for Client A to have high surviving rate and high reliability, the operating hours must be reduced from the total life span of 5 years, by neutralizing the standby period of the system. It is advisable that, when the system is not in use, the relative power supply into the loudspeaker will be zero, thereby reducing the usability of the system from 14 hours to an average of 5 hours by day (the direct usability period), therefore the operating hours at more improved system will be,

Operation hours = 5x365x5= 9125 hours.

This will increase the survival of the system to $R(t) = e^{-0.0001957 \times 9125}$= 16.7%

It is advisable that the life span of the loudspeaker be reduced as well as it operation hours in order to increase its reliability.

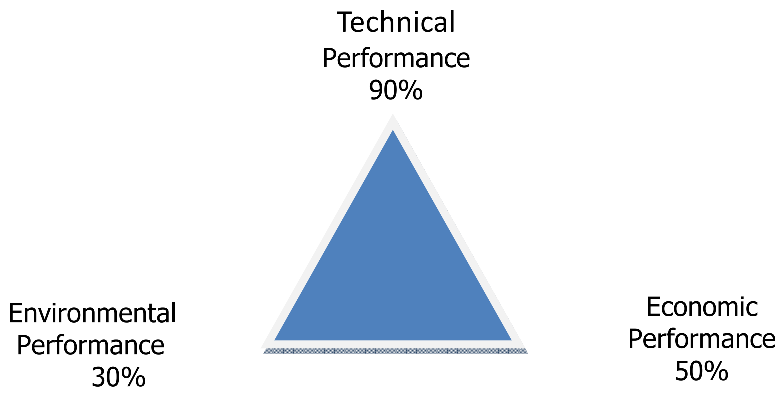

Figure1. Product Triangle for producing Loudspeaker for Client A

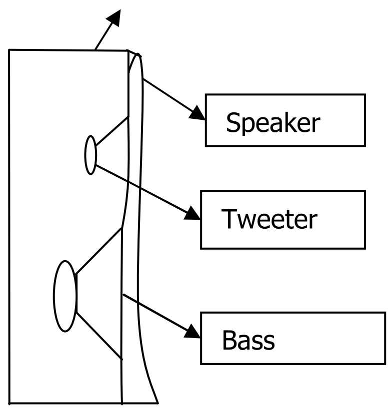

Figure 2. Product A Loudspeaker.

7.2.3. Economic Descriptions of Loudspeaker A

Economically, the cost of producing this product, increases from **£2.13 to £2.63, which** is relatively low and it can easily be afforded by most customers, with more value for their money and improved technical performance. The problem associated to this product is that when placed in a very wide sitting room such as shown in Fig 3 below, the efficiency of the loudspeaker reduces. It is manufactured for indoor purpose and cannot be used for outdoor purposes.

Figure 3. Showing a room with a dynamic loudspeakers. Paul McGowan (2011)

7.2.4 Environmental Effects of Loudspeaker A

The environmental effects of the loudspeaker is relatively low, it can pose a major threat if the speaker is turn to its maximum volume, and this is dangerous to human ear, as it can affect the ear drum.

7.3 Technical Description of producing loud speaker for Client B

Product B technically is made up of a lighter voice coil and voice cone, with a very high sound output and intensity. It is composed of multiply loudspeakers with optimally balanced sound delivery. Typically, these loudspeakers are enclosed with a crossover network to produce a nearly uniform frequency, with a woofer compartment. This loudspeaker requires more power input in driving all components effectively and the resonant frequency among the loudspeakers is minimized as well. A speaker comprises of tweeters (with high frequency sound signal) and a bass speaker is a superb woofer with a bass reflex enclosure used and extending the bass range of the loudspeakers.

The purpose of the woofer speaker is to serve as an impedance match to the surrounding or air, this gives the loudspeaker more driving force in powering it sound output, and the resulting output is a smooth sound with a high audio intensity.

Thus, in producing loudspeaker for Client B is highly environmental conscious in line with regulations irrespective of the cost of implementing a well functional loudspeaker, with a 90% environmental performance, 50% economic performance and 30% technical performance.

Table 3. Material Utility Analysis for Client B loudspeaker with an improved Sub-woofer

Component	Material utilization m	Cost of production /component y	Relative Production Cost X=y\∑y	Partial utilization value mX
MA	0.185 1.7\9.2	**£1.05**	0.319	0.059

MB	0.247 2.2\9.2	**£0.88**	0.268	0.066
MC	0.173 1.4\9.2	**£0.28**	0.085	0.015
MD	0.222 2.0\9.2	**£0.30**	0.091	0.020
ME	0.173 1.9/9.2	**£0.78**	0.237	0.041
TOTAL		**£3.29**	**1**	**0.201**

The efficiency of Client B producing a Loudspeaker with improved materials that is more environmental friendly will increase from 20.1%. Technically the loudspeaker performance is low, with a moderate cost of production, with materials that have very low or negligible environmental effects.

7.3.1. System Reliability

The loudspeaker is design for a life span of 5 years, of which the loudspeaker compartment is at use at 14 hours a day (both usage and standby) and switch off at 10 hours a day.

For 5 years, the total operating hours of the loudspeaker = 14x365x5= 25,550 hours

In assumption, 2 system fails in every 5,000 hours, thus an average of 10 loudspeakers is likely to fail throughout the life cycle of the system (due to low technical performance).

