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Failure Mode Analysis of Radiologic Equipment in a Tertiary Institution in South-Eastern Nigeria

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Abstract
Background: *A valid benchmark for Radiologic equipment failure analysis using a nine mode factor of chronological categories; Improper storage and transportation, Initial failure, Inappropriate handling, Inadequate maintenance, Environmental stress, Production deficiencies, Radom failure, Inappropriate repairs techniques, Wear-out failure.*
Objectives: *To present failure modes that analyze the causes of Radiologic equipment failure based on maintenance history and age of the equipment with preventive and repair maintenance policy*
Materials and Methods: *A triangulational research design (combination of quantitative and qualitative research) was adopted for the study. All radiological equipment failure and causes, repair service activity form of VAMED engineering company were analysed of one government owned tertiary hospital in South-Eastern Nigeria. Thirty nine causes/repair service report cases were studied and survey of radiologic equipment down time between 2013 and 2014. The radiologic equipment failures were categorized according to a factor model (nine failure mode) by radiographer, medical physicist, and repair technician. Ethical approval was obtained from the study institution and data was analysed using SPSS version 20.0. Descriptive statistic failure rate (frequency) and failure ratio (percentage) were deployed in the analysis.*
Results: *The results show that 20 (90.90%) equipment were state-of-the-art with age range of 2 to 9 years as at November, 2016. The major manufacturers of the radiologic equipment were used were General Electric (GE) 10 (45.4%) and Aloka 4 (18.1%). The radiologic equipment (General purpose static X-ray machine, Mobile X-ray, C-arm fluoroscopy, Conventional Fluoroscopy, Magnetic Resonance Imaging scanner, Computed Tomography scanner, Mammography, Ultrasound Machines) were introduced under different conditions (generations) from batch 1 to batch 4; before VAMED project, VAMED project and after VAMED project respectively between 2000 and 2014. The downtime of radiology equipment was 1 week to 9 months. The radiology department had comprehensive preventive and curative maintenance of radiology equipment with storage of spare parts. The common causes of radiological equipment failure based on 9 chronological categories, which are preventable include: Environmental stress 26 (69.23%) majorly unstable power supply; inappropriate handling and inadequate maintenance 5 (12.5%) respectively. The results showed that 38 (97.4%) of 39 were preventable causes of failure. The major specific causes of periodic radiological equipment break down was defective fuses 8 (20.51%), defective cable 5 (12.82%), lack of preventive maintenance 5 (12.82%), and loose cables 4 (10.26).*
Conclusion: *The major causes of radiology equipment failure were environmental factors (unstable power supply). Majority of the causes were preventable with comprehensive maintenance policy. This indicated absence of end-users involvement in the process of planning of preventive and curative maintenance policy, and user awareness of such policy existence. This may have accounted for the high rate of equipment failure and long downtime of radiology equipment even during stable stage of the equipment.*
Keywords: *Failure mode, Maintenance history, Radiologic equipment, Initial failure*

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I. Introduction

The field of medical imaging is rapidly evolving with the development of state-of-the-arts (less than 10 years of age) radiological equipment [1]. Even with the expensive nature of these facilities, many radiological centers have procured and installed in their various centers. The increased sophistication of these facilities comes with greater potential for breakdown and increased downtime [2]. Hence, failure of these equipment occur even when they are correctly installed in the appropriate environmental conditions, and appropriately used and maintained where quality control checks, planned preventive measures and attitude of prompt repairs are not in place [2].

Functional equipment failure refers to the inability of the equipment to perform its required function within specific limits of performance [3], which may be due to deterioration or breakdown of certain components that make up the equipment. Hence, Radiology equipment failure could be define as the inability of radiology equipment to perform its specified function either partially or completely. In other words, we can go further to define radiologic equipment breakdown as complete inability of radiologic equipment and devices to perform any of its most useful functions. According to statistics on medical equipment failures, about 80% of all failure cases are caused by preventable factors [4]. For instance, failures due to inadequate maintenance account for about 60% of all the failure cases. In this case, most failures arise from deterioration of accessories and consumable components. The deterioration time of the accessories and consumable components can, however, be predicted by carrying out maintenance and inspection. Therefore, 60% of all these failures can be prevented by replacing such ‘consumable parts’ on a regular basis, or replacing them immediately when the equipment becomes defective [4].

Since radiological equipment are very expensive to procure and maintain, they account for a large share of the hospital’s budget [5]. This could also explain the high rate of equipment breakdown and long down time reported in various studies [6,7], as hospitals managements tend to abandon some equipment when they are faced with the high cost of maintenance and repairs. Since most equipment fault can be predictable, well planned procurement pattern, planned preventive maintenance, quality control and prompt repairs are essential for effective and efficient radiological practice as well as increasing the lifespan [7].

