EPH - International Journal of Science And Engineering

ISSN (Online): 2454 2016
Volume 01 Issue 4 October 2015

DOI:https://doi.org/10.53555/eijse.v1i4.107

ANALYZING THE RELIABILITY OF A PERSONAL COMPUTER SYSTEM USING FAULT TREE ANALYSIS

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ABSTRACT *A system can be defined as a set of components interconnected to perform a given task. Such a system has a high possibility of failure compared to a single component, since it is a combination of different components consisting of different failure types. Thus, the analysis of failures of such systems should take into account both the time to failure and the type of the failure. The specialty in multiple failure type systems is that the failure occurrences yielding from different failure types cannot be regarded as independent from each other. Fault Tree Analysis (FTA) enables to address the problem of multiple failure types and it does not require the assumption of independence among failure types.*

A personal computer (PC) is made up of many interconnected components.The goal of this research is to provide an insight into using FTA for evaluating reliability of PC's which have failed due to various types of hardware failures. In this study, suitable parametric distributions were identified for each of the failure types and were applied to a fault tree constructed to depict the failure pattern of PCs. In the literature this type of research is not found in many studies which use FTA. FTA identified that hard disk, power unit and VGA failures are the most significant failure causes irrespective of the brand while the most reliable computer brand was also identified.

Keywords: *Fault Tree Analysis (FTA), Multiple Type Failures, Personal Computers (PC's), System Reliability, Component Reliability*

I.INTRODUCTION

The occurrence of unexpected breakdowns in Personal Computers (PC's)[1] affects the end-user satisfaction badly. Thus, the industry is keenly focused on securing the reliability of PCs in terms of controlling these sudden failures. Apparently a computer is a system and it can be considered as a compromise of two systems called hardware system and operating system (software). In this study the concern is only on hardware failures. PC failures can occur due to many reasons since the PC is a collection of components such as power unit, motherboard, processor, VGA, monitor, hard disk, etc. Non working state of one or more of these components affects the functionality of the whole PC. Thus, it is important to consider each and every component failure type in assessing the reliability of PCs. Therefore this study is focused on analyzing PC failures taking into account the type of the failure. In statistical terminology, this is called analyzing Multi-Type Failure Data[2].

The primary objective of this study is to explore an empirical application of analyzing multiple type failure data without incorporating the assumption of independence among failure types. The application of the study includes failure occurrences in PCs together with the type of the failure occurred. As the data comprises of two brands of PCs, the effect of the computer brand both on the occurrence of failures and also on the type of the failures is evaluated.

When considering the methods to meet the above objective, a PC is regarded as a system with a collection of interconnected components to perform the intended functionality of it. Thus, the methods for system reliability analysis are taken into account. In literature two perspectives of system reliability analysis can be recognized. One perspective is the adoption of statistical techniques which are not originally designed for system reliability analysis. In line with parametric modeling, the analysis of failure data with multiple failure types involves complicated life distributions. Thus the semi parametric method of Cox proportional hazards modeling[2] and extensions of the Cox models have been adopted from methods of analyzing survival data to perform system reliability assessment. The second perspective is the collection of multi component system reliability methods in which system reliability is derived from component reliabilities that makes up the system and these methods will be discussed in detail in the next section. This study uses the technique of Fault Tree Analysis (FTA) which also falls under this perspective, but the specialty of this study being, the fact that it incorporates parametric modeling also in to FTA.

The data were collected from a reputed computer solution company in Sri Lanka, which sells two brands of PCs and maintains a service unit for the PCs sold by the company. The two types of PCs are denoted by *brand 1* and *brand 2* as original brand names cannot be divulged owing to reasons of [3]. The date on which each PC was reported for repair is taken as the failure date and the number of days between the sale date of the respective PC and the repair date is taken as the time to failure of that PC. The failure remark mentioned under each repair is used to identify the type of the failure associated. As the occurrence of one failure type can affect the occurrence of another type/s of failure, the data cannot be regard as independent observations. The goodness of fit testing of the Fault Tree is done by assessing the adequacy of parametric models applied to the Fault Tree. Anderson Darling (AD) test and confidence limits were used in this. Finally, estimates for system reliability is obtained for the two brands by using suitable parametric densities over the fault tree designed to depict the failure pattern of PCs.

