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RELIABILITY PAPER

Optimization of mean life of brands under cost constraints with an empirical study on mobile handsets

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Abstract

Purpose – To a customer, higher quality is synonymous to higher expected life. Therefore, the purpose of this paper is to determine the existing life of the competing brands in a product field and suggest an improvement plan, under cost constraints, so that all the brands can be placed on a comparable scale.

Design/methodology/approach – For this, we consider Cox proportional hazard model for estimation of the mean life and suggest an optimization procedure for improving mean life under cost constraint. As the cost of redesigning the product is mostly known, the authors propose to take corresponding repairing cost as their surrogates and optimize the expected life for each brand subject to a fixed level of cost.

Findings – From Cox's model one can identify the causes of failure for the brands under consideration. Further, under the optimization techniques proposed herein one can order the brands for comparison purpose.

Practical implications – We have applied the proposed optimization techniques for ordering mobile handsets. In fact, based on the result obtained by our proposed method, the design engineers or the brand planners can take necessary actions to increase the product life, correct product design and improve the product performance.

Originality/value – The cost minimization approach under Cox's cause-wise setup can provide a tool for comparing different brands of different prices and order them to know the best performer.

Keywords Brands, Mobile technology, Communication technologies, Cox proportional hazard model, Reliability optimization, Weibull distribution, Mean life, Cost constraints

Paper type Research paper

1. Introduction

Customer is the king of the market nowadays. To appease them companies are offering their best offers rather the best quality product in the market. But to a customer, quality is generally synonymous with higher expected life and a manufacturer can reap profit by offering a reliable product. However, variations in both price and quality create

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a problem of indecision in the minds of the customers. According to value-price dictum, a firm wants to achieve the twin objectives of giving value and taking value back. Value pricing is the mechanism for this. There are three steps: first is to select the value that the market seeks. The second is to build that value in the product or services. And the third one is to capture back the due value into the company's exchequer through strong pricing strategy. For example, in case of mobile handsets, a consumer considers higher expected life of mobile handset as higher value. But mostly product analyst and researchers have stressed on reliability than expected life.

The concept of reliability optimization has been extensively studied in the literature under different types of constraints by Chern and Jan (1986). Sung and Cho (2000), under series system, had studied reliability optimization having budget constraints. Kuo *et al.* (1990) studied the possible limits of system reliability through optimization technique. Some authors have considered an alternative framework for cost minimization under reliability requirement (Elegbede *et al.*, 2003). To get an overview of the subject one may refer to Kuo and Prasad (2000). However, a better measure of value will be the conditional expected life given the conditioning variates as causes of failure. So, in this paper we would like to determine the conditional mean life of the mobile handset under study at the mean of the covariates and then attempt to improve the conditional expected life by using an optimization technique. Our proposed technique would not only provide valuable product to the customer but also generate high profit for the companies.

To enhance the performance of mobile phones Al-Darrab *et al.* (2009) had earlier used Taguchi's method for optimization. Similar concept may also be noticed in some of the three Porter's (1980) generic strategies. When the market is flooded with substitute products, then the overall cost leadership can be adopted by achieving economies of scale. At a later stage, product differentiation can provide with an appropriate strategy. Our optimization approach matches with that of Porter. Liang (2008) had used combination of neural network and genetic algorithm to predict reliability.