The lifespan of medical equipment is generally set at four to seven years depending on the type of equipment, with effective lifespan of six years [4].

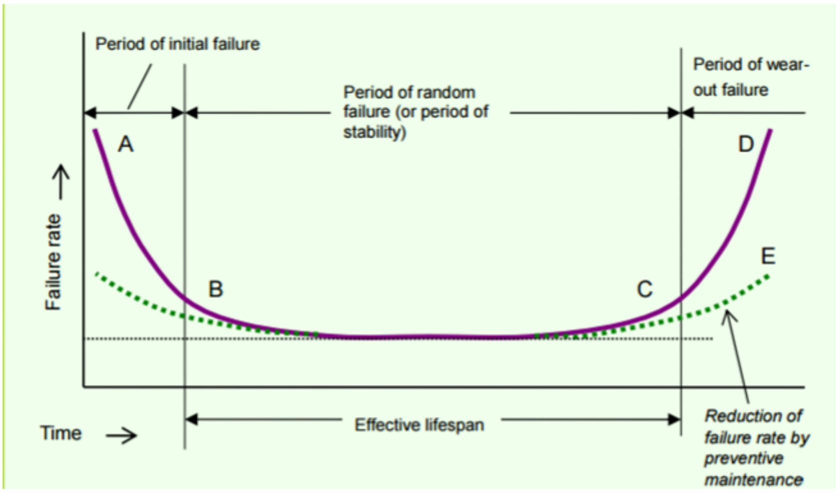

Figure 1: Failure rate curve of the same model equipment group without performing the maintenance

Source: JICA, 2014

Equipment failures can be categorized into three stages according to the occurrence rate with the passage of time. That is, since the causes and phenomena of the failures in each stage are different, these are: initial, random and wear-out failures respectively.

Initial failure is marked with high failure rate. This may occur as soon as the operation of equipment is begun (curve AB-as shown in figure 1), resulting from inappropriate circuit design, improper choice of components, faults in the production process, etc. Such defects generally may not be detected by the user, because such shortcomings are often observed and rectified during examinations/inspections after manufacturing in the factory or at the installation process [4]. However, because unexpected initial failures occasionally occur, reputable manufacturers set the one-year guarantee after the equipment installation [4].

The second stage, which is random failure (curve BC-figure 1), the state of the equipment changes, and the equipment failure rate decreases. During this period, failures occur at random, however the failure rate is low. This can be said to be a period of stability [4].

In the third stage, the curve is wear-out failure (CD), which shows that the equipment’s condition has deteriorated. Here, the failure rate starts rising again resulting from the deterioration, wear-out or breakdown of components of the equipment with the passage of time [4]. However, during this period, the failure rate can be reduced through replacement of worn-out or faulty components, and by their proper adjustments. Note that this will extend the lifespan of the equipment as shown by curve CE [4].

When failures appear repeatedly, the budget expenditure on repairs increases and the equipment's reliability and safety cannot be guaranteed anymore. This should indicate the end of the equipment's life [4].

Equipment failures can be from many other causes besides the above-mentioned failures. In the case of medical equipment, there is usually a zero tolerance of breakdowns [4]. The maintenance that prevents a breakdown of medical equipment, therefore, must be carried out even in the period of stability.

The lifespan of medical equipment is generally set at four to seven years depending on the type of equipment. Effective lifespan is about six years also in Figure 1 [4]. On the other hand, electronic circuits used in equipment have a long lifespan of ten years or more. For this reason, if maintenance to replace deteriorated components by new ones is carried out, actual lifespan of the equipment becomes ten years or more as shown in Figure 1.

Tools for predicting radiology failure mode analysis. Predictive or prospective analysis of failure is a more positive approach to a problem solving because emphasis is on preventive or mitigation of occurrences of failures and their consequences [4]. Failure reporting and analysis system is vital to the manufacturers continued control of user's failure reporting scheme during use, failure loss, failure reporting system for personnel use [4]. It helps hospital to maintain reliability and safety of medical equipment including radiology equipment [4]. The failure mode analysis involves from installation and operating environments, systems, failure locating, faulty components, equipment history [4]. Thus analysis of the cause of the failure is determined and classified as in figure 3. The failure 9 mode analysis uses the method of classification with nine (9) chronological categories:
In certain cases, some of the above-mentioned failures overlap [4].

1. Improper Storage and Transportation
Medical equipment is exposed to various stresses from the time of leaving the manufacturer and agency to arriving at the end-user. The equipment is possibly exposed to vibration, high temperature and high humidity due to inadequate infrastructure such as roads, storage facilities, etc., and such exposure can cause equipment breakdown.