II. Literature review of the methods for analyzing system failure data

A. Different Perspectives

In the literature associated with analyzing multi-component system reliability, one perspective can be identified as the adoption of methodologies which are not specifically developed for system reliability analysis and the other approach is deriving system reliability through the use of component reliabilities that makes up the system.

System reliability of a binary system (working/failed) was assessed through binary components by Natvig and Eide[4] with the assumption of independence of components. However, more recently research has found that the assumption of independence of components may be too strong to make in practice[3,5].

More practical and popular methods used in the literature for assessing system reliability that do not make this assumption of independence are, Block Diagram (RBD) [6,7], Failure Mode and Effect Analysis (FMEA)[7,8,9,10], Failure Mode Effect and Criticality Analysis (FMECA)[7,10] and Fault Tree Analysis FTA) [7,10,11] .

Fault Tree Analysis (FTA) is the translation of the failure behavior of a system into a visual diagram called Fault Tree which enables quantitative and qualitative evaluation of system reliability. It is a deductive (backward or top – down) approach used to determine various combinations of failures that could cause the undesired event[7,10,11].

B. Comparison of FTA with other methods

FTA is very good at showing how resistant a system is to single or multiple initiating faults. FMEA is good at exhaustively cataloging initiating faults, and identifying their local effects. It is not good at examining multiple failures or their effects at a system level (Wikipedia, retrieved on 30th May 2012). FTA considers external events, FMEA does not [12]

Instances where the FTA is compared with FMEA| FMECA or RBD can be commonly seen in the literature in order to highlight the effectiveness of FTA. Stamatelatos*et al.* [10] have compared FTA with FMEA and FMECA stating the direction of event (failure of the system) and traces backward to the causes of failures while FMEA and FMECA start with an initiating cause and traces forward to the resulting consequences. Further FMEA and FMECA analyze single component faults and their system effects, but these do not consider a combination of component faults while FTA is capable of this. Blischke and Murhy [7] have also discussed the same idea towards FTA and FMEA / FMECA by stating them as backward (or top - down) approach and forward (or bottom -up) approach respectively. RBD is an inductive system reliability technique, tracing forward to the resulting consequences while FTA is a deductive method. RBD divides the system into blocks that represent components or subsystems and combines, according to system-success pathway. But FTA analyzes failure space [10]. According to Meeker and Escobar [9] FTA is similar to the RBD in one sense and it is generally possible to translate from one to the other. But the FTA focuses on the critical failure causing top events such as loss of system functionality while the RBD is structured around the event that the system doesn't fail. RBD is dealing in "success space" while FTA is dealing in "Failure space" which can be described simply as RBD looks at success combinations while the FT looks at failure combinations.

Julwan et. al.[13] has applied FTA to assess the safety of nuclear power plants. In their study, they pointed out that it is difficult to provide in advance corresponding failure rates required to perform the conventional FTA and thus they have proposed a failure possibility based FTA approach to overcome the limitation of the conventional FTA. As our study deviates from conventional FTA in such a way that instead of assuming a constant failure rate for the components, suitable parametric distribution are incorporated for each component and the evaluation of the FTA is done through failure probabilities obtained by parametric distributions.

III. Methods and materials

A.Fault Tree Analysis (FTA)

The steps to obtain a successful FTA begin with defining the top event of the FT in which the undesired state of the system is stated very precisely (e.g.: unable to perform the basic functionality of a PC). Then the resolution of the FT is to be determined. The resolution, the level of detail to which the failure causes for the top event to occur, will be evaluated. The general principle is that the FT should be developed to the necessary depth to identify functional dependencies and to a depth that is consistent with the data available and the objectives of the analysis [10].

A.1.1). Construction of the FT

Generally FT is composed of many primary event symbols and gate symbols. For complex systems incorporation of different types of symbols to the FT is at high level and it increases the value and complexity of FTA. E.g.:- Basic Event (BE) is one category of primary event where the primary events are events which cannot be further decomposed. Gates (AND Gate, OR Gate, etc.) are used to illustrate how a fault at primary level affects the system[10,14].