2. Determination of value

The value of a product is mainly a function of appeal, or taste, or strength, or functionality or reliability or any combination of these. For certain products like paintings, appeal enhances the value. On the other hand, taste attracts the value for food items. Strength describes the capability of performing of an item under different environmental situations which in turn determines the value for the product. For instance, the performance of a gas lighter when given a stroke or firing of bullets from a gun decides the value of the product. Sometimes the number of functions added to a product determines the value like television set, automobile and mobile handsets. Important determinants of value are the reliability, the life of the product and the failure rate. The higher the reliability, higher is the value. In other words, we can say that lesser the failure rate higher is the value of the product. There can be several factors that result into the failure of a product. In case a product fails, the expected life of the brand becomes questionable. Consequently, it is necessary to determine the nature of life distribution followed by the brands, identify the problems causing failure and examine the failure rate of brand. Out of different techniques available like failure time models (Allison, 1995; Maciejewski *et al.*, 2002) and discrete-time model such as a logistic hazards specification (Yamaguchi, 1991), we propose to consider Cox proportional hazard model to study the effects of the causal covariates on the survival. This model was developed and is being used for various research studies (Cox, 1972, 1975; Kalbfleisch and Prentice, 2002; Ondrich, 2010). Survival analysis, such as Cox's proportional hazards model, is widely used to study the relationship between the latency of the occurrence of an event and the explanatory variables. This method finds significant applications in not only product life testing but also in wide range of disciplines from physics to econometrics (Cox and Oakes, 1984). Starting with the pioneering work of Haccou and Hemerik (1985), Cox's proportional hazards models have been used to analyze the behaviour of insects, in particular parasitoids (Godfray, 1994). As a result, this model has become one of the most extensively used tools in the field of statistics for analyzing the lifetime data in biomedical sciences and reliability. For our analysis, we have considered a non-parametric proportional hazard model with baseline Weibull hazard function as a model for the hazard function. The life of the handset is estimated at baseline as well as at the mean level of the covariates. Efforts have been made to optimize the expected life at the mean of the covariates subject to cost constraints. Measures have been taken to move from reactive improvement to proactive improvement as the cost of servicing a brand is expensive and the downtime of the brand negatively affects customer's satisfaction.

3. Mathematical formulation

The reliability of a product describes the probability of survival for a given mission time t. If $F(t)$ is the probability distribution function describing the life (T) of a mobile handset, then the survival function, $S(t)$, is defined as:

$$\Pr(T \geq t) = 1 - F(t) = S(t) \tag{1}$$

which in turn measures the product reliability. The corresponding hazard function and failure rate at $T = t$ are, respectively, given by:

$$H(t) = -\log S(t), \quad h(t) = \frac{f(t)}{1 - F(t)} \tag{2}$$

where $f(t)$ denotes the pdf of T, $h(t)dt$ represents the probability that the product will fail immediately, i.e. the interval in $(t, t + dt)$ given the condition that it has survived up to time t.

Now, conditionally given the p covariates $\underset{\sim}{z}_{p\times 1} = (z_1, z_2, \ldots, z_p)$, we may introduce the conditional failure rate as:

$$h(t|\underset{\sim}{z}) = \frac{f(t|\underset{\sim}{z})}{1 - F(t|\underset{\sim}{z})}, \tag{3}$$

where $f(t|\underset{\sim}{z})$ is the conditional pdf given $\underset{\sim}{z}$ and $F(t|\underset{\sim}{z})$ is the corresponding conditional distribution function. Under the Cox proportional hazard model, the conditional hazard rate is given by:

$$h(t|\underset{\sim}{z}) = h_o(t)\psi(\underset{\sim}{\alpha}, \underset{\sim}{z}) \tag{4}$$

with a choice of $\psi(\underset{\sim}{\alpha}, \underset{\sim}{z})$ as $\exp(\underset{\sim}{\alpha}', \underset{\sim}{z})$, $\underset{\sim}{\alpha}'$ is the vector of the regression coefficients and $\underset{\sim}{z}$ is the vector of causal variables.

Thus, we see that proportional hazard model can be decomposed into two components, the first component being the baseline hazard rate depending on time variable t and the second component being the effects of the causal variables independent of time t. Estimation of the parameters in the Ψ function will be carried out by standard non-parametric approach. A cause will be considered to be alarming when the regression coefficient is greater than 1. Thereafter, the parameters of the baseline hazard component will be estimated via parametric approach under Weibull setup.

In the Weibull setup baseline hazard rate is modeled as:

$$h_0(t) = \theta\beta t^{\beta-1} \tag{5}$$

where θ and β are the two parameters to be estimated. We know that the baseline hazard function is the hazard rate when the covariates have no influence on the failure pattern.