2. Initial Failures
This equipment breakdown occurs less than one year after installation as described earlier. Inadequacy in the design, improper choice of components, faulty manufacturing process, etc. bring this failure. Symptoms of this type of breakdown do not have specific characteristics; it is often similar to random failures and/or wear-out failures. In general, equipment that fails for any reason in the first year after installation is classified as having an initial failure even if the cause of the failure is random failure. In the case of production deficiency, the reputable equipment manufacturer makes it public.

3. Inappropriate Handling
Sophisticated equipment whose users have inadequate knowledge and skills to operate are often introduced. In addition to this, some local agencies are not able to install new equipment properly. In the case of imported equipment, the operators are not able to read the operating manuals either because of the foreign language or because they may not have any interest to read it. As a result, handling and operation of equipment is improper, and this causes equipment to break down.

4. Inadequate Maintenance
Generally speaking, medical equipment cannot be used without accessories and consumables. The lifespan of such 'consumable components (excluding daily consumables such as recording papers, disposable electrodes, gels and reagent)' is shorter than that of the actual equipment. For instance, bulbs for light beam diaphragm last about two years. In addition, some isolated components used for equipment assembly also deteriorate in a short time. These lifespans, of course, depend on the equipment usage.

5. Environmental Stresses
Medical equipment is composed of highly sensitive electronic circuits and structures. The installation environment of the medical equipment, therefore, demands clean air, good quality water, stable AC power supply, isolation from vibration and noise, appropriate temperature and humidity, etc. Improper environmental conditions can cause the occurrence of breakdown. In addition, there are many conditions where frequent power failure exists. In developing countries, however, it is not easy to put in place strict management of installation environments.

6. Production Deficiencies
Reputable medical equipment manufacturers launch their high quality products in accordance with national or international standards as well as internal quality control. However, malfunctions and failures of equipment of uncertain cause occasionally occur several years after equipment is put to use. This is as a result of inadequacy in the design, improper choice of components, improper manufacturing process, etc., and this is called production deficiency.

7. Random Failures

Random failures can occur, without warning, within any period of the equipment's lifespan, though they are most common between one and six years after installation. Equipment may suddenly fail even if it is operated appropriately. However, in this period, the rate of random failure is only about 5% of all breakdown cases; therefore, this period is also called the period of stability.

Although the failure rate is very low in the period of random failure. The failure rate is a result of deterioration of accessories and consumable components, not breakdowns of the main body of the equipment.

8. Inappropriate Repair Techniques

Logical troubleshooting using wide-ranging knowledge of operating principles, structure of the equipment, comprehension of electronic circuits, functions of electronic parts, etc. is required to repair medical equipment. However, failure often happens because of human error, including imitation and application of non-genuine parts. In addition, often no record of the repair process is kept, making it difficult or impossible to restore the item even after engaging an excellent engineer.

9. Wear-out Failures

In general, this type of failure occurs about five-six years after installation of equipment. Wear-out and deterioration of components that are composed of mechanical and chemical materials mainly cause this type of failure. The components that belong to this group include motors, switches, recorder heads, X-ray tubes, displays and charge-discharge capacitors, though all of these depend on usage time. In addition, the wear-out failures also occur in electronic components such as capacitors, resistors, transistors and ICs used in an improper circuit design.

In the case of wear-out failures, many parts are usually defective. For this reason, the wear-out failures need overall inspections. However, if the regular maintenance system has already been established, parts that are going to wear out or to deteriorate with the passing of time are almost predictable.