A.1.2) Evaluation of the FT

Fault tree evaluation includes both qualitative and quantitative analyses. The qualitative evaluation provides information on the minimal cut sets of the fault tree and qualitative component importance while the quantitative approach incorporates probabilities for the analysis. Quantitative evaluation produces the probability of the top event, probability of dominant cut sets and quantitative importance of each basic event contributing to the top event.

(i) Qualitative Evaluation

Obtaining cut sets and minimizing them to obtain the smallest combinations are primitive tasks under qualitative analysis. Boolean expressions and rules of Boolean algebra are utilized for obtaining minimal cut sets. Failure importance of minimal cut sets is obtained by ordering the cut sets according to their sizes.

A Cut set is a set of basic events which, if they all occur will result in the top event of FT. It relates the basic events directly to the top event. A minimal cut set is a smallest combination of component failures which if they all occur, will cause the top event. Although the minimal cut sets are obtained under qualitative analysis, it is the key for quantitative analysis too.

(ii) Quantitative Evaluation

Quantitative evaluations are performed in a sequential manner, first determining the component failure probabilities, and then the minimal cut set probabilities and finally the system failure probability. It is important to understand the fundamentals of component failure models used in quantitative evaluation of FT. In this study, the Lognormal and Weibull distributions [9] are used for modeling component failures.

(a) Component reliability characteristics

- **Component unavailability**

  Let q(t) be the component unavailability, then the q(t) can be defined as q(t) = Pr[component is down at time t and unable to operate if called on] where then q (t) = F(t) where F(t) is the cumulative distribution function.

- **Component failure occurrence rate**

  Let w(t) be the component failure occurrence rate and it is defined such that w(t) Δt = P[component fails in time interval t to t+ Δt]. The quantity w(t) Δt is the probability that the component fails in time interval t to t+ Δt irrespective of history. This means component operates without failure up to time t. The component failure occurrence rate w (t) is equal to the probability density function (PDF) of first failure (f(t)), i.e. w(t) = f(t)

(b) Minimal cut set reliability characteristics

Reliability characteristics of minimal cut sets are evaluated once the component reliability characteristics are obtained.

- Minimal cut set unavailability

  Let Q(t) be the minimal cut set unavailability or minimal cut set unreliability which can be defined as Q(t) = Pr [all components in the minimal cut set are down at time t] = Pr [system is down at time t due to the particular minimal cut set]. For a particular minimal cut set i the cut set unavailability $Q_i(t)$ equals to product of component unavailability's with the assumption of component failure independence. Therefore,

  $Q_i(t) = q_1(t)\, q_2(t) \ldots\ldots q_n(t)$

(c) System (top event) reliability characteristics

Determinations of system reliability characteristics are straight forward once the minimal cut set characteristics are obtained. The major concern is on system unavailability or the system unreliability.

- System unavailability

  Let Q_s (t) be the system unreliability defined as Q_s (t) = Pr[the system is down at time t and unable to operate if called on]

  If the top event of the fault tree is not a system failure, but some general event, then the Q_s (t) is the probability that top event exists at time t. It is approximated as the sum of the minimal cut set unavailability Q_i (t) and is given by $Q_s(t) \approx \sum Q_i(t)$ where the summation of i is from 1 to N.

  This is called "Rare event approximation" and generally the true unavailability is slightly lower than the value calculated by this equation. But it is usually used in FT evaluations due to the simplicity of the calculation and ability to truncate at any value of N [14].

Minimal cut sets (MCSs) and component Importance

Minimal cut set importance is the fraction of the system failure probability contributed by a particular minimal cut set while the component importance is the fraction of the system failure probability contributed by the particular component failure [14]. Let $E_i(t)$ be the minimal cut set importance. Then $E_i(t)= Q_i(t)/ Q_s(t)$. Let $e_k(t)$ be the component importance which is recognized as Veseley – Fussell's importance. Then for the k^{th} component the importance is $e_k(t) = \sum Q_i(t)/ Q_s(t)$ where the summation is for all the i's that include k.