This, baseline hazard rate can be estimated by first obtaining a baseline hazard function. $H_0(t)$ which is linear in *log t* under logarithmic transformation. So, by fitting linear regression for observed values of log $H_0(t)$ on *log t* we can get estimated value of β from the regression coefficient and the estimated value of θ from the exponentiated value of the intercept. Once θ and β are estimated, the expected mean life:

$$E(T) = \left(\frac{1}{\theta}\right)^{1/\beta}\Gamma\left(\frac{1}{\beta}+1\right) \tag{6}$$

can be estimated as:

$$E(T) = \left(\frac{1}{\hat{\theta}}\right)^{1/\hat{\beta}}\Gamma\left(\frac{1}{\hat{\beta}}+1\right) \tag{7}$$

where $\hat{\theta}$ and $\hat{\beta}$ are the estimated values of θ and β.

4. Optimization technique

In a practical scenario the idealistic situation of absence of covariates hardly exists. As a result, we would like to maximize the mean life not at the baseline but at the mean of the covariates which is given as:

$$E(x|E(\underset{\sim}{z})).$$

Under Weibull setup for the baseline hazard:

$$\begin{aligned} E(x|E(\underset{\sim}{z})) &= \Gamma\left(\frac{1}{\beta}+1\right)\left(\theta e^{\underset{\sim}{\alpha}' \; E(\underset{\sim}{z})}\right)^{-1/\beta} \\ &= \Gamma\left(\frac{1}{\beta}+1\right)e^{(-1/\beta)\;\underset{\sim}{\alpha}'\;E(\underset{\sim}{z})}\theta^{(-1/\beta)}. \end{aligned} \tag{8}$$

In the above expression both the parameters θ and β are unknown and are to be replaced by their estimators. To maximize the estimated expression of the expected life at the mean of the covariates we introduce a decision matrix D in this setup and:

$$\textit{Maximize}\;\; \Gamma\left(\frac{1}{\beta}+1\right)e^{(-1/\beta)\;\underset{\sim}{\alpha}'\;DE(\underset{\sim}{z})}\theta^{(-1/\beta)}$$

where D is the artificially constructed decision matrix where $D = \text{diagonal}(d_1, d_2, \ldots, d_p)$, each decision variable d_i taking the value 0 when the cause is removed and taking the value 1 when the cause remains present.

This maximization is equivalent to:

$$Min \ \frac{1}{\beta} \underset{\sim}{\alpha}' DE(\underset{\sim}{z})$$

because $\Gamma((1/\beta)+1)\theta^{(-1/\beta)}$ does not involve d_i's. The corresponding cost incurred can be expressed as $\sum C_i(1-d_i)$. Thus, the optimization problem reduces to:

$$Min \ \frac{1}{\beta} \underset{\sim}{\alpha}' \ DE(\underset{\sim}{z})$$

$$\text{Subject to } K + \sum C_i(1-d_i) \leq C_0,$$

where K is the average price of the handset and C_o is the available fund. Given C_0, different brands of different makes can be compared in terms of their maximum expected lives at mean of the covariates by arranging them in descending order of magnitude.

This reduction reduces the problem to binary linear integer programming problem which we can solve by branch and bound method. Earlier, Kuo *et al.* (1987) had studied reliability optimization using Lagrange multiplier and branch and bound method. Reliability estimation and optimization using non-homogeneous Poisson process approach were studied by Suresh and Babu (1997).

5. Empirical study

The revolution in the field of communication technology, especially the revolution in mobile technology has enthralled human life. This small powerful high-end device has entered into our life in such a way that it has become one of the most essential items we need to possess. Early models were low in technology and usage was also limited. However, the technology of mobile phones has improved significantly during the last few years. Now, with a mobile handset we cannot only make communication when we are on move but also utilize it for a number of purposes like short service messages, multimedia message services, surf internet, listen to music, use it as a camera, calendar, alarm clock, timer and calculator and this list goes on. Initially, owning a mobile was a costly affair but with the escalating demand of the mobile and increasing volume of operation countless manufacturers are making an entry into this segment resulting in drastic decrease in the initial price. Companies have started feeling the pressure of retaining their brand images and drawing strategies to ensure a competitive edge over the other global players. This is giving rise to intense competition from the new entrants. To retain the market share, the companies are adding several functionalities to their products to make the best market offer.