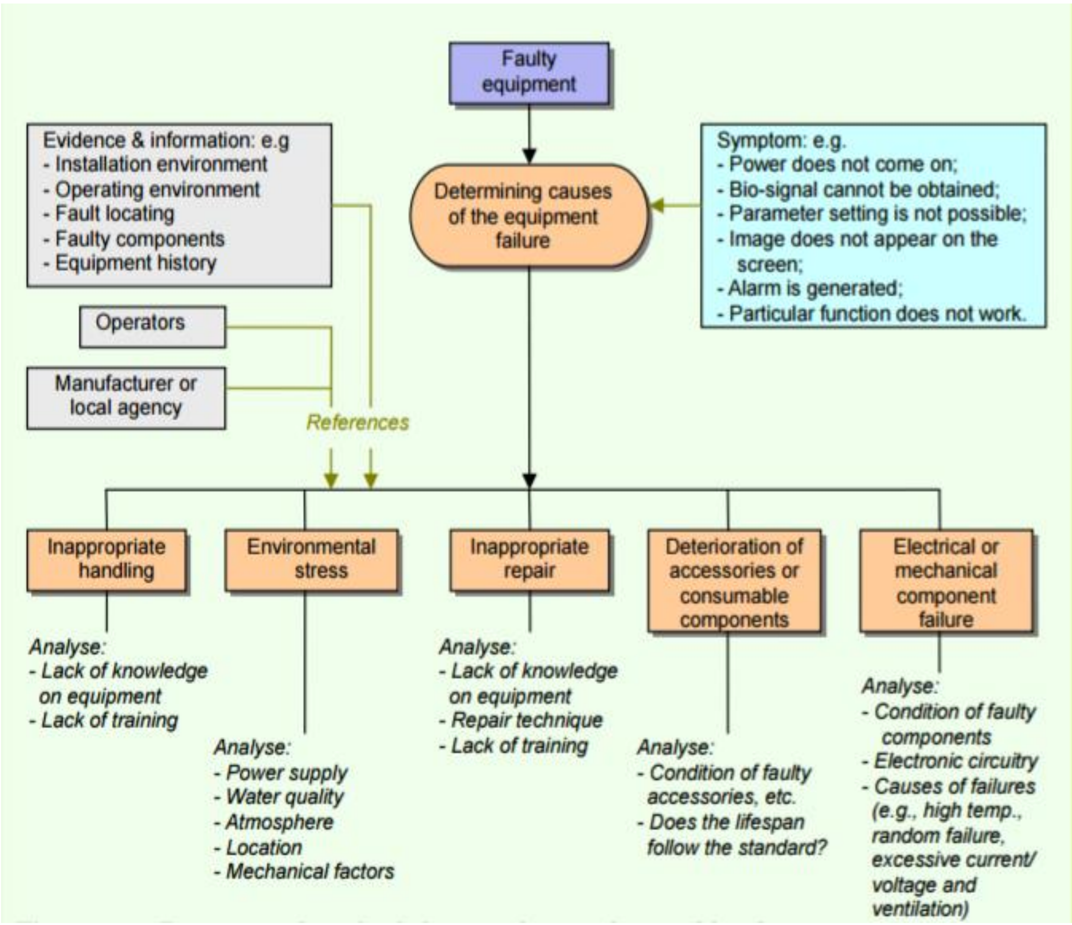

Figure 2: Basic procedure for failure analysis at hospital level

Source: JICA, 2014

Conceptual predictive lifespan of Radiological equipment at NAUTH based on Japan depreciation and cost management system[4]. The lifespan of radiologic equipment is set at 7 years for developed world. However, for developing world, lifespan of 15 years is for the study centre by the researchers. The effective lifespan is 5 years radiologic equipment life cycle. The installation year 2011/2012, effective lifespan 2013-2017, lengthening lifespan for additional 8 years 2018-2026 as shown in figure 3. This is due paucity of funds to procure new equipment that will replace the old once within 10 years of purchase.

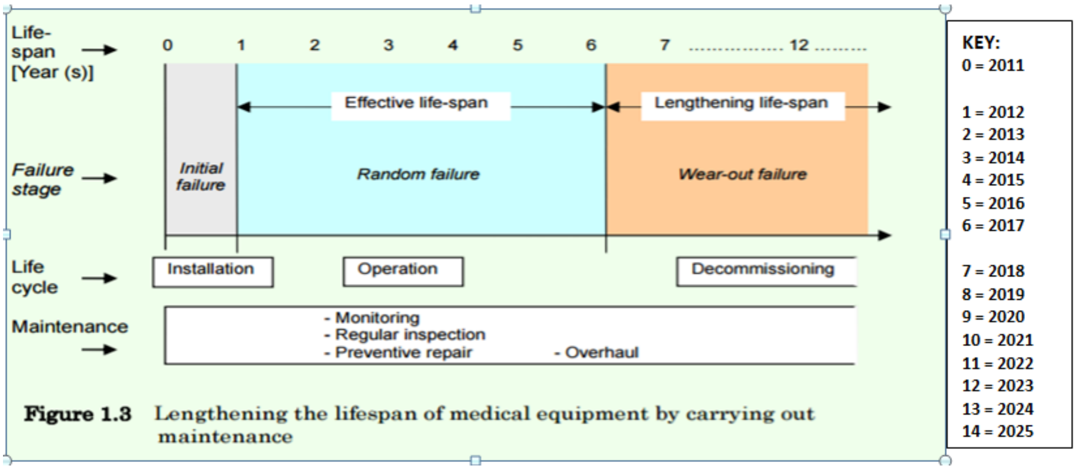

Figure 1.3 Lengthening the lifespan of medical equipment by carrying out maintenance

The objective of this present paper is to present failure modes that analyses the causes of Radiologic equipment failure based on maintenance history and age of the equipment that will enable future predictive failure mode that will ensure less downtime of equipment.