Failure rate of the loudspeaker for Client A;

λ= number of failure\total operating hours

= 10\ 25,550 = 0.0003914

MTBF = 1\ λ = 1\ 0.0003914 = 2555 hours

The Reliability of the loudspeaker at 5 years of 25,550 operating hours,

R (t) = $e^{-\lambda t}$= $e^{-t/m}$= $e^{-0.00039147 \times 25550}$= 0.9999

The probability of the loudspeaker surviving for 25,550 operating hours is 99.9%. This implies that the system has very negligible failure rate.

Thus, for the loudspeaker system for Client B have a high surviving rate and high reliability, the operating hours must be maintained with the total life span of 5 years, and a powerful standby system. It is advisable that the life span of the loudspeaker be maintained as well as it operation hours for effective performance and system reliability (Telsang, 2006).

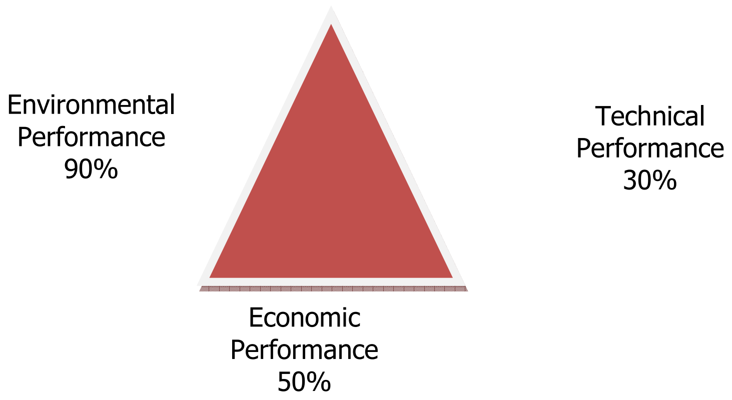

Figure 4. Project Triangle for producing Loudspeaker for Client B

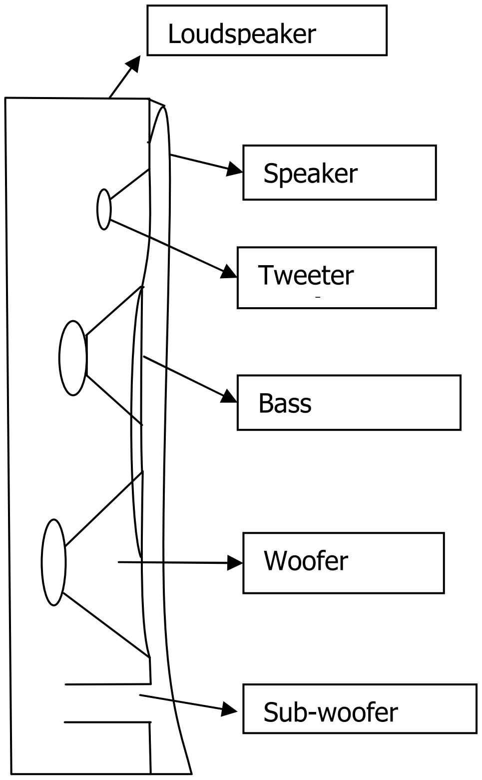

Figure 5. Product B Loudspeaker

7.3.2. Economic Description of Product B

Economically, the cost of producing loudspeaker for Client B is **£3.29,** this product is relatively high but it is still afforded by most customers. The loudspeaker is design for both sitting rooms, indoor and outdoor purposes.
The loudspeaker is more reliable with an efficiency of 20.1%, and a system reliability of 99.0%. Although, it mean time between failure (MTBF) is 2555 hours, which can be improve upon by a well supporting system that can regulate the energy supply to the system, reduces system vibration, and temperature, which can account for system failure (apart from factory fault).

Figure 6. Loudspeakers for indoor and out-door uses.
Wilson Audio's Alexandria x-2(2004)

The environmental effects of these products are very low or negligible with little effects on human hearing since it maximum sound output which is moderate to the hearing of the ear with a relatively low noise pollution, and its recyclability has no environmental effects when burnt and the unused once can be disposed by burning.

8. Comparative Analysis of Products A and B

Table 4. Comparative Analysis of Product A and B

PARAMETERS	CLIENT A	CLIENT B
System Reliability	0.68	0.73
System Supportability	0.92	0.67
Sustainability Index	0.12	0.24
Life Cycle Assessment	0.12	0.21
Material Utility Principle	0.03	0.01
Maintainability	0.001	0.002
Life Cycle Costing and Economic Analysis	0.41	0.21

Technological Obsolescence	0.51	0.31
Energy Use	0.005	0.07
Resource Management	0.25	0.31
TOTAL	0.304	0.332

Average mean ratio = client A/client B: client B / client A
1.057 1

The table above shows that client B is more than client A in terms of sustainability. By comparing the product of client A and B using the parameters above, shows that client A has 100% product sustainability while client B has about 106%. This implies that client B's product has 6% performance sustainability rate more than client A's product.

Table 5. Client Comparative

	Technical performance	Environmental performance	Economic performance	Total
Client A	0.9	0.3	0.5	0.17
Client B	0.3	0.9	0.5	0.17

Client B is most sustainable in terms of market needs because of high environmental performance of 90% and 30% technical and 50% economic performance respectively.

4. Conclusion

The market needs of client A and B product indicate that product B is more sustainable than A because it has 90% Environmental performance,30% technical performance and 50% economic performance. Since product A can only be used for indoor purposes while product B can be used for both indoors and outdoors purposes it therefore means that in terms of sustainability, reliability, life cycle assessment, affordability client B product is the best.

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