At present some of the leading brands are Nokia, Samsung, Sony Ericsson, Motorola and LG and some of the chasing entrants are HTC, Blackberry, Apple, Dell, Acer, Micromax, Huaie, etc. A wide variety of handsets are now available in the market at a reasonable and competitive price. For the purpose of our study we have selected five mobile handsets amongst several handsets available in the market. This selection of companies is solely based on the market share. Following Gartner Newsroom (2009) information on worldwide terminal sales as well as on market share of mobile phone, Nokia is leading with 39.1 per cent market share followed by Samsung, Motorola, LG and Sony Ericsson having market shares as 14.4, 10.2, 8 and 7.5 per cent, respectively. Once the selection is over, we have collected data from 2,771 users of mobile handset through extensive survey using questionnaire method. Out of these 2,771 handsets we have got 1,493 sets of Nokia, 460 sets of Samsung, 308 sets of LG, 253 sets of Sony Ericsson and 256 sets of Motorola mobile handsets. These data were categorized into two parts one is the failure event and the other is the censored event. Failure event is said to occur when a handset fails to work because of a cause of failure. In case of mobile handsets, the product under study, the major causes of failure identified by us are battery problem (B), integrated circuit problem (I), ringer problem (R), display problem (D), speaker problem (S) and virus problem (V). Any of these problems or any combination of these increases the failure rate and thereby affects the expected life of the brand. Whereas, censoring of data takes place when the information about the lifetime of the observed unit is incomplete.

Different circumstances can produce different types of censoring methods and these are used in survival analysis. Some of them are right-censoring, left censoring and interval-censoring techniques. Interval censoring mechanism arises when the event of interest cannot be directly observed and it is only known to have occurred during a random interval of time. Many modern approaches had been developed on interval censoring to models and methods for survival analysis of lifetime data (Lawless, 2004). Left censoring techniques are used when the event of interest has already occurred before the starting of the time. Whereas right censoring is suitable applicable when time is defined and the time terminates before the outcome of the event is observed. In our case, we have used right censoring technique of data collection in which we have observed the failure rate of the data till a specified date. In such a situation, some sets could not be observed till the time of the failure due to termination of study.

By using Cox proportional hazard model we would like to find out the marginal or the combined effect of the covariates on the expected life of the mobile handsets. From these failure rates product planners can determine the reliability of different handsets for different mission times.

5.1 A study on Nokia mobile handset

The data reveal that only 486 Nokia handsets did not encounter any problem within the specified period whereas the rest 1,007 cases registered failure in the same period of study. Using both these cases we have carried out Omnibus test of model coefficient to see whether Cox's model is a good fit to the data or not. The value of χ^2 test statistics is 621.001 with eight degrees of freedom having the tail probability nearly equal to zero. As a result, we can claim that Cox's model is a good fit to the data. We have also checked the individual impact of the covariates on the survival of the handsets through regression coefficient.

Table I clearly indicates that the impacts of all the covariates are highly significant in determining the life of the mobile handsets. But amongst all these factors, the integrated circuit problem, ringer problem and display problem are the major ones as shown by their regression coefficients. To completely determine the Cox's model, we have to find the baseline hazard function. Under the Weibull setup the two parameters of the baseline hazard function θ and β have been estimated as -8.872 and 1.204, respectively. Thus, the Cox proportional hazard model for Nokia mobile handset is given by:

$$h(x) = 0.00016888x^{0.204}\exp[0.000\,\mathrm{C} + 0.923\,\mathrm{B} + 1.015\,\mathrm{I} + 1.213\,\mathrm{R} + 1.212\,\mathrm{D} + 0.921\,\mathrm{S} + 0.991\,\mathrm{V}].$$

Since the parameters θ and β are known we can substitute these values in the equation (8) and estimate the expected life of Nokia mobile handset in the presence of the covariates at their mean level and it comes out as 755.952 days. Our objective is to increase this life by increasing some additional cost.

If we assume that the average cost after redesigning the set is to be at the most Rs. 8,000 for all the handsets, i.e. $C_0 = 8{,}000$ then the allowable cost of repairing the Nokia mobile handset is Rs. 1,530.553 as the average cost of a handset, K, equals 6,469.447. We have maximized the mean life at mean of the covariates given this cost constraint. Under this cost constraint, by solving the optimization problem, we could increase the expected life to 1,239.176 days and resolve its battery problem, integrated circuit problem, ringer problem and virus problem. Thus, two major problems and two minor problems have been removed.