II. Materials And Methods

A triangulational research (analytical survey) both quantitative (analysis of radiologic equipment maintenance history) and qualitative (survey of equipment downtime) study design was adopted for this study.

The source of data was a secondary type repair log record from maintenance history report of servicing company between March, 2013 to December, 2014 (22 Months) and survey research of equipment downtime of Nzotta *et al* [6].

The study area, which is Nnamdi Azikiwe University Teaching Hospital (NAUTH) which is a 440 bedded government based hospital in southeast, Nigeria. The Radiology unit has 22 radiologic equipment and devices. The Radiological equipment such as Conventional general purpose x-ray machine, Mobile x-ray, Fluoroscopy, Mammography machine, Computed Tomography (CT) machine, Ultrasound Machine, Magnetic Resonance Imaging (MRI), C-arm fluoroscopy. The department has accreditation from the following bodies; Postgraduate Medical College of Nigeria for training of Resident Doctors in Radiology, Radiographers Registration Board of Nigeria for training of Intern Radiographers and other continuous professional development programme. The annual patient throughput from the department was 14,430 as at 2013. The hospital had a maintenance agreement with a company, which was a comprehensive agreement for radiologic equipment for a period of 5 years (2010 to 2014). The agreement terms of 2014 covers both preventive and curative (repair) maintenance to involve the following; users training, spare part cycle management, maintenance cycle, and management equipment life cycle. Clinical engineers and technicians were used for the maintenance and regular inspection that ensures the following; prevent breakdown, maintain accurate, hazard free functional equipment and attain the expected lifespan of equipment

A census of thirty nine cases repair maintenance history of 22 months failure log reports available was studied ,in addition, downtime were analysed into two stages (2011/2012 and 2013/2014). The failure analysis was conducted by looking at the causes of equipment failure from the aspect of installation and operating environments, systems, fault locating, faulty component, equipment history using data capture sheet. This was according to Medical Equipment Failure mode Analysis according to JICA [4] guideline and NNRA Radiology equipment inventory form [6].

The failure rate (frequency) and failure ratio (%) was determined in time distribution of two stages:

Stage 1: Installation and commissioning and guarantee period 2011/2012

Stage 2: First operational stage 2013/2014

Data capture sheet of 9 failure mode analysis of causes of radiologic equipment was used. A second data sheet was used according to Nigerian Nuclear Regulatory Authority guidelines for radiology equipment inventory form was used. A survey research of Nzotta et al [6] of radiologic equipment downtime of the study centre was extracted and used for the study. The equipment life span from installation was set at 15 years (2011-2026) and effective life-span 5 years (2013-2017) as recommended by JICA [4].

Nine (9) chronological categories of classification were used. They are as follows:

1) Improper storage and transportation
2) Initial failure
3) Inappropriate handling
4) Inadequate maintenance
5) Environmental stress
6) Production deficiency
7) Random failure
8) Inappropriate repair technique
9) Wear-out failure

The six (6) categories of environmental stress were as follows: (JICA [4])

1. Unclean air
2. Poor quality water
3. Unstable AC power supply
4. Vibration and noise
5. Inappropriate temperature and humidity
6. Loose connection

Equations

I. Failure ratio (breakdown) level = $\frac{\text{Number of Equipment breakdown mode}}{\text{Total number of possible mode of breakdown}} \times 100$

Where, total number of mode of breakdown is 9
Non-failure ratio (non breakdown) level = (100-Breakdown level)%

The acceptable failure (breakdown) rate was set at 25%. Thus, optimal non-failure (non-breakdown) rate is 100% with zero tolerance to failure. Acceptable non-failure (non-breakdown rate) rate is 75%.

All breakdowns from January, 2015 to December, 2016 were excluded. Data generated was categorized based on the objectives of the study and statistical analysis done using SPSS version 20.0. Simple statistical tools such as descriptive statistics. The failure rate (frequency) and ratio (percentage) were analyzed using failure analysis. Research limitation/implication; the data collected for maintenance history were not sufficient due to non-availability of comprehensive historical maintenance data and the effect of researchers' error may cause uncertainty in the analysis. The consequential (effect on reliability and safety of equipment, cost implication of repair and downtime of machine) effects of radiologic equipment failure was not studied

III. Results

Results show that the equipment age range was 2 to 9 years as at 2016. The major manufacturer of the equipment was GE 10 (45.4%), followed by Aloka 4 (18.1%), HP/CCR-30 Drystay Axys 4 (18.1%) and least were APC Galaxy MEE main UPS 1(4.5%) as shown in table 1.