IV.RESULTS BASED ON EXAMPLE

A. Description

The data used in this study are from two groups of personal computers sold from 4th April 2004 to 29th December 2006 from which a data set of 18243 sales was obtained [3]. Their failure times were observed until 25th May 2007 and only the hardware failures occurring within this period were considered together with the type of the failure. The type of failure was categorized as 1-Keyboard Failure, 2-Mouse Failure, 3Monitor Failure, 4-Power Unit Failure, 5-Mother Board Failure, 6-Hard Disk (HD) Failure, 7-Processor Failure, 8-VGA Failure, 9-RAM Failure. Though the set of data is not quite current, it was well sufficient to illustrate the methodology of FTA incorporating parametric distributions.

B. Selecting Probability Distributions

The lognormal and weibull distributions were fitted to each of eighteen combinations (nine failure types * two brands) in order to select the distribution that best fits the combination. Probability plotting, and Anderson – Darling tests were used to select the appropriate distributions. Further maximum likelihood parameter estimates were obtained for the identified suitable distribution. The results are summarized in table 1.

TABLE 1 – SELECTED DISTRIBUTIONS AND PARAMETERS

FAILURE TYPE	DESCRIPTION	BRAND 1	BRAND 2
Type 1	Distribution	Lognormal	Weibull
	Location/shape parameter	11.6852	0.8625
	Scale parameter	2.5532	67458.7
Type 2	Distribution	Weibull	Lognormal
	Location/shape parameter	1.1171	12.9232
	Scale parameter	33249	2.9008
Type 3	Distribution	Weibull	Weibull
	Location/shape parameter	0.87	1.3745
	Scale parameter	230973	15414.1
Type 4	Distribution	Weibull	Lognormal
	Location/shape parameter	1.0825	9.4062
	Scale parameter	9371.69	1.9768
Type 5	Distribution	Lognormal	Lognormal
	Location/shape parameter	14.7791	12.1691
	Scale parameter	3.7982	2.7993
Type 6	Distribution	Weibull	Weibull
	Location/shape parameter	0.9044	1.6299
	Scale parameter	13975.7	2271.23
Type 7	Distribution	Weibull	Lognormal
	Location/shape parameter	0.7166	11.5626
	Scale parameter	459282	2.5017
Type 8	Distribution	Weibull	Weibull
	Location/shape parameter	0.9524	0.9988
	Scale parameter	29344.8	16985.7
Type 9	Distribution	Weibull	Weibull
	Location/shape parameter	0.8577	0.8960
	Scale parameter	357496	259731

C. Construction of the fault tree

After considering the requirements of the top event and availability of data, a top event for the PC was defined as "Loss of basic system functionality of PC after sales" where the entire fault tree was developed based on it. The level of detail to which the failure causes for the top event will be developed and this determines the depth of the fault tree. Component failure level was selected as the limit of the resolution of the FT as failure types are categorized up to nine component levels. Basic system functionality can be lost due to the non working state of input devices, monitor, power unit, processor, RAM, VGA, motherboard or hard disk. Therefore, those were connected to the top event using OR gates considering them as the immediate causes of failures of the top event. All the immediate events that were connected to

the top event were further resolved reaching up to the component level other than the non working state of the power unit since it can be arisen only due to the primary failure of power unit within the frame of the study. Input devices such as Mouse and the keyboard were considered as a subsystem in the analysis. Hence the malfunction of input devices has become a state of system and it is free to employ OR gate, AND gate or no gate for the further analysis of that event [10]. It was believed that both mouse and keyboard should be in a nonworking state in order for malfunction of input devices to arise. Thus the AND gate was decided to be used right after the event “Input devices not working”.
Part of the tree under the ‘G4’ gate was repeated for several intermediate events and that repetition was represented using a specific symbol, 

Primary events were named using letter ‘E’ while the gates were named using letter ‘G’. Nine primary events of fault trees are represented using the following component failures. E1- Primary failure of keyboard; E2-Primary failure of mouse; E3- Primary failure of monitor E4- Primary failure of power unit; E5-Primary failure of motherboard; E6-Primary failure of HD E7- Primary failure of processor; E8-Primary failure of VGA;E9-Primary failure of RAM
The final Fault Tree constructed is given in figure 1.

D. Fault tree evaluation

D.1) Qualitative evaluation

The most outstanding task under qualitative fault tree evaluation is determining the minimal cut sets. The minimal cut sets are the smallest combination of the primary failures that cause system failure (top event). Using Boolean equations to express fault events equivalent to its gate and rules of Boolean algebra to obtain minimal cut sets, seven single component, minimal cut sets and only one double component minimal cut set were determined. If the top event is represented by “T”, the minimal cut sets are connected to it as $T = E1. E2 + E3 + E4 + E5 + E6 + E7 + E8 + E9$. That is “Loss of basic system functionality’’ can occur due to eight paths of failure.