5.2 A study on Samsung mobile handset

For Samsung mobile handset, out of 460 data collected 162 handsets did not report any problem whereas 298 reported failure within the same specified period. As in the previous case, to check the suitability of fitting Cox proportional hazard model, we have carried out Omnibus test of model coefficient for Samsung mobile handset. The value of χ^2 test statistics is 3,017.289 with eight degrees of freedom with the tail probability nearly equal to zero. Thus, we can say that Cox's model is a good fit for Samsung mobile handset too. We have also checked the impact of the individual covariate on the life of the set. Table II shows the details.

From Table II it is evident that though all the covariates are significant in negatively affecting their impact on the life of the set, display problem and speaker problem are the prominent ones causing failure as shown by their regression coefficients. The corresponding parameters of baseline hazard function have been estimated as $\theta = -8.815$ and $\beta = 1.243$. Thus, Cox proportional hazard model is given as:

$$h(x) = 0.00018457x^{0.243}\exp[0.000\,\mathrm{C} + 0.804\,\mathrm{B} + 0.780\,\mathrm{I} + 0.881\,\mathrm{R} + 1.240\,\mathrm{D} + 1.049\,\mathrm{S} + 0.827\,\mathrm{V}].$$

Covariates	Regression coefficients (α)	SE	Degrees of freedom	Significance	Mean values of the covariates
Cost of the set (C)	0.000	0.000	1	0.035	6,469.447
Battery problem (B)	0.923	0.080	1	0.000	0.1671
Integrated circuit problem (I)	1.015	0.082	1	0.000	0.1370
Ringer problem (R)	1.213	0.102	1	0.000	0.0829
Display problem (D)	1.212	0.094	1	0.000	0.1096
Speaker problem (S)	0.921	0.093	1	0.000	0.0969
Virus problem (V)	0.991	0.092	1	0.000	0.1263

Table I.
Presenting the regression coefficient of the Cox model for Nokia mobile

The corresponding estimated value of the expected life of Samsung mobile handset is 603.112 days at the mean of the covariates. Now, by using the optimization technique we could not only remove all the covariates causing failure except the ringer problem but also have maximized the life of Samsung mobile handset to 1,065.358 days given the constraint that amount available for repairing is Rs. 2,140.400 as the average cost of the handset, K equals to Rs. 5,859.6. In this process both the major problems have been removed and in addition to that three minor problems have been removed.

5.3 A study on LG mobile handset

For LG mobile handset, out of 308 data collected 96 handsets did not report any problem whereas 212 reported failure within the same specified period. As in the previous two cases, the appropriateness of fitting Cox proportional hazard model have been checked by carrying out Omnibus test of model coefficient for LG mobile handset. The value of χ^2 test statistics is 122.868 with eight degrees of freedom with the tail probability nearly equal to zero. Therefore, we can claim that Cox's model is also a good fit for LG mobile handset. We have also checked the impact of the individual covariate on the life of the set. Table III shows the details.

From Table III it is apparent that all the covariates are causing considerable impacts on the life of the set. The regression coefficients indicate that all the factors are major causes inducing failure of a LG mobile handset. θ and β the parameters of baseline hazard function of the Weibull distribution have been estimated as -9.352 and 1.323, respectively. Thus, Cox proportional hazard model is given as:

Covariates	Regression coefficients (α)	SE	Degrees of freedom	Significance	Value of the covariates
Cost of the set (C)	0.000	0.000	1	0.715	5,859.6
Battery problem (B)	0.804	0.152	1	0.000	0.1304
Integrated circuit problem (I)	0.780	0.138	1	0.000	0.1674
Ringer problem (R)	0.881	0.195	1	0.000	0.0717
Display problem (D)	1.240	0.155	1	0.000	0.1304
Speaker problem (S)	1.049	0.174	1	0.000	0.0978
Virus problem (V)	0.827	0.198	1	0.000	0.0804

Table II. Presenting the regression coefficient of the Cox model for Samsung mobile