Table 1: Radiology equipment Inventory book (Data collected 17th November, 2016)

S/N	Machines	Age (years) From date of manufacture as at 2016	Manufacturer	Batches	Functional status/ Availability & practice of QC/QA	Downtimes 2014 (Nzotta et al, 2014)
1	Static X-ray (Room 1)	8	GE	B3	F/Nil	1week
2	Static X-ray (Room 2)	8	GE	B3	F/Nil	1week
3	Mobile x-ray	8	GE	B3	NF/Nil	2months
4	Fluoroscopy	7	GE	B3	NF/Nil	6months
5	Mobile C-Arm	7	GE	B3	NF/Nil	2months
6	CT-Scan	9	GE	B3	NF/Nil	9months
7	Mammography	6	AGFA	B2	NF/Nil	NA
8	Mammography	7	GE	B3	F/Nil	4months
9	MRI	7	GE	B3	F/Nil	2months
10	ULTRASONOGRAPHY 1	7	GE	B3	NF/Nil	NA
11	ULTRASONOGRAPHY 2	unknown	Unknown	B1	NF/Nil	NA
12	ULTRASONOGRAPHY 3	unknown	Unknown	B1	NF/Nil	1month
13	ULTRASONOGRAPHY 4	8	ALOKA	B2	NF/Nil	NA
14	ULTRASONOGRAPHY 5	8	ALOKA	B3	F/Nil	1month
15	Autopressor	8	ALOKA	B2	phase out/Nil	1month
16	CR-1 Work station 1	2	HP	B4	F/Nil	NA
17	CR-1 Work station 2	2	HP	B4	F/Nil	NA
18	CR-1 Work station 3	2	HP	B4	NF/Nil	NA
19	CR-1 Work station 4	2	HP	B4	NF/Nil	NA
20	UPS 450 KVA	unknown	APC	B3	NF/Nil	NA
21	UPS CT-Scan	9	GE	B3	F/Nil	NA
22	UPS MRI	7	GE	B3	F/Nil	NA

Key: F=functional, NF= not functional, NA =not available, PO= phased out, B1=batch 1, B2=batch 2, B3=batch 3, B4=batch 4, CR= computed radiography, UPS= uninterrupted power supply, MRI=magnetic resonance imaging.

Table 2: Specific Cause of Equipment Failure (Between 2013 and 2014)

S/n	Specific cause of radiological equipment breakdown	Failure rate	Failure ratio
1	Lack of Preventive maintenance	5	**12.82**
2	Software problem	**3**	**7.69**
3	defective cable	**5**	**12.82**
4	defective fuse	**8**	**20.51**
5	defective contactor	**1**	**2.56**
6	loose cable	**4**	**10.26**
7	loose bulb	**1**	**2.56**
8	damage hatch	**2**	**5.13**
9	stuck film	**1**	**2.56**
10	defective socket	**1**	**2.56**
11	Power code	**1**	**2.56**
12	defective light indicator	**2**	**5.13**
13	Damage MT 800 board	**1**	**2.56**
14	faulty step down transformer and amps contactor	**1**	**2.56**
15	Damage switch handle	**1**	**2.56**
16	wornout bolt (automatic processor)	**1**	**2.56**
	Total	**39**	**100.00**

Table 3: Distribution of Causes of Failure Rate and Ratio Calculated of Diagnostics Radiological Equipment (Between March 2013 and December 2014)

Failure occurrence record (Failure log)			
S/N	Failure mode(causes of equipment break down)	Failure rate(λ)	Failure ratio(i)
1	Improper Storage And Transportation (preventable)	1	2.5
2	Initial Failure (unpreventable)	0	0
3	Inappropriate Handling (preventable)	5	12.5
4	Inadequate Maintenance (preventable)	5	12.5
5	Environmental Stress (preventable)	26	69.23%
6	Production Deficiency (unpreventable)	0	0
7	Random Failure (unpreventable factor)	1	2.5
8	Inappropriate Repair Technique (preventable)	0	0
9	Wear-out Failure (preventable)	1	2.5
Total		39	100.0
10	Failure mode level 6/9 * 100		66.66%
11	Non-failure mode level 100 – 66.66		33.33%
12	Preventable factors	38	97.4%
13	Unpreventable (random failure) factor	1	1.6%
	Total	**39**	**100%**