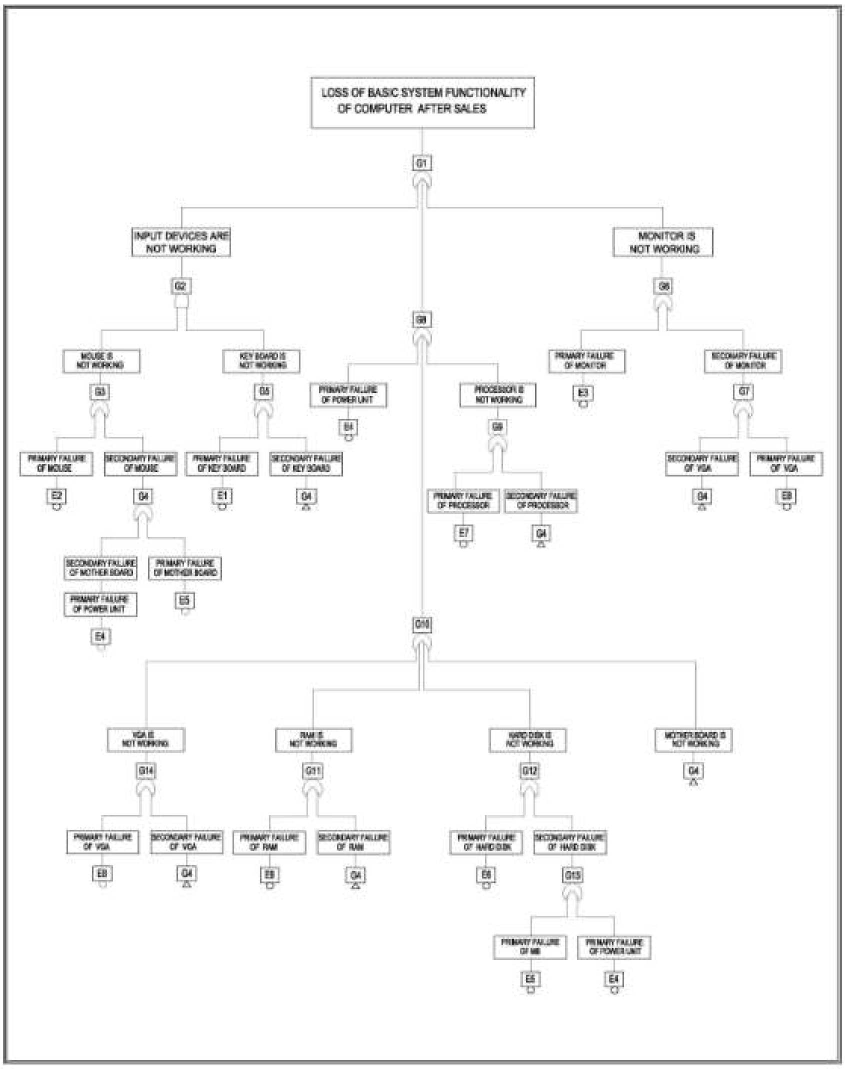

FIGURE 1 - FAULT TREE OF THE PERSONAL COMPUTER SYSTEM

D.2) Quantitative evaluation

Quantitative evaluation is a sequential process, where determining component failure probabilities, minimal cut sets probabilities and system failure probability come first, second and third respectively [11,13].

Prior to moving into the analysis, probability distributions of each component failure should be recognized separately under two brands [14,15,16]. Distribution identification was carried out under univariate tests. Several quantitative approaches are available for the FT analysis. Obtaining the top event probability through the minimal cut sets is one method while obtaining the gate probabilities from bottom to top by considering the mathematical operation and events associated with gates is another method. There are different methods such as Boolean algebra and Binary Decision Diagrams (BDD) even for obtaining minimal cut sets [14,15,16]. Minimal cut set quantification approach was performed using minimal cut sets obtained from Boolean algebraic theories. Reliability characteristics of FT were quantified for separate time intervals t=0 to 180 days (half a year), 0 to 365 days (one year), 0 to 545 days (one and half years) and 0 to 730 days (two years) for the comparison purpose of the two computer brands.