Covariates	Regression coefficients (α)	SE	Degrees of freedom	Significance	Meaun values of the covariates
Cost of the set (C)	0.000	0.000	1	0.019	3,906.117
Battery problem (B)	1.242	0.188	1	0.000	0.2395
Integrated circuit problem (I)	1.097	0.181	1	0.000	0.1392
Ringer problem (R)	1.251	0.224	1	0.000	0.1036
Display problem (D)	1.466	0.227	1	0.000	0.1100
Speaker problem (S)	1.163	0.229	1	0.000	0.0939
Virus problem (V)	2.039	0.365	1	0.000	0.0356

Table III. Presenting the regression coefficient of the Cox model for LG mobile

$$h(x) = 0.00011483x^{0.323}\exp[0.000\,\mathrm{C} + 1.242\,\mathrm{B} + 1.097\,\mathrm{I} + 1.251\,\mathrm{R} + 1.466\,\mathrm{D} + 1.163\,\mathrm{S} + 2.039\,\mathrm{V}].$$

In the presence of the covariates at the mean level the expected life of LG mobile handset is estimated as 513.430 days. However, with the additional fund of Rs. 4,093.88 available for removal of problems we could redesign the handset by utilizing Rs. 2,505.91 only and maximize the life of LG mobile handset up to 1,081.235 days by eliminating all the major and minor problems. In view of the same the expected life of the set can reach the highest level.

5.4 A study on Motorola mobile handset

In case of Motorola mobile handset, out of 256 data collected 78 data are censored ones and 178 are uncensored ones. The suitability of Cox proportional hazard model for Motorola mobile handset has been examined by carrying out Omnibus test of model coefficient. The value of χ^2 test statistics is 94.376 with eight degrees of freedom with the tail probability nearly equal to zero. Thus, we can say that Cox's model is a good fit for Motorola mobile handsets too. We have also checked the impact of the individual covariate on the life of the set. Table IV shows the details.

Table IV clearly depicts that though all the covariates are playing significant role in negatively influencing the life of the set, speaker problem, battery problem, virus problem and display problem are the major ones causing failure as shown by their regression coefficients. The parameters θ, β of baseline hazard function of Weibull distribution have been estimated as -9.049 and 1.249, respectively. Thus, Cox proportional hazard model can be written as:

$$h(x) = 0.00014677x^{0.249}\exp[0.000\,\mathrm{C} + 1.310\,\mathrm{B} + 0.862\,\mathrm{I} + 0.732\,\mathrm{R} + 1.147\,\mathrm{D} + 1.436\,\mathrm{S} + 1.247\,\mathrm{V}].$$

Once θ and β are estimated, we have obtained the estimated value of the expected life of Motorola mobile handset as 632.893 days at the mean of the covariates. Since the average cost of Motorola handset is 5,589.572, we are left with Rs. 2,410.43 for further improving the life of the set. In this process all the problems pertaining to Motorola mobile handset have been removed by employing only Rs. 2,199.56 and the life has been increased to Rs. 1,305.165 days which is the maximum attainable limit under the proposed optimization technique.

Covariates	Regression coefficients (α)	SE	Degree of freedom	Significance	Mean values of the covariates
Cost of the set (C)	0.000	0.000	1	0.668	5,589.572
Battery problem (B)	1.310	0.207	1	0.000	0.1712
Integrated circuit problem (I)	0.862	0.195	1	0.000	0.1479
Ringer problem (R)	0.732	0.233	1	0.002	0.0973
Display problem (D)	1.147	0.239	1	0.000	0.0934
Speaker problem (S)	1.436	0.240	1	0.000	0.1012
Virus problem (V)	1.247	0.223	1	0.000	0.1206

Table IV. Presenting the regression coefficient of the Cox model for Motorola mobile

5.5 A study on Sony Ericsson mobile handset

In case of Sony Ericsson mobile handset, out of 253 data collected 181 are censored whereas 72 data are uncensored. Like in the previous cases, to check the applicability of fitting Cox proportional hazard model, Omnibus test of model coefficient has been carried out for Sony Ericsson mobile handset. The value of χ^2 test statistics is 80.906 with eight degrees of freedom and the tail probability is nearly equal to zero. Consequently, Cox's model is the right choice for Sony Ericsson mobile handsets too. We have also checked the impact of the individual covariate on the life of the set. Table V shows the details.