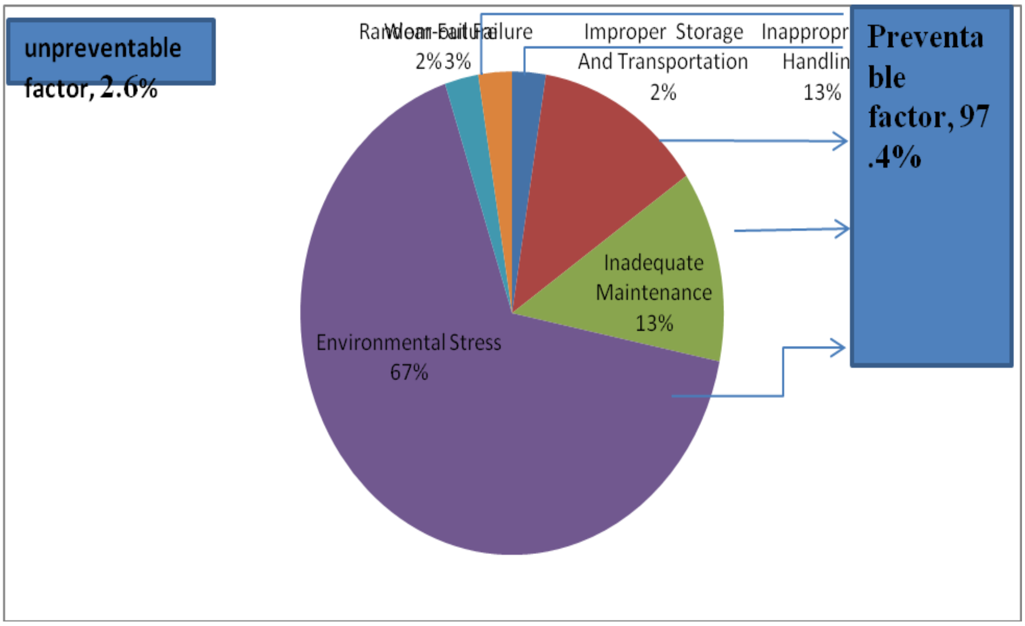

Figure 1: Variation in the failure rate of a Radiology Equipment throughout its lifespan

Table 4: Environmental failure occurrence distribution of diagnostic radiological equipment (Mar2013-Dec.2014)

S/N	Different modalities	Un-clean air	Poor quality water	Unstable A/C supply (%)	Vibration and noise (%)	Inappropriate temperature and humidity (%)	loose connection (%)	Failure rate(λ)	Failure ratio(i)
1	GR	0	0	9(33.3)	0	1(3.7)	0	10	37
2	Fluoro	0	0	1(3.7)	0	0	0	1	3.7
3	Darkroom	0	0	1(3.7)	0	1(3.7)	2(7.4)	5	18.5
4	C-arm	0	0		0	0	1(3.7)	1	3.7
5	CT-Scan	0	0	1(3.7)	0	0	0	1	3.7
6	MRI	0	0	3(11.1)	0	0	0	3	11.1
7	Ultrasound(X 5)	0	0	2(7.4)	0	0	0	2	7.4
8	Mammography	0	0	1(3.7)	0	0	1(3.7)	2	7.4
9	Mobile X-ray	0	0	0	0	0	0	0	0
10	UPS 450 KVA	0	0	2(7.4)	0	0	0	2	7.4
Total		0	0	20(77.8)	0	2(7.4)	4(14.8)	26	100

Key: UPS= uninterrupted power supply, MRI=magnetic resonace imaging, C-Arm= mobile fluoroscopy machine, GR= general (static) radiography static.

IV. Discussion

Results show that of the 22 Radiologic Equipment and accessories studied at the centre, more than 90% were state-of-the-art and are less than 10 years old from date of manufacturing. This was likely because of VAMED project of 2010, Federal government of Nigeria policy on revamping the tertiary institutions in the six geopolitical zones of the country. NAUTH was among the hospitals that benefited from the Southeast zone. The major manufacturer of the transmissive radiation equipment was GE 10(45.4%), Aloka-ultrasound machine 4(18.1%). The choice of the manufacturers is very good due to high reliability rating of GE and Aloka Medical Equipment, state of user friendliness.

The introduction of the radiology equipment in was done in batches

Batch 1 equipment procured by Hospital before VAMED project of 2010 were 2 (9%), which are all non-functional and one had no name and year of manufacturing (ultrasound machine). It is expected that these machines must have served their effective life span of 6 years and extended life span. These equipment are over one decade and have been out of use for a decade.

Batch 2: Equipment donated by donor Agency Rotract Club was one (4.5%) mammographic machine which is non-functional. This could be due to expectation from the radiology managers that the donor should be responsible for its maintenance and repairs.