(a). **Component unavailability**

Component unavailability (q(t)) is equal to the unreliability (c.d.f = F(t)) of the component.Unavailability of components for each time interval were calculated using probability distributions identified for each component separately for two brands. $q_i(t) = F_i(t)$ For i = 1, 2, 3… 9 and are presented in table 2. Components unreliability or the failure probability at 't' days of operation is higher in brand 2 than Brand 1 at all time points except for component 6 which is the hard disk at 6 months. Failure probabilities of power unit, hard disk and VGA seemed to be higher than other components in all time periods for both brands.

TABLE 2 - COMPONENT UNRELIABILITY OF BRANDS 1 AND 2

Time interval / Brand 1 components	t= 0-180	t=0- 365	t= 0-545	t= 0-730
Keyboard $q_1(t)$	0.005503	0.011737	0.017488	0.023066
Mouse $q_2(t)$	0.002934	0.006451	0.010077	0.013941
Monitor $q_3(t)$	0.001974	0.003648	0.005167	0.006658
power unit $q_4(t)$	0.013767	0.029359	0.044948	0.061154
Motherboard $q_5(t)$	0.005804	0.0097	0.012801	0.015571
hard disk $q_6(t)$	0.019336	0.036329	0.051788	0.066921
Processor $q_7(t)$	0.003613	0.005989	0.007975	0.009824
VGA $q_8(t)$	0.007787	0.01521	0.022202	0.029223
RAM $q_9(t)$	0.001482	0.002717	0.003829	0.004918
Time interval / Brand 2 components	**t= 0-180**	**t= 0-365**	**t= 0-545**	**t= 0-730**
Keyboard $q_1(t)$	0.006009	0.011029	0.015549	0.019962
Mouse $q_2(t)$	0.003851	0.007736	0.011216	0.014547
Monitor $q_3(t)$	0.002203	0.005812	0.010062	0.014999
power unit $q_4(t)$	0.01653	0.038054	0.058099	0.077356
Motherboard $q_5(t)$	0.006349	0.01256	0.018026	0.023188
hard disk $q_6(t)$	0.015923	0.049537	0.093036	0.145500
Processor $q_7(t)$	0.005446	0.011801	0.01772	0.023491
VGA $q_8(t)$	0.010599	0.021357	0.031705	0.042223
RAM $q_9(t)$	0.001476	0.002778	0.003977	0.005164

(b)**Minimal cut set unavailability**

Minimal cut set unavailability or the minimal cut set failure probability is obtained by the product of component unavailability (unreliability) of components belonging to a particular minimal cut set. Since the first seven minimal cut sets are one component cut sets their unavailability is again equal to the unavailability of a particular single component. But for the eighth minimal cut set which is the only double component cut set, minimal cut set unavailability is obtained from, $Q(t) = q_1(t).\ q_2(t)$

Minimal cut set unreliability of second, fourth and sixth cut sets are prominent for both computer Brands through all time points. Least minimal cut set unreliability is associated with eighth cut set for both Brands.

(c)System unavailability

System reliability characteristics are identified through a minimal cut set reliability characteristics. Keen interest is on system unavailability which means the failure probability of system or the probability of the top event. It is obtained by the approximation,

$$Qs\ (t) \approx Q1\ (t) + Q2\ (t) + \ldots\ldots\ldots + Q8\ (t)$$

$$Qs\ (t) \approx q_3(t) + q_4(t) + q_5(t) + q_6(t) + q_7(t) + q_8(t) + q_9(t) + q_1(t)\ .\ q_2(t)$$

System failure probabilities and system reliabilities of two brands for all time intervals are presented in table 3 and the graphical illustration of system reliability of two brands is shown in figure 2. Although the calculations of four time periods are presented on same tables for two brands, this is similar to evaluating eight fault trees as two FTs for two brands per time period. The same FT and the same minimal cut sets can be used in each case for the same system is evaluated in all cases. System reliabilities of two brands for the short time period (half a year) seemed to be similar and very high which depict values closed to 0.95. There onwards, Brand 1 shows a higher reliability than brand 2. Further, it is important to note that after 2 years of operation the reliability of brand 2 has decreased to a level less than 0.7 where as brand 1 lies above 0.8.