From Table V we can clearly understand that all the covariates are significantly affecting the life of the set but none is a major one. However, relatively speaking integrated circuit problem, display problem and speaker problem are approaching criticality as depicted by their regression coefficients. The two parameters θ, β of baseline hazard function of Weibull distribution have been estimated as -7.907 and 1.152, respectively. Thus, Cox proportional hazard model is given as:

$$h(x) = 0.00042412x^{0.152}\exp[0.000\,\mathrm{C} + 0.680\,\mathrm{B} + 0.910\,\mathrm{I} + 0.243\,\mathrm{R} + 0.860\,\mathrm{D} + 0.874\,\mathrm{S} + 0.264\,\mathrm{V}].$$

With the estimated parameters the expected life of Sony Ericsson mobile handset is calculated as 484.087 days in the presence of the covariates at the mean level. As the average cost of the handset for Sony Erricsson (K) equals to Rs. 7,103.26 the allowable cost of repairing the handset is Rs. 896.78. Under this cost constraints by solving the optimization problem we could increase the expected life to 740.755 days and can remove all the major problems. But two problems, i.e. battery problem and integrated circuit problem will remain.

Thus, the final comparative picture of ordering the mobile brands in terms of the life of the handset is shown in Table VI.

6. Conclusion

The growing applications of any brand and its emerging demand in the market may lead to high influx of manufacturers in that segment. As a result the choice set of a customer will get increased by manifold. To succeed in this severe competition a manufacturer has to focus on both quality and price. Striking a balance between these two is a difficult proposition, especially when the brands are subject to different types of failures requiring different remedial measures with varying costs.

Covariates	Regression coefficients (α)	SE	Degree of freedom	Significance	Mean values of the covariates
Cost of the set (C)	0.000	0.000	1	0.645	7,103.245
Battery problem (B)	0.680	0.172	1	0.000	0.2411
Integrated circuit problem (I)	0.910	0.187	1	0.000	0.1779
Ringer problem (R)	0.243	0.317	1	0.444	0.0553
Display problem (D)	0.860	0.290	1	0.003	0.0672
Speaker problem (S)	0.874	0.196	1	0.000	0.1542
Virus problem (V)	0.264	0.222	1	0.235	0.1186

Table V. Presenting the regression coefficient of the Cox model for Sony Ericsson mobile

Table VI.
Showing the life of the set when the cost of redesigning the product is fixed at Rs. 8,000

Name of the brand	Allowable cost of repairing (Rs)	Cost of repairing (Rs)	Problem removed	Existing expected life at mean of the covariates	Enhanced life under optimization scheme (days)
Motorola	2,410.428	2,199.560	All problem removed	632.893	1,305.165
Nokia	1,530.553	1,416	Battery problem, integrated circuit problem, ringer problem, virus problem	755. 952	1,239.176
LG	4,093.883	2,505.910	All problems removed	513.430	1,081.235
Samsung	2,140.400	1,917.997	All except ringer problem	603.112	1,065.358
Sony Ericsson	896.775	877.727	All except battery problem and integrated circuit problem	484.087	740.755

We have presented a mathematical framework for solving this problem. Not only that, we have examined the problems causing failure of some of the selected popular brands of mobile handsets and their impacts on survival. We have also evaluated the expected life when estimated at the mean of the covariates. Ordering of the brands when the life is estimated in the presence of the covariate at their mean values reveals that Nokia is leading followed by Motorola, Samsung, LG and then Sony Ericsson. However, this does not depicts the real picture as prices are not comparable. Under the proposed optimization framework, we have notionally made the brands comparable at fixed cost of Rs. 8,000 per handset and the resultant ordering of the sets when they are redesigned shows that Motorola is giving maximum life followed by Nokia, LG, Samsung and then Sony Ericsson.

Though at present market share wise Motorola is enjoying the second position, they can outperform Nokia and become the market leader if they undertake optimization plan under price quality consideration.

The most important and interesting aspect found in the empirical study is that Motorola can remove all the causes of failure under study, whereas with the same cost constraints Nokia is able to remove only two major causes of failure and two minor causes of failure.

We cannot ignore yet another brand of mobile handset, i.e. LG. With this optimization technique they can occupy the third position and remove all the covariates causing failure to the set at a much lower effective cost of the set.

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