Batch 3: Equipment introduced by VAMED project of federal government were 16 (72.7%) in 2011/2012. Seven (43.75%) were functional while 9 (56.25%) were non-functional as at 2016 but all 16 radiology equipment were functional as at 2014. This is due to termination of VAMED comprehensive preventive and repair maintenance contract in 2014 by the company due to maintain spare parts cost variation.

Batch 4: Equipment introduced post VAMED project by the hospital in 2014 were four computed Radiography image reader and cassettes. Two (50%) of the CR were functional while two (50%) were not. This may be due to poor handling, unstable electricity, lack of know-how of in-house service section and lack of contractual agreement with vendor. The four set (100%) of CR (HP/Dryster) are from one vendor and manufacturer.

The results of this study was in keeping with findings of Nzotta *et al.* (2014)[6] on equipment downtime. The radiology equipment down time ranges from 15 days to over 24 months assessment year, 2016 according to Adejoh *et al.* (2016) [8]. This is due to poor maintenance policy of the radiology managers. The radiology equipment breakdown (failure rate/ratio) log sheet of 2011/2012 were not available.

The radiologic equipment cause of failure during 2013-2014 shows that the major cause of failure rate and ratio was environmental stress 27(69.3%), inappropriate handling and inadequate maintenance 5(12.5%) The major cause of equipment failure was wrong installation environments, poor equipment usage and poor maintenance. The result shows that 97.4% of all radiology equipment failure cases are caused by preventable factors. This is due to inadequate installation environment (69.23%), inappropriate handling (12.5%), inadequate maintenance (12.5%) and wear-out failures (2.5%). This is similar to the findings of Okeji (2014)[9 & 4]. All these failures are preventable by providing adequate installation environment condition, training and retraining of users and replacing consumable parts on regular basis or immediately when they are defective. These 97.4% radiology equipment failures are preventable in 2013/2014, which is in agreement with reports [4].

This failure rate/ratio of 2013/2014 radiology equipment is not in conformity with the theoretical and statistical failure occurrence. The 2013/2014 based on theoretical and statistical failure is expected to be very stable [4].

The major causes of environmental stress was unstable AC supply 20(77.8%), loose connection 4 (14.8%) and least inappropriate temperature and humidity 2(7.4%). The radiology equipment host highly sensitive electronic circuit and structure which is easily affected by sudden power outage, fluctuation of current, waveform and voltage. The unit had mechanism for stable power supply through the main UPS KVA, dedicated generator, and main power distribution company. The breakdown among other things due to low quality wiring cables that can affect the voltage and current even when stable. And sudden interruption of light by generator operators of the radiology unit. This is in agreement with JICA 2014 that in developing countries that it is very difficult to maintain stable power supply.The VAMED engineers' preventive and corrective contract agreement was terminated in 2014. Thus, the hospital uses in-service and contracted out-services (preventive maintenance 2015). The equipment breakdown log book was discontinued in 2015. The wear-out failures was expected from January 2019 after six years of installations 2011/2012 from the failure predictive model. This wear-out failure should have been prevented if installations and operating conditions adequate and QC/QA in place.

It is expected that radiologic equipment in batch 3 by 2018 would have experienced complete overhaul of all the deteriorated parts and replacement with ones, and calibrating the electronic circuits. This is to prevent wear-out failures and extend the machine lifespan up to 2026 (8 years additional life span); hence, giving 15 years lifespan.The managers of radiologic equipment need to implement a system of monitoring utilization of equipment and to replace deteriorated accessories and components regularly.

Failure due to inappropriate (operation) handling in NAUTH account for among the least of failure cases. Thus the operators (radiographers) are highly skilled in handling of equipment. Only one out of five ultrasound machines is functional. Thus, the operators need further training in equipment maintenance and operations.

V. Conclusion

The Radiology equipment causes of failure metrics was determined on 9 factor failure modes. The facility failed on 6 (66.6%) of the 9 quality factors assessed. Thus, the rate and ratio of failure was unacceptable. The major failure mode was environmental factor, more specifically unstable electricity supply due to fluctuation of current and sudden power outage. Majority of causes of Radiologic Equipment were preventable. The high failure rate/ratio and long down time can be reduced by having a committee on radiology equipment management that will comprise radiologists, chief radiographers, a radiographer in charge of equipment, medical physicist, medical records, in-service engineer/technician, contract service representative, representative of hospital management, with terms of reference is to manage the equipment life cycle and maintenance/repair cycle and spare parts cycle. This will help reduce equipment down time, failure rate, effective life span and life span of equipment. In addition, equipment reliability and safety.

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