TABLE 3 - SYSTEM FAILURE PROBABILITIES AND SYSTEM RELIABILITIES OF TWO BRANDS

		Time intervals			
Brand	Description	t= 0-180	t= 0-365	t= 0-545	T= 0-730
1	Qs (t)	0.053779	0.103028	0.148886	0.194591
	1- Qs (t)	0.946221	0.896972	0.851114	0.805409
2	Qs (t)	0.0585491	0.1419843	0.232799	0.332211
	1- Qs (t)	0.9414509	0.8580157	0.767201	0.667789

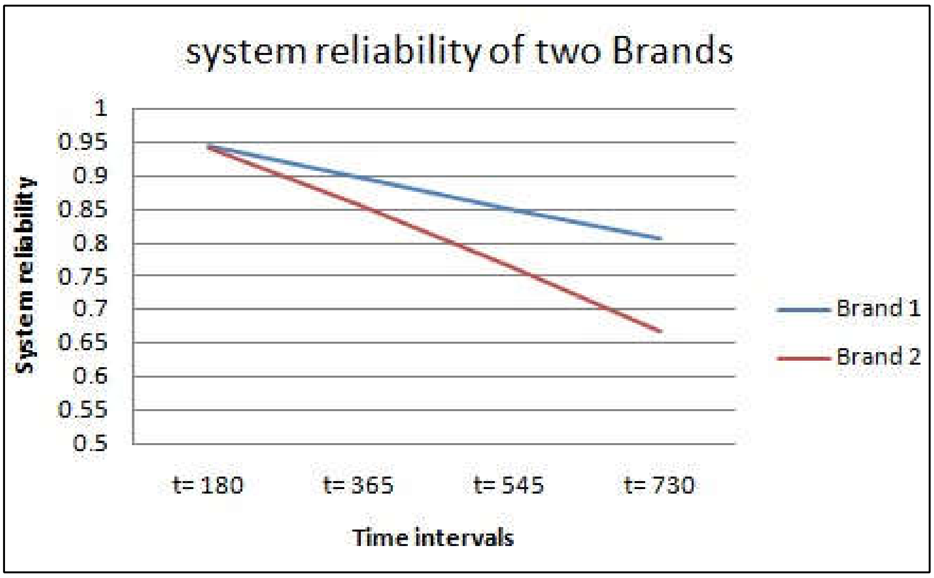

FIGURE 2 - SYSTEM RELIABILITY OF TWO BRANDS

D.3) Minimal cut sets and component Importance

One of the basic objectives of the FTA is to find the way of improving system performance by reducing its failure frequency following a suitable maintenance, repair or improvement process. There is an orderly arrangement of components or MCSs in a system since some are more critical than others in terms of the functionality of the system. For that ranking purpose, minimal cut set and component importance play a major role by assessing the contribution to the overall system unreliability. Several definitions of the reliability importance of components and MCSs are available, namely Birnbaum's importance, Criticality importance, Veseley – Fussell's importance Barlow- Proschan's importance and cut set importance[14]. Since the minimal cut set evaluation procedure was followed, Veseley – Fussell's importance and cut set importance were determined as most appropriate to be used for personal computer system. Cut set importance and Veseley – Fussell's importance becomes equal for the study since the components were not repeated in more than one MCSs obtained for the computer system. Thus only the Veseley – Fussell's importance was quantified since it is capable of measuring the component importance. Veseley – Fussell's importance of components within t (= 180, 365, 545 and 730 which correspond to within half a year, within one year, within one and half year and within two years) days of operation were presented in percentages for two brands in table 4. Here the components were ordered in descending array according to their importance. Components were ordered according to the importance values of 180 days of operation for both brands where the order was not altered when the operation time period increases. Order of components seemed to be similar for both brands. Hence the importance of components for the unreliability of a computer can be ordered from most critical to least critical as hard disk, power unit, VGA, motherboard, processor, Monitor, RAM, keyboard and mouse irrespective of the brand. The highest Veseley – Fussell's importance is associated with hard disk, power unit and VGA which contribute to more than 70% of system unreliability in all operation time periods for both brands. In the reliability enhancement program for manufacturers', hard disk, power unit and VGA need maximum attention to enhance the system reliability since they have a high effect on system failure. Overall system reliability can be improved by boosting the reliability of these components. Least significant contributors to the system unreliability are keyboard and mouse which enumerate about 0% importance in all time intervals. It can be commented on the minimal cut sets importance also by looking at table 4 since the Veseley – Fussell's importance equal to the cut set importance within the study. It can be revealed that cut sets which are made up of only one component can be considered as the most critical paths to the system failure. Because the importance of the path of double component, minimal cut set has least significant values near to zero. Some components show an increment in importance and some show decrement in importance over operating time in both brands. As an example for the same component hard disk, the importance reduces when the operating period increases under Brand 1 while the inverse situation can be revealed under Brand 2. When considering a component which depicts a decreasing trend on Veseley – Fussell's importance within period of operation, their contribution to the overall system failure is high within short operation periods. This means there is high possibility for personal computers to break down within a short time of operation due to this kind of issues. Hence, these components become significant issues for the occurrence of system failure within a short period of operation such as half a year. Components which behave inversely to the above tendency can be considered as the significant issues for arising computer system failure within a long period of operation, since these contribute highly to the system unreliability in long operating periods such as two years. Some components equally contribute to the system failure irrespective of the length of operating duration. Hard disk, motherboard and processor failures seemed to be the prominent reasons for arising system failure within a short time of operation under Brand 1. Most probably the failures of computers which perform long period can be arisen due to power unit failure for Brand

1. For Brand 2 power unit, VGA, motherboard and processor have become the outstanding components for recent system failures after sales. It can be seen that Brand 2 computers, which operate more than one year without failure have high possibility to break down due to hard disk failure since it has a high contribution (more than 40%) to the system failure in extensive operating periods. In both computer brands monitor and RAM equally contributed to the system failure on all operating periods.

Table 4 - Veseley – Fussell's importance of Brand 1and 2 components

Brand 1 Components	Importance of components within t days of operation (%)			
	t= 180	t= 365	t= 545	t= 730
hard disk	36	35	35	34
power unit	26	28	30	31
VGA	14	15	15	15
Motherboard	11	9	9	8
Processor	7	6	5	5
Monitor	4	4	3	3
RAM	3	3	3	3
Keyboard	0	0	0	0
Mouse	0	0	0	0
Brand 2 Components	Importance of components within t days of operation (%)			
	t= 180	t= 365	t= 545	t= 730
hard disk	27	35	40	44
power unit	28	27	25	23
VGA	18	15	14	13
Motherboard	11	9	8	7
Processor	9	8	8	7
Monitor	4	4	4	5
RAM	3	2	2	2
Keyboard	0	0	0	0
Mouse	0	0	0	0

V. Discussion

Through the minimal cut sets obtained by qualitative evaluation of the FT, it was revealed that monitor, power unit, mother board, hard disk, processor, VGA and RAM are individually capable to disrupt the basic functionality of a PC while the keyboard and mouse have combined effect. One of the most significant evaluations of FTA is observing the components and minimal cuts importance for the top undesired event which will be able to assist in system modifications or maintenance. It can be listed from most important to least important as hard disk, power unit, VGA, motherboard, processor, Monitor, RAM, keyboard and mouse irrespective of the brand where the impact of keyboard and mouse are insignificant. Hard disk, power unit and VGA cover about 70% of system unreliability within all considered time durations. Further Hard disk, motherboard and processor failures have more impact on system unreliability of Brand 1 in short operation periods such as half a year where power unit, VGA, motherboard and processor have the similar impact for Brand 2. Finally, it can be concluded that Brand 1 is more reliable than Brand 2 and Hard disk, power unit and VGA are the most significant failure causes of computers irrespective of the brand. Development of FTA discussed in the study is unique for the defined computer system which depends on the capacity of data. However, this can be extended to a more complicated personal computer structure or any other electronic system by following the procedure constrained to the level of data availability. When reviewing the literature of FTA, it can be seen that the accuracy of the analysis is not addressed as a primary requirement because most of the time it depend on assumptions. (E.g.: assumption of λ-model, assumption of getting reliability of top event).

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